The Report of the Oil and Gas Institute in Krakow

The Polish Petroleum and Natural Gas Market

2012

2012 № 7

Honourable Patronage:

Minister Gospodarki RP

The main Sponsor:

LOTOS

Partner:

pwc

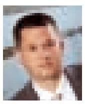
INSTYTUT NAFTY I GAZU

www.pwc.pl

PwC Energy Group
– Your trusted oil & gas advisor

pwc

Contact:



Wojciech Słowiński
Partner
tel.: +48 (22) 523 4420
wojciech.slowinski@pl.pwc.com

Tomasz Barańczyk
Partner
tel.: +48 (22) 523 4852
tomasz.baranczyk@pl.pwc.com

For years we have supported our clients with knowledge and experience of the oil & gas market. We provide business advisory, legal and tax advisory, audit and accounting consultancy.

Let’s talk about the needs of your business.

Contents:

Editor:

The Polish Petroleum and Natural Gas Market
ISSN 1896-4702

Publisher:
Oil and Gas Institute
31-503 Kraków, ul. Lubicz 25A
Tel.: +48(12) 421 00 33
Fax: +48(12) 430 38 85
email: office@inig.pl
www.inig.pl
REGON: 000023136
NIP: 675-000-12-77
KRS: 0000075478

Editor's Office:
Oil and Gas Institute
31-503 Kraków, ul. Lubicz 25A
Tel.: +48(12) 421 00 33,
Fax: +48(12) 430 38 85
email: nafta-gaz@inig.pl
www.inig.pl

Marketing and promotion:
Wojciech Łyko
e-mail: Wojciech.Lyko@inig.pl

Layout, DTP:
Paweł Noszkiewicz
e-mail: pawel.n@webkreator.com.pl

Editors:
Agnieszka J. Kozak
Wojciech Łyko

Editorial Collaboration:
Maria Woźny,
Rafał Wardziński,
Jacek Ciborski,
Anna Kowalewska,
Agata Stafiej-Bartosik,
Iwona Patyk,
Grzegorz Kuś,
Mateusz Konieczny,
Tomasz Barańczyk,
Konrad Michalak,
Jarosław Grzywiński,
Jadwiga Zalewska,
Marek Dohnalik,
Anna Zajezierska,
Wiesława Urzędowska,
Zbigniew Stępień,
Irena Matyasik,
Karolina Pirowska,
Delfina Rogowska,
Arkadiusz Majoch,
Martynika Pałuchowska,
Jan Lubaś,
Wiesław Szott.

Translation into English:
Renata Woźniak
Jarosław Sygnat
Elżbieta Woźniak
Tomasz Żuk

Illustrations:
The photos and drawings inserted in this publication are printed after the news bulletins: sxc.hu, istockphoto, and company archives of: Grupa Lotos S.A.", Instytut Nafty i Gazu, PNiG Sp. z o.o.
The remaining illustrations have been prepared by text authors.

Printing:
Drukarnia i Agencja Wydawnicza „ARGI"
Wrocław, ul. Żegiestowska 11

Edition:
1200 copies


Index
Total
Sector 1

WICEPREZES RADY MINISTRÓW
MINISTER GOSPODARKI
Waldemar Pawlak

Warsaw, 14 August, 2012

Introduction by the Vice Prime Minister, Minister of Economy Waldemar Pawlak, to the yearly "Polish Oil and Gas Market" issued by the Oil and Gas Institute

Waldemar Pawlak – Vice Prime Minister, Minister of Economy

Welcome to this year`s edition of the yearly publication of "Polish Oil and Gas Market" which I highly recommend to you.

The report describes the current situation and the challenge for the fuel and energy sector. Competitiveness in this sector, its balanced development and security of supplies are still fundamental for the Polish energy policy. Since December last year, in the Ministry of Economy works are in progress on the so-called triple energy package consisting of the Gas and Energy Law and the one related to the renewable energy sources (RES). In changed regulations, we propose stable and long-term solutions which support the sector, with special emphasis on using the local resources of energy, enhancing the effectiveness of energy and the rights of energy recipients.

It is our priority to ensure the development of the natural gas market and security of supplies. Therefore, in the project of the gas law we included, among other things, the principles concerning supplies for the protected recipients, the possibility of supporting the recipients of sensitive natural gas and regulating the principles of expansion of the transmission and distribution system.

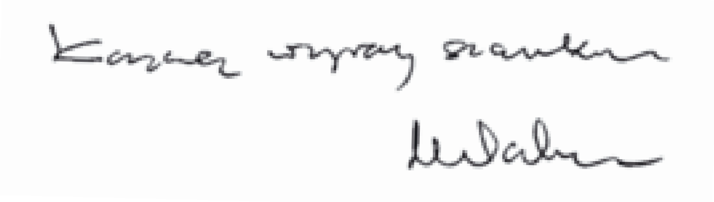
The project Energy Law contains many issues which organize the work in energy sector, e.g. certification of the transmission system operator. It also contains solutions supporting the consumer rights, e.g. support for the so-called 'sensitive recipients'.

What is more, among the most important elements of the new act on renewable sources of energy we should mention unchanged principles of assistance for the installations based on renewable sources and preserving the current system of support for the equipment already operating. We will also introduce a system of guaranteed prices for selected technologies generating electrical energy or heat in micro- and small-scale installations based on renewable sources.

I am convinced that in this publication of the Oil and Gas Institute we will be able to read about the changing legislation. I encourage discussion on the issues, as the voice of experts and representatives of the branch is really precious for us and always taken into consideration while making the new law.

„The Polish Oil and Gas Market" is an interesting proposition not only for specialists in the energy sector, but also for those wishing to broaden their knowledge related to the generally understood oil and gas sector.

I warmly invite you to read this year`s edition.



The Economy of Oil and Gas

Taxation of gas from shale formations

Fiscal policy in favour of investors

Tomasz Barańczyk, Iwona Patyk, Grzegorz Kuś

Despite a number of the government`s announcements, the new solutions concerning taxation of shale gas and in fact all the hydrocarbons are still not known[1]. It produces the air of uncertainty for the investors who limit their prospecting works to indispensable minimum.

At present, there is no special tax in Poland on extraction or sale of natural gas. A question arises then: is the introduction of a new fiscal burden for extraction branch justified? In order to answer the question, it is necessary to analyze the current system of taxes and fees in Poland and compare it with the best world practices and trends.

What liabilities are the extracting companies burdened with?

The current tax system for entities dealing with prospecting, recognition or extraction of gas from both conventional and unconventional deposits does not differ much from the burdens borne by entrepreneurs in other economy sectors. These entities pay income tax at the same rate as other firms, have the same obligations as remitters of personal income tax of employees as well as social insurance contributions. In this way, due to relatively low – as compared to some European countries – CIT tax rate of 19%, Poland is an attractive place to locate capital consuming prospecting investments. For comparison, the standard CIT rate in Norway is 28% and in Denmark 25% – and apart from that, there are also some special income taxes in force, which can even amount up to 52%.

However, there are certain differences in relation to other Polish enterprises, which are related to the necessity of bearing certain fees by companies prospecting for or extracting natural gas that result from the Geological and Mining Law Act. This act imposes some kinds of payments, which have to be borne by an entrepreneur who executes works related to prospecting, recognition and exploitation of deposits.

These payments are of various nature: remuneration for establishing mining usufruct is of civil legal nature, whereas fees for prospecting, recognition or extraction of gas are precisely described in the quoted Act and are of regulatory nature. Even though the other kind of fees are governed by relevant regulations of tax ordinance concerning tax obligations, in the formal-legal aspect, none of the above payment categories are taxes (at least with regard to linguistic legal interpretation of domestic regulations, because on the level of European Union there may be some doubts in respect of classification of some of them). Moreover, these fees are relatively small, considering the current prices of raw materials.

1 *As of 23.07.2012*

Table 1	
Exploitation fee for extracting 1000 m^3 of gas in Poland	5,89 PLN
Average market price of 1000 m^3 of Russian gas in Europe in June 2012	about 452 USD = about 1525.5 PLN
Average market price of 1000 m^3 in American market in June 2012	about 88 USD = about 298.32 PLN

Source: the International Monetary Fund (http://www.imf.org/external/np/res/commod/index.aspx)

Regardless of whether the legislators decide to introduce a new tax (similar to the one on some minerals, including copper and silver) or if they increase the burden resulting from the geological and mining law, these actions should be preceded by thorough analysis of economical results and social discussion, especially with entrepreneurs who may be affected by these regulations.

Will the new tax concern shale gas only?

In the media and in some statements of politicians, the introduction of new (or higher) taxation is most frequently related to extraction of natural gas from shale formations. However, it should be remembered that introduction of taxes only on 'shale' is rather unlikely. There is no reason though that the criterion deciding on taxation should be the method of gas extraction (this is basically the difference between exploitation of conventional and unconventional deposits, including the shale gas).

For this reason, very likely seems a broader approach to the subject of new tax and taxation of all the hydrocarbons, especially natural gas and crude oil. Presumably, it is in this direction that the government initiative is going (during the conference canceled at the last moment on 13 June 2012, the Ministry of Environment was going to present a draft of the 'Act on Hydrocarbon Extraction, Taxation and Funds'). It has to be noted that new tax solutions will have the key meaning not only for profitability of (chiefly foreign) investments in exploitation of shale gas but also – and perhaps first of all – for the companies operating in the domestic market which have been extracting conventional gas for many years.

Principal models of taxation of hydrocarbons in the world

Taxation on hydrocarbon extraction has also been functioning for many years in other countries. The form

and kind of taxation depend on very many factors, first of all on the legislative system of conducting extraction (concession and contractual models) and on the level of development of fiscal administration in a particular country.

In general the burdens can be divided into fees and taxes: 1) collected before commencing exploitation, 2) those due during extraction period, 3) fees related to possessed assets.

1. The first group includes various application and tender fees, e.g. for issuing the concession and various kinds of additional fees: signature/discovery bonus.
2. Among the fees collected by countries at the stage of exploitation, the most important are income tax and royalties.
3. In respect of income tax, it should be noted that in some countries, apart from income tax paid by all entrepreneurs – an additional tax is imposed on entities operating in the gas-oil branch (or an increased tax rate).

However, the most characteristic fiscal instrument for that sector is royalty collected in many countries. In practice, this royalty takes diverse forms in different countries. The oldest solution is the royalty due depending on the volume of extracted gas – *quantity based royalty*. This form of royalty is quite a simple solution because it is based on a established amount rate per a volume unit of extracted raw material (an example of this rent is the Polish exploitation fee, mandatory in Poland). Great advantage of this form of liability is its transparency and easy supervision. Simultaneously, the substantial drawback for the extracting companies is the fact that the fee is collected regardless of extraction profitability. When the rate of royalty calculated in this way is high, it may be a valid discouraging factor for investors who undertake gas prospecting and extraction in a particular country.

Another form of royalty is the one calculated on the value of extracted raw material – *ad valorem royalty*. The value of the raw material may be defined in different ways (e.g. on the basis of determined market prices or as a sum of gross income on sale minus costs). Unfortunately, this form does not always take into consideration the financial resources of the investors, as it does not depend on their achieved financial result.

The most advanced form of royalties is a fee depending on the income on extracted gas – *profit/income based royalty*. This solution assumes taxation on receipts from extraction diminished by extraction costs (also, frequently there is a sum exempt from fee). From the point of view of investors it is the most beneficial option because they pay the fee only when their venture generates profits. Therefore, they are also ready to accept high rate of royalty more willingly. This form of royalty makes an effective investment incentive. Simultaneously – as this method of calculation and supervision over determining the correct basis for taxation is in this situation rather complicated – this solution is applied in practice only in a few most developed countries, which have effective tax administration. The fees based on assets include e.g. real estate taxes or other taxes which depend on the value of entrepreneur`s property assets.

Norway, which is frequently quoted as having a model taxation, applies the *profit based royalty* model burdening the extracting companies with an additional income tax. Similar models are applied in Denmark or Great Britain. Whereas in Canada and in some states in the USA, apart from CIT – a standard rate of income tax for legal entities, there is also the *royalties ad valorem* system. However, it is worth noting that most of these legal regulations also allow a number of tax concessions, especially concerning depreciation of fixed assets used for extraction, relief on research and development works related to prospecting and extraction and also the possibility of tax loss settlement within 20 years or even without a time limit.

The Polish legislator, while deciding on introduction of new public levies, whether in a form of new tax or by increasing the existing fees, should take advantage of experiences of other countries. Creating a new law, they also should not forget about the extraction sector specificity.

What should be remembered while introducing new levies

It seems that first of all the new system of public levies concerning extraction should be constructed in such a way as to secure the interest of state on the one hand but on the other hand, not to discourage investors to gas prospecting in Poland. A bitter example can be the situation in Alberta province, Canada, where, after the royalties had been raised in 2008, a mass withdrawal of investors occurred. As a result, the levies were diminished, and now the authorities are trying to regain the reputation of an interesting place for investments.

Moreover, each public legal burdening with a new tax or fee should be the tax deductible for the entities which bear them. The solution introduced by the Polish legislator in respect to the copper and silver tax (Taxation of Some Minerals Act) features excessive fiscality as this tax could not be deductible for income tax purposes.

The next important factor, which should be taken into account by the Polish legislator is time consumption of the investment process in the oil and gas sector. From the moment of commencing prospecting works to gas extraction on the industrial scale, a few or even a dozen or so years may pass. The concessions for gas prospecting and recognition are issued for 5-6 years on average and are frequently extended. In this context, the period for tax loss settlement in Poland i.e. maximum 5 years from incurring the loss is definitely not suited to the specificity of exploration works.

The principles of settling the costs over the time and depreciation of fixed assets are essential as well. The legislator could consider preferences justified by the character and time consumption of this kind of operations for selected categories of costs/assets of extraction companies.

When creating new law, it is also worth trying to specify the status of boreholes, which are mining excavations, as well as the equipment located in them with regard to real estate tax. Such taxation is still disputable and the verdict of the Constitutional Tribunal of the Polish Republic (file no. P 33/09) leaves no doubt that the taxation regulations in this respect are faultily constructed. At the same time, the prospect of 2% of tax on the borehole value encourages the local authorities (the beneficiaries of the real estate tax) to institute proceedings and leaves the investors with the perspective of many years lasting court dispute in order to obtain the answer to the question on the obligation and amount of this tax.

The last issue, which due to the specificity of prospecting and extraction operations painfully strikes the sector (very often preventing the investments) is the lack of more precise tax regulations concerning running and accounting of joint ventures. Implementation into the Polish system of worldwide and typical for the branch *farm-out and joint operations agreements*, apart from a number of legal obstacles may even result in losing the right to include some of the expenses in the tax deductibles.

> The new system of public levies concerning extraction should be constructed in such a way as to secure the interest of the state on the one hand, but on the other hand, not to discourage investors to gas prospecting in Poland.

Summary

Taxation of the upstream business in Poland does not belong to the highest in the world. Many other countries obtain proportionally larger benefits form extraction of the same amount of gas than the Polish budget. Therefore modification of the taxation sys tem for this kind of operations in Poland – referring to the current economic situation – seems to be just the matter of time. Nevertheless, each change should be thoroughly analyzed, as excessively high burdens may effectively discourage investors from further gas prospecting, especially very risky and costly exploration for shale gas. Simultaneously, while changing the system, the Polish legislator should take into account the risks specific for the sector and potential solutions, which successfully operate in other countries.

The authors are employees of the Tax and Legal Department at the PwC

Tomasz Barańczyk – Partner
Iwona Patyk – Manager
Grzegorz Kuś – Senior Consultant

Economy and LNG – based gas sector management

Energy security and clean environment

Rafał Wardziński

Over the last 50 years, the structure of energy consumption has transformed considerably. Although the prevailing energy sources are still mineral fuels, their significance is systematically falling in general production, on account of technological advancement and development of alternative sources. In times of omnipresent struggle against global warming, what can be considered one of the most ecological fuels is natural gas.

The forecast for the gas market is very optimistic. Significance of this fuel, both in the Polish and world economy is rising, which is the effect of said ecological character of this fuel, i.e. its relatively decreased pollutive input. Also, owing to implementation of very restrictive regulations of the climate and energy package which imposes far reaching restrictions with reference to greenhouse gas emission on all EU member states, "blue fuel" seems to be the optimal solution.

> According to forecasts, in 2020 the demand for natural gas in domestic market may reach the volume of about 25 billion m^3, mainly on account of development of modern Polish electric power systems, and first of all, construction of gas units.

The prospect for using natural gas substantially widened when LNG technology appeared. LNG is natural gas – mixture 85-99% of methane with slight additions of other gases: ethane, propane butane, nitrogen (LNG composition and heating value depend on its "origin" and extent of "purification"), chilled to temperature -163°C, which permits 600 times reduction of its volume, which makes it more economic in transport. In liquid form its density is 0.42–0.49 g/cm^3, i.e. less than half of the water density. The return to gaseous

state is the result of reverse process – liquid is heated to normal temperature at constantly monitored pressure. All that makes LNG an ideal substitute in the Polish gas market, which is known, apart from domestic extraction, to be dependent in about 63% on the import from Russia.

Besides the application in industry and energetics, there is one more possibility to use LNG as fuel. The Baltic Sea belongs to the SECA zone created by the International Maritime Organization for environment protection by implementing regulations which limit pollution emitted by ships, i.e. heavy marine fuel. New regulations limited the use of traditional heavy oils for the benefit of more ecological fuels, and LNG is one of discussed alternatives. According to available analysis, in 5-10 years` time most of short distance ships will be powered by LNG, because this fuel is relatively cheap, easy in transport and it deposits exist in many places in the world. The possibility of refueling ships powered by gas may be an additional functionality of the terminal in Swinoujscie in the future.

LNG – not only support for diversification of gas supplies

Liquefied natural gas plays ever increasing role in global gas transport, as alternative for the gas pipeline technology, among other things on account of its price and logistics. Its merits are also more and more appreciated in our regional market. The primary goal of constructing an LNG receiving terminal in Swinoujscie is creating a new, geographically unlimited access for Poland to the world LNG market, which will allow to secure gas supplies in case of disturbances in its continuous flow from other sources.

Additional advantage for the recipients, resulting from the specificity of LNG market is liberty and flexibility in customizing the portfolio of gas import based on various supplies or sources, and also possibilities of management in respect of duration of the contracts. This will enable the market participants to purchase gas fuel in the "spot" markets, which will make it possible to take advantage of favourable ratings. Moreover, the currently conducted liberalization of the gas market in Poland aims at opening the market for new participants, which will eventually result in creating the optimal business model for using the gas infrastructure, e.g. through the demand for supplementary services, such as: transport by road tankers, by rail or bunkering of smaller ships. All these options are analyzed for business possibilities by Polskie LNG company and once the investment will have been completed, they will make (apart from the long-term contract between Qatargas and PGNiG, which is an element of national energy security) a very attractive offer for the commercial market in Poland.

With sufficiently developed regasification infrastructure and secured diversification of sources, LNG may also constitute the core of the national energy security, as it can be seen in Spain.

If it comes to business justification of the logistics of LNG transport, the key advantages of large *methane carriers*, e.g. the Q-flex or Q-max type, are their relative flexibility of supplies and the ability to run long-distance, due to which the cost of LNG transport goes down with the distance covered. Any potential gas recipient may adjust the schedule of supplies to the LNG terminal, depending on their needs, capacities of regasification infrastructure, transmission and storage reservoirs, etc. The only risk factors in marine transport, are the straits (Bosphorus, Ormuz, Bab El-Mandeb or Malayan strait), and also piracy and terrorism.

According to current estimates, the year 2030 will be a breakthrough, because LNG will dominate the natural gas market – its trading volume will reach 340-600 billion m^3, while traditional gas pipelines will transport about 340-390 billion m^3. (Source: EIA)

Better than gas pipelines

It should be noted that LNG has an advantage over traditional gas pipelines: it makes it possible to transport the resources by sea from any direction, from any supplier. This is where we see the "real" diversification of gas import to Poland, this is our "real" energy security. Moreover, the development of LNG technology brought about significant reduction of production and logistics cost. As a result, the LNG application and trade are more and more common, mainly owing to financial instruments developed for other resources, mainly crude oil. The best recommendation is the fact that according to the International Gas Union (IGU) in 2011 the LNG trade increased by 8% (i.e. by nearly 18 million tons) and achieved its record volume, amounting to 241.5 million tons of gas. The principal reason for this was the earthquake and tsunami which hit Japan in March 2011. The disasters led to shutting down all the nuclear reactors in the area of the Land of the Rising Sun and starting gas-fired power units. Hence, day by day, Japan has become one of the largest LNG recipients, becoming also the leader in the short-term market.

While discussing the questions of LNG trading, it should be noted that it is sold chiefly on the basis of price formulae which are indexed according to oil prices. Details relating to setting the formulas, or the transactions themselves concluded on that basis, are business secrets – they are not revealed to the public.

The development of LNG terminals

In 2011, as many as 15 new terminals were put into operation in the whole world, as the Netherlands, Norway, Sweden and Thailand. Presently, as many as 27 countries are already capable of using the LNG technology (source: International Gas Union – World LNG Report 2011). In most of these countries the environment and climate protection issues are the matter of absolute priority. Not to mention the fact of significant changes of their geopolitical or economic position on the world map.

The new LNG installations are the only safe solution for diversification of fuel supplies for many countries. But there are also examples of countries such as the Netherlands or Norway, for which the LNG trading (besides own consumption) strictly business-oriented solution, aimed at generating profits.

Speaking of the costs of natural gas liquefaction, it is estimated that the liquefaction terminal's construction costs along with the storage tanks will amount to about 40-45% of the costs of complete LNG project, assuming that typical business model for LNG consists of mainly four areas which comprise:

- prospecting and extraction area called "*upstream*": this one includes e.g. outlays for boreholes, production infrastructure, specialist equipment for gas purification or gas pipelines for local transport of the resource to liquefying plants;
- production area called „*downstream*", where the most significant cost is the liquefaction installation, tanks and loading infrastructure (the cost of the LNG liquefaction terminal is several times higher than the costs of regasification terminal construction);
- transport area – usually involving specialized shipping companies, as they provide a fleet of LNG carriers. Very often, gas producers have their own shipping fleet;
- regasification part – regasification terminal with essential infrastructure.

Characteristic elements in the regasification installation being constructed in Świnoujście by the company Polskie LNG and GAZ-SYSTEM, are two LNG tanks of capacity of 160 thousand m^3 each, an external port with unloading station, unloading arms and flyover connecting the offshore and onshore part of the terminal. The presently executed gas pipeline Swinoujscie-Szczecin, which will connect the LNG terminal with the national transmission network, should be also included. In the first phase, the terminal infrastructure in Swinoujscie will allow to offtake 5 billion m^3 of gas annually with the possibility of expansion to 7.5 billion m^3/year, which will make up a half of the Polish annual demand for gas (14 billion m^3/year).

The author is a Chairman of the Board of "Polskie LNG S.A."

Strategies of communication with local communities in the context of investments in gas from unconventional deposits – an account of opening

Emotions vs. facts

Agata Stafiej-Bartosik

Short though, but full of surprises, the history of prospecting for gas from unconventional deposits in Poland reveals many mechanisms which govern social communication. Taking a closer look at these basic regularities gives an interesting image of the civic dialogue conducted so far and it also points to the necessity of starting a real, rational discussion on one of the key subjects shaping the energy future of Poland.

In March this year in the town of Łukta in the Warmian-Masurian Voivodeship, the citizens started withdrawing agreements for geological exploration on their plots. When asked for the reason they answered: *'We do not want shale gas here. If they find gas on my field they will be able to expropriate me, and with the family we run a farm here and we do not want to give it up'.* There would be nothing strange in this reaction, as in majority of locations the inhabitants react in this way to the appearance of geologists. However, no one is searching for gas in Łukta. Under the supervision of Professor Marek Lewandowski, the Institute of Geological Sciences of the Polish Academy of Sciences is conducting research concerning geological structure of Poland.

Demagogy?

This episode nicely illustrates the state of ignorance and fears. When there is lack of information, imagination suggests the worse solutions. Can we put the blame on shortage of information, though? The debate concerning the pros and cons of prospecting and extracting gas from shale formations has already been going on for some time. The Internet is full of reports, summaries, appeals and films of both opponents and supporters. The former sound the alarm pointing out to hazards for the environment and human health which according to them are brought by the technology of *fracking*. They demand the concessionaires to withdraw, to implement stricter regulations and at best to stop prospecting for unconventional deposits of hydrocarbons. The latter see in the gas the chance to provide the energy security for Poland for many years, independence from external supplies of gas and prospects for development of poorer regions of the country.

Even though the media draw our attention chiefly to those protesting, the polls invariably show that as a society we are for. According to the polls conducted in June by the Polish Public Opinion Centre (CBOS), almost three out of four poll participants (73%) support the extraction of natural gas from shale formations in Poland. The opposite view is represented by 4% of respondents and almost a quarter of them (23%) have no opinion.

The opponents of shale gas extraction see not only the hazards resulting from the process of prospecting and extraction, but also blame the concessionaries for poor communication – meetings with inhabitants are held, in their opinion, too late, the information is incomplete and materials received from investors are not true.

How to talk?

Meanwhile, prospecting enterprises are looking for the ways of communication. Some of them bring from abroad ready templates, specimens and ideas for constructing relations with the local communities. They run activities professionally, according to the best standards tested e.g. in the USA. However, it does not always work. The Polish society is different from American one, it approaches the information with different experience related to the communist propaganda and years of abuse in the area of social communication. Therefore, it is very difficult for the companies to construct such a model of communication which will provide requested information on time. Some enterprises choose direct meetings, which does not always end well. Both the BNK/Saponis, Lane Energy, Chevron, San Leon, and PGNiG have encountered dissatisfaction of the inhabitants – not always related to their activities. Many times, representatives of these firms had to respond to accusations and allay fears related to prospecting and extraction of gas. Some of the local groups claim that they are especially afraid of pollution of the environment, contamination of water, degradation of the nature and damage due to drilling and *fracking*.

> 'If the shale gas was to be extracted near your place of residence would you be for or against this decision?' As many as 71% of respondents – inhabitants of Lubelskie Voivodeship answered they would be for, 21% of them were against and only 8% chose the answer 'difficult to tell'.

Others, according to the NIMBY idea (*Not In My Backyard*) declare: *'We are not against the shale gas but we are against drilling in close vicinity of our homes'.*

In order to dispel doubts of the inhabitants, experts travel around Poland, but, in the opinion of combatively predisposed inhabitants even they prove to be selected in a way to say things, which a company wants them to say: *'Experts, who are said to be independent, come to us, but they present only the advantages of drilling. To some questions important to us they have no answer or their answers miss the point'.* (the opinion of an inhabitant of the town of Żurawlow in Lublin Voivode-

ship). Another problem for the society is their disapproval of the lack of complete knowledge on the part of the company concerning their works, resources, results of some operations: the inhabitants do not accept the fact that certain issues will be determined only on the basis of results of executed prospecting works.

Even though protests are spectacular and attract the media, the number of opponents is actually substantially smaller than the number of indifferent persons or supporters. The surveys of public opinion presented by the European Parliament Member, Professor Lena Kolarska-Bobińska, are quite interesting. The question: 'If the shale gas was to be extracted close to your place of residence, would you be for or against this decision?' – as many as 71% of inhabitants of Lubelskie Voivodeship answered they would be for, 21% of them were against and only 8% chose the answer 'difficult to tell'. The surveys were conducted in November 2011 on a representative sample of 1000 persons – the inhabitants of Lubelskie Voivodeship.

Indeed, most of the prospecting works were executed as planned and according to the schedule. No significant effect on the nature of the concession areas was noted. Such a conclusion is grist to the mill for the investors who are closed to the dialogue with the society and the followers of an old method DAD (*decide, announce, defend*). Unfortunately, you can still hear some investors claiming that the protesting care only about money.

Winning over by supporting

In order to soften adverse emotions, the firms often decide on actions supporting essential needs of the local communities. They organize picnics, renovate roadside shrines, fund foreign language courses and scholarships. A popular method is also organization of training for local authorities and local journalists. If we could gather and sum up the contribution of concessionaires in the development of areas comprising concessions, the effect might look impressive.

Meanwhile, the most united and determined opponents do not waste time. The concessionaires face the so called 2.0 protesters who get information in the Internet, who by utilizing social networks mastered control of the democratic art of uniting. Thanks to the energy of opponents, at least three new associations have been formed, the objective of which is to act for the sake of protection of the environment in the areas covered by concessions.

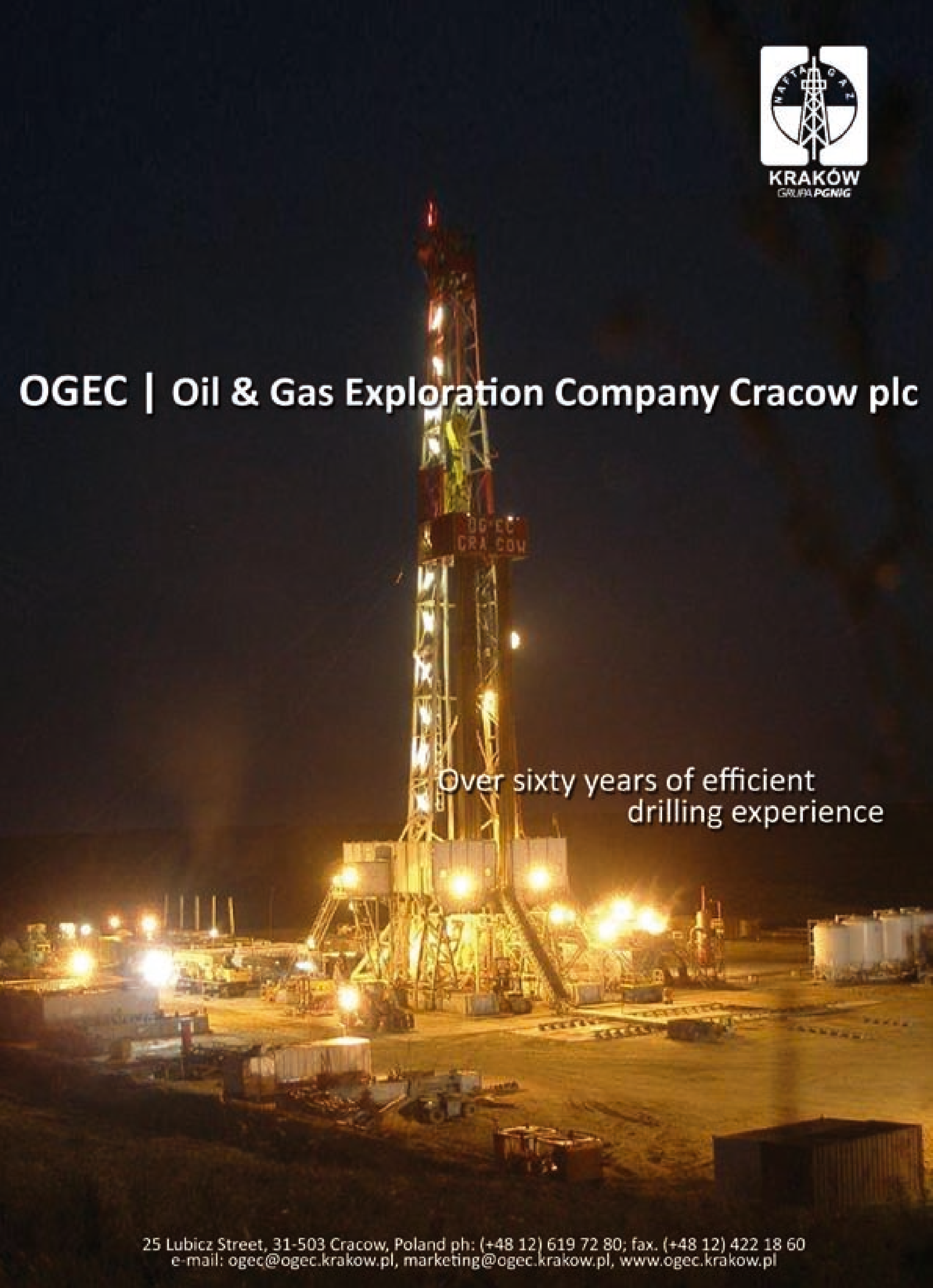
Great emotions, dispersed operations and large stakes of the game should indicate necessary actions to the concessionaires. One, common voice of all the concessionaires is necessary: whether under the aegis of branch organizations or with the aid of some other speaking tube, the concessionaries have to start speaking with one voice in order to consistently fight off the myths related to extraction of gas from unconventional deposits. It is also necessary to understand that one mistake or crisis at any location becomes the problem not only for one entity but for the entire branch. The divergence of business interests should not limit possibilities of cooperation in other areas, such as e.g. the contact with the local communities.

The investors should also listen to fears, remarks and needs of the inhabitants. Popular, informative meetings called by the village leaders are only one of possible forms of action. There is a number of more interesting and more beneficial solutions for both parties. None of the concessionaires have created a dedicated medium communicating the inhabitants in a regular way important events in the project at the place of their residence. Also no institution required by the European Bank for Reconstruction and Development or by the European Investment Bank has been started yet which would operate e.g. granting credits for execution of an investment which is a liaison officer for communication with the local communities. Indeed, such a person is an ideal solution both in the question of maintaining relations with the community and for early detection of social unrest or conflicts arising in the context of executed investments. It is always a good idea to be aided with examples from a related branch – interesting experiences and many good practices can be found among actions of firms such as the Gas-System or Polskie LNG.

Lack of a reliable information campaign on the part of the Government is also distinctly perceptible. The entrepreneurs take on all the burden of education and convincing the local communities, without distinctive support of the government. In comparison with controversies with the mining law, which in colloquial perception allows the expropriating and evictions, the concessionaires are put in a difficult role of explaining stipulations of the act to the excited crowd of inhabitants.

There is still much hard work ahead of everyone involved in the investment process, before the natural gas from shale formations appears in gas cookers and household stoves. Perhaps by that time we will learn to debate and practice cooperation in order to make joint decisions about the future of Poland both at the level of small fatherlands and at the level of entire country.

The author is a Senior Manager in the Sustainable Business Solutions team at the PwC


KRAKÓW
GRUPA PGNIG
OGEC | Oil & Gas Exploration Company Cracow plc
Over sixty years of efficient
drilling experience
25 Lubicz Street, 31-503 Cracow, Poland ph: (+48 12) 619 72 80; fax. (+48 12) 422 18 60
e-mail: ogec@ogec.krakow.pl, marketing@ogec.krakow.pl, www.ogec.krakow.pl

Transformation in the gas market

Are we heading in the right direction?

Jacek Ciborski, Anna Kowalewska

The natural gas market in Poland is about to undergo a deep transformation directed at its liberalization and meeting the directives of the EU requirements. Liberalization of the gas market is a priority not only for the European Commission, which attentively watches the processes occurring in the Polish market, but mainly from the perspective of the Polish economy, for which the cost of natural gas is the basic factor of competitiveness.

Transformation directed at liberalization of the gas market and elimination of all the obstacles preventing new entities from entering the market are currently in the preparation phase or at the initial stage of execution. For several years, an investment programme has been operated, related to the gas infrastructure. Also, changes are introduced in the organization and ownership structure of infrastructure operators. Other key initiatives are the works on gas market liberalization, which began in the end of 2011, including the creation of the gas exchange. According to the assumptions, the initiatives are supposed to facilitate the development of competitiveness in the market, which in turn, in accordance with the declaration of the President of the Energy Regulatory Office is to be the basis for abolishing the tariff duty. In the first place, the duty is to be abolished for industrial entities and then – for individual recipients.

The execution of particular undertakings and adopted principles of introducing the changes will determine the shape of the future gas market. Are they going to bring a chance for a free market? Let us look in detail at particular processes and initiatives.

Expansion of the infrastructure and making it available for third parties

Existing limitations on the Polish map of transmission infrastructure are mostly the consequence of historical factors. For many years, the gas infrastruc-

Essential conditions for the operation of free gas market:

- free gas flow between the domestic and neighbouring markets, and thus, facilitating deliveries from new directions,
- freedom of the gas recipients to choose the natural gas supplier, as well as switch to another one,
- free and equal access to gas infrastructure, i.e. transmission network, gas storage reservoirs and distribution network for all interested entities,
- introduction of market mechanisms into gas trade, and in the long term – increase in significance of the gas exchange where the reference price of natural gas will be established.

Fig. 1. Present and planned import capacities of the gas infrastructure (in billion m³/year). *Source: PwC*

ture was built to serve deliveries from the East. As a result, the capacities of the entry point to the national system from other directions are limited, which is currently the key barrier to entry for independent entities.

In order to do away with that barrier and facilitate free gas flow between Poland and neighbouring countries, as well as diversify the sources of supplies, the company responsible for the development of infrastructure – GAZ-SYSTEM S.A. – has been executing for many years a large-scale investment plan. Its effect was the initiation of new capacities at the end of 2011 and the beginning of 2012 at junctions with the neighbouring countries – the Czech Republic and Germany. Moreover, after GAZ-SYSTEM S.A. had started the operation of the Yamal gas pipeline, the available capacities were used at the entry to the domestic system in Lwówek and Włocławek, as part of the so-called virtual reverse flow on the principles of discontinuation, making it possible to contract additional natural gas supplies from Western European partners. Presently, it makes up in total about 3.5 billion m³ of new capacities at the entry to the system. Allocation of the new capacities was executed on the principles of TPA. Each time, the interest in the new capacities exceeded the level of capacities made available several times, which indicates the market demand for further expansion of the infrastructure.

Further investments are planned, which will enable diversification of the directions of supplies. A new gas terminal is under construction in Swinoujscie and it will constitute a new entry point to the transmission system with initial capacity at 5 billion m³. Currently, analyses are also performed related to the construction of connections with the Czech Republic, Slovakia and Lithuania (in the last case, it will be an export connection). Potentially, there is also the possibility of further extension of the existing pipeline, or construction of a new interconnector with Germany, as well as providing the physical reverse on the Yamal pipeline. What's more, it's possible to increase the capacity at the exit points from Yamal in Włocławek and Lwówek and making them available for the purpose of increasing the natural gas supplies within the framework of virtual reverse.

For the development of the gas market the storage infrastructure which ensures a safe functioning of the system is also very important. For gas trading companies, the availability of storage reservoirs allows to gain competitive advantage over other entities through securing increased supplies in winter, trade balance, optimization of purchase prices and satisfying the requirements in respect of mandatory reserves, in unison with binding regulations.

On account of growing consumption of natural gas, and increased market demand for storage capacities, PGNiG S.A. (Polish Oil and Gas Company) executes the programme of expansion of the underground gas storage reservoirs. According to the information announced by the company, consistent increase in their total capacities by 1.4 billion m³ is planned by 2015, when about 3 billion m³ capacity is to be available, and the target value in the year 2020 is planned to be 3.5 billion m³.

> GAZ-SYSTEM S.A. is expanding the inter-system connections, but the process of arrangements and execution of infrastructural investments takes a lot of time.
>
> It should be expected that in the coming years there will still be deficit in capacities at the entry point from the West, which will hinder the trading competition.

To some extent, the function of storage reservoirs can be taken over by other market solutions, arising in connection with market liberalization, as e.g. ensuring the trade balancing within the framework of a liquid gas exchange, or legislative solutions which make possible maintaining the obligatory reserves outside the country, when suitably advanced infrastructure appears on inter-system connections. The current wording of the Act on obligatory reserves in this respect is the following: „*Obligatory reserves of natural gas may be maintained outside the territory of the Republic of Poland – in the territory of another member state of the European Free Trade Association (EFTA) – a party to the agreement on the European Economic Area, in storage installations connected to the gas system*". Interpreting it literally, we should infer that gas storage outside Poland is possible in the territory of Norway, Iceland and Lichtenstein, which is practically not feasible. Planned formulation of the Gas Act, which is to replace regulations concerning the gas sector included in the Act on stocks of crude oil, petroleum products and natural gas allows the gas storages to be located outside Poland, also in the territory of EU member states.

According to the information provided by PGNiG, together with implementation of the EU directive and appointment of the Storage System Operator (SSO), all the new capacities will consecutively be made available on the market on TPA principles. In the years to come, also the capacities used by PGNiG so far, will be offered on the principle of equal access. Currently, the official results of two procedures for making the capacities available are known. In the first case, in 2009, no other company, apart from PGNiG, reported any demand, probably on account of the lack of physical opportunity of supplying natural gas to Poland, and consequently – no need to contract the capacities to satisfy the Act on stocks of crude oil, petroleum products and natural gas. A year later, another procedure was carried out, in the result of which applications of three companies, independent from PGNiG, were received. However, they were rejected for formal and legal reasons. Hopefully, the operation model of making the storage capacities available on TPA principles by the SSO will be tested in practice in the next procedures, of which the one related to Mogilno will be settled as soon as in August this year.

Considering the number of infrastructural limitations in the gas system, in order to optimize the use of the infrastructure, it seems justified to implement and keep to the "*use it or lose it*" rule, both in respect of the transmission system and storage capacities. Solution of this kind would increase the extent of infrastructure utilisation, it would limit the possibility of blocking the capacity by the market participants and it would have a positive impact on the development of competition. The already established solutions, contained in the Instructions for Operation and Exploitation of Transmission Network, which enable the system operator to collect the unused transmission capacities did not become an effective optimization tool for maximizing the usage of the existing infrastructure.

Unbundling as the tool of non-discriminatory access to the infrastructure

The third Gas Directive sets principles concerning separation (*unbundling*) of the proprietorial and operational function related to transmission, distribution and storage, from production and turnover. The main goal of the requirements enforced by the Directive is the prevention of any conflict of interests in exploitation of the infrastructure and making investments.

The directive imposes the requirement of legal, operational and decision-making independence in respect of all other kinds of business unrelated to trans-

Models of unbundling specified in the Third Gas Directive

- Full separation – the ownership of the assets and the operator`s function fall within the competence of an entity which must not be related in any way with the business connected with production or trade.
- Independent system operator, the so-called ISO model – assets and the operator`s function are allocated to a separate entity linked by means of capital with the company dealing with production or trade.
- Independent transmission operator, the ITO model – assets are the property of the company operating in the field of extraction or turnover, a separate company related through the capital with this company fulfills the function of operator of the assets.

Having an access to storage gives an advantage in the remaining areas of operation over other entities, regardless of the stage of market development.

In view of the fact, in order to facilitate the development of competition, it is essential to ensure complete transparency in respect of available storage capacities and their allocation.

mission, distribution and storage also for the storage area, but it does not specify in equal detail the separation model. The role of *unbundling* is to eliminate all the incentives to discriminate in respect of access to the network. Therefore, the common and critical item for all the solutions is the necessity to ensure full independence of infrastructural functions from extraction and trade. Appropriate supervision concerning meeting the requirements is then essential, particularly at the level of the member states – through active commitment of the energy market regulators.

The model of complete separation which ensures formal, legal and capital separation of the entities corresponds best to the idea of *unbundling* which ensures full transparency. This model was used in Poland with reference to the natural gas transmission network by allocating the infrastructure ownership and operator`s function to GAZ-SYSTEM. Moreover, it is now being considered to separate the supervision of PGNiG and GAZ-SYSTEM into two government departments: the Ministry of Economy and the Ministry of Treasure.

Activities aiming at ensuring independence are also gradually undertaken with reference to the storage system. Since June 2012, a PGNiG subsidiary has accepted the OSS function. At the same time, the storage assets remain the property of PGNiG. This model must be recognized as compatible with the Directive, but ensuring complete independence and transparency within this model may require additional solutions, such as implementation of internal procedures and regulations within the OSS, which would guarantee the company`s full decision-making independence from PGNiG. An appropriate point of reference in this respect seem to be the specific terms formulated in the Directive for operators of the transmission system. In this context, it also seems indispensable to ensure regular supervision over the regulator in order to meet the requirements concerning independence.

Gas exchange and changes in the Instructions for Operation and Exploitation of Transmission Network

Besides infrastructural issues, liberalization of the market requires the implementation of a number of changes in the system. Liberalized gas market cannot function without the introduction of solutions associated with the transmission system, such as, e.g. a virtual trading point and suitable tools enabling the trading between market participants, as well as establishing the place where the reference price of natural gas can be shaped.

Currently, numerous actions connected with the arrangement and implementation of such solutions are in progress. The new network code for the transmission system introduces the concept of virtual point, simplified principles of balancing the transmission network, solutions which facilitate total allocation of the storage volumes and capacities at the junction points between storage facilities and the transmission system. It also enables switching the gas supplier without the risk of losing access to the network (the so-called '*rucksack principle*'), which simplifies the change of supplier and creates favourable conditions for the development of competition.

In addition, works on the opening of the gas exchange are being conducted in the framework of the Polish Power Exchange. According to the Energy Law, the trade in gaseous fuels on the gas exchange will not, by definition, be subject to tariffs. Entities taking part in the trade will not have to have physical access to the network entry and exit points. The target plans include opening a spot market as well as futures market with physical delivery.

Considering the significance of equal transparent access to the infrastructure for the market participants, it is necessary to ensure independence of the infrastructure operators from companies dealing with production and supplies.
Supervision over the operators should be performed by the President of the Energy Regulatory Office who also has the power to react in case of confirmed violation.

Gas release programme

Implementation of solutions such as a virtual point and a gas exchange is necessary for the development of the market. It must be noted though, that with infrastructural limitations, entering the market by new entities, as well as fostering competition without the introduction of additional solutions is impossible. Entities independent from PGNiG do not presently have any chances to provide significant supplies to the national market.

In numerous European markets, in order to facilitate the entry of new players to the market, programmes were implemented, the goal of which was to create conditions for development of competition. Gas release programmes (run in the form of auctions, exchange obligation), or other programmes of this kind are supposed to weaken the position of the dominant entity. The practice observed in other countries demonstrates that their implementation had a negative effect for the incumbent companies.

The goal of conducting the gas release programme in Poland is creating a wholesale market and leading to the development of competition in the gas market which will allow to abolish tariffs, and dismiss the concerns of the European Commision on the fact of maintaining regulation of prices in the gas market in Poland. At first, price liberalization is to concern the institutions, with maintained tariffs for individual recipients, for the purpose of protecting households against potential increase of prices. Price liberalization for this group is expected at a later time, in 2015 at the earliest.

According to the original shape of the programme, the sale of gas by PGNiG was to assume the form of auction organized with the aid of the Polish power exchange. The volume was assumed to be about 70% of gas consumption in Poland, which corresponds to the annual consumption of industrial recipients. Remarks on the gas release programme, prepared by PGNiG as part of social consultations actually covered all its aspects. The main reservations concerned the method of price calculation, participation of the PGNiG group companies and end users in auctions and the range and flexibility of products offered in the auctions. The European Commission remarked that the gas release programme in the suggested form may not be sufficient for market liberalization and creating the conditions of real competition.

Keeping in mind the market expectations and the EU remarks, the president of the Energy Regulatory Office (ERO) proposed execution of the programme in two stages. In the first stage, the gas stock market is to be opened. PGNiG would play the role of the market animator, offering the natural gas to market participants. In the second stage, introduction of the exchange obligation was proposed, following the example of the already operated solution in the energy market. In unison with the position taken by the president of ERO at the end of May, introduced obligation was supposed to refer to 70% of gas sold by the largest market participants.

Parliamentary project of revision in the Energy Law of June 2012 assumes much smaller volume, imposing the duty to sell 15% of natural gas pumped to the network, which corresponds to about 2 billion m^3 a year. It is difficult to expect that introducing the stock obligation at such level will significantly change the gas market, i.e. bring about an increased number of alternative suppliers and diminished concentration. There

are doubts then, whether the 15% obligation will allow to achieve one of the main goals set by the ERO president for the programme: liberalization of gas prices for industrial recipients.

In the proposed solution one can see a parallel to the electricity market which also operates the exchange obligation of 15%. However, it should be kept in mind that there is a different situation in the wholesale energy market – before the solution was introduced, the liberalization of long-term contracts had been conducted, and there were four energy producers in the market.

It must be stated then that the appropriate direction for regulatory changes should be: increasing the volume covered by the obligation above the proposed 15%, or introducing the mechanism of progressive obligation, or supplementing the obligation with additional open tender.

Effective process of market liberalization requires coordination of activities and consistency between them. The procedures of changing the supplier may have a considerable effect on the success of the programme. The European Commission remarked on the necessity of adaptation of the Polish law to the formulation of the Third Gas Directive in this respect and making it possible for all recipients to easily change the supplier within three weeks. Apart from that, the development of competition would also be enhanced by ensuring the possibility of partial reduction of contracted gas volumes, in the contracts concluded between the recipients and the dominant entity. The regulations do not specify relevant requirements, but from the point of view of national entities bound by contracts for gas supplies, such a possibility is a necessary condition for participation in the gas release programme (GRP). This issue should then be subject to agreements before the introduction of the programme.

Conclusions

Free and equal access to the intersystem connections and storage infrastructure is the main condition for the development of competition. Therefore, activities undertaken recently and comprising the expansion of infrastructure, making it available on TPA principles to interested entities and enhancing the OSS operation transparency must be recognized as favourable to the market liberalization. Still, a lot remains to be done though, and one should wait for notable effects of the commenced activities, in the form of e.g. elimination of bottlenecks in connections with the western and southern neighbours.

In the situation in which we can expect infrastructural limitations in the coming years, implementation of initiatives such as the gas release programme may contribute to increased competition, however only elimination of barriers preventing from entering the market may lead to its actual liberalization. Nonetheless, solutions directed at liberalization of the sector should be introduced on conditions dictated by the market. The most important works connected with anti-monopolization should be coordinated independently from the dominant entities. Also, gas liberalization should also concern the demand side – through simplification of the process of changing the supplier and enabling the partial termination of contracts.

In the period of introducing the most important liberalization changes, the regulator should have suitable tools to facilitate efficient supervision over the market participants and the possibility of appropriate reaction. Therefore, it should be justifiable to increase the authorization for the president of the ERO as the body which supervises the development of the market. Also, a complete implementation of the formulation of the third directive is indispensable.

> The key for the stimulation of the development of competition in the sector is an effective gas release programme. The market regulator equipped with appropriate tools should be the guarantee of success in its implementation. The main criterion for selection of the solutions within the programme, including the determination of volumes covered by the programme, should be a liberalization of the market consistent with the assumptions and schedule adopted by the regulator.

It must be noted that many processes are in progress, which engage various institutions and entities. In order to make sure that liberalization should proceed according to an expectations, the coordination of actions is vital in keeping the appropriate order of implementation and ensuring consistency in implemented solutions.

Legal condition as of 24 July, 2012

The author, Jacek Ciborski,
is Vice Director in Business Advisory at PwC

The author, Anna Kowalewska,
is Senior Consultant in Business Advisory at PwC

Consequences of embargo on Iranian oil

How important is the Iranian oil for Europe and the world?

Maria Woźny

In the recent years, the whole world has anxiously been watching the activity of Iran in respect of acquisition of nuclear energy. The Iranian nuclear programme was the subject of much controversy many times, provoking other countries to impose ever increasingly severe sanctions. The conclusions included in the report by the International Atomic Energy Agency (International Atomic Energy Agency) published in the autumn of 2011 proved to be so alarming that they induced the world to take still more determined and coordinated action. As a result, many countries stopped or substantially limited the import of Iranian oil.

Will the steps taken against Iran prove effective? What impact on global economy will imposing such severe sanctions have on the country which is the third large exporter of oil and significant producer of natural gas? We will know the answer in the months to come.

Abundant resources and sanctions against Iran

Iran is an important point on the energy map of the world. According to the Oil & Gas Journal, documented oil deposits in the territory of Iran reach 137 billion barrels[1], which makes up 9.3% of the world reserves and over 12% of OPEC reserves. Quite interesting is the fact that in July 2011 OPEC announced that the Iranian reserves amount to 151 billion barrels, however, a considerable number of analysts believe the estimates are hardly credible, as they were published soon after increased forecast volumes of oil reserves had been announced in the territory of Iraq which occupies the second place after Iran in the ranking of countries with the richest oil resources in the world. The update on the volume of resources by Iran, in the opinion of some, appears then as the desire to increase the distance with regard to the eternal rival.

All the natural resources of Iran are the national property – private and foreign ownership of resources is constitutionally forbidden. No wonder then that national ownership of such rich resources guarantees high budget receipts – it is estimated that over fifty per cent of the Iranian budget may be generated by the export of oil. The dependence of the Iranian government on the "black gold" is then very high and it is just this relationship that became the main tool for the Western countries to exert influence on the actions of the regime of ayatollahs. For many years, the export of about 2.4-2.5 m barrels a day has ensured Iran the third place in the ranking of the largest global oil exporters.

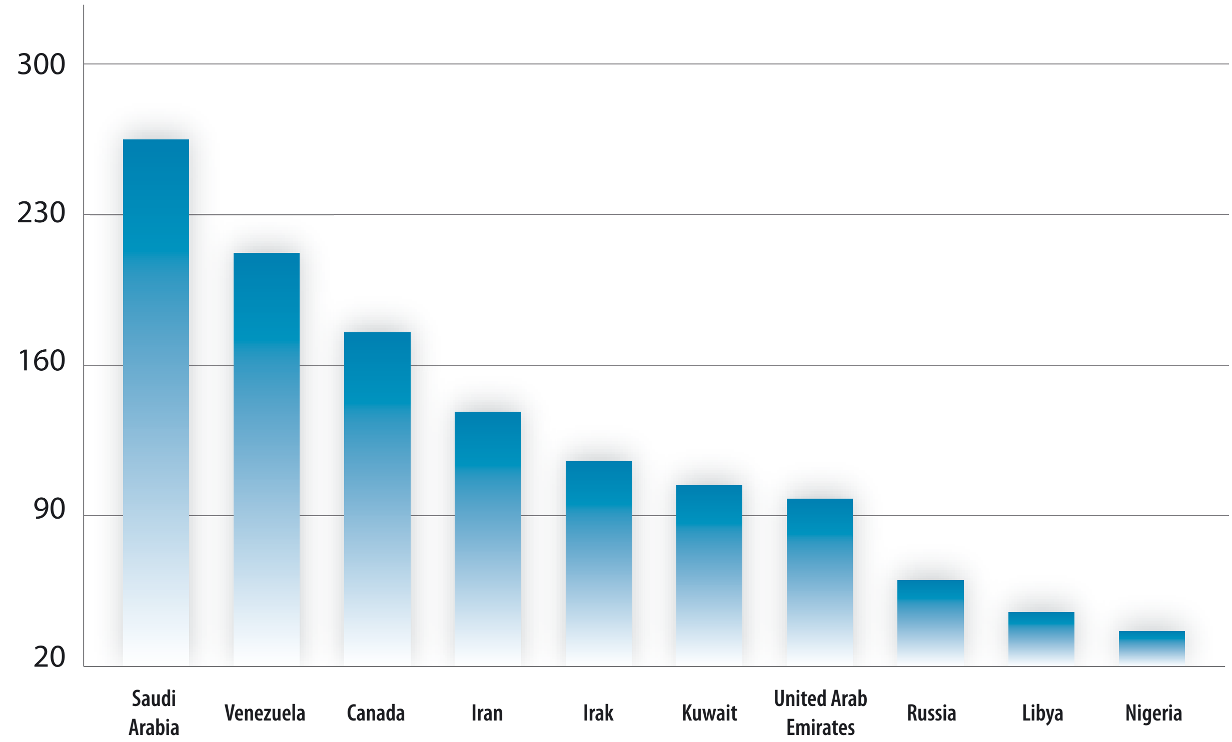
However, in the recent months, a notable fall in the demand for the Iranian resource has been noticed. This situation is a direct consequence of radical sanctions imposed and persistently implemented by the USA and European Union. As a result, the volume of exported Iranian oil is presently at the lowest level in thirty years, equal to about 1.5–1.6 m barrels per day.[2]

1 As of January 2011

2 Reuters

Diagram 1. Oil reserves (as of 1 Jan. 2011) in billions of barrels

Source: Oil and Gas Journal, 2011



Sanctions on Iran have been imposed by various countries and organizations for many years previously. The main reason for this is the nuclear programme developed by Iran, which – according to the assurance of the government – is to serve peaceful goals. However, suspicion on the part of considerable part of the world indicates that it may serve military goals. The USA, already since their breach of diplomatic relations with Iran in 1980, imposed increasingly restrictive sanctions which eventually resulted in stoppage of all trade between the two countries. Simultaneously, as the consequence of Iran`s refusal to abstain from enriching uranium and to undertake cooperation with International Atomic Energy Agency, the UNO – since 2006 – has imposed on this country other sanctions which resulted in, e.g. suspension of delivery of weapons and nuclear technology by the member states to the territory of Iran and blockade of the financial resources of the most important persons and enterprises of the Iranian nuclear industry.

However, the most essential thing proved to be the publication of a report by International Atomic Energy Agency in the autumn of 2011. The included conclusions alarmed the whole world so much that they led to global mobilization, the effect of which is imposing a series of radical sanctions by the countries of all continents. The said report claims that the Iranian government has already taken the most vital steps to start producing nuclear weapons, and even suspects Iran of conducting works on its own bomb since at least the year 2010.

In response to such a claim, in December 2011, the president of the USA, Barack Obama, signed an act imposing sanctions on foreign banks conducting transactions of purchase and sale of oil with the Iranian central bank.

Echo of the embargo

Regardless of the actions taken by the USA, on 23 January 2012, ministers of foreign affairs of the European Union reached a common decision to impose an embargo on import of the Iranian oil, freezing the resources which belong to the central bank of Iran and stopping all trade in gold and other noble metals with the Iranian central bank and public institutions. Moreover, the ministers decided to postpone the date of introducing the embargo by 1 July 2012 so as the member states had enough time to find alternative sources of importing oil.

As soon as the information concerning the action planned by the USA and EU saw the light of day, the

Diagram 2. Export of oil (barrels per day)

Source: CIA, the World Factbook

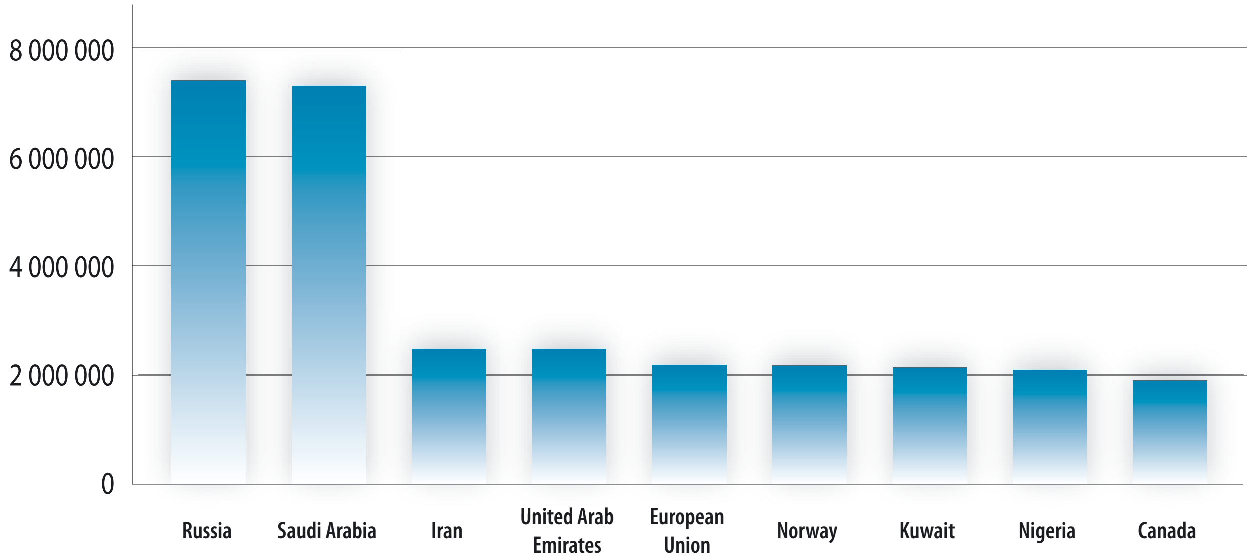
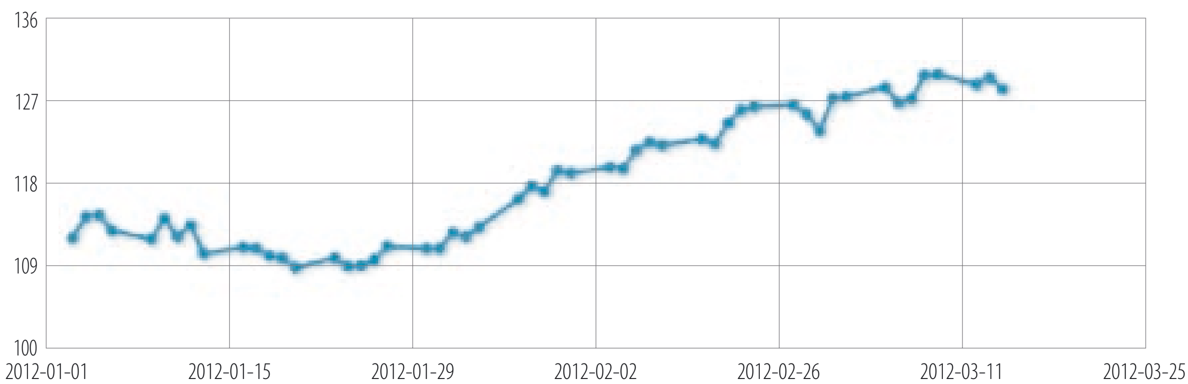


Diagram 3. Rising prices of Brent oil from January to March 2012 (in USD)

Source: Reuters, www.reutersknowledge.com



analysts of the market of raw materials and economists began to create forecasts of the impact that the steps taken would have on the oil market and global economy. In the first weeks, only skeptical opinions seemed to prevail. The analysts remembered first of all the December threats from Iran, according to which Iran was to block the Ormuz strait, if the USA and UE imposed sanctions on the export of Iranian oil. Blockade of the strait which serves as transmission channel for as much as 40% of the world trade in oil by sea, and 20% of total world trade in oil at the time when global economy deals with problems, in a short time might jack up the oil prices to an unprecedented scale and upset the economic balance of the world.

Further course of events is difficult to foresee. In the opinion of vast majority of experts, Iran could block the strait only temporarily, although some analysts think that the world does not appreciate the military power, determination, and also international support that Iran can count on, and they assess that clashes in the waters of the Ormuz strait might establish a new economic order in the world.

It must be noted that there are premises pointing out to the fact of providing support to the Iranian nuclear programme by Russia. It is suspected that Russia executed the deliveries of enriched uranium for Iran and supported that country in respect of technological *know-how*. The Russian minister of foreign affairs officially declared that military intervention in Iran would be a serious mistake and might entail effects impossible to predict. The Iranian nuclear programme is also said to be supported by Pakistan and North Korea which challenged the world many times already by testing nuclear weapons. Though the majority of analysts assess such scenario as rather unlikely, and soon after the sanction was announced, Iran itself withdrew its threats relating to the blockade of the Ormuz strait, investors were forced to take into account the risk of military conflict in their prognosis of prices of oil, which is clearly demonstrated in Table 2.

More expensive oil due to restrictions

According to estimates by EIA, the sanctions resulted in the fall in the world supplies by about 800 thousand – 1 million barrels a day, which translates to an increase in prices from about 110 USD to about 130 USD (increase by almost 20% within a little over a month). Higher prices contributed to an increased number of embargo opponents who doubted the effectiveness of introduced sanctions. In conditions of dynamically rising oil prices, budget receipts from the export of "black gold" might prove higher, even at lower volume of sales – which completely upset the legitimacy of introduced sanctions. Besides, Iran found a way to circumvent the EU embargo – the Iranian tankers transported oil to Egypt, and then it was sent by pipelines to the European refineries.

Analysts pointed out that apart from Iran itself, the sanctions established by the USA and EU would be severe for countries which satisfy significant part of their demand for oil with Iranian resources.

Dependence on the Iranian oil

In the European Union, the countries which are the most dependent on import from Iran were the member states whose economies were in a very poor condition: Italy, Spain and Greece. Italy and Spain together collected almost 75% of Iranian oil exported to the EU. In 2011, both countries covered about 13% of their total demand for oil due to Iranian fuel.

In spite of the fact that Greece imported only small part of the Iranian oil, it strongly relied on it – EIA estimates that in 2011 this country satisfied over 50% of its demand for oil with import from Iran. This situation resulted largely from financial problems that Greece was trying to overcome in the recent months. Low flow and limited availability of debt financing induced the Greek government to increase the import of cheap oil from Iran which did not require any bank guarantee on the Greek purchase. No wonder then that it was Greece that became the loudest opponent of embargo in the EU.

However, for many years, the largest recipients of the Iranian oil were Asian countries, and it was that group that was to suffer most from the consequences of sanctions introduced by the USA; it concerns e.g. China, Japan, India, South Korea and Turkey. The sanctions found Japan at a particularly difficult time – closing down the nuclear power station in Fukushima increased its demand for other sources of energy – including oil. Turkey, which like Greece was strongly dependent on the Iranian oil, criticized the sanctions very long and objected to cooperation with the USA and EU, claiming that it will not be affected by actions which have not been ratified by UNO. The Turkish government was also well aware of the fact that the approval of embargo by UNO was impossible, as Russia and China would not let that happen and they certainly would not hesitate to use their right of veto.

In March this year, president Barack Obama announced that the countries which by 28 June 2012 would not reduce significantly their import of oil from Iran, would be cut off from the American financial system. Also in March, the Union decided to cut off Iran from the SWIFT system which maintains the communications network used in international transactions between financial institutions. These actions were clearly the signal that neither EU nor the USA are going to temper their policy towards Iran and they will persistently aim at a situation where the fall in receipts from oil export will force Iran to undertake cooperation with International Atomic Energy Agency and verification of its nuclear programme.

What in exchange for the Iranian oil?

Well aware of the fact that high oil prices make the imposed sanctions pointless and that they increase the number of their opponents, the USA intensified their actions aiming at provision of reliable replacement for the Iranian oil – the USA government representatives

Iran – oil export (January-June 2011)

Country	% export from Iran	Volume of oil imported from Iran (in thousands of barrels per day)	Iranian oil as % of imported oil
China	22	543	11
European Union	18	450	
Italy	7	183	13
Spain	6	137	13
France	2	49	4
Netherlands	1	33	2
Germany	1	17	1
Great Britain	<1	11	1
Other	1	22	1
Japan	14	341	10
India	13	328	11
South Korea	10	244	10
Turkey	7	182	51
South Africa	4	98	25
Sri Lanka	2	39	100
Taiwan	1	33	4

Source: EIA

went to Saudi Arabia in order to negotiate higher oil output. Saudi Arabia agreed to fill the gap in the world oil supplies left by Iran, in spite of the fact that the latter warned to initiate retaliatory action against a country which chooses to take such steps. Official argumentation provided by Saudi Arabia pointed at the necessity of reducing the prices of "black gold" in order to stimulate the global economy which – in condition of continuously soaring prices – might experience serious difficulties in overcoming the stagnation in which it has been plunged for over a year. Such a situation would translate into a long-term fall in global demand for oil and eventually – fall of the influence of OPEC countries.

As the result of actions taken by Saudi Arabia, in April 2012 production of oil in all OPEC countries had gone up to record volumes over the last 30 years, amounting to approximately 31.85 million barrels of oil a day – i.e. by over 5% more than is the official output limit of OPEC countries (30 million barrels a day). According to EIA estimates, in the effect of higher production of oil by Saudi Arabia in April 2012, in the global oil market a surplus appeared of about 2 million barrels a day. At the same time, the G8 countries announced that they would not hesitate to use their strategic reserves if, on account of sanctions imposed on Iran, oil prices were still rising. As IEA informs, the assurances should be treated seriously, as similar situation had taken place during the crisis in Libya.

Political determination to maintain the oil rating at a low level is enormous – president Barack Obama himself officially assured his allies that oil prices would not rise. Moreover, EIA was obliged to monitor and forecast the availability of oil and its price levels and its derivatives in countries other than Iran, and submit a report with relevant conclusions to the USA Congress every 6 days, so as the Congress can intervene when necessary.

Simultaneously, politicians are making attempts to reassure analysts, reminding them that intervention in Iraq resulted in diminished world oil supplies by about 3 million barrels a day, which makes up a value as much as three times bigger than the fall in supplies created by sanctions imposed on Iran, and despite the fact, the increase in oil quotations was not that dynamic. The effect of all the actions described above is reversing the rising trend of oil ratings in mid-March 2012, which is demonstrated in Table 3.

Profiteers or reaction of the market?

As OPEC reports, in April, May and June this year, oil quotations lost almost 10% each, which made up the longest and gravest wave of falls in the recent 13 years. The reasons for such significant reductions in oil prices are – in the OPEC`s opinion – several factors: mass speculative sales of fixed-term contracts for oil, a surplus of supplies due to increased production by Saudi Arabia, threatened stability of the euro zone and poor macro-economic data, also in relation to China and India. According to OPEC data, the period with particularly high activity of speculative investors was May, when the players who occupied long positions, sold over 830 thousand of contracts within just two weeks.

Along with the fall of prices, grew the political pressure on the oil importing countries. Although the EU embargo was to be introduced only on 1 July, 2012, majority of the member states stopped the import of the Iranian oil already in the first months of the year. After Iran had been cut off from the SWIFT system and when difficulties appeared in handling the trade with Iran, also Greece – very reluctant towards imposed embargo – had to replace the import of the Iranian oil with deliveries from Russia and Saudi Arabia. And it is just the two countries, together with Libya, that replaced Iran in the role of supplier of oil to the European market. On account of the fact that by the end of March all the European countries stopped or substantially reduced the volume of oil import from Iran, they were relieved of the sanctions imposed by the USA already in the first days of April.

Apart from embargo, the EU sanctions included also a ban on insuring the Iranian oil transport by sea by the European insurance companies. It should be noted that as much as 95% of global oil transport by tankers is insured by companies based in London. Although, similarly as with embargo, the above ban was to become effective only on 1 July this year, the political pressure accelerated this process. The lack of possibility to insure the cargo discouraged the companies dealing with oil transport by sea from further cooperation with Iran. Considering the fact that execution of deliveries of the Iranian oil by tankers sailing under the native flag is hindered as the Iranian tankers will not be allowed to enter a great number of international harbours, introduction of the ban had very painful effect on Iran. In the opinion of many experts, the ban turned out to be more severe than the embargo itself.

Soon, Europe was followed by Asian countries. According to Reuters, Japan, which in 2011 imported on average 340 thousand of barrels a day, in March 2012 reduced the purchase of the Iranian oil to 300 thousand barrels a day, and after a month – to about 120 thousand barrels a day. Owing to such perceptible cuts, in April, the USA lifted the sanctions concerning Japan.

Diagram 4. Dynamics of Brent oil prices from January to June 2012 (in USD)

Źródło: Reuters, www.reutersknowledge.com

It should be emphasized that the government of the Land of the Rising Sun emphasized many times that they were not able to completely stop the purchase of the Iranian oil. Therefore, when it was no longer possible to insure tankers with EU companies which used to do that before, the Japanese government established national guarantees on insurance of the Iranian oil deliveries in the territory of Japan up to 7.6 billion USD.

India, Turkey, South Korea and South Africa, which had been blacklisted by the USA for a long time, and had no intention to accept the American sanctions, finally also took steps to diminish their purchase of oil from Iran. As Reuters informs, India and particularly Turkey, critical of the sanctions, managed to reduce the Iranian oil import by about 20%, South Africa by about 40%, and South Korea, on 1 July, 2012 decided to completely suspend the purchase of oil from Iran. By the way, the decision of the Korean government was induced in the first place by complications in the insurance market. As a result, on 11 June, these countries were relieved of the sanctions imposed by the USA.

Chinese exception

Quite a riddle has become lifting the sanctions imposed on China which is the largest investor in the territory of Iran, and also the biggest importer of oil extracted there. It should be remembered that the oil market in Iran is monitored by the National Iranian Oil Company (with subsidiaries) which reports to the Ministry of Oil, and public ownership of natural resources is guaranteed by constitution, so running investments by foreign companies is considerably hindered. Officially, foreign companies may engage only in extraction projects by the so-called "*buy back contracts*". However, on account of successive restrictions imposed on Iran, for many months one could observe the outflow of foreign investors from this country. In spite of that, projects like *upstream* are still being executed together with the Chinese companies, as in case of the Azadegan deposit (26 billion barrels of documented reserves, according to EIA), which is the greatest discovery in the territory of Iran in the last 30 years. This deposit is exploited by the group China National Petroleum Corporation; originally, also Japanese company INPEX was to take part in the project, but in 2010 it totally withdrew from the venture.

China is also the largest importer of Iranian oil. According to EIA estimates, it is the recipient of about 22% of oil extracted in the area of Iran. Simultaneously, China emphasized many times that they would not obey any sanctions imposed on Iran. Therefore, the world observed with great astonishment the actions of the Chinese government in the first quarter of the year, when the import of Iranian oil to China fell by nearly 33% on the year 2011. However, as it proved later, the fall was most probably caused by a misunderstanding between the governments of both countries with relation to price for executed oil deliveries, but it was not the result of abiding by the international sanctions on the part of China. This hypothesis seems to be confirmed by the fact that although in the first quarter of 2012 the import of the Iranian oil to the territory of China went down, in April and May it already noted an increase relatively by about 48% and 35%, taken month by month.

Many analysts indicate that real sales of oil from Iran to China may be higher than official data, as Iranian ships turned off the positioning systems so the deliveries were impossible to trace. In this situation, the announcement that China is relieved of sanctions imposed on Iran, as the answer to alleged obedience of China to the American directives, in the last week of June made the US government lose credibility in the eyes of many observers. To tell the truth, some analysts predicted that China would be excluded from sanctions, but nobody expected such argumentation. It was expected that official reason given to the public would be closer to reality, like e.g. that the USA would point to the question of national security.

The risk of military conflict

In July, BBC informed that Iran found another way to circumvent the EU embargo. 15 out of 39 of Iranian tankers sail under the flag of the Tuvalu island, transporting the oil from Iran to the whole world. However, in spite of finding more and more sophisticated methods of bypassing the sanctions, there is no denying that Iran severely felt their effects. According to EIA estimates, the effect of sanctions imposed by the USA and embargo introduced by the EU was comparable. Both the sanctions and embargo brought about a fall in global demand for the oil from Iran by about 500 thousand barrels of oil a day. Total fall in demand by 1 million of barrels a day, i.e. nearly by half in relation to the mean volume in the recent years, substantially reduced receipts to the Iranian budget, which most probably was more noticeable by ordinary citizens than the regime. It is true that so far, no rumours have been heard about social unrest or strengthening of opposition on a scale comparable with the one that took place in Egypt or Libya during the Arabian "Springtime of Nations" in 2011, but it can be expected that maintaining the present situation in the long run will increase the risk of outbreak of social upheavals.

Unexpected fall in demand for the Iranian oil, at unchanged level of production and small storage capacity at the disposal of Iran forced the country to store the surplus of oil in tankers. When those had been exhausted, Iran had to considerably limit production. As EIA informs, production of Iranian oil is at present at the lowest level in 10 years. In published OPEC report in June, the fall between January and May amounts to about 16% – according to OPEC`s own estimates based on external sources. Quite interesting is the fact that information supplied to OPEC by Iran itself points to about 6% increase in production in the same period, however, the data seem to be hardly credible.

High decline in extraction (8-13% annually) from Iranian deposits makes it necessary to perform costly intensification of exploitation, whereas the outflow of foreign capital and low receipts from the export of oil translate to the lack of funds to finance such procedures. Since the sanctions were imposed, total number of projects executed in the *upstream* sector in Iran have been reduced, and those which are still operated are slowed down due to lack of access to specialist knowledge, technology and financing. As a result, EIA estimates that production capacities of Iran will go down by about 15% by the end of 2012.

After sanctions were introduced in Iran, general number of projects executed in the upstream segment in this country has substantially diminished, and those currently in progress have slowed down, due to lack of professional knowledge, technologies and financing. As a result, according to EIA estimations, the output capacities of Iran will have fallen by about 15% by the end of the year 2012.

The effects of imposing sanctions by the USA and UE proved to be really severe for Iran. Probably even more severe than the analysts, economists and even Iran itself forecast at the beginning. However, it is difficult to predict how this fact will influence the actions of the Iranian government, cooperation with International Atomic Energy Agency and development of the situation in respect of the Iranian nuclear programme. This program is the question of the national pride, and also, in the eyes of the Iranian politicians, is closely connected with national security, therefore it will be rather difficult to convince the ayatollah government to abandon it. The more so that quite recently, Iran could observe what happened to the regime of the countries which collapsed during the Arabian "Springtime of Nations", which had not happened in North Korea which owns nuclear weapons.

At present, the threats of introducing blockade of the Ormuz strait by Iran also seem hardly credible. On the other hand, the oncoming presidential election in the USA suggest that Barack Obama will also try to tone down the situation and at least, till the autumn, maintain the present *status quo*. At the same time, as the recent months have shown, the American determination to keep the oil prices at a low level is very strong, which brings to mind that in case of further pressure on increasing the oil prices, the USA would make another intervention, using, among other things, its relations with Saudi Arabia – which for several months efficiently replaces Iran in the role of oil supplier.

In spite of insistence from many OPEC member states to keep to the assumed extraction plans of 30 million barrels a day, it is rather unlikely that Saudi Arabia, strongly befriended by the West, should limit the oil extraction in the months to come. In this situation, the most likely seems a scenario in which at least by the end of the year 2012 sanctions against Iran will have no significant impact on the world or European economy. In addition, the forecast by OPEC and IEA, according to which dynamics of higher global demand for oil will substantially decrease, makes one think that imposing embargo on oil from Iran should not have great consequence for the economies of Western countries, even the next year. Also, some analysts expect that the destructive influence that the sanctions have on the economic condition of Iran will lead to protests of the society and that will make the ayatollah government more inclined to cooperation with the USA and UE.

It is obvious though that when no peaceful settlement of the argument between the Western countries and Iran is achieved soon, the USA will have to take a more decisive position towards China, because if it does not begin to obey the established sanctions, it is hard to imagine the effectiveness of the restrictions. What is more, the risk of military conflict, though less probable, is real and should not be ignored. The situation is so strained that a small spark might trigger the outbreak of international war, the effects of which are difficult to predict. Simulations of the conflict run by the American military forces do not exclude even the use of tactical nuclear weapons.

The author is Senior Consultant in Business Advisory at PwC

OIL:
exploration, extraction, sales

Best Available Techniques guarantee LOTOS sustainable development

Top priority – exploration and production

The volatility in the macroeconomic environment of the oil sector, waiting for clear signs of an economic revival in Europe, and the opinions of experts who expect that oil prices will maintain the level of USD + 100/bbl in the long-term perspective are forcing oil companies to take pro-active development action.

Oil sector peers which hold their own crude deposits and deep conversion refineries are in a much more favourable position. LOTOS, thanks to the development strategy launched a year ago and the successful strategic investment project – 10+ Programme – fulfils both the abovementioned criteria. For LOTOS, the next and following years will see further development, aimed at enhancing the security of the Polish energy sector, strengthening its position on the fuel market and increasing its goodwill.

The potential cutting edge of LOTOS is already provided today by the refining area. Due to planned and professionally completed investments, such as the construction of new systems for oil processing and the production of liquid fuels (within the 10+ Programme), LOTOS is today in a privileged position to achieve major benefits from the expected improvement of the macroeconomic situation.

Europe is starting to experience a shortage of modern oil processing capacities necessary to produce high-margin fuels. But the LOTOS refinery plant provides products of the highest quality and processes feedstock within high conversion standards, which enhances the financial effectiveness of the operational segment and reinforces the competitive position of the entity in the market. The clearly defined strategy of development at LOTOS and its effective execution were confirmed by record-breaking results for 2011. Sales revenues generated by LOTOS in 2011 after four quarters achieved a level of almost PLN 30 billion and were higher by 49% year-to-year. In 2011, the company's EBIT amounted to PLN 1,016 million and net profit exceeded PLN 654 million.

> Owing to production from the fields, LOTOS will obtain double benefits: it will provide the security of supplies from own resources and obtain feedstock at a cost lower than the market price.

Lower emissions, greener plant

Why have technologies become the strength of LOTOS? The answer is clear. At the start of the previous decade, LOTOS planned its development so as to outstrip the competition and to adapt its product offer to new market demands. The Management Board recognised that a technological leap in development was not a question of choice but a necessity. Only the development of the refining plant and its modernization, based on Best Available Techniques, enabled LOTOS to take a strategic position among European refineries.

The 10+ Programme, the value of which amounted to EUR 1.5 billion, proved the largest industrial investment project of the last decade in Poland. It was a gigantic investment programme, not only on a domestic scale but also in the European downstream industry, and also a technological and organizational leap into the future. The 10+ Programme became a permanent element of the energy security of Poland, as the refining plant in Gdańsk increased its output capacity by 75%, from 6 million to 10.5 million tonnes per year. Professionalism in the approach to this investment project is visible as the refining plant has the guaranteed long-term perspective of safe operation with the highest technical parameters and the best market results.

Due to the changing market of oil prices, it gives the potential to obtain the maximum of high-margin products, such as medium distillates, regardless of the oil grade. Owing to the construction of two-train independent crude distillation units, the refinery has gained the option of non-stop operation, even during shutdowns, which is of great importance for technical, market and financial efficiency.

The effects of these improvements were already visible in 2011. The consolidated sales of LOTOS exceeded 10 million tonnes of products, recording a 14% rise compared to 2010. At the same time, the company is capable of offering the market products that comply with stringent EU requirements. Environmental standards are tightened year by year, therefore, the environmentally-friendly LOTOS plant already operates in a cheaper and safer manner. The smaller amounts of heavy products mean less impact of the plant on the environment. The applied 'green' technology effectively reduces the ecological costs of the refining plant's operation. The higher production capacities of the refinery in Gdańsk result in a broader sales offer.

Crude derived from own fields

A professionally managed oil company has to be active in the area of hydrocarbons exploration and production. Such activities directly raise its valuation, provide the stability and security of operations in the long-term and improve the profitability of production.

fot. Mateusz Cabak

Therefore, the segment of oil exploration and production is a priority in the LOTOS strategy for 2011-2015. In practice, this implies continued involvement in upstream projects in Poland, Norway and Lithuania.

According to the adopted strategy, LOTOS plans to produce 1.2 million tonnes of crude annually by 2015. It is estimated at present that the available resources of oil under licenses managed by LOTOS amount to approximately 55 million barrels and 4.5 billion m^3 of natural gas. LOTOS is focusing on Europe, consciously selecting a region characterised by a low-risk level (including legal, political and social-cultural risks). Owing to production from the fields, LOTOS will obtain double benefits: it will provide the security of supplies from own resources and obtain feedstock at a cost lower than the market price. This is important, as according to analysts oil will become more expensive in the long-term. As a result, if a clear recovery in the global economy occurs, the demand for this product will rise as well.

The decreasing number of easily available oil fields enhances the exploration of new deposits, which implies more difficult conditions and a higher price per barrel. Therefore, LOTOS keeps systematically activating its upstream programmes. LOTOS Petrobaltic has 7 licenses on the Baltic Sea, which entitle it to search for conventional and non-conventional hydrocarbon fields. They are located in the Eastern part of the Polish exclusive economic zone of the Baltic Sea. The B3 field operates on the Baltic Sea (oil and natural gas). Moreover, temporary production is conducted from the B8 field.

Finally, gas fields, B4 and B6, are available for production. LOTOS carries on negotiations with potential partners on these fields. In Norway, LOTOS Exploration and Production Norge AS has 8 available exploration and production licenses on the Norwegian Continental Shelf, and works as an operator under 3 licenses, i.e. is a leading company in the whole process of developing a field and commencing commercial production. In Q2 2012, an appraisal drilling well is planned under the PL497 license, where LOTOS Norge has a 10% share. Under the PL498 license, where LOTOS Norge is an operator, preparations are underway to make an appraisal drilling well, which should be completed in Q3-Q4 this year.

Owing to the acquisition of 100% in AB Geonafta (at present LOTOS Geonafta), LOTOS has gained access to onshore oil fields located in Lithuania. The company operates 4 appraisal and exploration wells. Moreover, LOTOS is interested in the exploration and production of shale gas in Lithuania. The company intends to make one appraisal drilling well this year to search for non-conventional gas and to determine the field potential. If LOTOS finds partners for these projects, more wells can be bored. LOTOS realizes that the production of shale gas is a difficult task on a great scale, which requires specialist experience, complex technology and a large budget. It also relates to environmental and social issues. Shale gas can definitely improve the safety of the power sector; however, many years have to pass before concrete results, i.e. commercial production and distribution, are obtained.

State-of-the-art retail network

According to data by JBC Energy in 2012 the planned increase in demand for oil in Central and Eastern Europe will amount to 35 thousand bbl/d. In Poland, this surge will be at almost 4%. This trend results primarily from the stronger domestic demand for diesel in transportation.

To meet clients' growing needs and to place larger volumes of products stemming from 10+ Programme installations LOTOS is developing its distribution and retail sales network intensely. In July 2011, LOTOS Optima, a new brand of economic petrol stations, was launched. Until the end of 2011, 50 sites were opened, within the target of 150 LOTOS Optima stations operating in the network in the near future. At present, more than 360 sites operate in LOTOS. Owing to the development and modernization of its retail, LOTOS' share in domestic sales totalled 8.2% in February 2012. That has strengthened the company's position in the market. The share in the wholesale fuel market in that period reached 35.1%, i.e. 5.1 percentage points more than the planned strategic objective. These results prove the high production capacity of the refining plant, which is fulfilling the growing demand of wholesale clients, and the rising demand for high quality fuels offered by LOTOS. ■

Oil Pipeline Exploitation Enterprise „Friendship”

PERN “Przyjaźń“ S.A. is a dynamically developing Group of companies which comprises five subsidiaries, apart from **PERN “Przyjaźń“ S.A.**: OLPP Sp. z o.o., NAFTOPORT SP. z o.o., CDRiA Sp. z o.o., PETROMOR Sp. z o.o. and Siarkopol Gdańsk S.A. The Group is supplemented with an International Oil Company SARMATIA Sp. z o.o. – a company whose goal is to study the profitability of the construction of the Eurasian Oil Transport Corridor. In total, the Group has almost 3.0 million m^3 oil storage capacity and 1.8 million m^3 liquid fuel capacity. It also has an offshore trans-shipment terminal of capacity of 34 million tons of oil per year. Its operations comprise oil transport, trans-shipment and storage, fuel trans-shipment and blending, and laboratory study of oil products.

PERN “Przyjaźń“ S.A. – the company which dominates in the Group, is a company with 100% shares in the State Treasury. It was created in 1959 in order to transport oil from Russia to Poland and to Eastern Germany. The company manages directly the network of over 1500 km of oil and product pipelines.

The company’s main task is to exploit the network of pipelines which transports Russian oil to the largest fuel producers in Poland and Germany. The rendering of this service is possible owing to the “Przyjaźń“ pipeline which goes from Adamowo (near the Polish-Belarusian border) to Płock and then to Schwedt in Germany. The most vital factor in oil supplies to the Polish refinery is the Pomeranian Pipeline which connects Płock with Gdańsk and which enables transport of the resources in both directions. The oil may be pumped to Naftoport in Gdańsk and then it is transported by oil tankers for export. This pipeline creates a possibility of supplies for the Polish and German refineries with materials which come from other directions than “Przyjaźń” pipeline. Consequently, it results in the so-called supplies “from the sea”, trans-shipment in Naftoport and the material is pumped towards Płock.

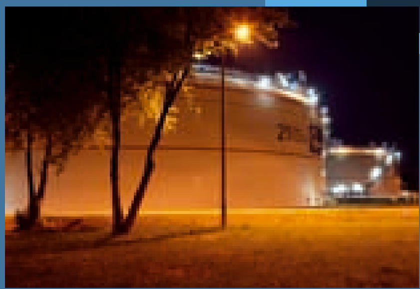
Apart from the network of pipelines transporting oil, **PERN “Przyjaźń“ S.A.** also has a network of product pipelines used for transporting liquid fuel produced by refineries. This network branches from Płock towards Warszawa, Poznań and Częstochowa.

The most essential service – for the energy security of the country – rendered by **PERN “Przyjaźń“S.A.** is oil storage. The company has three storage reservoirs: in Adamowo, Płock and Gdańsk, they are equipped with containers of a capacity ranging from 32 thousand to 100 thousand m^3.

Przedsiębiorstwo Eksploatacji Rurociągów Naftowych „Przyjaźń” S.A.
ul. Wyszogrodzka 133, 09-410 Płock

tel: (024) 266 23 00
fax: (024) 266 22 03

e-mail: zarzad@pern.com.pl
www.pern.com.pl




Possibility of increasing the oil recovery factor

More oil from a reservoir

JAN LUBAŚ, WIESŁAW SZOTT

In the age of considerable interest in unconventional hydrocarbon resources, conventional oil reservoirs, whose discovery required huge investments, should not be underappreciated. The size of the identified resources is quite significant and exceeds 100 million tonnes. During this time of rising oil prices, increasing the recovery factor is not only important due to economic reasons but also for the prestige of the Polish oil industry, a pioneer in the worldwide petroleum industry.

Petroleum production is particularly economically justified and effective when methods of enhanced recovery, appropriate for existing reservoir conditions, are adopted. When only primary production methods are applied, i.e. recovery is driven by the natural reservoir energy, only a low recovery factor can be achieved. Secondary and tertiary production methods, i.e. oil displacement due to external energy and media injected into a reservoir, allow for effective recovery production which complies with the best mining practices.

The primary recovery factor results from the natural energy of a reservoir and, depending on the natural reservoir pressure, can vary between 5 and 60% [5], although typically it ranges between 5 and 20% [6]. With the methods of enhanced oil recovery, the result can even be twice as high. Because enhanced oil recovery techniques utilise already existing underground and surface infrastructure, this increase has a significant impact on the final economic result.

Previous projects carried out in the Polish petroleum reservoirs

In Poland, particularly in the Carpathian region, methods of enhanced oil recovery have been used with very good results since the 1930s. Techniques applied in that early period included the following:

- water injection,
- natural gas injection,
- air injection,
- in situ combustion,
- microbial method.

In later periods, these methods were also extended to reservoirs in the Polish Plain and the Baltic Sea. Particularly worth mentioning are water injection operations applied on a large scale in the Osobnica, Kamień Pomorski and B-3 (Petrobaltic) oil reservoirs.

Due to the water and gas injection techniques applied in the **Osobnica** reservoir, the recovery factor in this reservoir reached 33%. If the technical conditions had been more favourable than those encountered in the reservoir, particularly if the quality of the casing seal in injection wells had been better (determined using tritium tracers), a recovery factor of 40% could have been achieved. The recovery factor in the comparable Węglówka (central element) reservoir, where no enhanced recovery techniques have been used, is 21% at its final production stage.

Water-injection operations carried out in 1976 in **Kamień Pomorski** utilised three wells. The main aim was to stop the reduction of reservoir pressure and to keep it above the saturation pressure of 16.18 MPa. The operation allowed the spontaneous recovery from those wells to be extended and the oil recovery factor to be increased. Due to the shape and size of the structure, peripheral water injection was used. The method of water injection used resulted in the displacement of oil from the perimeters towards the main part of the reservoir, which significantly increased the recovery factor.

In 1994, the program of reintroducing sulphur-rich natural gas, produced during gas-oil separation, was launched [8], and until now nearly 10 million Nm^3 of gas has been injected. This operation stabilised the reservoir pressure at a level of 20 MPa and resulted in a high oil recovery factor which currently is 42%.

B-3 Petrobaltic: natural water encroachment into the reservoir became apparent during the production, but the aquifer influence was not sufficient to maintain the reservoir pressure. After about 5% of the oil-in-place had been recovered, the reservoir started to transform into a dissolved-gas system. According to estimates, a further decrease in the reservoir pressure would lead to the production with a final recovery factor of 10%. Therefore, a program of peripheral water injection was designed and implemented [3]. The locations of wells were designed in such a way that they could possibly cover the whole area of the reservoir and ensure good displacement of oil towards the production wells. The injected water caused an increase in the reservoir pressure to a level of about 11 MPa, which exceeds the saturation pressure. During the initial period, the average ratio of injected water to recovered fluids (water and oil) was between 1.4 and 1.8 [4], while currently it is about 1.0 to 1.2 SCm^3/SCm^3. Over 3.6 million tonnes of oil has been recovered, while the current recovery factor has reached a level of 27%.

Potential of new projects

The Polish Plain

The main reservoir formation in the area of the Polish Plain comprises dolomite strata which are both source and reservoir rocks. Calculations based on simulations [7] showed that for the largest carbonate reservoir (BMB), characterized by double porosity and combined energy mechanism, the recovery factor from the primary production using the existing grid of wells should be around 20%. If additional horizontal and vertical wells were drilled this value should increase to about 23%.

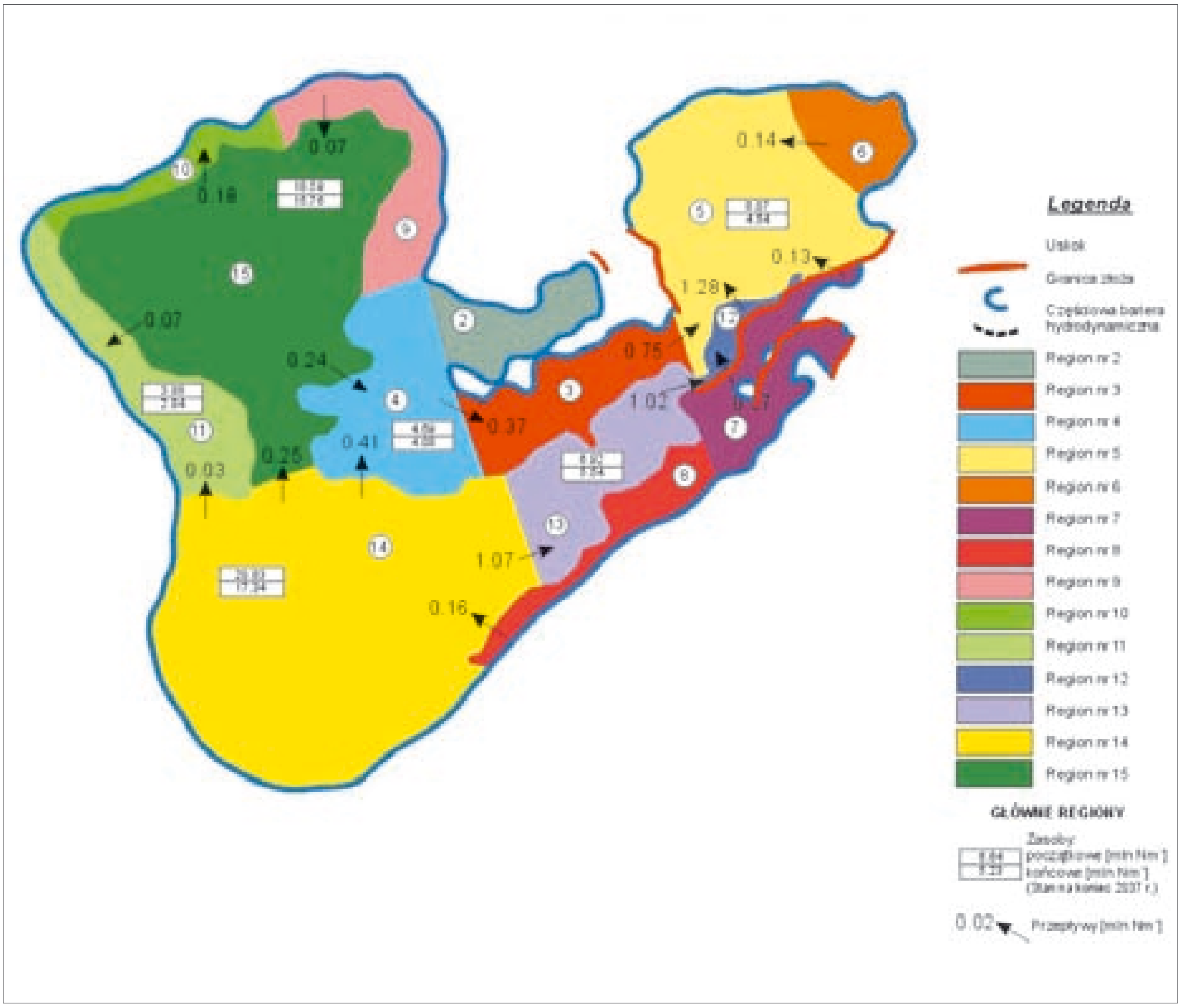


Fig. 1. Amount of recoverable reserves in selected regions, reservoir simulation results [7]

These are average data as the recovery factor values vary for the individual parts of the reservoir as follow (Fig. 1):

- eastern part – 32%,
- central part – 24%,
- western part – 16%.

The ultimate recovery factor of 23% is not a satisfactory result. Thus, as part of the research program [7], a series of experiments and simulations were carried out. The most important included the following:

- drilling optimisation, supplementary wells;
- simulation modelling of reinjection of excess natural gas into the gas cap;
- long-core oil displacement tests using various fluids and their combinations;
- simulation modelling of the processes of water injection as well as injection of CO_2 from the Gorzów power plant and H_2S from the Różańsko field.

Figure 2 presents the results of long-core oil displacement laboratory tests which were carried out using various media under the reservoir conditions (temperature of 119°C and pressure of 45 MPa):

- gas (natural gas from the BMB reservoir, Cychry reservoir, H_2S, and CO_2; last two gases under supercritical conditions);
- gas with a condensate buffer, volume of the condensate was 6–14% of the pore volume;
- water, also with a gasoline buffer; volume of the condensate was 6% of the pore volume.

The highest recovery factor ranging between 70 and 90% was reached using gas injection with a significant amount, i.e. 12–14%, of the condensate buffer. Slightly poorer results, ranging between 40 and 55%, were

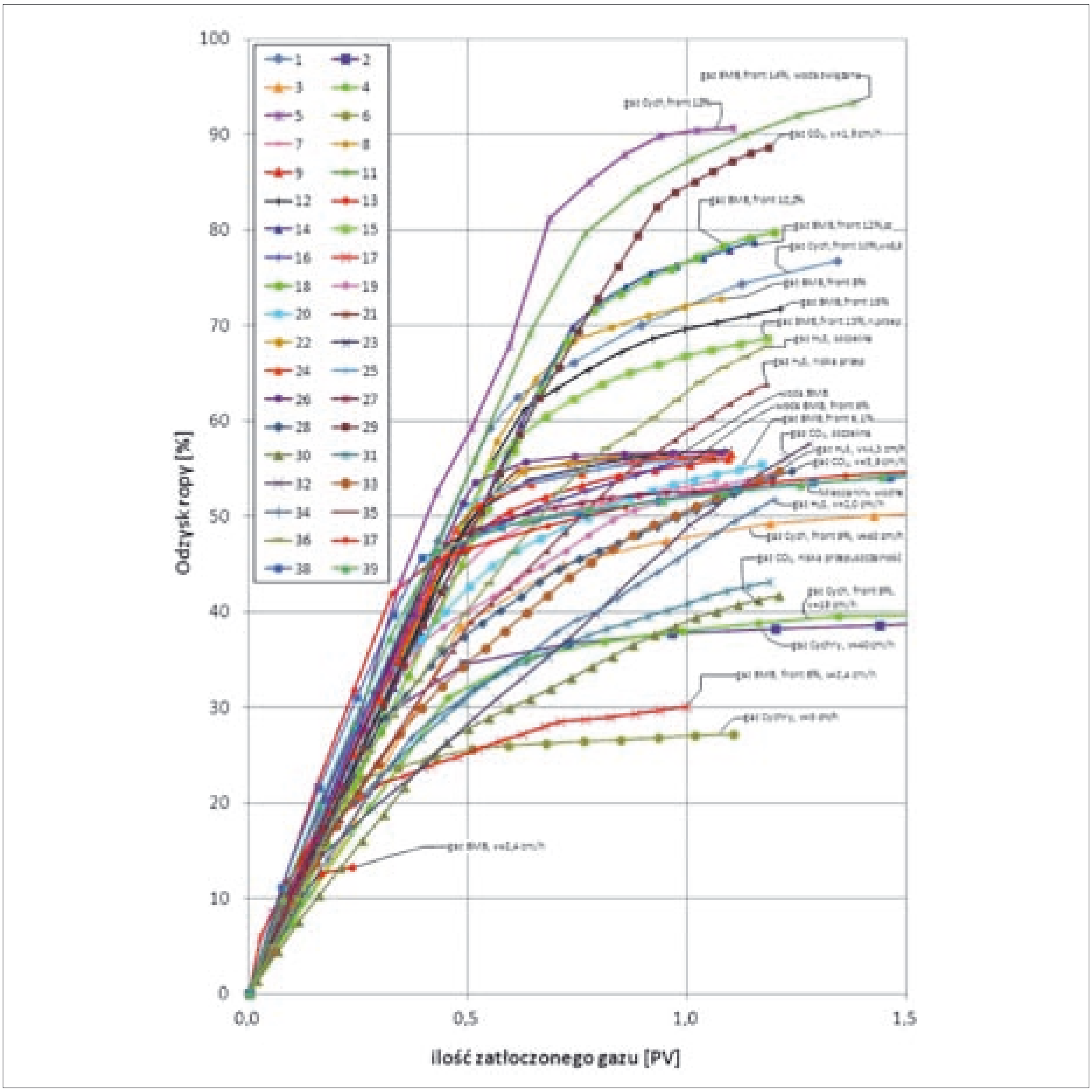


Fig. 2. Results of long-core oil displacement tested in the laboratory using various fluids [7]

achieved using water injection or gas injection with the condensate buffer of less than 9% in volume. For natural gas injection, the lowest recovery factor values were reached, and were between 15 and 40% depending on the gas composition and flow rate. A slightly higher result, i.e. between 40 and 55%, was reached for the supercritical CO_2, while for the supercritical H_2S the recovery factor reached 50 to 65%. Because quite good recovery results were found for the water injection, further reservoir simulations were carried out for that process. The final result of the water injection depends on the number of injection wells drilled, which are particularly necessary in areas of poor drainage. Because every large-scale project should be preceded by a pilot study, such a study has been launched.

The analysis involved the possibility of using the tertiary production technique of CO_2 injection which would follow the completion of water injection.

Figures 3 and 4 show the simulation results of initial and final stage of the water injection into the BMB reservoir as a secondary method. The existing production wells were converted into injection wells and a new production well was introduced. The figures show the oil distribution by volume per area.

Comparison of the distribution maps presented above indicates that the water-injection program

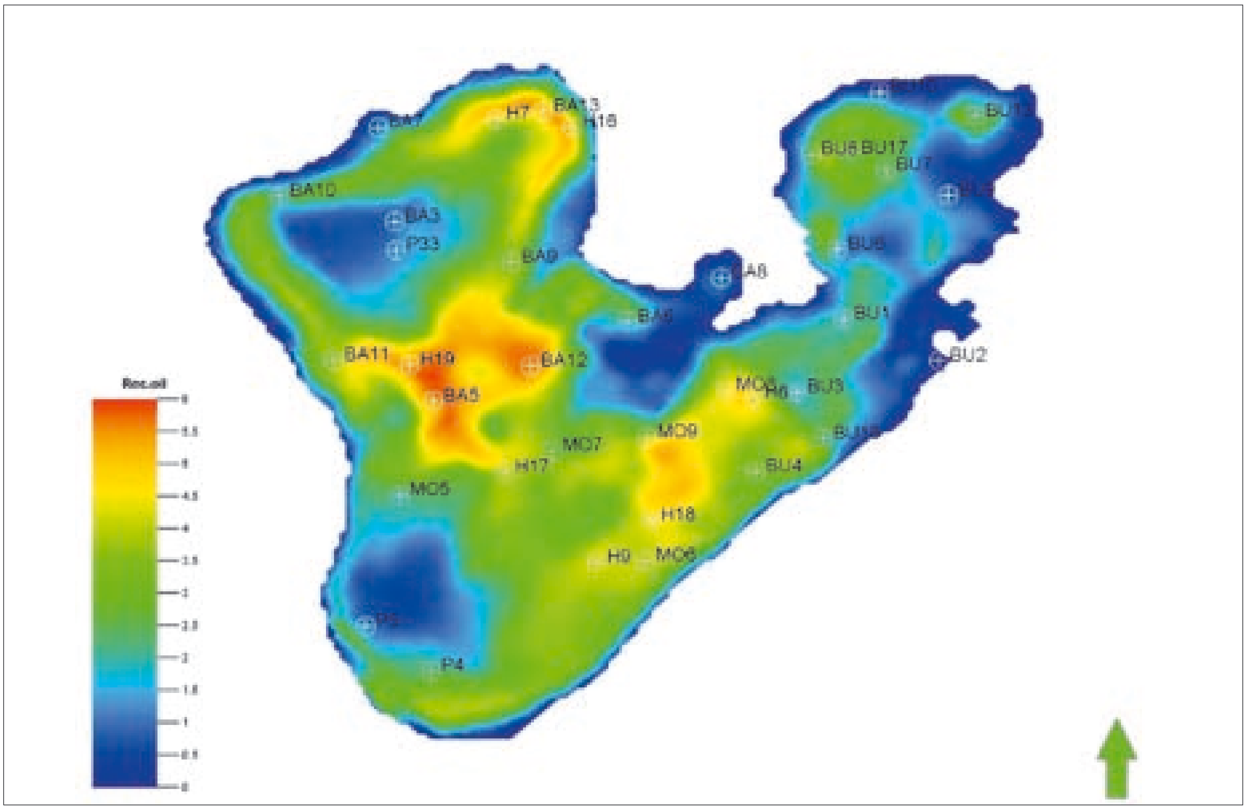


Fig. 3. BMB oil reservoir. Oil reserve distribution by volume per area. Initial stage before water injection

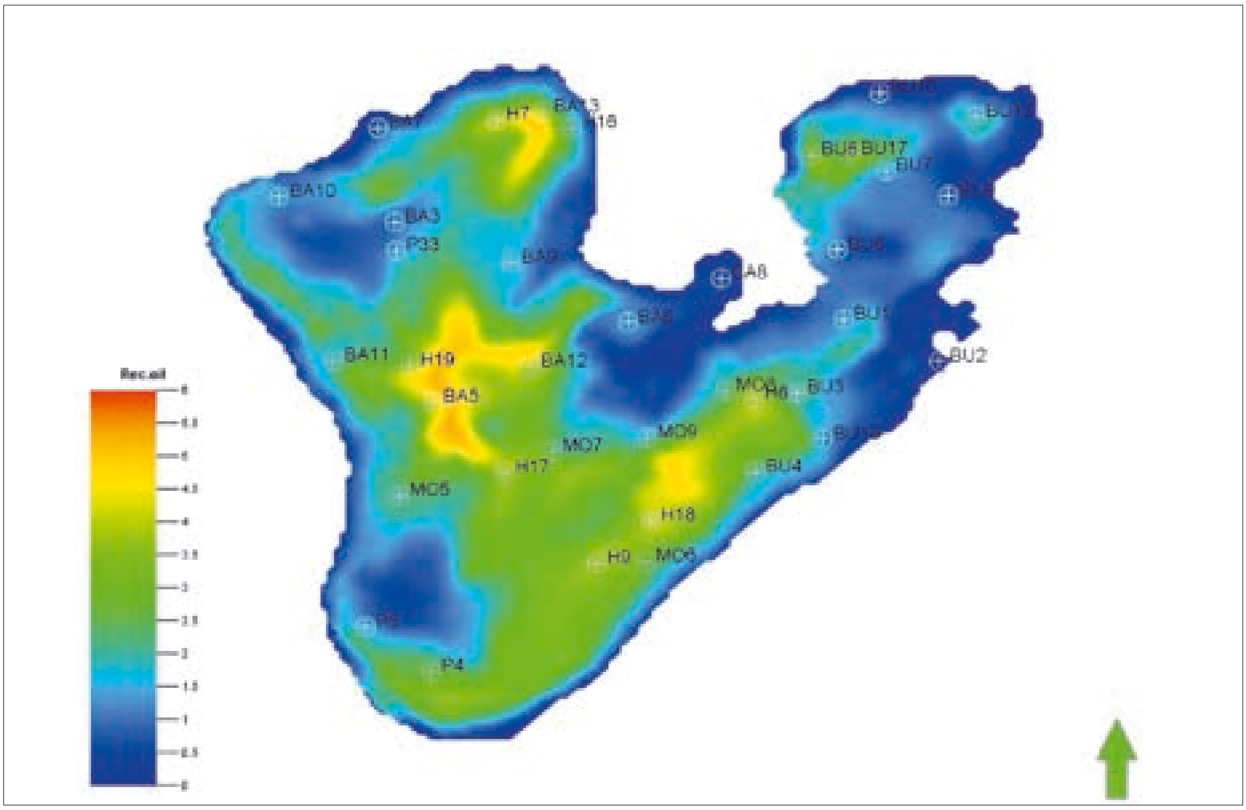


Fig. 4. BMB oil reservoir. Oil reserve distribution by volume per area. Final stage after completion of water injection

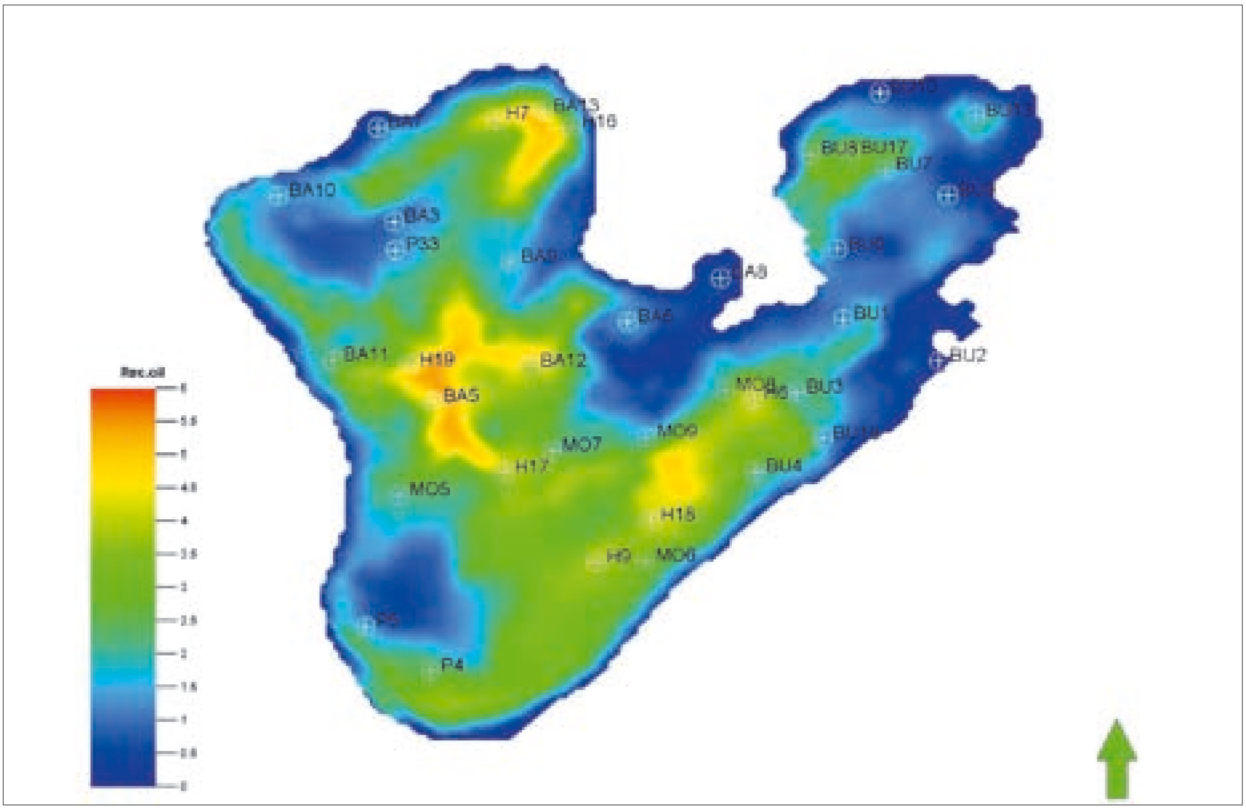


Fig. 5. BMB oil reservoir. Oil reserve distribution by volume per area. Initial stage before CO_2 injection

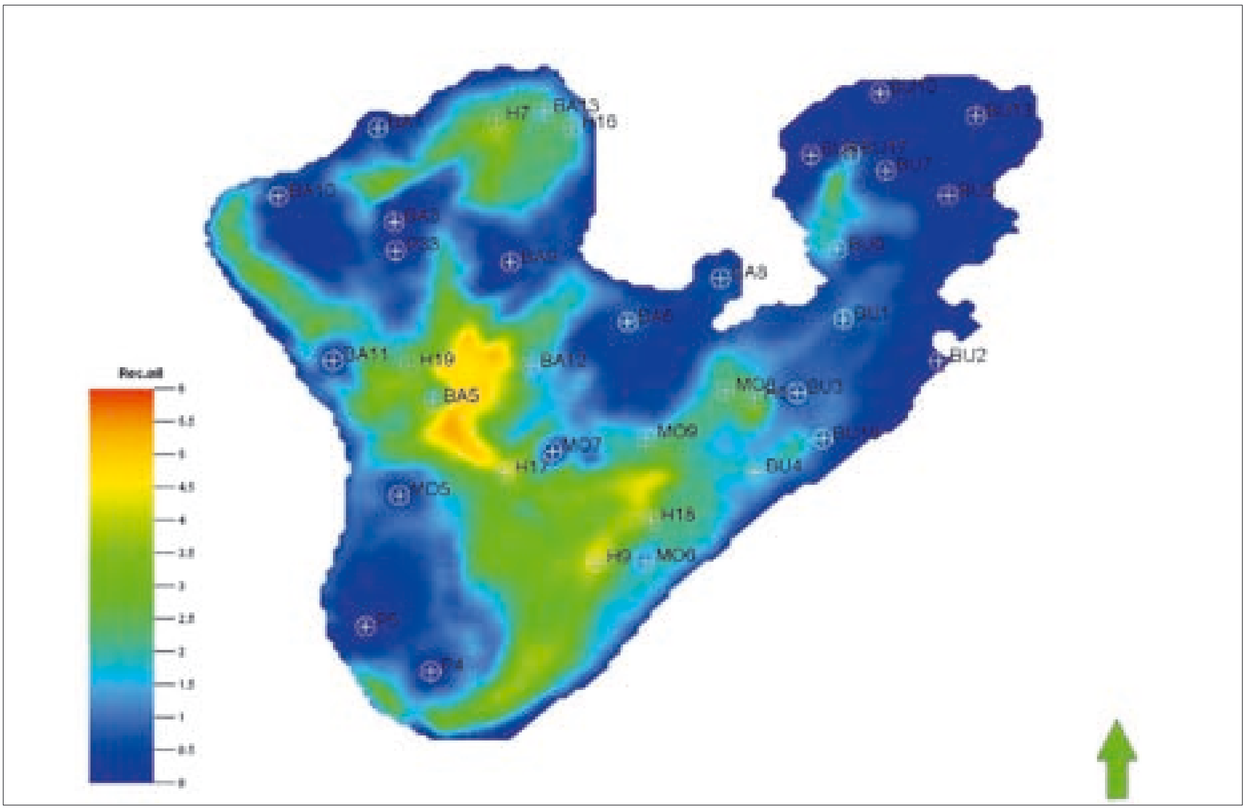


Fig. 6. BMB oil reservoir. Oil reserve distribution by volume per area. Final stage after completion of CO_2 injection

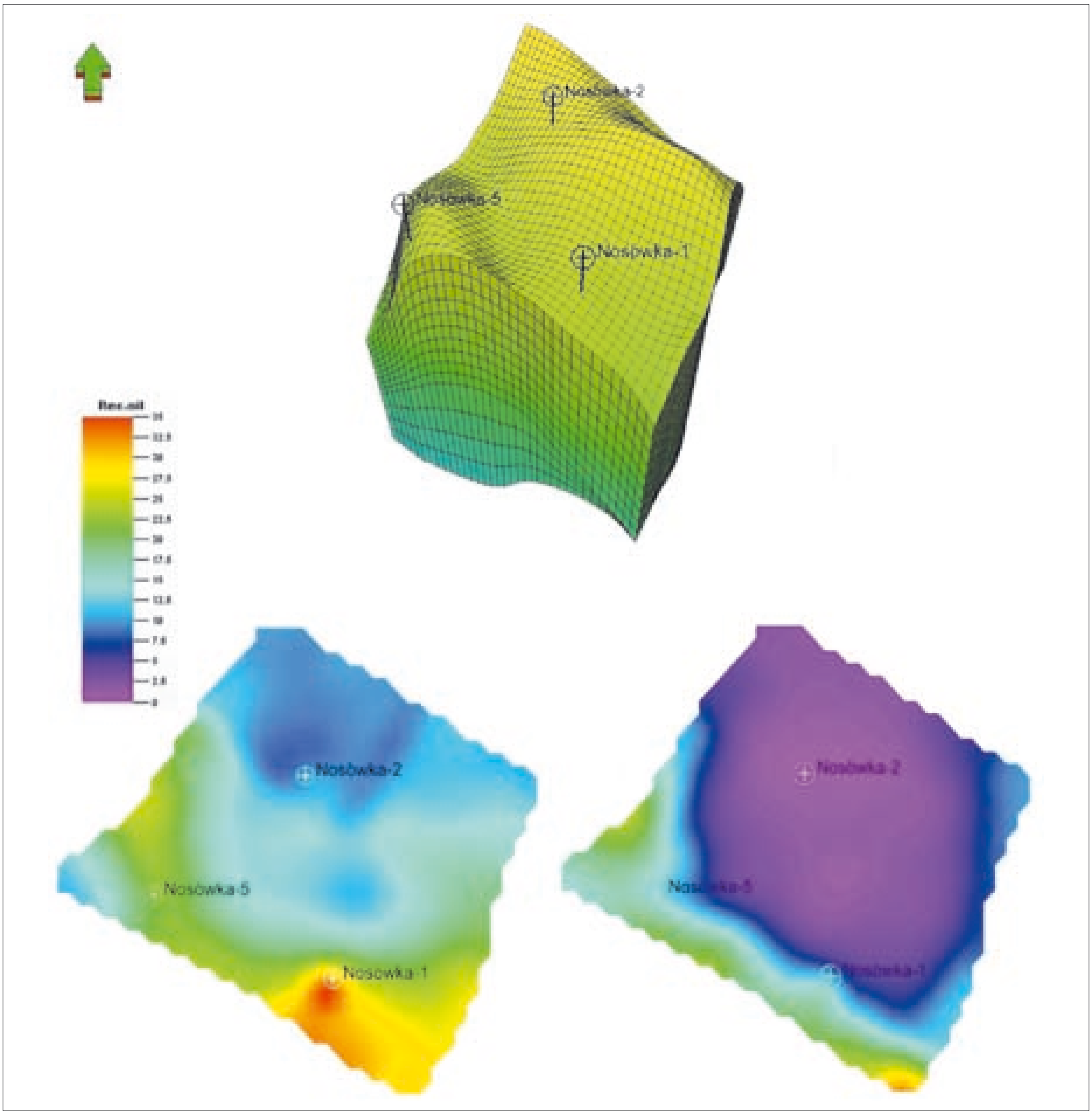


Fig. 7. Nosówka oil reservoir. The results of CO_2 injection simulations for the reservoir model (upper image). Oil reserve distribution by volume per area. Initial stage before CO_2 injection (left image); final stage after completion of injection and production (right image)

would lead to a general increase in production and strong heterogeneity of oil recovery. Due to the secondary production method used, which involved water injection, the oil recovery factor would increase by 5.4% when compared with the results of the primary production techniques. If a larger number of water-injection wells are drilled, particularly in areas of poor drainage, better results should be expected.

Figures 5 and 6 show the same distribution for a tertiary production method used (after completion of water injection). The simulation results of the initial and final stage of the CO_2 injection process into the BMB reservoir is presented. The operation utilised the existing injection wells and three new wells located at the most optimal locations. Five new production wells were also introduced.

The applied method leads to a further significant increase in the oil recovery factor together with the practically complete recovery of the oil-in-place in some parts of the reservoir. The application of tertiary production methods improved the recovery factor by 11.4% when compared with the results of the secondary production methods. The ultimate oil recovery factor after applying secondary and tertiary methods is expected to be 40%.

At the final stage, the BMB reservoir could be transformed into a CO_2 storage site with a CO_2 sequestration capacity of over 30 million tonnes.

The Carpathian region

The Carpathian region is a perfect example of an area where secondary and tertiary production methods have been used, often with good results, since the 1930s [1]. Despite that, there are several oil reservoirs where secondary and tertiary methods have never been used. They include such reservoirs as Węglówka, Nosówka and Jaszczew. The central block of the Węglówka reservoir has been estimated to comprise approximately 1.3 million m^3 of oil-in-place. If the production period is assumed to be the same as for the Osobnica reservoir, i.e. 55 years, up to 21.6% of the oil-in-place can be recovered without applying enhanced recovery methods [1]. If secondary and tertiary production methods are used, however, it is possible to achieve a higher recovery factor.

As part of the program [9], simulation modelling of the CO_2 injection has been carried out for the Nosówka reservoir. Figure 7 presents the simulation results of the initial and final stage of CO_2 injection into the Nosówka reservoir.

Figure 7 shows the distribution of oil reserves by volume per area. The image on the left presents the situation before CO_2 injection, while the image on the right shows the state after the completion of CO_2 injection and oil production. It should be mentioned that in the Nosówka reservoir, the most optimum is the option of CO_2 injection before the start of oil production. As a result, the oil recovery should be 17% higher than the primary recovery factor. The CO_2 sequestration capacity of the Nosówka reservoir has been estimated at 0.6 million tonnes. The authors think that it would also be worthy to carry out simulations to determine the effectiveness of water injection.

Conclusions

The examples presented here indicate that it is possible to nearly double the oil recovery factor provided that methods of enhanced recovery are applied in the Polish reservoirs. Thus, it will be necessary to implement advanced oil production methods in both recently discovered reservoirs and those already producing with primary methods.

The authors are researchers at the Oil and Gas Institute in Kraków

Literature

1) *Lubaś J., Such J., Sobolewski J.: Analiza wybranych przykładów dotychczasowego sczerpania karpackich złóż ropy naftowej i możliwości jego zwiększenia. Materiały Kongresowe. III. Polski Kongres Naftowców i Gazowników, Bóbrka 2008.*
2) *Stefan St. et al.: Modyfikacja zawadniania i technologia eksploatacji złoża Kamień Pomorski. Praca IGNiG. Krosno 1980.*
3) *Szott W. et al.: Program zawadniania złoża B-3. Praca IGNiG. Krosno 1996.*
4) *Zarębska B. et al.: Eksploatacja złoża B-3: Zastosowanie zatłaczania wody do złoża w celu zwiększenia współczynnika sczerpania zasobów. XVI Międz. Konf. N-T. AGH 2005.*
5) *Papay J.: Development of petroleum reservoirs. Budapeszt. 2003.*
6) *Stalkup F.: Miscible Displacement. SPE AIME. New York. 1984.*
7) *Lubaś J., Szott W., Warnecki M. et al.: Wybór i optymalizacja wtórnej metody oddziaływania na złoże BMB w celu uzyskania maksymalnego stopnia sczerpania fazy ropnej. Prace INiG wykonane w ramach Umowy Ramowej na zlecenie PGNiG S.A. Oddział w Zielonej Górze. Krosno 2011.*
8) *Lubaś J. et al.: Technologia zatłaczania do złóż ropy naftowej gazów ziemnych o wysokiej zawartości składników kwaśnych. Krosno 1994.*
9) *Lubaś J., Szott W., Łętkowski P.: Program wspomagania wydobycia ropy naftowej i gazu ziemnego z krajowych złóż węglowodorów przy zastosowaniu podziemnego zatłaczania CO2. Praca zlecona przez Ministra Środowiska.*

Application of non-deterministic and geostatistical methods in estimating subsurface parameters

New technologies in geophysics

All models are wrong, but some are useful

George Box

Karolina Pirowska

In order to better understand the world that surrounds us, we have to use models which, being simplified versions of reality, are not precisely accurate. The same applies to the oil and gas industry: constructing models and estimating parameters that describe them is necessary in the process of establishing subsurface parameters. Therefore the models offer the only chance for identifying the location of potential hydrocarbon resources and recovering them.

Particularly crucial is estimating as accurately as possible the wave velocity field in the subsurface. This is because velocity models are starting models for estimating geometrical properties, lithological variability as well as petrophysical parameters of rocks.

Despite many years of work by researchers worldwide focused on velocity analysis, the optimal solution to the velocity modelling problem still remains elusive. As the data acquisition techniques develop and new equipment becomes available, both for seismic and other geophysical methods, constantly improving the existing analysis methods and developing new ones is necessary. Recently both the number and quality of surveys have significantly increased. Due to the increasing speed and calculation capacity of computers, processing large amounts of data has become possible. Thus, the traditional solutions become insufficient because they require multiple simplifications to be adopted and therefore the resulting models have low accuracy. Therefore, increasingly more often, evolution techniques, neural networks, fuzzy logic as well as geostatistical methods are used, hence available information can be better used for data analysis and interpretation [17].

From statistics to geostatistics: geostatistical methods as an antidote to imperfections of the classical statistical methods

Geostatistics is a set of statistical techniques based on the random functions theory which during data analysis take into account spatial and temporal locality. The geostatistical methods can be used to identify and model the spatial and temporal structure of a given phenomenon or body, to estimate its parameters and to simulate alternative solutions. Geostatistical methods, discovered and developed in the mining indus-

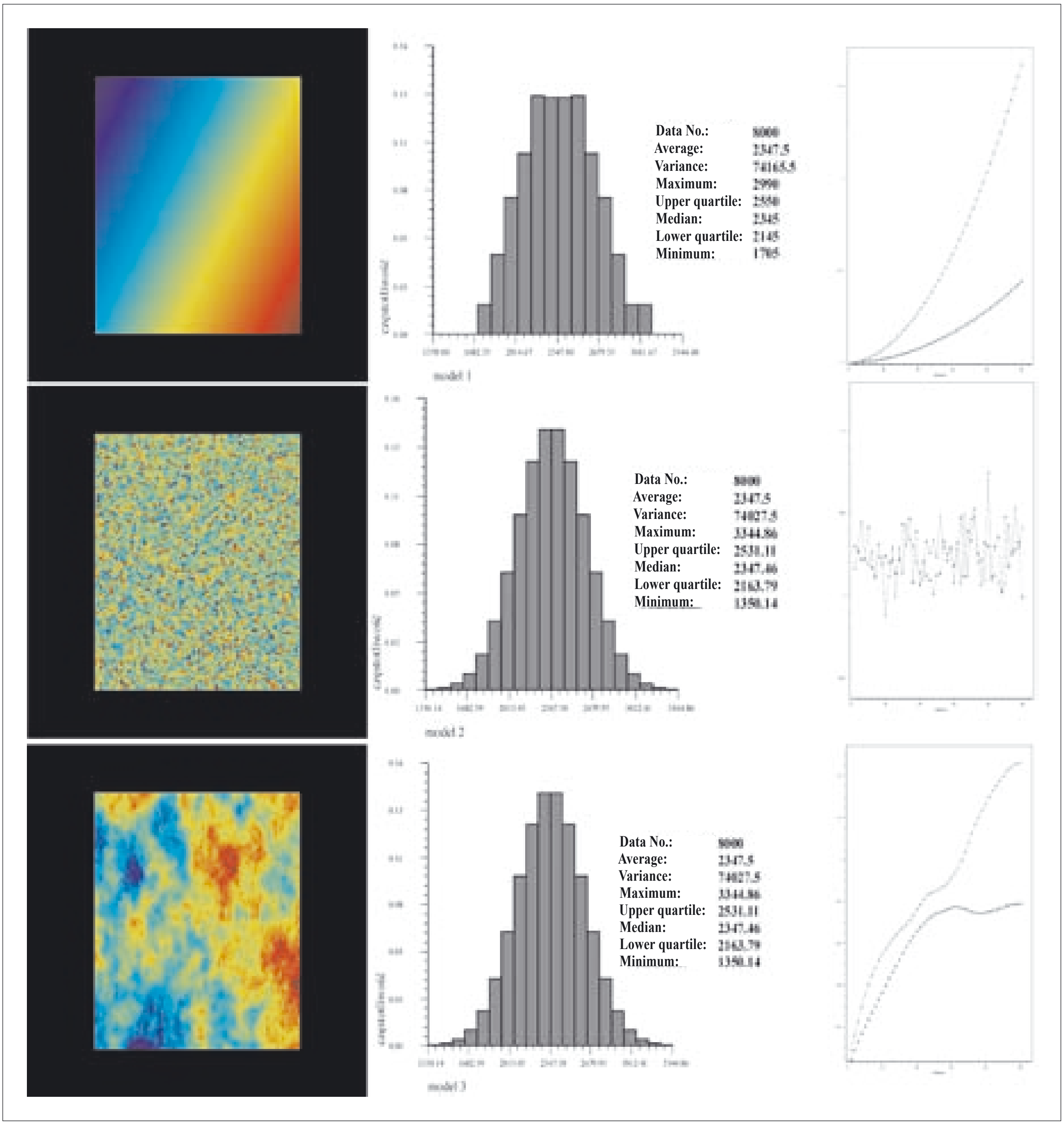


Fig. 1. Statistical and geostatistical description of the parameter-value distribution. The first column presents examples of the distribution of parameter values, the second column shows their corresponding histograms, while the third one shows variograms for the data distributions calculated in both directions, i.e. horizontal and vertical

try by G. Matheron (1963) [12], have been widely used since the publication of the pioneer works of such authors as A. Journel (1978) [8] or H. Omre (1987) [18].

One of the main differences between the geostatistical approach and the traditional statistical analysis is presented in Figure 1.

Based on Figure 1, the superiority of the geostatistical methods over the classical statistical description can be noticed. The histograms* calculated for completely different models have very similar shapes and parameters. However, based only on the histograms, it is not possible to recreate the initial model with which the histogram was calculated. Much more information about the spatial variability is provided by the variogram. Based on it, we can determine that in the case of the first model the given property has a nearly linear variability; in the second model, the property values are randomly distributed, while based on the last model we can determine that the property values vary more laterally than vertically.

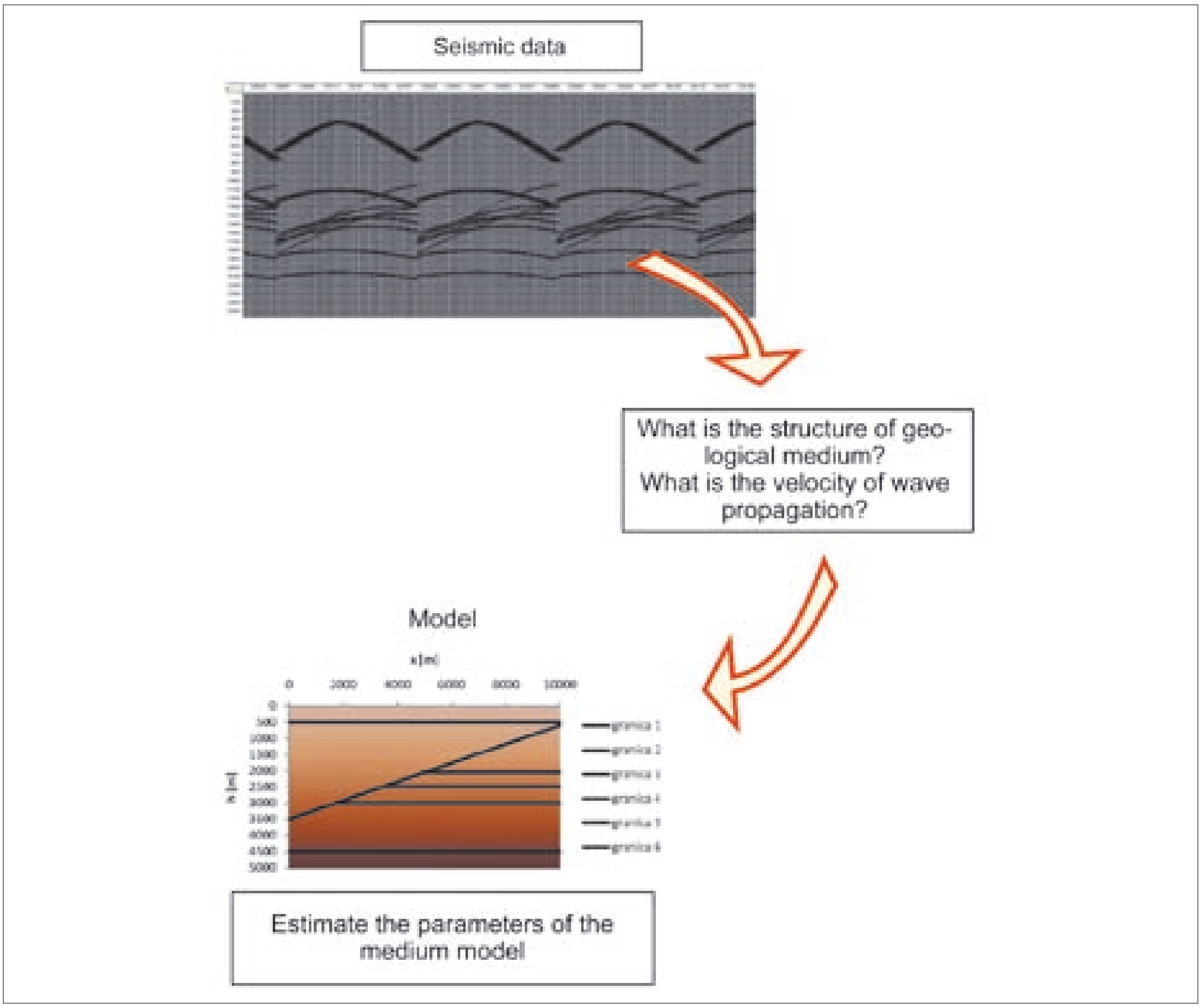


Fig. 2. Problem of estimating parameter values describing the subsurface as a geophysical inverse problem

Geostatistical methods are helpful in estimating the subsurface parameters from available well data, i.e. geophysical logs or core-test results, which are typically scarce in relation to the area of interest. Well data analysis and constructing experimental and model variograms is the first phase in estimating the values of a given parameter using geostatistical methods. As a next step, the parameter values in areas between boreholes can be estimated using such techniques as kriging or conditional simulation which are based on the variograms.

The advantage of geostatistics is that such techniques as co-kriging and co-simulation can be used to determine petrophysical properties from seismic data. These methods can be very helpful in solving the current problems of the oil and gas industry in Poland. Permeability and porosity are parameters which included in criteria for assessing risks in shale-gas exploration [13]. The geostatistical methods also offer a chance to use all available information known from various geophysical methods (as long as they do not contradict themselves). Examples of an integrated approach to various types of geophysical data, many new methods and techniques can be found in the manuals [4] and [6].

However, despite the obvious advantages, "*[...] Geostatistical methods are much less understood than other statistical methods, which is a result of their rapid development and complexity. Appropriate use of the geostatistical methods requires a thorough understanding of them and good skills as well as practical experience in their use. This cannot be replaced with even the most elaborate geostatistical software [...]*" as J. Zawadzki [30] said. Commercial geostatistical software for geomodelling has become widely available. Significant barriers to their appreciation and application is the Polish reality. As the cost of drilling wells and geophysical logging is huge, the number of wells is limited, causing problems in availability of data.

Let's learn from nature: meta-heuristic global optimisation algorithms

The problem of estimating parameters which describe the subsurface can be treated as a geophysical inverse problem (Fig. 2). One of the ways of constructing a model which most accurately approximates the subsurface is the optimisation approach. The optimisation problem lies in finding parameter values for which the target function, i.e. the function describing the difference between measured and synthetic data generated for the model, has the lowest value.

The problem appears to be simple, but in practice it can be very difficult to solve. Typically, available data are not complete, are associated with a large measurement error and are vulnerable to various random events which during acquisition affect data quality. As the Earth's crust may be associated with a very complex geology, the problem becomes very non-linear and ambiguous. In such cases, the traditional deterministic optimisation methods, which require many assumptions and simplifications to be adopted, do not give satisfying results.

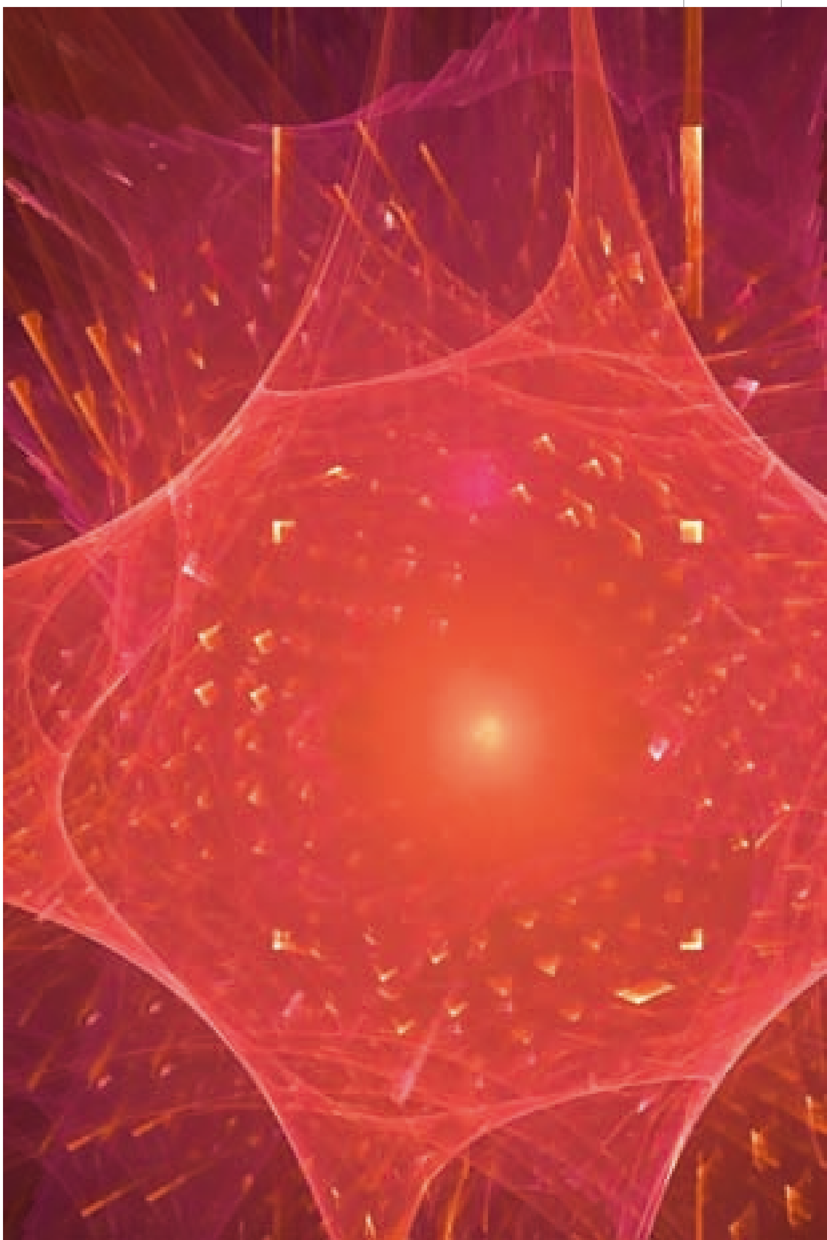
Much better results can be achieved by adopting global optimisation algorithms inspired by observations of nature, including such methods as genetic algorithms or the method of simulated annealing.

Meta-heuristic** methods of global optimisation include:

- genetic algorithms (Holland 1960/1970), evolution strategies (Rechenberg & Swefel 1960), evolutionary computation (Fogel et al. 1960);
- simulated annealing (Kirkpatrick et al. 1983), tabu search algorithm (Glover 1986), particle swarm algorithm (Kennedy & Eberhart 1995), differential evolution method (Storn & Price 1996/1997);
- the latest algorithms including harmony search (Geem et al. 2001), honeybee algorithm (Nakrani & Tovey 2004), firefly algorithm (Yang 2008), cuckoo search (Yang & Deb 2009).

The simulated annealing (SA) method is a method which imitates the process of substance crystallisation. During such processes, in order to obtain the minimum energy of a substance, it is first heated up to a very high temperature and after that it is very slowly cooled. The optimisation process is analogous. The equivalent of the energy of the substance, which should be limited to the minimum, is the target function, while the temperature is compared to the parameter describing the size of the searched sub-volume. The solutions of subsequent iterations are randomly generated according to the established workflow which consists of a large number of iterations.

The purpose of the genetic algorithm is to find an optimal solution in a way imitating biological evolution. In nature there is the constant fight of species for survival, where the living biological species represent the strongest ones, and surviving in a hostile environment is the optimal solution. In the same way, in the case of the genetic algorithm, the output generation is the set of best solutions to a given optimisation problem. The genetic algorithm is analogous to the principles of genetics in medicine. Starting with a randomly adopted initial population, the descendant generation is constructed. The population and the later generations



represent sets of solutions to an optimisation problem. Only the best-adapted specimens, i.e. those for which the target function for a given problem has optimal values, can pass on to a next generation. Solving subsequent iterations, i.e. construction of descendant populations, is done using the three operators of selection, crossover and mutation. Selection (reproduction) is a random selection of specimens from a population; during crossover (recombination) randomly chosen parts of specimens' codes are exchanged; while mutation is an operator which differentiates the population. Detailed description of the genetic algorithms was presented by D.E. Goldberg [5].

Between the theory and the practice

For a long time, the non-deterministic methods of optimisation were treated by researchers as the last resort. This is because they are much more difficult than strict mathematical analysis. Even the very choice of an appropriate method for a question can be problematic. In the case of non-deterministic methods, there never can be complete certainty that a given method is better than another. This fact was addressed in the "no free lunch" theorem formulated in 1997. It says that none of the optimisation algorithms can be treated as the best and universal for all problems [27]. A decision regarding which method should be chosen can only be made based on trial-and-error. Choosing appropriate steering parameters, which have a significant influence on the solution, may also be difficult. Applying heuristic methods requires many experiments and tests to be carried out. Experience and knowledge of particular problems solved with particular methods is important.

Another difficulty is that convergence to a global optimum is not guaranteed by any methods. Only for some algorithms of simulated annealing can it be proved under certain conditions that an appropriately chosen set of steering criteria guarantees finding a solution close to the global minimum of the target function (proofs are in stochastic processes language, Markov chains).

However, examples show frequently that non-deterministic methods provide better solutions than conventional methods, which certainly encourages their application. Their application is particularly useful in all complex non-linear problems as well as when the searched model involves a large number of parameters. The method has the strong advantage that it does not use information about the gradient of the target function and does not require operations on matrices to be carried out. It is also highly independent from the starting model; randomness is a good way to extend the search for a model on a local scale to the global scale. As X. Young [29] stated, heuristics, which is the basis for the mentioned methods, is a trial-and-error method for creating an accepted solution to a complex problem in a reasonable period of time.

The first attempts at applying the method of simulated annealing in geophysics (for problems related to non-linear inversion, statistical mechanics as well as static corrections) were presented by D.H. Rothman (1985) [22]. Huge input into the investigation of new techniques was made by M.K. Sen and P.L. Stoffa (1991,

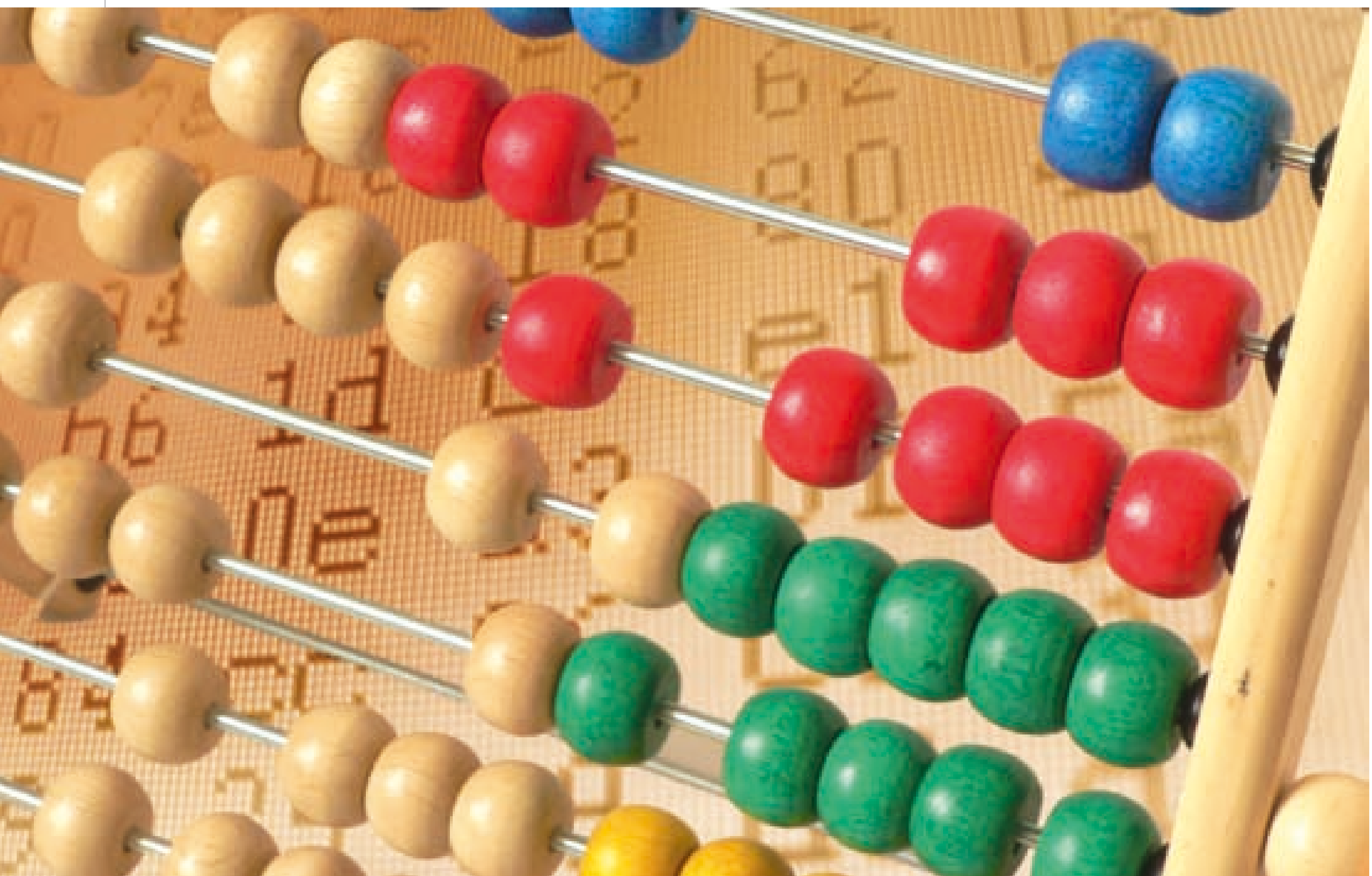
1995) [23, 25] as well as K. Mosegaard and A. Tarantola (1995) [15]. P.D. Vestergaard and R. Mosegaard [26] investigated the possibility of applying the simulated annealing methods in determining travel times and reflection coefficients by inversion optimisation of selected fragments of migrated seismic profiles. It was also proven that the method gives reliable results even without initial information about optimisation parameters. The results presented by P. Carrion and G. Bohm [2] showed that when the simulated annealing methods are applied in reflection topography, seismic interfaces and lateral velocity gradient can be imaged even when peaks are wrongly identified and with a significant level of noise. Important research was conducted by Ma Xin-Quan [28] who applied simulated annealing to assess acoustic impedance and depths of strata boundaries based on post-stack seismic data. One of the latest applications of simulated annealing in estimating the acoustic and elastic impedance was presented by R.P. Srivastava and M.K. Sen [24].

The increasing application of these methods is shown by the numerous publications, including that by V. L. Oswaldo [19] who reviewed the application of genetic algorithms in the petroleum industry. Genetic algorithms are effective and relatively simple methods, particularly when a given problem involves multiple parameters and when there are multiple good solutions. Practical works and applications include reservoir rock characterisation [21], underground gas storage, issues of inversion [23, 25], enhancing oilfield operations, petroleum processing, or production strategies and monitoring.

There are novel solutions in the specialist software for data processing. The 2009 release of Petrel includes a stochastic inversion module (available to the Department of Seismic of the Oil and Gas Institute). The package includes completely integrated genetic inversion algorithm for solving problems of structural and stratigraphic variability between wells where data is available. The entry data, apart from the well data, include seismic data which are the basic source of information for hydrocarbon production. The new module can be used to generate 3-D impedance models directly within Petrel. It is possible to identify the geological formations and to fully characterise the reservoir.

In Poland, publications and doctoral theses described the results of applying stochastic methods to geophysical problems appeared only in recent years. Such subjects as application of the Bayesian inversion in seismic tomography (Dębski 2004) [3] as well as application of simulated annealing in interpretation of magnetotelluric data (Miecznik et al. 2003) [14] have been studied.

A. Leśniak and G. Pszczoła applied genetic algorithms to two reverse problems [10]. The first was to describe the source of seismic shocks where the unknown parameters included three spatial coordinates of the seismic source as well as its time. The second problem dealt with the electroresistivity data and described the parameters of the subsurface, i.e. thickness and resistivity of individual strata. Geostatistical methods employed to identify reservoirs were discussed in 1994 by J. Mucha [16]. Geostatistics used for data analysis was presented by A. Leśniak and S. Porzycka, while reservoir variability modelling and reserve evaluation using the kriging method was described by Z. Kokesz. In 2007, as part of the research carried out in the Department of Seismic of the Oil and Gas Institute under the supervision of Prof. Halina Jędrzejowska-Tyczkowska, the author of this publication tried to apply simulated annealing to an inverse problem of the



kinematics of PS waves [7]. The current works also deal with the application of genetic algorithms as well as geostatistical methods for estimating seismic velocity field and other parameters of the subsurface [20]. These methods were addressed by the research programme Application of the geostatistical methods in estimating subsurface parameters, Ref. No. NN525 349038 carried out in 2010–2012 and funded by the Ministry of Science and Higher Education.

Examples in the literature frequently indicate that geostatistical and non-deterministic methods of global optimisation are a subject of worldwide interest of geophysicists. In the case of many problems, their results are better or equally good as those from traditional methods. However, even more important is the fact that the new techniques offer solutions to problems which cannot be solved using the traditional methods. This encourages their introduction in Poland.

The author is a researcher at the Oil and Gas Institute in Kraków

Glossary of terms:

*A **histogram** is a graphical representation of data distribution. It consists of adjacent rectangles above the coordinate axis. These rectangles represent intervals of a property values, while their height describes the number (or frequency, frequency density) of elements included in each variable interval.

(http://pl.wikipedia.org/wiki/Histogram)

A **metaheuristic is a general method (heuristic) used to find solutions to computational problems. A metaheuristic algorithm can be used to solve any problem which can be described with certain qualities defined by this algorithm. It is most often applied to find solutions to optimisation problems. The term was created by combining the words ***meta*** (***higher***, here ***higher level***) and ***heuristic*** (gr. heuriskein – search), which is due to the fact that such algorithms do not solve directly any problem, but indicate a method for creating an appropriate algorithm. The term ***metaheuristic*** was used for the first time in 1986 by Fred Glover.

(http://pl.wikipedia.org/wiki/Metaheurystyka)

Literature

1) *Boschetti F., Dentithz M.C., and List R.D., 1996,* ***Inversion of seismic refraction data using genetic algorithms,*** *Geophysics, vol. 61,1715–1727.*
2) *Carrion P., Bohm G., 1994,* ***Seismic reflection tomography via simulated annealing****, The Leading Edge.*
3) *Dębski W., 2004,* ***Zastosowanie techniki Monte Carlo do rozwiązywania wybranych zagadnień sejsmologicznych****, Instytut Geofizyki PAN.*
4) *Dubrule O., 2003,* ***Geostatistics for seismic data integration in earth models****, 2003 Distinguished Instructor Short Course, EAGE, SEG.*
5) *Goldberg D.E., 1998,* ***Algorytmy genetyczne i ich zastosowania,*** *WNT.*
6) *Grana D., Dvorkin J., 2011,* ***The link between seismic inversion, rock physics and geostatistical simulations in seismic reservoir characterization studies****, The Leading Edge.*
7) *Jędrzejowska-Tyczkowska H., Pieniążek K., 2007,* ***Zastosowanie metod optymalizacji globalnej, a szczególnie symulowanego wyżarzania (simulated annealing), do rozwiązania odwrotnego zadania kinematycznego w metodzie sejsmicznej****, Nafta-Gaz, no. 12.*
8) *Journel, A.G., and Huijbergts, C. J., 1978,* ***Mining Geostatistics****, New York: Academic Press.*
9) *Kokesz Z., 2006,* ***Trudności i ograniczenia w geostatystycznym modelowaniu zmienności złóż i szacowaniu zasobów metodą krigingu****, Gospodarka Surowcami Mineralnymi, Tom 22, Zeszyt 3.*
10) *Leśniak A., Pszczoła G., 2006,* ***Algorytmy genetyczne w rozwiązywaniu zagadnień odwrotnych w geofizyce****, Geoinformatica Polonica.*
11) *Leśniak A., Porzycka S., 2009,* ***Geostatistical computing in PSInSAR data analysis****, Computational Science, Proceedings of ICCS 2009: 9th international conference: Baton Rouge, LA, USA, May 25-27 2009.*
12) *Matheron G., 1963,* ***Principles of Geostatistics****, Economic Geology 58, 1246-1266.*
13) *Matyasik, 2011,* ***Nowe wyzwanie dla poszukiwań złóż gazu****, Rynek Polskiej Nafty i Gazu 2011, p. 90-95.*
14) *Miecznik J., Wojdyła M., Danek T., 2003,* ***Application of nonlinear methods to inversion of 1D magnetotelluric sounding data based on very fast simulated annealing****, Acta Geophysica Polonica 2003 vol. 51 no. 3 s. 307–322.*
15) *Mosegaard K. and Tarantola A., 1995, Monte* ***Carlo sampling of solutions to inverse problems****, J. Geophys. Res. 100, 12431–12447.*
16) *Mucha J., 1994,* ***Metody geostatystyczne w dokumentowaniu złóż****, zeszyt naukowy AGH.*
17) *Nikravesh M., Aminzadeh F., 2001,* ***Past, present and future intelligent reservoir characterization trends****, Journal of Petroleum Science and Engineering, 31 (2–4), 67– 79.*
18) *Omre H.,* ***Bayesian Kriging – merging observations and qualified guesses in kriging****, 1987, Mathematical Geology, 19, 25–39.*
19) *Oswaldo V.-L., 2005,* ***Genetic algorithms in oil industry: An overview****, Journal of Petroleum Science and Engineering, 47, 15-22.*
20) *Pirowska K.,* ***Zastosowanie algorytmu genetycznego do estymacji parametrów ośrodka geologicznego na podstawie pomiarów sejsmicznych****, artykuł przyjęty do druku w czasopiśmie Nafta-Gaz.*
21) *Romero C.E., Carter J.N., 2001,* ***Using genetic algorithm for reservoir characterization,*** *Journal of Petroleum Science and Engineering, 31, 113-123.*
22) *Rothmann D.H., 1985,* ***Nonlinear inversion, statistical mechanics and residual statics estimation****, Geophysics 50, 2784–2796.*
23) *Sen M., Stoffa P.L., 1995,* ***Global optimization methods in geophysical inversion****, Elsevier.*
24) *Srivastava R.P., Sen M.K., 2010,* ***Stochastic inversion of prestack seismic data using fractal based initial models****, Geophysics 75, no.3, R47-R59.*
25) *Stoffa P.L., Sen M.K., 1991,* ***Nonlinear multiparameter optimization using genetic algorithms: Inversion of plane-wave seismograms****, Geophysics, vol. 56, 1794–1810.*
26) *Vestergaard P.D., Mosegaard R., 1991, Inversion of post-stack seismic data using simulated annealing, Geophysical Prospecting 39, 613-624.*
27) *Wolpert D.H., Macready W.G., 1997,* ***No Free Lunch Theorems for Optimization****, IEEE Transactions on Evolutionary Computation 1, 67, http://ti.arc.nasa.gov/m/profile/dhw/papers/78.pdf*
28) *Xin-Quan Ma, 2001,* ***A constrained global inversion method using an overparametrized scheme: application to poststack seismic data****, Geophysics vol. 66 no 2, p. 613-626.*
29) *Yang X.-S., 2008,* ***Nature-Inspired Metaheuristic Algorithms****. Luniver Press.*
30) *Zawadzki J., 2011,* ***Metody geostatystyczne dla kierunków przyrodniczych i technicznych****, Oficyna Wydawnicza Politechniki Warszawskiej.*

The role of biomarkers in oil prospecting

Biomarkers – modern genetic description of oil systems

Irena Matyasik

Fossils are plant and animal remains stored for millions of years with unchanged appearance. They are the outcome of fossilization, that is replacing the organic with inorganic matter in appropriate conditions. Fossilization is the process of saturation with silicon dioxide, calcium salts, plant resins (amber), oil derivatives (wax, asphalt) or the process of freezing.

The age of the remains is established by means of index fossils and by physical and chemical methods. The index fossils are characterized by a narrow stratigraphic and broad geographic range. These are the organism remains which, in strictly restricted geological epochs were commonly found all over the Earth. Being the age „markers" of their own geological layer, they allow to establish the age of the neighbouring layers situated above and below.

An example of physical and chemical method is the isotope method of radioactive carbon-14. This isotope disintegrates into non-radioactive one, and the proportion of both of them in the atmosphere is approximately constant and has not changed for thousands of years as a result of cosmic radiation. Both isotopes are built into the living organism bodies in the same proportions. After their death the amount of carbon-14 is reduced exactly by half after every 5730 years (half-life). The relation of ^{14}C to ^{12}C in fossil organic master enables to estimate its approximate age. The method does not allow to evaluate the age of remains older than a certain threshold value above which it cannot be stated whether the radiocarbon content has changed or not. Other radioactive elements (e.g. uranium) are used for estimating the date of remains in longer periods of time.

Organic geochemistry, as a branch of geological sciences, studies the natural history of Earth from the chemical point of view. One of its main goals is to present the physical and chemical characteristics of geological environments and to present the chemical processes which enabled their existence, and another goal is to track the geochemical changes in geological scale and identify factors which had an influence on these changes. Geochemistry uses the notion of molecular markers, i.e. biomarkers [6]. These compounds, generated biosynthetically, whose basic structural skeletons are relatively resistant to geochemical changes, undergo small transformations in diagenetic processes and thermal maturation of sedimentary matter and they are used in oil prospecting.

The significance of oil geochemistry in prospecting for hydrocarbon deposits

All the deposit discoveries in the Carpathians were mainly based on surface cartographic work, oil geologists experience and their intuition. During almost

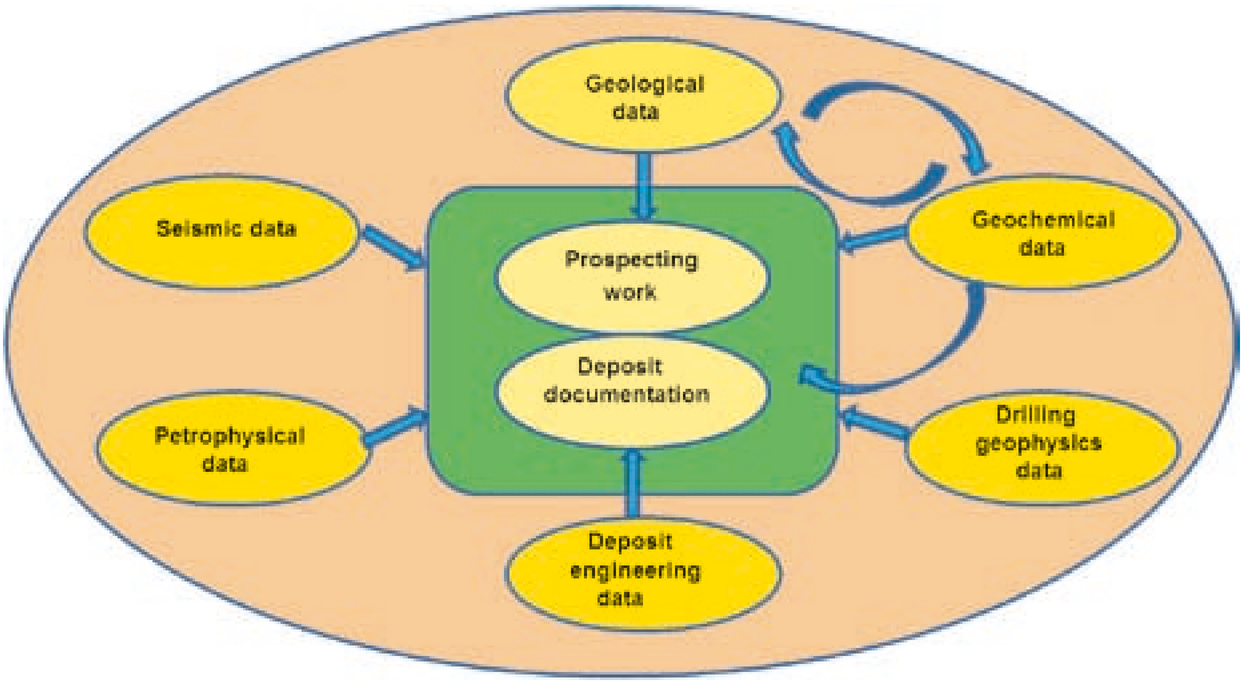


Fig.1. Diagram showing the cooperation of geochemical sciences with petrophysics, drilling geophysics and seismics in hydrocarbon prospecting and providing deposit documentation

160 years of exploration in this region, 75 oil and gas deposits were found, out of which more than 13 million tons of oil and more than 14 billion m^3 of gas were extracted [7].

Gradually, the exploration spread to other regions of Poland. In the post-war period it moved to the area of the Carpathian foreland basin and the Kuyavia and then to the region of the Polish Lowland. It was in these places that prospecting was conducted on the basis of the first results of seismic studies. The effect of the whole oil industry in Poland is the discovery of about 130 deposits in the region of the Carpathian foreland, mainly of natural gas in Miocene deposits. So far, more than 95 billion m^3 of gas were extracted from these deposits, while in the Carpathian foreland more than 22 million tons of oil were extracted.

By the year 2010, more than 55 oil deposits and about 90 natural gas deposits were found in the Polish Lowlands and the biggest deposits in Poland were in Barnówko-Mostno-Buszewo with oil resources exceeding 10 million tons and deposits in Międzychód-Lubiatów with resources of about 4 million tons of oil [9].

All of these deposits in Poland were discovered on the basis of seismic studies. Both 2D, 3D and 3C seismic data, and the results of exploratory, prospecting or extraction drilling are constantly providing us with new data concerning the geological structure. Although the obtained data provide plenty of geological information about the rock core, layer system and the possibility of potential hydrocarbon trap occurrence, the contemporary oil geology needs the cooperation of some sciences, e.g. geochemistry, mineralogy, petrology, sedimentology and other ones which help reduce the exploratory risk (Fig. 1).

When difficulties in discovering new deposits appeared, in spite of convenient conditions for their occurrence, i.e. structures, it became clear that explanation should be found in other geology and oil geochemistry fields.

Oil geochemistry was becoming more and more important in explaining issues relating to the composition of oil, its origin and the way of migration. Another essential thing was the knowledge about changes in oil composition with increasing depth, temperature

> The theory of organic origin of oil is closely connected with living organic matter which consists of hydrocarbon elements or protohydrocarbon and carbohydrates, proteins or fats which, under the influence of microorganism activity and heat of the Earth, are transformed to create hydrocarbon compounds being part of oil or natural gas.

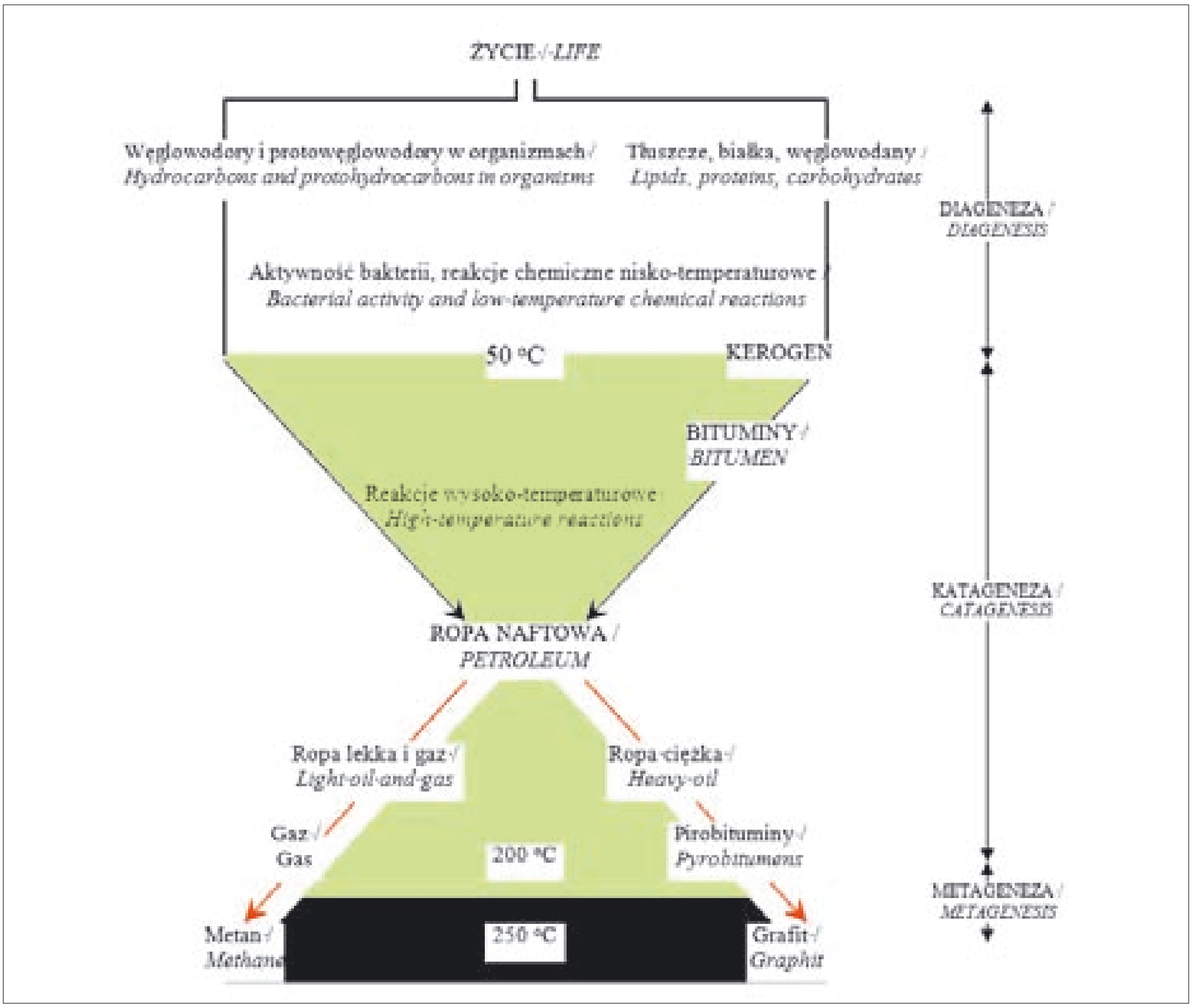


Fig. 2. Thermal transformation from sediment diagenesis to metagenesis which leads to transforming the living organism matter into hydrocarbons (according to Hunt 1996)

and pressure. In the history of oil geochemistry development, various concepts appeared which attempted to reconstruct the process of obtaining oil which, in different places and in different form, was found in various types of deposit traps. The theory of organic origin of oil is closely connected with living organic matter which consists of hydrocarbon elements or protohydrocarbon and carbohydrates, proteins or fats which, under the influence of microorganism activity and heat of the Earth, are transformed to create hydrocarbon compounds being part of oil or natural gas. About 10-20% of hydrocarbon accumulation was obtained directly from hydrocarbons synthesized by living organisms or from their parts and they usually contain more than 15 atoms of carbon per molecule.

On the other hand, 80-90% of hydrocarbon accumulation comes from substances such as: lipids (fats), proteins and living organism hydrocarbons which were converted in geological periods in order to create the so-called dispersed organic matter in sedimentary rocks which is called kerogen.

Generally, oil and gas generation is a simple process which might be compared to a „huge boiling" of an organic matter (thermal cracking) contained in sediments rich in organic carbon. The progressing rise in temperature connected with these sediments' immersion causes thermal degradation of sedimentary organic matter. Then mobile products arise, enriched in hydrogen (hydrocarbons) and non-mobile – residue with poor hydrogen content (i.e. kerogen and pyrobitumen). This is how all the oils and most of gas are generated, with the exception of a few types of gas which are created as a result of bacterial activity in low temperatures in lower sediments in a reducing environment. These kinds of gas are described as biogenic, they contain mainly methane and they are thought to constitute 20% of all the discovered gas deposits in the world. Temperature and time are the main factors which rule the chemical reaction laws, leading to hydrocarbon generation (Fig. 2) [6].

Oil geochemistry in Poland, as in the countries of Western Europe and the USA, developed quite rapidly during the last three decades. As a scientific discipline, it became generally accepted in 1959 during the 5th World Petroleum Congress in New York. Initial research concerned the analysis of the deposit media. Later, scientists were more interested in source rock (matrix), and as the analytic technique was progressing, more modern scientific methods were introduced relating to rock samples, oil and accompanying media [8].

Geochemical research of rocks enables to answer the question whether there is matrix rock in the region of hydrocarbon prospecting and whether the conditions in which it was generated during geological periods could lead to hydrocarbon production. One of the important issues is the understanding and recognition of the original conditions in which various processes were arising – at first, there were characteristic types of sedimentary rock, then their thermal evolution began, which in geological periods changed into a complicated system of determinants leading to generation and expulsion and later to migration and accumulation of hydrocarbons.

Most of sedimentary rocks contain dispersed organic substance which is characterized by various origin and methods of origin, it has various physical properties and chemical composition. This substance contains 85-90% of carbon which has an organic origin and it also contains 8-10% hydrogen.

The composition of organic substance is diverse and it depends on many factors:

- conditions for sedimentation,
- geochemical conditions present during sedimentation (reducing, oxidizing in sea or lake environment),
- the type of initial organic material (e.g. plant or animal matter, benthos, plankton) and further transformations it was subject to.

There are three types of kerogen (organic substance) which can generate gas or oil depending on the depth of the sediment and the temperature. For instance, at the depth of about 2.5-4 km at the temperature of 90-120°C oil and a little bit of gas might be created, and when there are higher temperatures – of about 150°C – there might be almost only natural gas.

Geochemical research, whose main goal is to estimate whether the rock drilled in a specific profile of the borehole is matrix, is conducted systematically for all the stratigraphic levels and it constitutes a constant element in prospecting work.

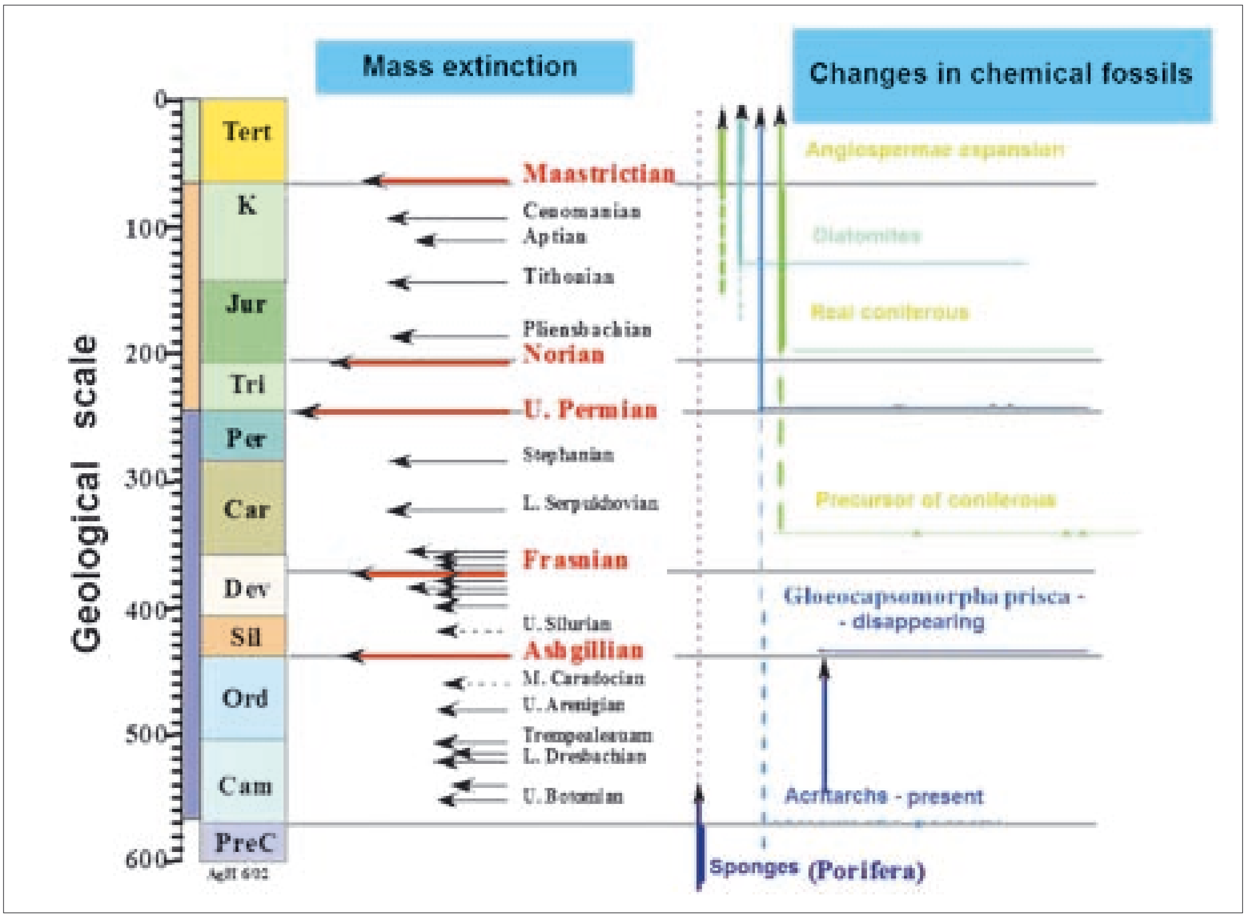


Fig. 3. The occurrence of chemical fossils (biomarkers) in geological history (according to Holba 1998) [4, 5]

The Oil and Gas Institute performs most of the geochemical analyses which aim at identification of the quality of the organic substance, so that it is possible to estimate the place, time and amount of generated hydrocarbons and also attempt to find genetic connections with the source substance, including the environment of the deposit.

Biomarkers as carriers of genetic information and thermal changes

The development of analytical techniques, such as gas chromatography and mass spectrometry enables more and more precise analysis of trace amounts of compounds called "biomarkers" – biological markers which can be found in oil and in bituminous extracts from rocks, which carry valuable information when describing genetic connections and the history of oil in a particular deposit. In the Polish oil industry the analysis of these specific compounds was introduced in mid-nineties and is used increasingly in most prospecting and exploration work. It is important in the aspect of the theory of biogenic origin of oil [8] to prove structural relations between organic compounds in oil, matrix and living organisms, e.g. angiosperm, porphyrin, chlorophyll.

Biological molecular markers, in the literature commonly called biomarkers, are organic compounds which can be found in matrix rock or oil. The carbon skeleton of these compounds is stable in geological period. The term biomarker (chemical fossil, molecular fossil) is used for naming any biogenic compound which is in oil or in bituminous extract from a potential matrix rock whose basic carbon skeleton shows that it is connected with its natural biological precursor. Biomarkers are mostly microfossils of a diameter less than 30 µm. They are marked by the stereochemical diversity which enables linking of these compounds with proper living organisms – organic substance precursors [1, 2, 5, 10]. The first works on the application of biomarkers in oil geology were written in the late 1960s when Eglinton and Calvin found microfossils of animal and plant origin both in sediments and in oil [11]. Since then, research was conducted in various oil basins, which resulted in discovering a consid-

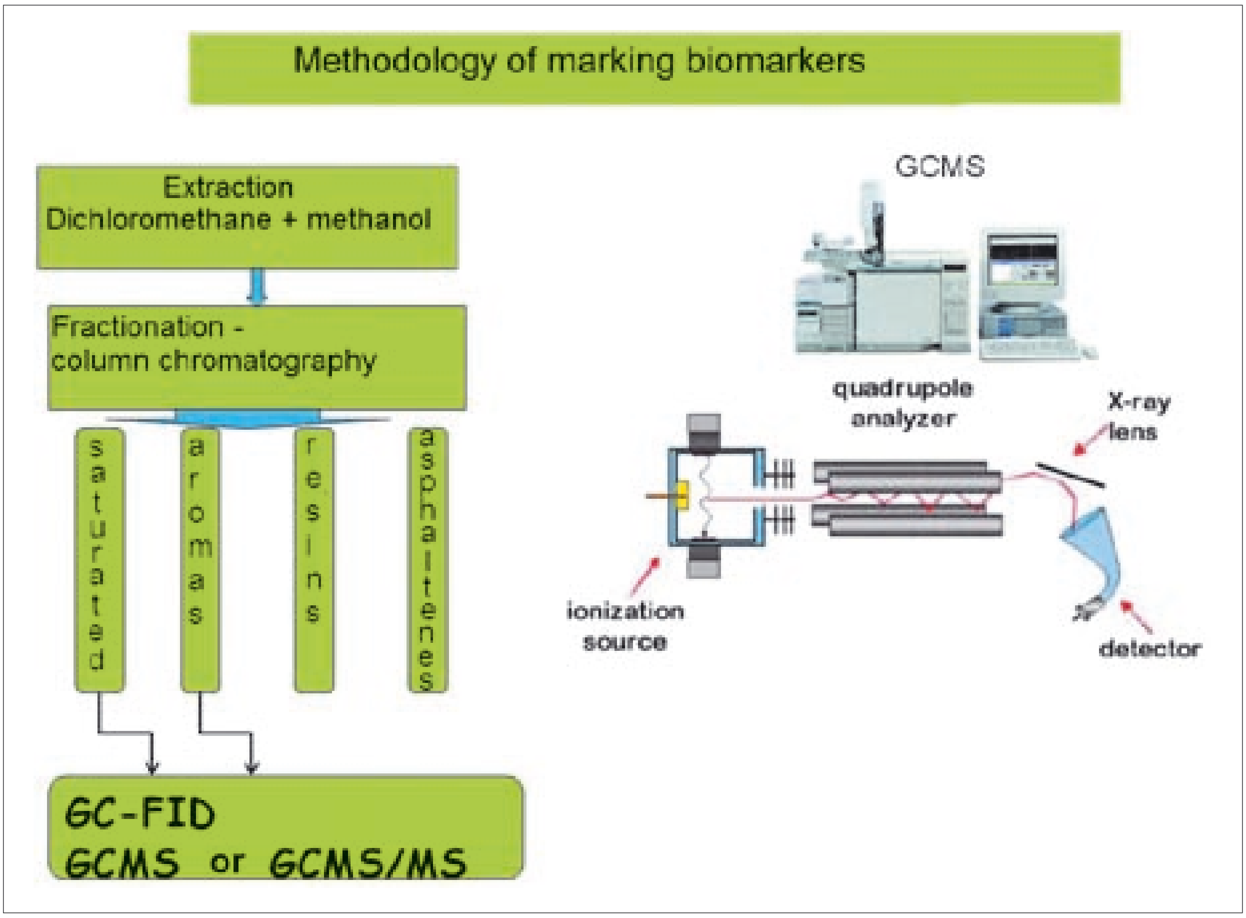


Fig. 4. This diagram shows the method of treating samples which contain biomarkers

erable number of new compounds genetically linked with living organisms (Fig. 3). The simplest and earliest biomarkers found are n-alkanes and acyclic isoprenoids and some of the aromatic compounds (e.g. naphthalenes and phenanthrenes) [10, 11]. Biomarkers of a complex chemical structure need analysis with the use of a linked technique of gas chromatography coupled with GCMS mass spectrometry (Fig. 4), which owing to great sensitivity enables the measurement of compounds, such as: sesquiterpenes, triterpenes, hopanes and steranes, which usually occur in geological samples in very small quantities [1, 8].

In spite of very low concentrations, biomarkers are carriers of valuable information for estimating genetic relations of deposit media with source rocks and the history of oil in a particular deposit. Their role in description of oil systems is important because of the necessity to determine the genetic relations between the matrix rock and the accumulated hydrocarbons, and also for defining the level of thermal maturity in shaping thermal history of the basin [1, 3, 6]. Temperature and time are the main factors which cause changes in configuration of particular compounds. Such an approach leads to reduction of hydrocarbon prospecting risk, because it enables to estimate the age of source rocks, their lithological type and it enables to determine thermal transformations, which in correlation with discovered hydrocarbons considerably narrows the exploration range, the so-called generative kitchen.

Biomarker studies in Poland so far involved many petroleum samples originating from the deposits of the Carpathian Flysch, Carpathian Foreland and from deposits of the main dolomite, Carboniferous and also the Middle Cambrian in the Peri-Baltic Syneclise. Similar studies were also carried out on potential Bedrock of the Carpathian Flysch and Mesozoic and Paleozoic deposits of the base structure of the Carpathian and dolomite in the Polish Lowlands. The study of specific biological markers was used in correlation work where biomarkers from the group of hopanes, steranes, triterpenes and such specific compounds as *oleanane* or *gammacerane* [8] were analyzed.

Biomarkers of aromatic fraction in turn, are widely used to describe the thermal maturity of petroleum and organic substance contained in the bituminous extracts. In the aromatic group of biomarkers the analysis covered alkylnaphthalenes, alkylphenanthrenes and derivatives of dibenzothiophene whose mutual quantitative relations change with increased thermal transformation. The applicability of these indicators refers particularly to the stage of catagenetic transformation and they can be related to other acknowledged indicators to determine maturity of sedimentary rock, e.g. the measurement of vitrinite reflectance or T_{max} from the Rock-Eval pyrolytic analysis.

The current oil prospection studies of specific biomarker groups identified on the basis of characteristic mass spectrum made it possible to identify the appropriate biomarkers for the matrix – useful in correlation work. The research conducted in Poland is an essential contribution to the knowledge on the nature of the original sedimentary rock which is the source for hydrocarbon generation and subsequent accumulation. Those studies have one principal goal: to determine the genetic relationship between the sedimentary rock and petroleum accumulation, which allows to predict the directions of prospection for new accumulations, simultaneously reducing the risk of conducting prospective works.

The definition of genetic relationships between types of petroleum in the regional scale may help to identify the different sources of its supply. The correlation is based on the analysis of many indicators received as a result of the studies:

The basis for correlation method is the assumption that particular matrix types arising in the same environment will generate the same kind of oil. Therefore the specific biomarkers prevailing in the matrix should be found in the oil generated from this rock. This relationship is ambiguous, however, on account of such factors as:

- varying generation time for different depths of the deposit,
- changes during the accumulation itself (washing with water, biodegradation, maturity, secondary migration, contamination),
- which must be considered in correlation works.

The correlation of oils is an extremely vital issue in the prospective industry – it allows to identify directions for the works in the new borehole area, where, following the discovery of several types of oil deposits we can – considering their characteristics – assess the lateral or vertical propagation of the prospection levels. Each oil family shares its specific characteristic features, typical of a single oil system. Determination of the number of oil groups enables to determine the number of oil systems, which narrows down any further research within a particular type of matrix or identified structures. The correlation between oils allows to specify e.g. the continuation of reservoir rock in dislocation zone and answer the question whether the geochemical composition of oil and gas types in different extraction levels may originate from a single source. Modern analytical techniques are sufficiently sensitive to be able to either prove or exclude the similarity of the two oil families. A substantially more difficult task is to establish the quality of the changes during oil migration from the matrix to the reservoir rock or physical-chemical and chemical changes in those two genetically identical oils after they have accumulated.

Examples of biomarker application in the Polish oil basins

Biomarker studies performed by a uniform method for potential matrix and discovered oil accumulations in selected geological units in Poland demonstrated that they might considerably facilitate the assessment of the oil basin. The assessment was made on the basis of specific compounds in the groups of pentacyclic terpenes, steranes and tricyclic terpanes and oleanane and gammacerane, etc. The correlation also takes into account the aromatic compounds, including sulphuric and individual combinations from this group, like retene or cadalene. Obviously, results of these studies must be interpreted with the support of proper geological diagnosis, which enables further appropriate development of basin modeling.

One of the described oil systems was the Jurassic-Cretaceous one in the Carpathian Foreland in the western part of the block of Lesser Poland; potential matrix was characterized genetically on account of the occurrence of hydrocarbon accumulation in this region. While most of the oil deposits show similar qualities of physical and chemical parameters, each of the accumulations demonstrates different genetic properties in detail, which makes it necessary to look for their sources in different types of matrix.

For the oil generation in the region of Grobla-Pławowice, the Lower Carboniferous (Culm facies) and alternative Jurassic deposits – Malm – could be acknowledged as its matrix, on account of its genetic similarity. Considering the bimodality of biomarker distribution, two sources of feeding must be taken into account for the Grobla deposit.

Other deposits, in turn (e.g. Pilzno), prove to be genetically independent for their content of oleanane, gammacerane and a high content of tricyclic terpenes with dominating t_{19} structure (fig. 5). As this type of petroleum differs from the other ones in the Jurassic-Cretaceous system, the Jurassic deposits are probably the only source which generates liquid hydrocarbons for it.

Whereas the other ones that do not contain oleanane, may be correlated with Paleozoic deposits (Lower Carboniferous or Devonian).

Distribution of biomarkers reflects very well the variable conditions of the sedimentation environment and its genetic properties, therefore it should be used in profiles of boreholes for identification of lithofacies corresponding to the generation levels.

Taking into account the composition of biomarkers and different geochemical indicators calculated on that basis, certain characteristic qualities are revealed in all deposits in the Carpathian Foreland, on account of the matrix substance type, the environment of its sedimentation and the extent of thermal transformations, which will be a collection of valuable information for the future development studies in this area. Changeability of genetic properties is visible not only among the stratigraphic layers, but even within one layer. Nonetheless, a few sedimentation groups can be isolated which differ in mutual indicator relationships

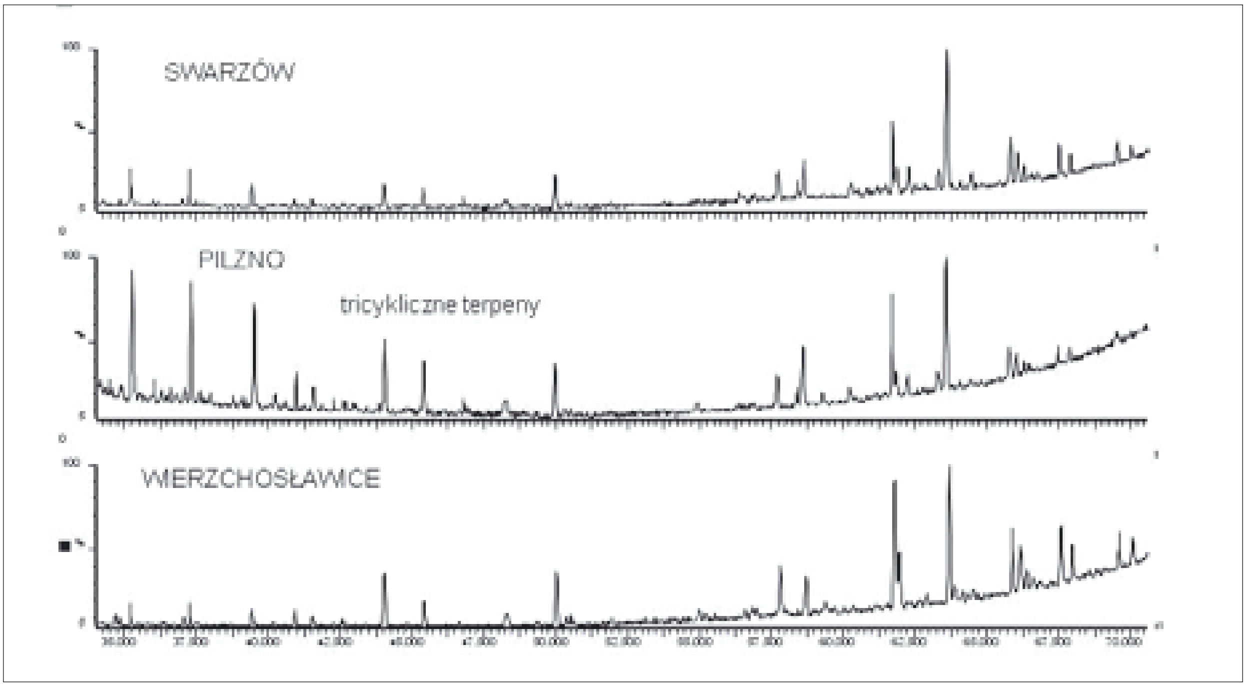


Fig. 5. Distribution of biomarkers in the terpene group (m/z 191 fragmentogram) in the three representative Jurassic deposits in the Carpathian Foreland which demonstrates very subtle differences resulting from the influence of genetic features of the source organic matter [8]

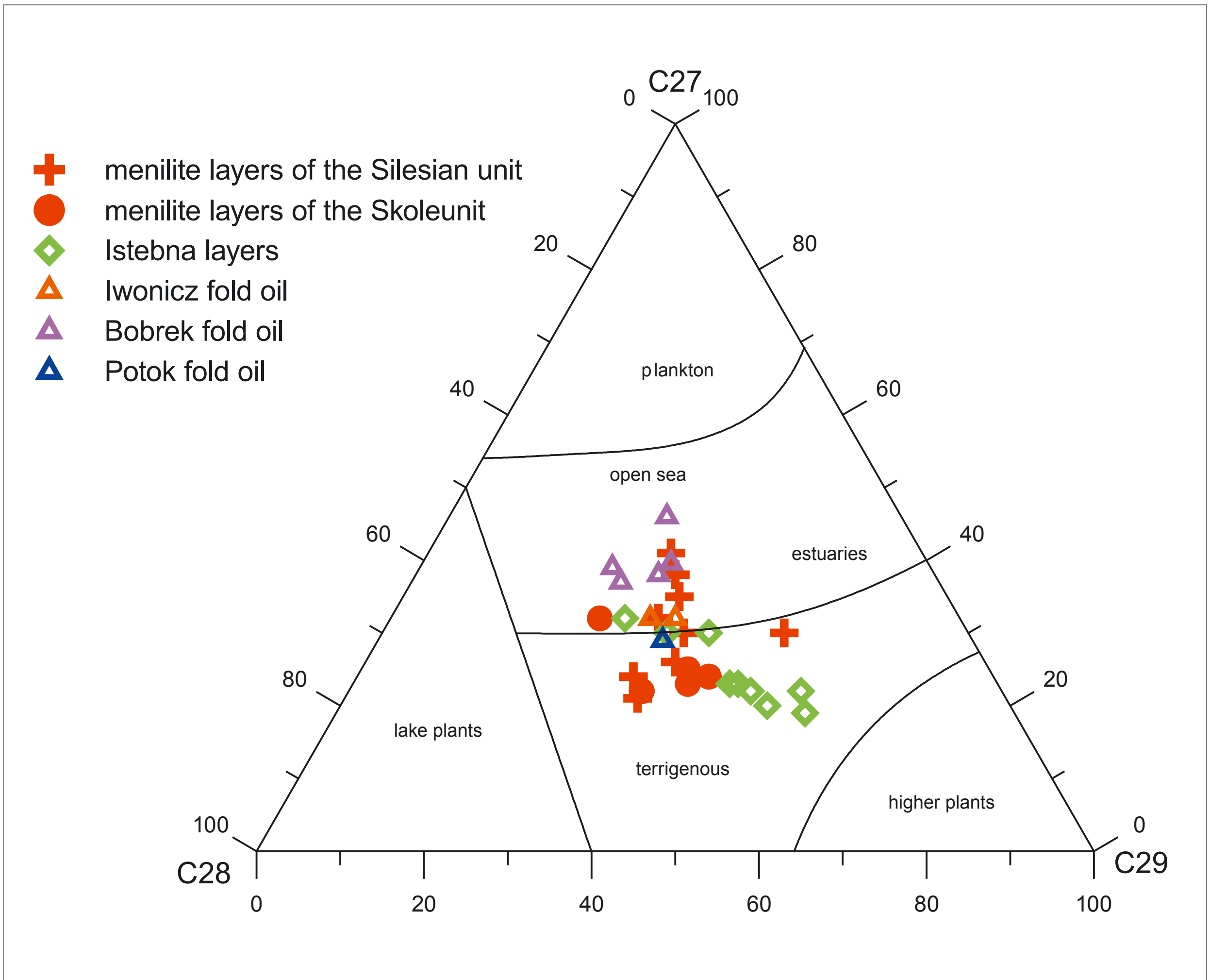


Fig. 6. Correlation diagram for selected Carpathian oils with potential matrix, based on steranes` composition [8]

resulting from different environment types or thermal transformation levels.

For the Carboniferous deposits in the block of Lesser Poland, the distribution of biomarkers from the group of tri- and pentacyclic terpenes indicates certain qualities which allow to distinguish them from the samples taken from other Paleozoic deposits. They include:

- relatively low content of tricyclic terpenes with relation to hopanes,
- domination of tricyclic terpene t_{23} in this group of biomarkers,
- the presence of tetracyclic terpene T_{24},
- relatively high content of norhopane C_{29}.

The Ordovician deposits feature the highest extent of oxygenation; similarly high level of oxygenation is typical of the Sylurian deposits. Whereas Carboniferous deposits prove to have environment with low oxygen content, and Devonian deposits demonstrate a reducing one. Definitely, the Malm deposits stand out genetically (marine character with high content of steranes C_{27} and C_{29} norhopane) and dogger, with significant share of land substance, where steranes C_{29} made up more than 60% in this group of biomarkers, which proves considerable share of vascular plants, decomposing in the presence of bacteria. Such specific features are often decisive in correlation works.

The results of biomarker studies also enabled to describe many Carpathian deposits, whose oil system requires a different approach, as the style of the tectonic structure implies discussion during correlation work which should be done within isolated tectonic units (Fig. 6).

Biomarker studies proved to be of great usefulness for the evaluation of secondary changes which occurred in accumulated oils and for recognition of repeat episodes of filling the deposit traps, which was noted particularly in the Carpathians, in oils accumulated in the Potok fold. The genetic description of menilitic layers recognized as one of the best matrix rock in the Carpathian Flysch in Poland was considerably expanded. For these layers located particularly in the Skole unit in the region of Łodyna-Paszowa correlation was carried out between the deposits located deep in the ground with those unfolding on the surface. The organic substance of this litho-stratigraphic zone was defined as marine-land – it was deposited in a shallow basin with sub-oxygenated conditions suitable for preserving the organic matter. The main correlation compound is bisnorhopane which occurs in the Skole unit predominantly in all the samples, having a great advantage over the other terpenes, specifically in low maturity samples. The remaining qualities diagnosed owing to the biomarker studies are:

- among hopanes – the oleanane content, which testifies to the presence of the organic substance on land ($O/C_{30\ hop}$ between 0.20-0.31),
- trace amounts or none of tricyclic terpenes,
- among hopanes – the isomers of configuration R, similarly, among steranes there were mostly isomers aaR, which proves their low thermal maturity.

Moreover, compounds of the norhopane type dominated, which may attest either to the hydrocarbon degradation or paleo-spill during sedimentation, or high activity of bacteria in the organic substance destruction.

Many of these features enabled positive correlation of all the oil types in the Skole unit and recognition of their genetic differences when compared with other examined oils in the Silesian or Sub-Silesian units. All the oil types in the Skole unit were diagnosed to contain C_{28} -bisnorhopane (BNH).

Many samples of menilitic layers were found to include, next to oleanane, also retene, which is the evidence of material found on land. The presence of retene suggests the contribution of gymnosperm plants (gymnospermae). Typically, it is identified in samples with low thermal maturity.

Biomarkers may considerably help with reconstruction of tectonic structure of the Carpathians, owing to the possibility of genetic correlation of samples taken on the surface with core samples, often representing deep borehole profiles. However, one must always keep in mind the complementary function of information obtained from biomarker study in relation to the whole range of geological and deposit data. Essential is also the fact that the biomarker science is still developing and – along with the new studies – it may contribute to changing the established views (in accordance with the currently feasible records) related to the genetic status.

> Taking into account the composition of biomarkers and different geochemical indicators calculated on that basis, certain characteristic qualities are revealed in all deposits in the Carpathian Foreland, on account of the matrix substance type, the environment of its sedimentation and the extent of thermal transformations, which will be a collection of valuable information for the future development studies in this area.

The author is researcher at the Oil and Gas Institute in Krakow

Literature

1) *Al-Arouri K. R., Mckirdy D. M. & Boreham C. J., (1998) Oil-source correlations as a tool in identifying the petroleum systems of the southern Taroom Trough, Australia. Organic Geochemistry, 29 (1): 713–734.*
2) *Bordenave M.L. (1993) Applied Petroleum Geochemistry. Editions Technip, Paris.*
3) *Demaison G.J., Bardley J., Huizinga, (1991) Genetic Classification of Petroleum System: AAPG Bull., Vol. 75, p. 1626-1643.*
4) *Fowler M. G., (1992) The influence of Gloeocapsomorpha prisca on the organic geochemistry of oils and organic rich rocks of Late Ordovician age from Canada, in M. Schidlowski, and et al., eds., Early Organic Evolution: Implications for Mineral and Energy Resources: Berlin, Springer-Verlag, p. 336-356.*
5) *Holba A. G., Dzou L. I. P., Masterson W. D., Huges W. B., Huizinga B. J., Singletary M. S., Moldowan J. M., Mello M. R. and Tegelaar E., (1998) Application of 24-norcholestanes for constraining source age of petroleum: Organic Geochemistry, Vol. 29, p. 1269-1283.*
6) *Hunt J.M., (1996) Petroleum Geochemistry and Geology, Freeman and Co., New York, 743 p.*
7) *Matyasik I., Dziadzio, P.S. (2005), Reconstruction of Petroleum System Based on Integrated geochemical and geological Investigation: selected examples from middle Outer Carpathians in Poland, AAPG Memoir 84, p. 1-21.*
8) *Matyasik I. (2011). Biomarkers in genetic characteristics of petroleum systems. Studies by INiG No. 177, Krakow, p. 220.*
9) *Mizerska M., (2004), Press Conference of the Ministry of Environment and National Geological Institute, Geological Survey, vol. 52, no. 7.*
10) *Peters K. E., Walters C.C. & Moldovan J.M. (2005), The biomarker guide. Biomarkers and isotopes in petroleum exploration and earth history. Ed. 2. University Press, Cambridge: p. 1132.*
11) *Philip R.P. (1985), Fossil Fuel Biomarkers. Application and spectra. Elsevier, Amsterdam, p. 280.*

Factors which induce development of assessment methods of lubricating oil properties during engine operation

Safe and trouble free engine operation

Wiesława Urzędowska, Zbigniew Stępień

Progressing development of combustion piston engines exposes the lubricating engine oils to ever increasing operation burden. It is related to continuously growing power of engines per unit and at the same time diminished volumes of lubricating systems and extension of running periods between oil exchanges.

Changes in engine construction, as well as composition of fuels resulting from requirements of natural environment protection are additional factors which exert undeniable influence on accelerated loss of utility properties of lubricating oil during engine operation. They have resulted in implementation of regulations concerning reduction of harmful components of exhaust gases from combustion engines all over the world. The fulfillment of ever stricter 'Euro' exhaust gas purity standards is the challenge not only for engine designers but also for manufacturers of fuels and lubricating oils.

Lubricating oil is an element of the system comprising also an engine, exhaust gas cleaning system and fuel – linked by mutual interaction. It occurs at various levels and has an extremely important influence, among other things, on the extent and quality of changes in the operational properties and oil change frequency.

Oil used in the engine is exposed to high temperatures and combustion products generated during engine work and simultaneously, it can be diluted with fuel which accelerates the process of oil oxidation when it contains a biocomponent. Additional hazards which can cause sudden, premature deterioration of lubricating engine oils are adverse interactions between the oil and fuel, resulting most frequently from antagonistic interaction of their components which are not always compatible. Moreover, changes in the oil composition are significantly affected by the requirements of exhaust gas aftertreatment systems (three-function catalyzers in case of spark-ignition engines (SI), SCR catalyzers (*Selective Catalytic Reduction)* and particulate matter DPF filters *(Diesel Particle Filters*), including CRT filters (with *Continuously Regenerating Trap*) – in case of the SI engines). In catalytic convertors and in particulate matter filters, precious metals are used as catalytic agents sensitive to the effect of some elements (e.g. lead, phosphorus, sulfur, zinc). These elements may cause disturbances in operation of catalyzers and DPF filters and even cause their permanent damage. This fact resulted in introduction of low SAPS lubricating oil with low content of sulfur, phosphorus and sulfurous ash to lead-free petrol and low sulfur diesel oil.

In discussion on the processes of degradation of lubricating engine oils during engine operation we have to remember that conditions in which they are operating have a great impact on determination of operation periods between oil changes. For marketing reasons, the operating manuals provided by car manufacturers usually define the periods of operating the vehicle between oil changes assuming ideal conditions of vehicle operation. Whereas the actual conditions tend to be rather difficult or hard, mainly for the following reasons:

- short distance driving (repeated warming up and cooling down of an engine),
- driving in traffic jams (driving conditions called '*stop and go*'),
- prolonged idle run of the engine (driving and frequent stops in traffic jams),
- frequent starting up of an engine in low temperatures,
- car exploitation which requires substantial, variable motor load (alternated overheating and cooling of an engine),
- driving with heavy motor load (driving on a highway, hauling of a trailer),
- driving on unhardened roads.

These conditions may cause more rapid loss of operational properties of lubricating oil and consequently substantially reduce the periods between its change (sometimes more than by half).

The above discussion points out to large diversity, complexity and variability of factors affecting the lubricating engine oil. Therefore, in order to guarantee safe and trouble free operation of an engine – it would be best if the conditions were close to optimal – it is necessary to monitor multiple changes in properties of lubricating engine oil during work, for which relevant procedures and research methods are indispensable.

Changes in properties of lubricating engine oil during its operation

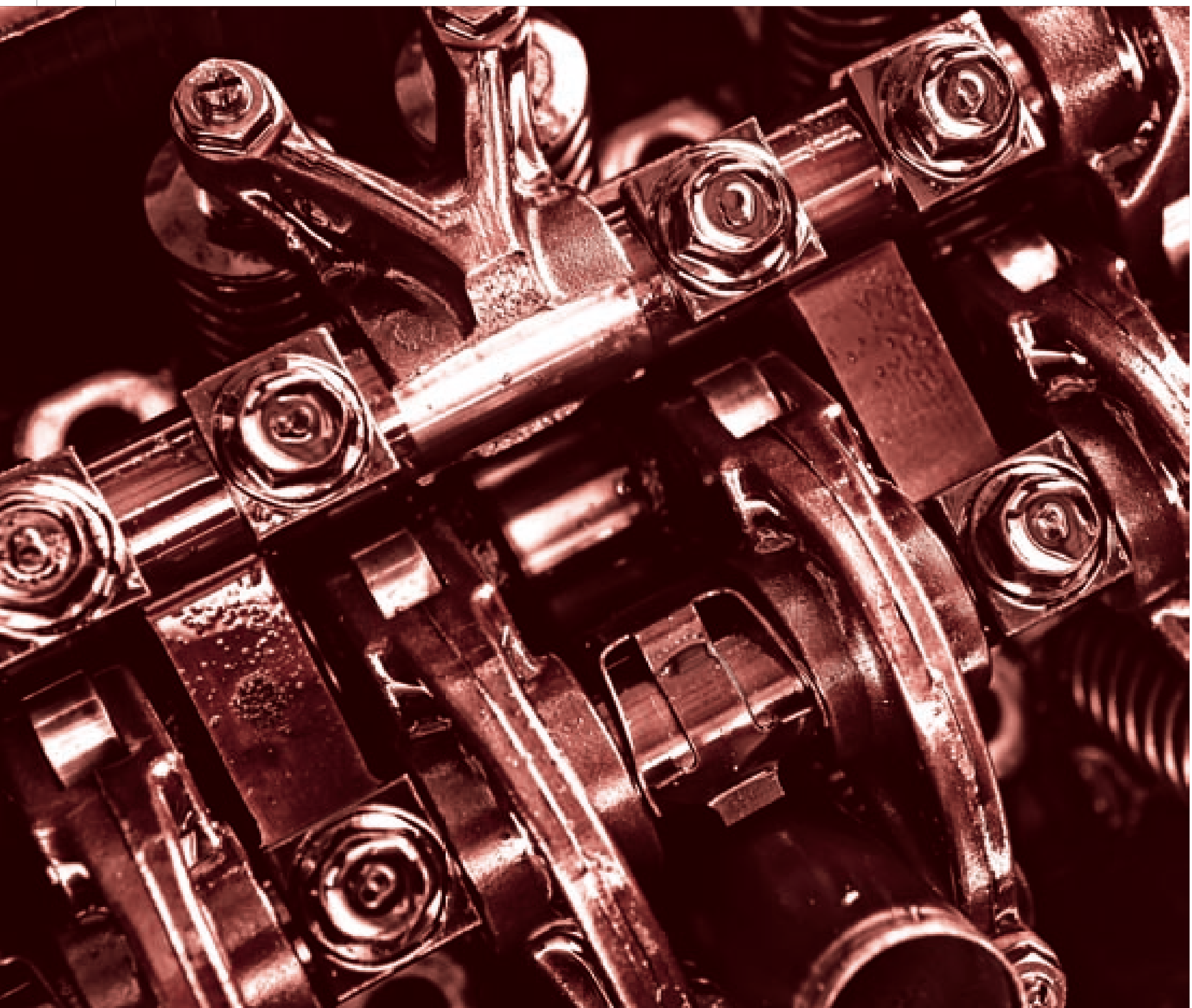
Lubricating engine oil undergoes numerous processes during its operation and it is exposed to various factors resulting in gradual loss of its operational properties. For example, diluting the lubricating engine oil with fuel leads initially to the loss of its viscosity. Depending on the lubricating engine oil viscosity class, already 10-15% of fuel content causes its dilution to the values critical for lubrication (viscosity below approx. 6 mm^2/s), resulting in breaking of the lubricating film, occurrence of marginal or even dry friction, instead of liquid or at least semi-liquid. Such phenomenon may be hazardous for the engine, causing increased wear and tear of its working elements (damage and then destruction of the slide layer of the main and crankshaft bushings, seizing of journal in bushings, damage

of honed layer on the surface of cylinder bushings, seizure of pistons in cylinders, etc.).

In case of polluting the lubricating oil with hard particles originating from the wear of engine working elements or those getting into the engine with the sucked air due to filter damage, the particles are pressed into the soft surface of bushings, forming a kind of 'grater'. In the course of further operation it results in premature wear of bushings and journals or other working surfaces (cams of cam shafts, piston surface cladding, piston ring groves, etc.). Additionally, the destructive processes described are intensified by acids formed in gradually degrading oil, causing formation of corrosion foci on internal elements of the engine.

Changes in the operational properties of lubricating oil can also be due to its chemical degradation, frequently premature, in the result of adverse interaction between the oil and components of fuel refining package or biocomponents used.

The problem of changes of the physical and chemical properties (aging) of engine oil during its work and especially accumulation of soot, formation of gels, sludge and polymeric structures increasing its viscosity is crucial for safe and economical engine operation. These processes occur due to interaction of engine oil components, especially additives present in it, under the influence of thermal and mechanical factors during operation, as well as due to the effect of refined



engine fuels and substances formed during their combustion in the engine.

In the recent years, additional problems have been arising due to more and more widely applied biofuels which – being in different phases of oxidization which results from the process of their accelerated aging as well as incomplete combustion in combustion chambers of an engine – get into the lubricating oil, causing initially a drop in viscosity and increased oxidization of the lubricating oil and they sometimes form insoluble, precipitating compounds and sludge in interaction with its components. In the effect, accelerated corrosion of slide bearings containing copper and lead may occur. Generally speaking, low resistance of biofuels to oxidizing enhances formation of sediments in the engine, and so does their high iodine value, accelerating coke sedimentation on injection nozzles and at the same time increasing the tendency to formation and deposition of sludge on internal elements of engines. When oil is diluted with fuel including biocomponents, harmful interaction between esters and engine oil may occur, especially with one of its basic components – i.e. viscosity modifier.

At present, the basic requirements and expectations which have to be satisfied by lubricating oils used in automobile engines are:

- maximal reduction of friction between cooperating elements of engines (improvement in mechanical efficiency);
- extended operational durability of the oil, including its refining additives;
- reduction of emission of harmful substances to the atmosphere;
- compatibility with secondary exhaust gas processing installations.

However, the fulfillment of these requirements is very often contradictory, because:

- the development of exhaust gas aftertreatment systems, accelerated due to continuously increasing restrictions in respect of reduction of harmful components emission requires the limitation of the content of sulfur, phosphorus and sulfate ashes in oil, as it has to be compatible with the said systems. It is also associated with the application of sulfur-free detergents;
- necessity of eliminating ZDDP-based additives (*Zinc Dialkyl Dithio Phosphate*) implicates increased volumes of antioxidants contained in oils and drastic reduction or elimination of anti-wear additives, which include sulfur and phosphorus;
- improvement in mechanical efficiency of engines makes it necessary to apply larger volumes of additives which reduce friction, i.e. anti-wear agents containing sulfur and phosphorus, which is in contradiction to requirements of the exhaust gas aftertreatment system and elimination of the ZDDP;
- extension of periods between oil changes is connected with the necessity of increasing the oil durability, which means that while composing the oil formula, the content of ingredients including sulfate ashes, phosphorus and sulfur will increase, moreover, the application of higher quality oil base and larger amount of anti-oxidants is necessary. These requirements also clash with the requirements of exhaust gas aftertreatment and elimination of the ZDDP [1, 2, 3].

Therefore, in the recent years, one could notice e.g. the tendency to reduce phosphorus content in engine lubricating oils applied in automobiles. Also e.g. considering the engine oil classification API, the content of phosphorus for oil of the SH quality class diminished from 0.12% in case of the GF-1 requirements to 0.10% for the GF-2 [1].

> The problem of changes in the physical and chemical properties (aging) of engine oil during its work and especially accumulation of soot, formation of gels, sludge and polymeric structures increasing its viscosity is crucial for safe and economical engine operation.

Due to the fact that phosphorus constitutes one of the principal components of additives which prevent oxidization of oil and engine wear, reduction of its content is hazardous to the oil, as it leads to formation of increased volume of various precipitation products and greater wear of engine elements. This situation has led to elaboration of new generation ash free additives substituting or complementing the diminished number of additives containing phosphorus. However, the tests which have been conducted so far according to the research procedure ASTM D5302 (*VE Sequence* and the one substituting it for more reliable assessment of ash free additives without phosphorus content – *Sequence VF dual plug*) demonstrated that substituting additives is not always fully effective and further lowering of the phosphorus content below 0.1% requires much higher doses of such additives or the elaboration of different ones. Summing up, it has to be stated that the aspiration to lower the content of additives including phosphorus in engine oils and substitute them with other ash free kinds may have influence on increased formation of gels, sludge and even resins and hard waxes in engine oils.

Currently, two basic tendencies are binding in elaboration of new engine oils, i.e. lowering the oil evaporation speed (volatility) and extending the periods between oil changes. Engine and road tests performed up till now allowed to make the following observations in respect of the above tendencies. Extended use of highly volatile oils (rapid evaporation speed) leads to increased concentration of metallic additives in the oil, with the elapsing time of its operation. In case of extended work of low volatility oils (slow evaporation speed) reversed tendency occurs, i.e. slightly lowered concentration of metallic additives in oil. Lowering of additive concentration is caused by their gradual degradation due to various factors affecting the used oil. Consequently, the oil with small volatility in the progress of its work demonstrates diminished resistance to oxidation, increased tendency to form sediments and it gradually fails to protect the elements of the engine against wear. The oil with high volatility evaporates quickly during extended work, which results in the necessity of its periodical refilling (refreshing). On the one hand, it leads to supplementing the additives degraded in the course of work, and on the other, evaporation of light fractions of base oil results in gradual increase in thickness of such oil.

> Due to the fact that phosphorus constitutes one of the principal components of additives which prevent oxidization of oil and engine wear, reduction of its content is hazardous to the oil, as it leads to formation of increased volume of various precipitation products and greater wear of engine elements.

Described changes in respect of technologies of produced fuels and engine lubricating oils, their preconditioning and especially problems resulting from possible mutual incompatibilities in composition of the liquids and threats they pose to safe engine operation are the ever growing challenge related to the methods of their examination, diagnosing the mechanisms of their formation and assessment of obtained results [4, 5].

Monitoring of changes in properties of engine lubricating oil in its operation

In the last few years, more and more procedures of monitoring changes in properties of engine lubricating oil have been elaborated and applied. Their goal is to provide required operational features for the lubricating engine oil, by verification of intervals between oil changes depending on conditions of its work, closely related with quantitative and qualitative processes of lubricating oil degradation processes. Owing to it, not only safe and trouble free operation may be guaranteed of an engine in which specific technical solutions have been applied, but also it is possible to monitor whether conditions of its operation are optimal from the point of view of interaction with the lubricating oil, whose property changes are the result of conditions of vehicle operation.

Basically there are three mutually complimentary directions (areas) of assessment of changes in lubricating oil properties during work:

- quantitative and qualitative assessment of change dynamics for the wear elements and those polluting the lubricating engine oil. In this case, oil samples taken from upper and lower (below the crankshaft axis) sections of an engine are assessed in respect of contained hard metallic polluting particles, taking into consideration at least nine elements, such as: Cu, Fe, Cr, Pb, Sn, Al, Mo, Si, Na. However, selection of the group of analyzed elements depends to large extent on the construction materials of a particular engine type and may also include such elements as: Sb, Ba, Cd, Mg, Mn, Ni, P, Ti and V. The changes in content of elements in the oil obtained in the result of the assessment are then analyzed for possible sources of their origin and possible causes of their generation;
- assessment of physical and chemical changes of lubricating engine oil. For this purpose the infrared spectroscopy with the Fourier's transformation (FTIR – *Fourier Transform Infrared Spectroscopy*) is commonly used for analysis of: the degree of oil oxidation, soot content, content of products including sulfur (acids), products of nitration and contents of fuel, water and glycol in oil;

- additional analyses aiming at extending the range of information concerning changes in properties of lubricating oil in different areas or to confirm (more precisely) previous assessments executed with the FTIR method. The analysis usually concerns: TAN, TBN, kinematic viscosity, high temperature viscosity HTHS, fuel content in lubricating engine oil and other components (increasingly more specialist ones). The obtained results concerning changes of particular properties are analyzed further in respect of their possible causes and potential results which they could have for the operational properties of oil or damage of the engine.

Necessity for development of assessment methods of changes in lubricating oil properties

Unfortunately, more and more frequently, unexpected, premature and frequently violent processes of degradation of lubricating engine oils occur, largely due to growing loads which they undergo and occurrence of mutual, multi-platform, contradictory reactions between lubricating oil, fuel and the engine. Also, it has been found that processes of mutual adverse interactions between lubricating oil and fuel continuously evolve with implementation of new technologies concerning engine construction, appearance of alternative fuels and modification of lubricating oils. However, the currently available, popular methods of studies are not always sufficient for a complete, reliable identification, assessment and understanding of mechanisms of these negative phenomena. Therefore, modification, development and implementation of these methods is absolutely vital.

Also, the current method of examination of lubricating oils is reported to be unsatisfactory e.g. in respect of identification of antagonisms between commonly used additives for engine fuels and lubricating oils. These antagonisms lead to accelerated degradation of lubricating oils, which may result in formation of slimy deposits described as sludge. As an example, we can use the method of infrared spectroscopy with Fourier's transformation (FTIR), commonly applied for assessment of the extent of pollution and degradation of lubricating oil products. It is an instrumental technique which consists in examining the ability of a substance to absorb, transmit or reflect infrared rays. In case of analysis of engine oils, the infrared spectroscopy method allows to observe the depletion of zinc dialkyl dithio phosphoranes applied as antioxidants and antiwear additives (band approx. 976 cm^{-1}), assess the influence of nitrogen oxides on engine oil (nitration and nitratation, bands within the range 1650 to 1600 cm^{-1}), watch the processes related to formation and transformations of carbonyl compounds (bands ranging from 1800 to 1670 cm^{-1}) which can be related to oxidizing processes [6]. Also approximate assessment of the fuel, water and glycol content in oil is possible. However, detection of products of oxidizing and sulphonation is not reliable and in the case of assessment of component change in oil degradation products, the margins of sensitivity of this method are not precise enough.

The FTIR does not permit definite detection of many forms of pollution in oil (e.g. water), therefore verification by other methods is indispensable.

Generally, the application of FTIR in analysis of used oil requires considerable experience in spectral analysis and interpretation of obtained results. For example, FTIR analysis of sludge formed in an engine due to adverse interactions of polyizobuthylene and polypropylene glycol present in the refining package of engine petrol with lubricating oil did not demonstrate increased content of carbonyl compounds typical for processes of oil oxidation or nitrating compounds in registered bands. Monitoring of the changes in operational properties of the discussed lubricating oil with the FTIR method and assessments of viscosity changes and acid value did not allow to predict rapid degradation and sludging of the oil, which led to engine seizure. Only the application of gel chromatography GPC (*Gel Permeation Chromatography*) and proton, paramagnetic nuclear resonance Proton NMR (*Proton Nuclear Magnetic Resonance*) allowed to determine of causes of premature sludging of the engine oil [5].

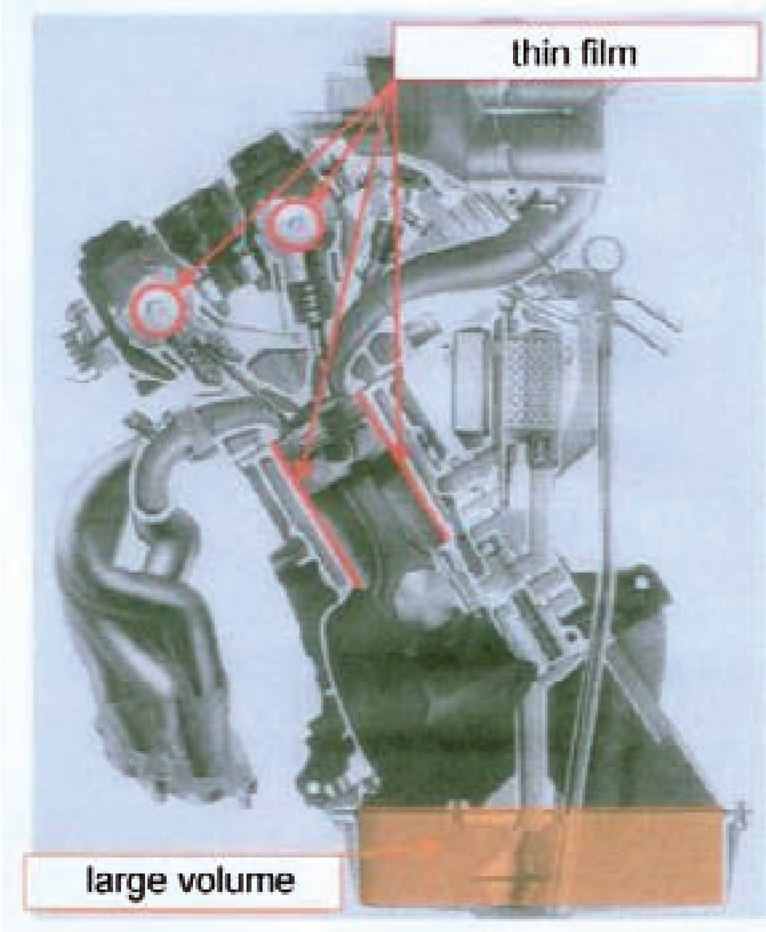


Fig. 1. Demonstration of areas on transverse cut section of an engine in which various mechanisms of oil oxidation take place

Thus, monitoring of changes in lubricating oil properties requires the application of more diverse assessment with the use of additional, modified and extended or newly developed and adapted research methods.

At the Oil and Gas Institute, we have been trying for some time to extend the testing range of lubricating oil in operation and to implement new, frequently our own *in-house* methods [7].

Taking into account substantial influence of fuel composition (including the bio-component) as well as operating conditions of lubricating oil on processes of its destruction, at present two basic mechanisms are distinguished in the studies of oil oxidation stability which are applied at the Oil and Gas Institute in testing of the used engine oil, i.e.:

- oxidation occurring in large volumes of oil. A situation like this takes place in the engine oil pan where it is continuously mixed at higher temperature and in contact with the air, which is the factor stimulating its oxidization and formation of insoluble sediments – Fig. 1. Assessment of oxidization stability is made in the case of lubricating oils for self-ignition engines, according to the procedure ASTM D 7545 modified at the Oil and Gas Institute, entitled: '*Standard Test Method for Oxidation Stability of Middle Distillate Fuels – Rapid Small Scale Oxidation Test* (RSSOT)'. Modification of the procedure was to be adapted to the assessment of lubricating oil oxidation.
- Oxidation occurring in thin oil film which separates the surfaces of elements cooperating in slide friction, intensified due to high temperature of lubricated parts. Such a situation occurs in thin film of oil covering the surfaces of cylinder bushes and rings of pistons which cooperate with them – Fig. 1. Assessment of oxidation stability is made in case of lubricating oils applied in self-ignition engines, according to the procedure ASTM D 4742 modified by the Oil and Gas Institute, entitled '*Test Method for Oxidation Stability of Gasoline Automotive Engine Oils by Thin-Film Oxygen Uptake*' (TFOUT). The said procedure is intended for assessment of sta-

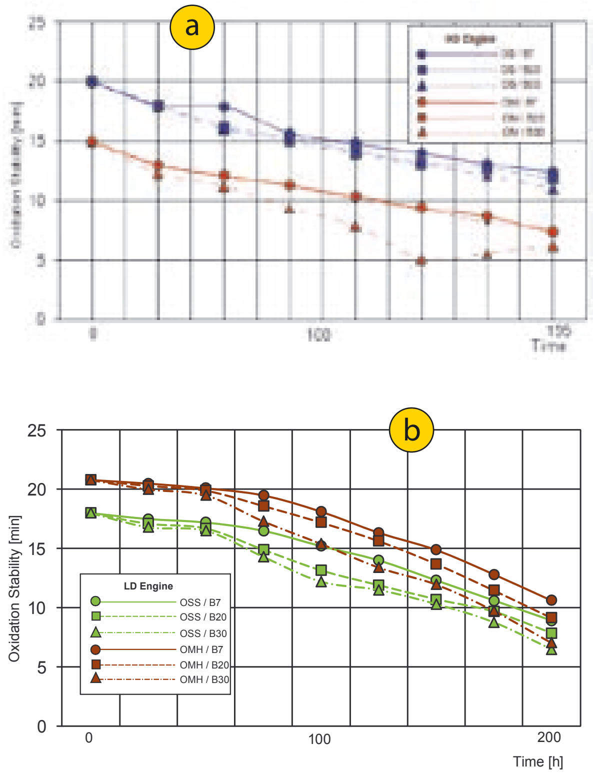


Fig. 2. Comparison of different resistance of lubricating oil in large volumes to oxidation, depending on the fuel used for powering the engine type HD (a) and LD (b) [9]

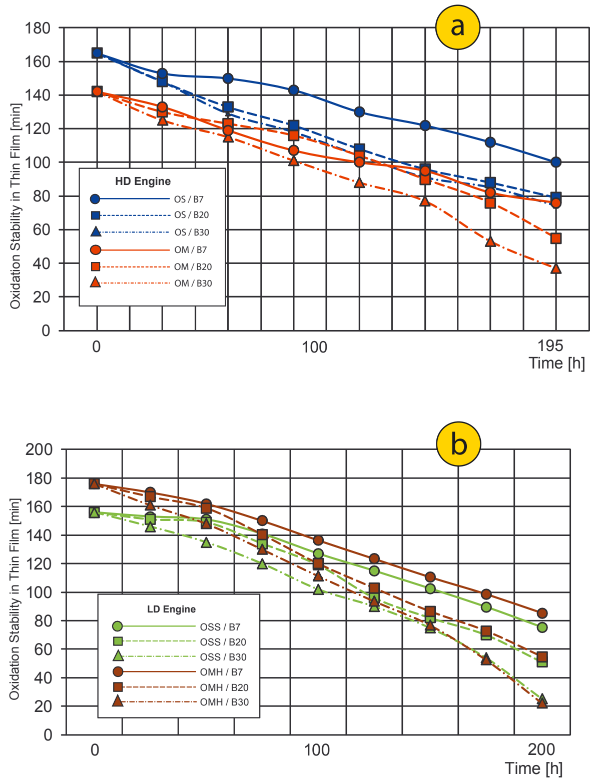


Fig. 3. Comparison of different resistance of lubricating oil in a thin film to oxidation, depending on the fuel used for powering the engine type HD (a) and LD (b) [9]

bility of oxidation occurring in thin oil film used for lubricating spark ignition engines. Generally speaking, modification of this procedure consisted in its adaptation to assessment of stability of oxidation occurring in thin lubricating oil film (of varying extent of degradation) originating from operated diesel engine. The hypothesis assumed that in a thin film, the oil would oxidize faster, which, in view of limited time of running engine simulation tests would allow easier demonstration of occurring processes of oil degradation and better differentiation of the extent of their advancement in tested oils [8].

The assessment of above mentioned, modified methods of testing oxidation processes of engine lubricating oil was performed at the Oil and Gas Institute on two research engine stands. One of them was equipped with an engine fulfilling the requirements of Euro 2, with self-ignition type HD (for propelling buses and trucks), while the second stand – with an engine fulfilling the requirements of Euro 4, with self-ignition type LD (for passenger cars). In both engines testing covered both lubricating engine oil based on minerals (in case of the HD engine marked with the 'OM' symbol, and in case of the LD engine marked with the 'OMH' symbol), and on synthetic base (in case of the HD engine marked with the symbol 'OS', and in case of the LD engine marked with symbol 'OSS') – Fig. 2 and 3. The engines were supplied with the same fuel which contained respectively: 7, 20 and 30% (*V/V*) RME and were marked as B7, B20 and B30. Complete test results were published at the SAE 2011 World Congress April – Cobo Center Detroit Michigan USA [9], and some selected results are presented in Fig. 2 and 3.

Analysis of the results demonstrated, among other things (Fig. 2 and 3), that increased content of bio-component in fuel cooperating with (diluting) the engine oil accelerates oxidation processes in lubricating oil, both mineral and synthetic. In case of assessment of oils in thin film, analyzed oxidation processes are more progressive and demonstrate greater differences, depending on the content of bio-component in the fuel which diluted the lubricating oil.

Other innovative methods which facilitate broader assessment of changing properties of lubricating oil monitored during operation and implemented recently at the Oil and Gas Institute are:

- assessment of remaining life-span (remaining usability of oil) according to the RULER – ASTM D 6971 method. It is a volumetric method which allows to assess the content of active part of antioxidants in the used lubricating agent. An unquestionable merit of this method is the possibility of identification of the content of all the different types of additives (of different chemical structure) which prevent oxidation, introduced to engine oil [10];
- membrane patch colorimetry (MPC). It is the method which helps assess the contents of insoluble pollutants in oils with the aid of spectral analysis. This method identifies soft pollutants which directly contribute to oil degradation. This method is so recent that the research procedure for it has not been published by the ASTM yet, a ready draft of which is awaiting approval [10];
- PQ-index method – is used for measuring the contents of all the ferromagnetic wear products in a sample of the lubricating agent; however, it is not sensitive to their volume. The test results are compared with those obtained by the AES method (Atomic Emission Spectroscopy) in which identification of ferromagnetic particles >5 μm is not possible [10];
- distribution of pollutant sizes – the application of microscopic method or automatic particle counter allows to determine the amount of all pollutants in lubricating oil in established size ranges [10].

Summary – conclusions

Rational management of lubricating agents and the guarantee of safe, reliable and durable operation of engines will require the application of broader, multi-directional, frequently unconventional research into progressing loss of operational properties of lubricating oils in order to forecast in the most precise way the eventuality of their oncoming rapid degradation.

Further development of piston combustion engines with growing diversification of applied fuels will impose changed formulation of lubricating oils, taking into account the application of new groups of refining additives. Consequently, there will be necessity of continuous development and implementation of new methods of studying changes in properties of lubricating oil in operation, adjusted to qualitative changes of the above mentioned products and conditions of their operation.

Also, the processes of mutual adverse interaction of lubricating oils with fuels are subject to continuous evolution, as well as implementation of new technologies in respect of engine construction, alternative fuels and relevant modification of lubricating oils. Identification, assessment and understanding of the mechanisms of these adverse phenomena will accelerate the introduction of more advanced, innovative research methods.

The authors are researchers at the Oil and Gas Institute in Krakow

Literature

1) *Roby S.H. and Supp J.A. Formulating for ILSAC GF-2 – Part 1: Obtaining Valve Train Wear Protection While Reducing the Phosphorus Content of a Motor Oil – SAE 952342*
2) *Bardasz E. Future Engine Fluids Technologies: Durable, Fuel-Efficient, and Emissions-Friendly – 11th Diesel Engine Emissions Reduction Conference, August 21-25th 2005, Chicago*
3) *Lawrence L, J. Heavy-duty Diesel Engine Oil Developments and Trends – www.machinerylubrication.com*
4) *Hancsok J., Auer J., Baladincz J., Kocsis Z., Bartha L., Bubalik M., Molnar I. Interactions between Modern Engine Oils and Reformulated Fuels; Petroleum & Coal, ISSN 1337-7027*
5) *Thiel Y. C., Hayden T.E. The Fuel Additive/Lubricant Interactions: Compatibility Assessments in Field Studies and Laboratory Tests – SAE Paper 2001-01-1962*
6) *Robinson N., Hons B. SC. Monitoring oil degradation with infrared spectroscopy – Wearcheck Division of Set Point Technology ISSUE 18*
7) *Urzędowska W., Stępień Z. Oddziaływanie olejów napędowych zawierających FAME na systemy wtrysku paliwa typu CR oraz na tempo degradacji smarowych olejów silnikowych – Przemysł Chemiczny, 6 (czerwiec) 2011 PRCHAB 90(6) 1113-1273 (2011), PL ISSN 0033-2496, str. 1217 – 1224*
8) *Urzędowska W., Stępień Z. Monitorowanie degradacji oleju smarowego współdziałającego z różnymi paliwami w warunkach symulacyjnych testów w silniku Diesla - Przemysł Chemiczny, PRCHAB 88(7) 765 – 844 (2009) PL ISSN 033-2496 str. 789 – 795*
9) *Stępień Z., Czerwinski J., Urzędowska W., Oleksiak., Research on Emissions and Engine Lube Oil Deterioration of Diesel Engines with BioFuels (RME) – SAE Paper 2011-01-1302, SAE 2011 World Congress April 12-14 2011 Cobo Center Detroit Michigan USA*
10) *Oleksiak S., Żółty M.: Wybrane metody badań do monitoringu środków smarowych – prezentacja, Środki Smarowe 2012, Zagadnienia eksploatacji środków smarowych w urządzeniach przemysłowych, transporcie i komunikacji, 16 – 18 maj 2012 – Muszyna Złockie.*

Computer models and reservoir simulations

Modern methods for recovering hydrocarbon reserves

Wiesław Szott

Recovery of hydrocarbon reserves from underground geological structures involves carrying out complex projects which last many years and require effective management systems. Such management systems can only be effective when they are based on the fullest and most consistent sets of data which characterise the hydrocarbon reservoirs, and on correct quantitative assessment of their operation. Computer models and reservoir simulations are tools which can fulfil all of these requirements.

Petroleum reservoirs start their existence in the human mind with the start of exploration leading to their discovery. The subsequent stages of the reservoir life include delineation, development and production. The final stage is abandonment of the reservoir.

Each phase of the reservoir life requires a series of management operations to be carried out. As with any other projects, whether the reservoir management is carried out in an appropriate way or not determines the economic results of the project.

The management process includes the following: setting up objectives, planning activities, following the plans, monitoring and reviewing, and potentially introducing corrections and changes as well as evaluating the results. Many of these activities require alternative predictions of hydrocarbon production to be adopted and analysed. At the current stage of technology development, reservoir simulation models act as the most precise and reliable tool for this purpose.

However, the reliability of the simulation predictions depends on the accuracy of the reservoir model used. Such models should provide basic parameters describing the reservoir shape, size, segments, structural irregularities and many other features. Thus, reservoir modelling and simulation are also important elements aiming to better understand hydrocarbon reservoirs and the processes within them.

Models and simulations

In accordance with the commonly accepted definitions [1]:

- **a model** is a structure, diagram or description of the operation, composition, properties or relationships of a phenomenon or object.
- **a simulation** is a man-made reconstruction (in a laboratory or using computers) of the properties of an object, phenomenon or space present in natural conditions although difficult to observe, investigate and recreate.

These definitions demonstrate the aim of modelling and simulating hydrocarbon reservoirs. In recent years such processes have been carried out almost exclusively using computers, and are based on mathematical models of objects located outside the reach of direct observations with very limited access for direct measurements. Reservoir simulations are carried out for inaccessible or difficult to investigate targets, which, however, provide certain benefits. They use abstract mathematical models of all important elements of reservoirs, i.e. properties of reservoir rocks and reservoir fluids as well as techniques of their extraction.

Thus, the key aspect of reservoir simulation is the application of mathematical models of reservoirs as well as processes within them in order to determine the characteristic properties of hydrocarbon reservoirs, mechanisms of resource extraction as well as to predict the reservoir behaviour in various production conditions. It should be emphasised that from a practical point of view, the most important advantage of reservoir simulation is (as mentioned in the definition given above) the possibility to simulate (repeat) reservoir behaviour in various mutually exclusive, hypothetical conditions in contrast to those created by the nature or chosen by the reservoir operator at a certain stage of production. Due to this aspect of reservoir simulation, reservoir models and simulations play an important role as a tool for optimisation of reservoir management and the production of resources.

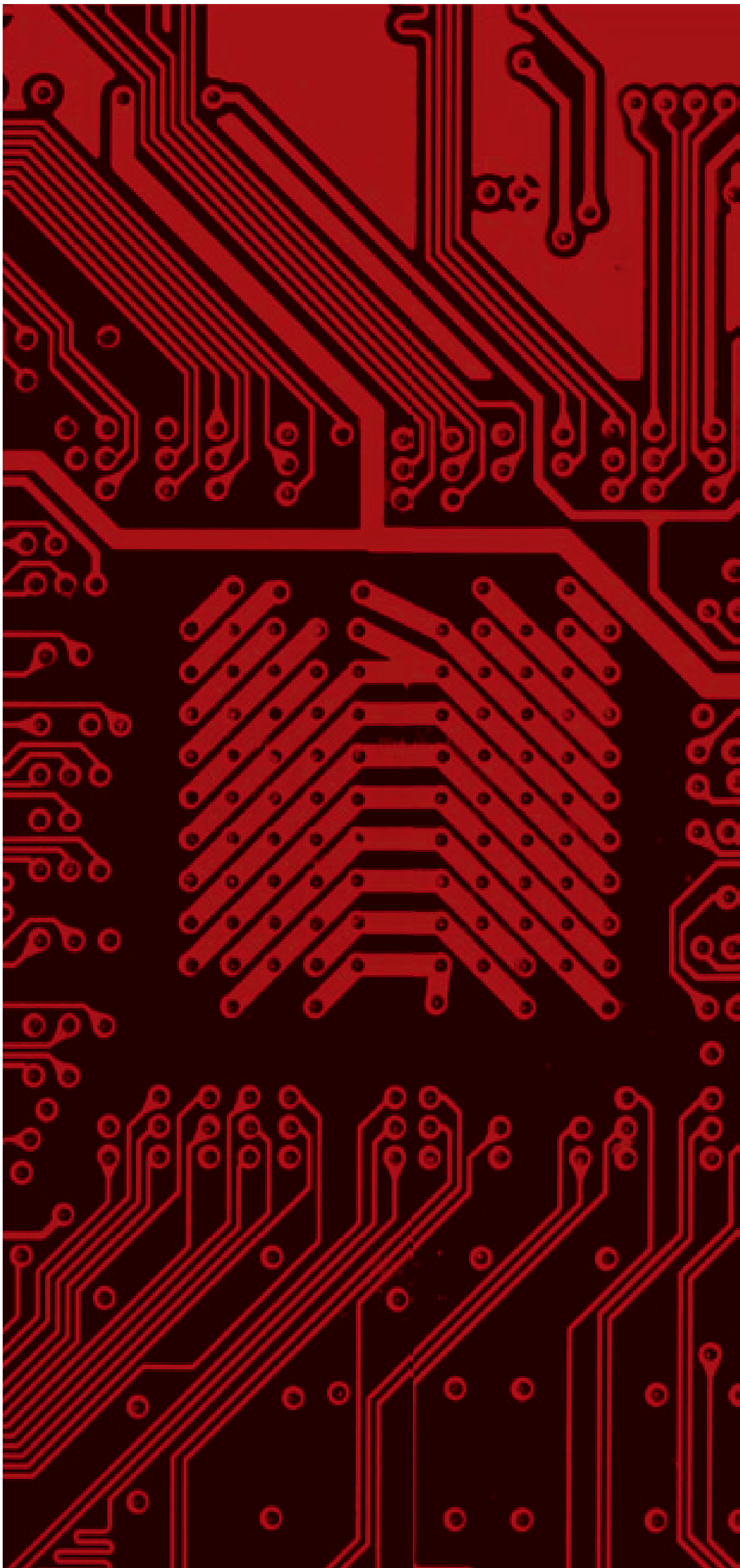
Data for reservoir modelling

Reservoir simulation models are created using various and most often numerous datasets. Such data represent a very wide spectrum of information describing a hydrocarbon reservoir, including geological, geomechanical, petrophysical, production and thermodynamic parameters as well as many others. The type of parameters and their relation to the actual object which they describe are important during the processing and further analysis.

The simplest group of parameters, classified in terms of the above criteria, are constants. This group includes such parameters as the density of reservoir fluids (petroleum, natural gas, reservoir water) in normal pressure and temperature conditions.

Another category includes those parameters which are treated as dependent variables. Here an example is the group of reservoir fluid properties most often determined in the laboratory and depending on the conditions of the experiment, i.e. most often temperature and pressure. They include fluid viscosity, compressibility and formation volume factor.

The next group includes parameters which depend on the time when measurements or observations are carried out. They include important reservoir production data such as the volume of production of each reservoir fluid or wellhead and bottom-hole pressure of wells.



The last group of data are parameters which depend on spatial coordinates and in certain cases also on time. These parameters represent time-independent or time-dependent distributions. They form a very important category of data as they include basic reservoir-modelling parameters, although reproducing them is a very problematic process.

The second classification criterion, already mentioned in the introduction, is their relationship to the described reality. In this publication, "relationship" means the method as well as extent of measurement (observation) in relation to the tested object. Here, several categories can be distinguished:

1. intensive (local) properties measured directly with an option of repeating the measurement in the same conditions; this category includes all properties measured in laboratories such as the pressure-volume-temperature (PVT) properties of reservoir fluids or petrophysical properties of rock samples;
2. properties determined from interpretation of other measurements using various interpretation models; these are typically averaged results of field tests carried out on samples of relatively large volumes; examples typically include geophysical data from wells collected in order to establish the porosity and permeability of the near-well zone, hydrodynamic tests in order to establish average effective parameters in the near-well zone, seismic survey data for identification of stratigraphic surfaces, etc;
3. properties (distribution) describing a laterally extensive area (reservoir scale) which are based on measurements taken in a relatively small fragment (one-millionth by volume) of the total volume; this category includes an important group of parameters describing reservoirs in terms of their geology (such as porosity and permeability); these properties are a necessary part of all reservoir models.

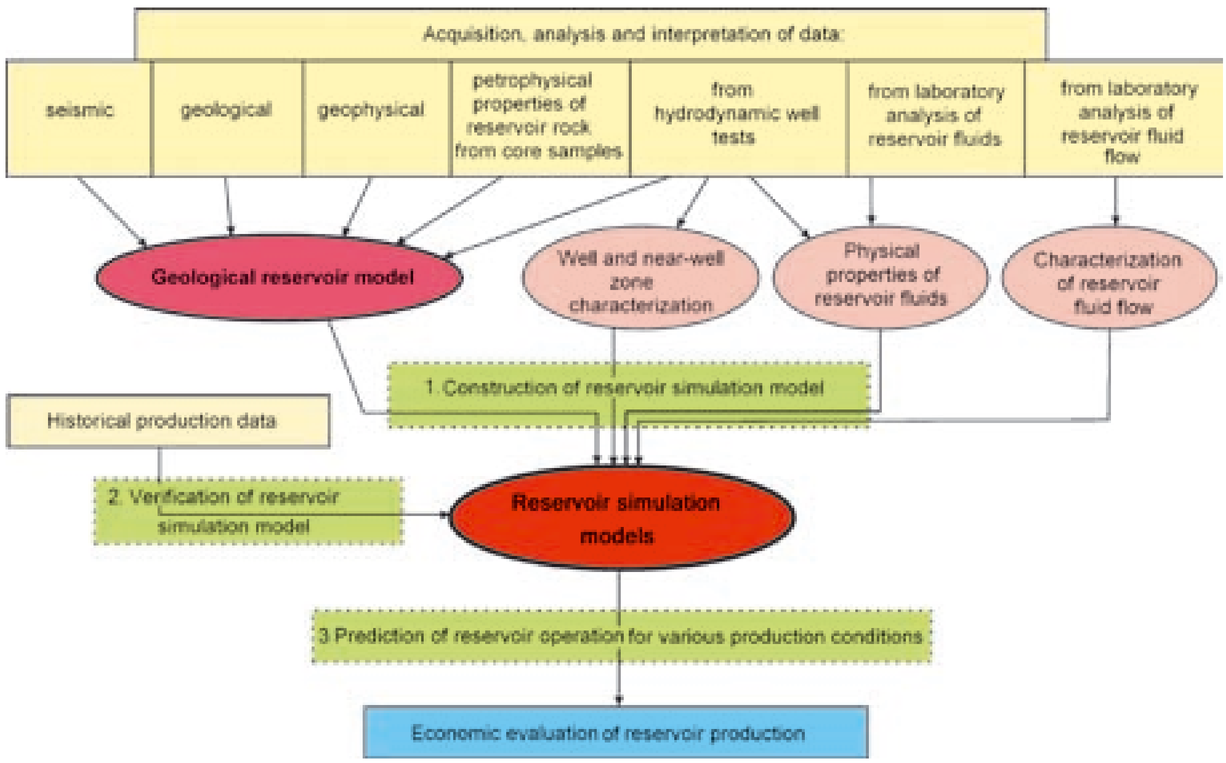


Fig. 1. Workflow for reservoir simulation and modelling

Methods of data analysis

All types of data are typically quantitatively analysed in detail. All of the types of data, ranging from the simplest scalar values from laboratory measurements, through interdependent parameters to multi-dimensional distribution of reservoir parameters, require application of an appropriate mathematical methods. Here, the tools traditionally applied include statistics and data modelling.

A specific group of data are parameters describing the geological properties of reservoirs. These parameters have an attribute which distinguishes them from others, i.e. apparent and effective stochasticity, which is a result of the character and origin of the geological structures they describe. Despite the deterministic laws which govern the origin of such structures, due to their nonlinear character and the extreme sensitivity of sedimentary processes to environmental conditions, these properties are strongly stochastic and it is necessary here to apply advanced statistical methods.

In addition to that, a limited number of measurement data collected from a small section of the whole volume of a geological structure leads to the necessity to predict (interpolate) their properties in areas inaccessible for direct measurements. This makes the results less reliable, therefore the best use of available information as well as applying the most effective methods for their interpretation is necessary.

For such parameters, the geostatistical method helps to find the right solution to spatial interpolation problems, to assess the uncertainty of the interpolation, i.e. it allows us to statistically evaluate the parameter values at specified points accessible for direct testing. Such evaluation is possible due to earlier identification of spatial correlation of analysed parameters. The final result of applying the geostatistical methods, i.e. generating a full spatial distribution of geological data through supplementing the measurements available from a limited number of points (wells penetrating a reservoir) with data for the remaining locations (reservoir), is a necessary element of developing reservoir simulation models.

Simulation models as the central element of reservoir characterisation system

Acquisition, analysis and interpretation of necessary data describing petroleum reservoirs are the first and indispensable elements in the workflow for full characterisation of reservoir performance. The workflow with the remaining main elements and activities necessary for creating such an integrated description, i.e. a model, is presented in Fig. 1.

Reservoir simulation is placed at the centre of the workflow with all other elements of the process leading to it. The exception is the economic evaluation of reservoir production, mainly supported by forecasts based on the reservoir simulation model.

The reservoir simulation model undergoes modifications during reservoir simulations. These involve computer programs which together with a reservoir model can be used to calculate various physical and chemical processes which take place in a hydrocarbon reservoir when production is carried out. These processes include:

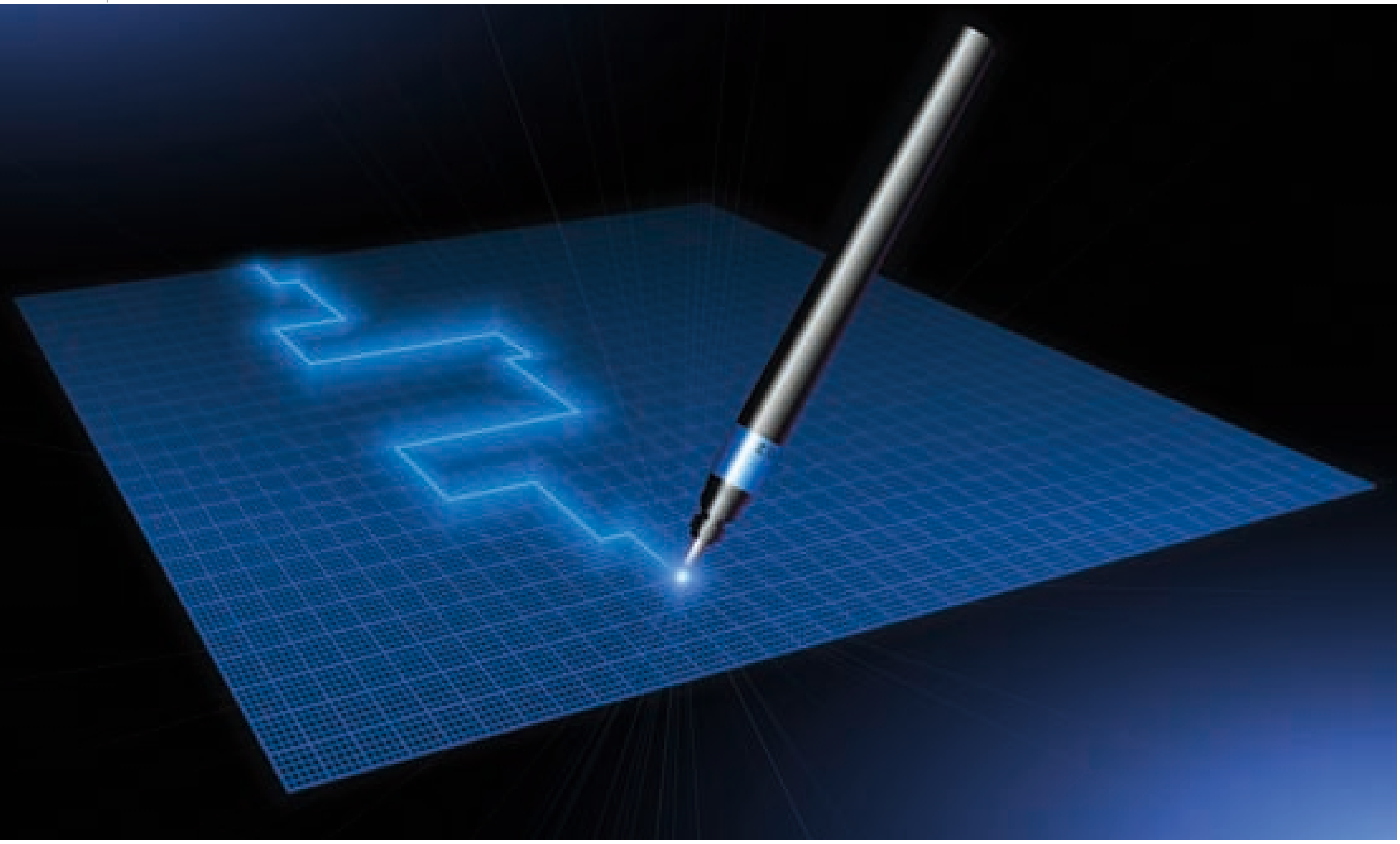
1. multiphase flow through porous and fractured rocks based on Darcy's law and its modifications,
2. phase processes in a multicomponent system (hydrocarbon and non-hydrocarbon components) based on the thermodynamic equation of state,
3. geomechanics of porous media based on the stress-strain equations for rocks,
4. physical diffusion and dispersion phenomena in porous media based on Fick's law,
5. thermal phenomena in the rock/reservoir-fluid systems based on the law of heat transfer,
6. chemical reactions between rock and reservoir fluids based on equations for chemical transport, stoichiometry and kinetics of chemical reactions,
7. biological reactions in porous media based on equations for nutrient transport, growth, death and chemotaxis in microorganisms,
8. adsorption and desorption phenomena based on equations for adsorption and desorption of reservoir fluids.

When these processes are taken into account, effective simulation of various types of petroleum reservoirs (conventional and unconventional, including shale reservoirs) can be done and different operation methods can be applied (primary, secondary and tertiary method).

The huge progress in the field of reservoir simulation [2] with regard to all three basic elements of this technology, which took place over the past 30 years, established its dominant role in data acquisition, analysis and verification as well as in predicting reservoir operation. These three elements are equipment, software and people.

Equipment

Practically all contemporary reservoir modelling and simulation utilise digital technology. Thus, com-



puter technology plays a key role in the availability, effectiveness and economics of reservoir modelling and simulation. At the beginning of the 1980s (1982), the price of the most modern computer (Cray-1S Supercomputer) was 17 million USD; it could carry 27 million operations per second, while its cache memory was slightly above 20 MB. Nowadays (in 2012) on the desks of the majority of specialists working in the petroleum industry are personal computers (such as PC HP with Intel® Core™ i7 980 XE processor) which are 10 000 times cheaper, have 40 000 times higher performance (940 MF/s) and have 200 times larger cache memory (4 GB), see Table 1.

These changes revolutionised many disciplines, particularly those where intense mathematical calculations are necessary. These disciplines include also reservoir modelling and simulation.

Software

Although not as spectacular, the progress in terms of computer programs (simulators) used for reservoir simulation is also significant. Practically, all processes which occur in reservoirs have their mathematical description as well as software application. One of the up-to-date examples is simulators which take into account unconventional tight-gas and shale-gas reservoirs. A more detailed review of the evolution of capabilities of simulators is given in Table 2.

It should be emphasised that the development of computer software for reservoir modelling and simulation includes not only (visible to the user) extensive capabilities in terms of new reservoir processes but also new calculation methods and techniques which accelerate the progress in this field. It also should be stressed that the increase in the potential of the contemporary simulators happens practically without any increase in the cost of their purchase and application.

People

The involvement of a large group of companies, institutions and individuals in the development described in the above two paragraphs is obvious. Additionally, with the increased potential of simulations as well as their reduced cost, their application was significantly increased. Among other things, this resulted in the creation of a new specialist group, i.e. simulation engineers, and the popularity of reservoir simulation training courses.

Table 1. Comparison of computer equipment

Computer	Cray-1S Supercomputer (1982)	PC with Intel® Core™ i7 (2012)
Cost (USD)	17 000 000	~1 000
Performance (GFLOPS)	0.027	109
Memory (MB)	22	4 000

Table 2. Evolution of simulation software

Decade	Simulator capabilities
1950	2-D simulators; two-phase simulators (uncompressible phases); simple geometry
1960	3-D simulators; three-phase simulators; black-oil reservoir simulators; many wells taken into account; realistic geometry; coning processes
1970	Compositional simulators; miscible displacement; chemical simulators; thermal simulators
1980	Realistic well management; fractured reservoirs; realistic fault modelling; graphic user interface
1990	User-friendly simulators; detailed geological models and upscaling; local grid refinement; complex geometry. Combined with modelling of surface installations
2000	Geomechanical simulators; biological simulators; probabilistic effects; solid-phase simulators
2010	Simulators of unconventional tight and shale gas/oil reservoirs

Petroleum reservoir simulation in Poland

In Poland, the simulation projects date back to the second half of the 1970s, when analogue methods were used, while from the first half of the 1980s digital techniques were utilised. In those years, the Oil and Gas Institute as well as teams from other scientific and research organisations from the petroleum industry started to apply first analogue, then hybrid and finally digital simulation models to Polish reservoirs. These simulations utilised mainframe computers.

Today in Poland, hydrocarbon simulation models are used in relation to the majority of processes of hydrocarbon extraction and their underground storage. Besides all natural mechanisms of hydrocarbon recovery, also used are methods of sustaining reservoir pressures such as injecting water, gas or injecting water and gas interchangeably, methods of mobilising hydrocarbons such as gas injection which involve miscible displacement, including CO_2 injection, as well as processes of underground gas storage in depleted reservoirs, aquifers, salt cavern formations and other facilities.

There are several centres in Poland which regularly carry out simulations. These include the Department of Reservoir Engineering of Lotos Petrobaltic S.A. in Gdańsk, Department of Reservoir Engineering in the Zielona Góra and Sanok Branches of Polskie Górnictwo Naftowe i Gazownictwo SA (PGNiG), and Faculty of Drilling, Oil and Gas of the AGH University of Science and Technology in Kraków. One of the leading centres is the Oil and Gas Institute (Department of Hydrocarbon Reservoir Simulation and Underground Gas Storage). The most significant achievements of the Oil and Gas Institute include:

1. Simulations of underground gas storage facilities in Wierzchowice and Husów. The underground gas storage plant in Wierzchowice is the largest in Poland. Due to mixing of injected gas with nitrogen-rich original natural gas, detailed simulations were carried out to simulate this mixing phenomena [3].
2. Simulation model and program for water injection into oil reservoir B-3 in the Baltic Sea, which used to be the largest operating oil reservoir in Poland [4].
3. Construction, calibration and application of a reservoir model for the largest oil and gas reservoir

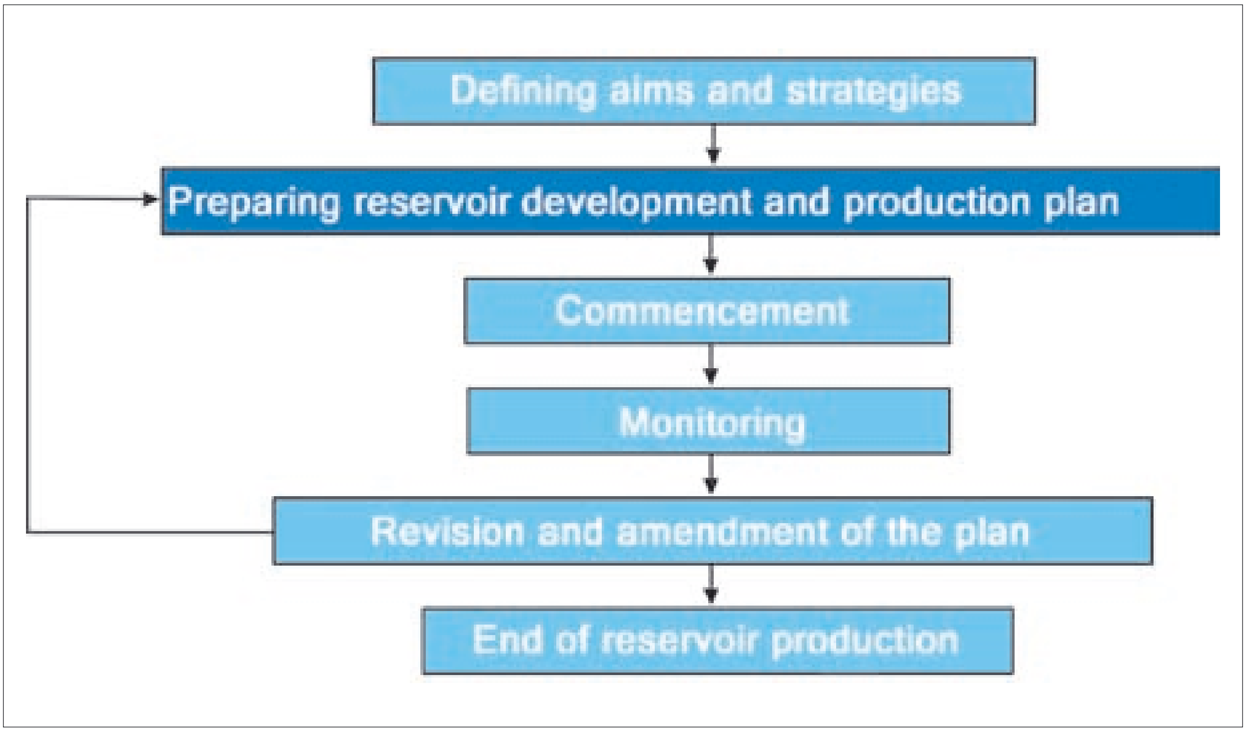


Fig. 2. Workflow for managing reservoir production

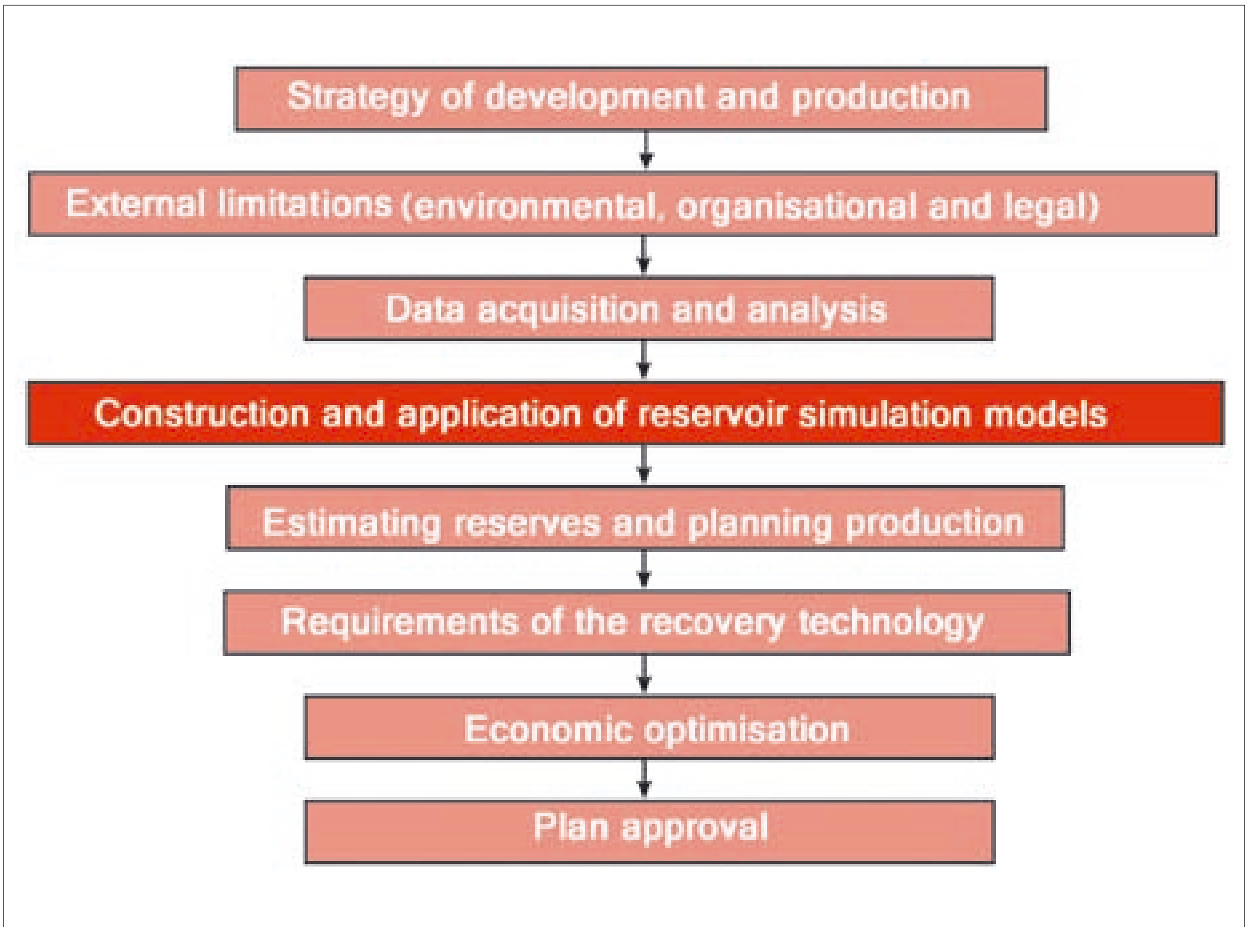


Fig. 3. Reservoir development plan

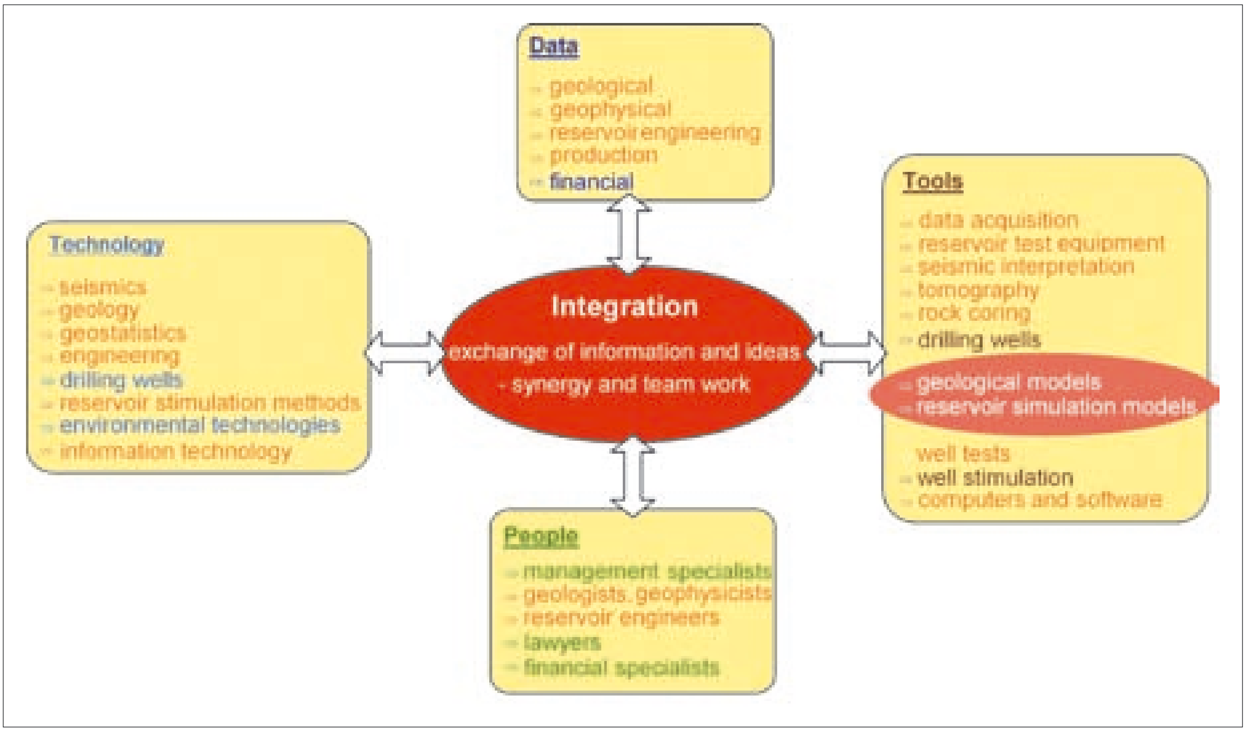


Fig. 4. Integrated reservoir management

in Poland, i.e. BMB reservoir, in order to enhance recovery of reservoir fluids, including analysis of secondary and tertiary recovery methods [5].

4. Constructing simulation models and their various applications for the recently discovered Lubiatów–Międzychód–Grotów–Sowia Góra oil reservoir [6].

The role and significance of reservoir simulation models in reservoir management

Managing petroleum reservoirs involves a well-defined chain of processes [7] which are shown in Fig. 2. In terms of the management process, the most important of the above elements is an effective and appropriate reservoir management plan. This plan is also a process which includes many elements [7] (Fig. 3).

At the centre of the plan is the construction and application of reservoir simulation models. In Fig. 4, all management elements (technology, data, people and tools) which are part of the process of constructing, verifying and applying reservoir simulation models are in red. As is shown, such models, which themselves are an element of reservoir management, involve a large group of other elements, thus they arrange and simplify the workflow for reservoir management. In other words, reservoir simulations are a key element of modern, integrated reservoir management. They fulfil this function due to their basic qualities which are independent of the application of the simulation process in reservoir management. The basic qualities of reservoir models are:

- they stimulate data acquisition and storage as modern database systems,
- they require and intensify the integration of work of specialists from different fields (geologists, geophysicists, reservoir engineers and others),
- they can be used to verify interpretations, assumptions and conclusions with regard to main reservoir characteristics (through comparison of simulation results with real production data),
- they provide knowledge about a reservoir, its operation in various production conditions (potential to run virtual scenarios of reservoir operation),
- they help to determine the dependence of results of reservoir production on the variability and errors in basic reservoir parameters, thus providing the probabilistic elements of estimating reserves and their recovery.

Application of reservoir simulation models provides certain benefits to the analysis and selection of an effective plan of reservoir development. Without these models, the process of preparing a reservoir development plan virtually lacks the possibility of carrying out quantitative assessments, which leads to unreliable economic analysis of the whole process.

The reservoir simulations have two purposes in reservoir management. They can be used to create short-term plans, i.e. as operational models for solving such issues as optimisation of parameters of proposed wells (such as their type, completion intervals, direction and length of horizontal section), recovery of reservoir fluids from each well (such as specifying its optimum rate and composition) and many others.

The simulation models reveal their main value in the context of strategic aspects of reservoir prediction when full-scale simulation models are used. They can be used to determine:

- predictions of primary production,
- choice of enhanced recovery methods,
- recoverable reserves,
- relationship between recovery and type and size of drilling projects as well as surface installation projects,
- data for further economic analysis and determination of economic reserves.

Conclusion

Effective recovery of petroleum resources from their natural sources such as hydrocarbon reservoirs involves complex and long-term economic projects which require efficient management procedures. Reservoir simulation models have a vital role in this process.

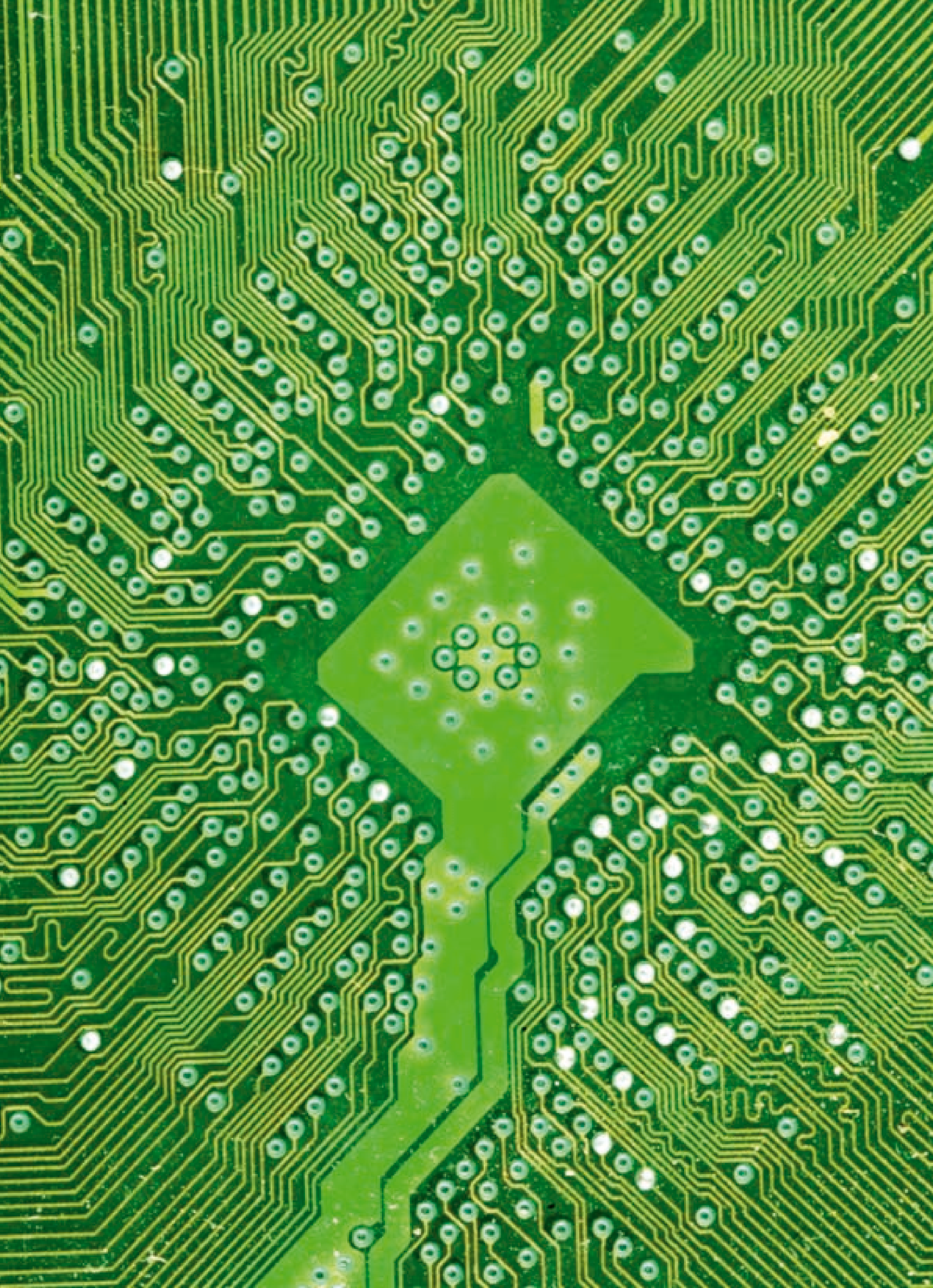
The technological progress with regard to the methods and tools for numerical analysis of data observed in the past 30 years as well as the expected future development indicate a further increase in the relevance of reservoir simulation models as the leading tool for reservoir management.

In Poland, a strong increase in the application of reservoir simulations is observed, both in terms of number and variety of projects. The Oil and Gas Institute actively participates in this process and offers its knowledge and experience to the country's petroleum industry.

The author is employed by the Krosno Branch of the Oil and Gas Institute

Literature

1) *Uniwersalny Słownik Języka Polskiego, PWN.*
2) *Breitenbach E.A. Reservoir Simulation: State of the Art, Journal of Petroleum Technology, September 1991, vol. 43, 1033–1036; Mustafiz S., Islam M.R. State of the Art: Petroleum Reservoir Simulation, Petroleum Science & Technology, 2008, vol. 26, 1303–1329.*
3) *Szott W. et al., Projekt KBN Technologie wytwarzania i eksploatacji podziemnego magazynu gazu Wierzchowice INiG, Kraków - Krosno, 1997, w tym symulacyjny model złożowy PMG. Szott W. et al., Aktualizacje modelu złożowego PMG Wierzchowice. IGNIG/INiG, Krosno, 1998–2008.*
4) *Szott W. et al., Symulacyjny model złoża B3 dla nadzoru przebiegu jego eksploatacji. INiG, Krosno, October 2004.*
5) *Szott W. et al., Optymalizacja warunków wydobycia płynów złożowych z uwzględnieniem analizy metod oddziaływania na złoże, w tym zadania: Budowa modelu geologicznego złoża BMB uwzględniająca wyniki najnowszych badań, Konstrukcja modelu symulacyjnego złoża ropno-gazowego BMB, Analiza możliwości zwiększenia stopnia sczerpania z zastosowaniem otworów poziomych, Wybór i optymalizacja parametrów wtórnej metody oddziaływania na złoże BMB w celu uzyskania maksymalnego stopnia sczerpania fazy ropnej, INiG, Krosno, 2004–2006.*
6) *Szott W. et al., Wykonanie modeli symulacyjnych dla złóż ropy naftowej Lubiatów – Międzychód – Grotów – Sowia Góra. INiG, Krosno, March 2007.*
7) *Scatter A. J. et al., Reservoir management: Technical Perspective, SPE Paper 22350, 1992.*



Microfocus X-ray computed tomography

To see the invisible

Jadwiga Zalewska, Marek Dohnalik

The investigation of various objects is possible mainly thanks to light, which also helps us to see the world around us. In order to investigate the micro-world, either hidden inside our own bodies or inside other objects, we can also use X-rays.

A large number of parallel, two-dimensional images, produced by X-ray scanning, can be used to generate a three-dimensional (3-D) image showing the internal structure of objects. Such a 3-D data volume can be manipulated in order to generate multiple cross-sections at various orientations, and to analyse them quantitatively. It can also be used to extract various information about selected properties which describe the object.

The method which can be used to "look inside" non-transparent, solid objects is microfocus X-ray computed tomography (µCT). This modern, experimental and totally non-invasive method is applied in many fields of science, and is also a valuable tool for geoscientists.

X-ray microtomography system

The three main components of the microtomography system are the X-ray source, object manipulator and detector (Fig. 1). The X-ray source is an X-ray lamp having a specific voltage and electric current. The purpose of the object manipulator is to orientate a sample before the test and to rotate it during the scanning process. The detector converts detected X-ray energy into an electric signal which is recorded as an image. The sample holder is located between the X-ray source and the detector. Thus, the sample can be moved in three different orthogonal directions, which allows the projection on the detector to be zoomed in and out,

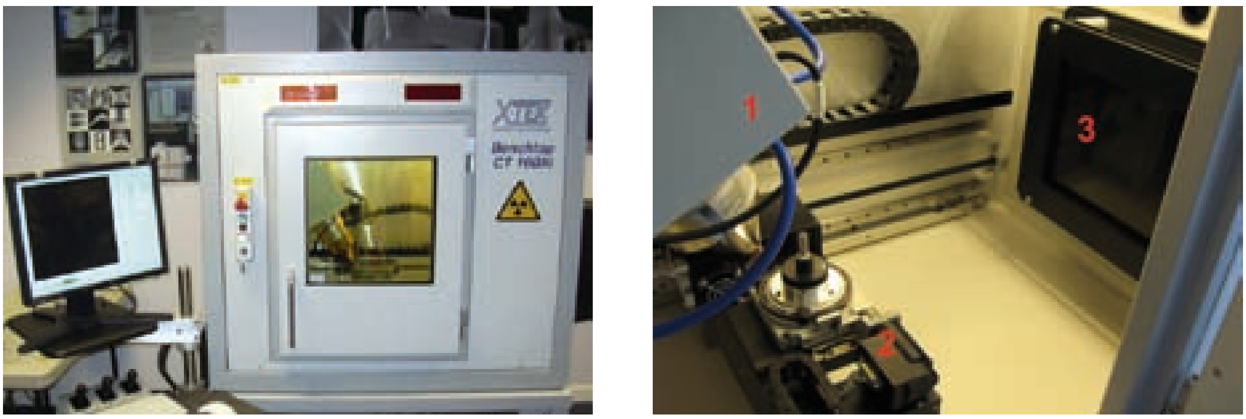


Fig. 1. Benchtop CT-160Xi microtomography system
a) Photo of the scanner, b) interior of the scanner: 1 – X-ray source, 2 – object manipulator, 3 – detector.

X-ray computed tomography (CT) was developed in Great Britain in the early 1970s as a method of medical imaging [Hounsfield 1972, 1973]. The prototype of the CT scanner was constructed by G.N. Hounsfield, and its commercial production started in 1973. For this discovery, G.N. Hounsfield and A.M. Cormack were awarded the 1979 Nobel Prize for Physiology or Medicine [Wikipedia].

The first CT scanner was used at Atkinson Morley Hospital in Wimbledon, London (England), exclusively for brain scanning. Later, whole-body scanners were developed.

In those years, geologists gained the permission of the only institution in the city to let them use this modern technology. In order to use it for their imaging and analysis, they used perfectly clean and sterile equipment, often bringing rock cores into the hospital at night in order to avoid attracting anyone's attention [Kayser et al., 2006].

Not much time was need for non-medical specialists to notice the vast potential of CT technology in testing various materials. In the early 1980s, CT scanning was applied in many fields of science, including geology, while geoscientists quickly joined the group of specialists investigating increasingly smaller details of the internal structure of various objects. CT scanning was for the first time used to evaluate reservoir rock properties in 1987 by Wellington and Vinegar [Wellington and Vinegar, 1987]. Since that time the CT method has been used in the petroleum industry as a valuable tool for rock-sample analysis, offering a non-invasive method for testing and describing rock cores. The first **microfocus X-ray computed tomography** (μCT) equipment was presented in 1998 by Sasov and Van Dyck, while in 2000 it was introduced to geology by Van Geet [Van Geet et al., 2000].

Since that time, the method has undergone rapid development. In the Polish petroleum industry, X-ray microtomography was first presented in 2008 at the International Scientific Conference GEOPETROL organised by the Oil and Gas Institute. The workshop titled *Three-dimensional visualisation of the pore structure using microtomography* explained some of the applications of the μCT method and presented the first research results [GEOPETROL, 2008]. Since that time, systematic work has been carried out aiming to collect a database of parameters, which is constantly expanding, describing pore structure in rocks; other objectives include generating models of pore networks based on tomographic images, and developing methods of network modelling in order to predict fluid-flow properties of rocks [GEOPETROL, 2010]. The Oil and Gas Institute remains a leader in Poland in μCT analysis of rocks.

and to focus the image on any interesting feature before scanning is started.

Operation principles

The operation of the microtomography system involves three main phases as shown in Fig. 2. The first phase is the scanning process (red area). When the lamp is turned on, an X-ray beam passes through the sample and casts a "shadow" on the detector which converts the X-ray image into a digital signal. A portion of the radiation recorded by the detector is absorbed (attenuated) by the tested sample. The higher the density of the object, the stronger the attenuation of radiation. At the next stage, the sample is rotated at a small angle, scanned again, and a new projected image is recorded by the computer. The process continues until the sample is rotated by 360°. The precision of scanning depends on the angle of each sample rotation and the number of 2-D images taken at each position. Thus, the smaller the angle of rotation, the higher the precision of the image, and also the longer the time of testing. Such an image is referred to as a projected image or radiographic image.

The second phase is reconstruction, which involves transformation of individual projected images into a spatial image of the investigated object; this phase allows the internal structure of the tested material (blue area in Fig. 2) to be looked at.

After uploading data into the appropriate software (such as AVIZO or ImageJ), sample cross-sections can be generated and viewed along any direction (Fig. 4).

The reconstructed 2-D images comprise pixels, each of which is defined by one horizontal (x) and one vertical (y) value or by a colour corresponding with the value (each pixel has its own brightness). The number of colours each pixel can express depends on the computer used and the number of bits per pixel that can be processed. Typically in the case of eight-bit images, these values, ranging between 0 and 255, are expressed in grey scale where 0 is black and 255 is white. The number of pixels used to create an image defines

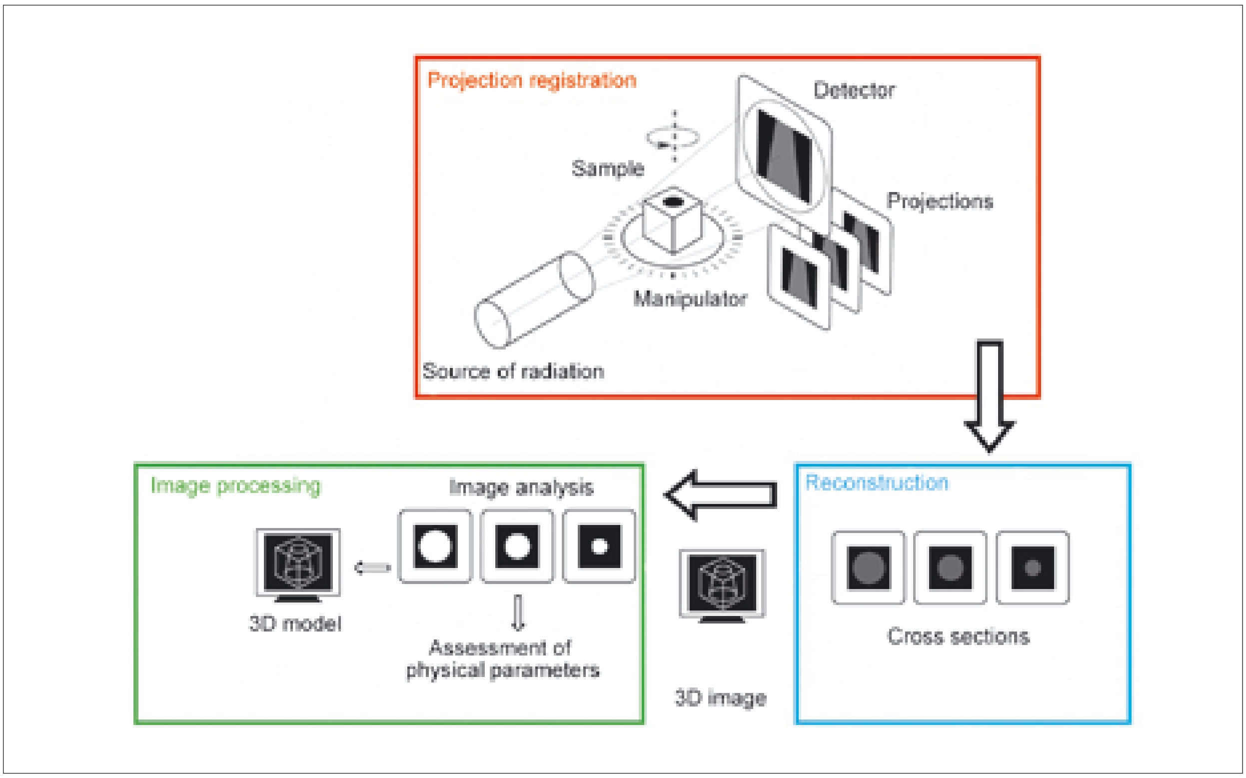


Fig. 2. Workflow for X-ray microtomography

its resolution. Gradually, when larger numbers of pixels are used, the image is displayed with higher precision or resolution [Kayser et al., 2006].

The last phase involves processing and analysis of spatial μCT images (green field in Fig. 2).

Application of microtomography in reservoir-rock testing

Microtomography carried out on rock samples by the Oil and Gas Institute

In geology, microfocus X-ray computed tomography is used mainly for 3-D visualisation of minerals and rocks.

As a rock testing method, the μCT technique can be used for non-destructive, precise and quantitative assessment of the internal structure of materials, particularly the spatial distribution of rock pores. This method offers a range of information about the porosity of rocks which includes identifying the length and number of pore channels, tracing their connectivity, visualisation and evaluation of their curvature and permeability, observation of water or oil penetration into rock, analysis of the degree of pore saturation with various gases and fluids as well as visualisation and analysis of the wetting process.

Reliable analysis of permeability (along three orthogonal directions) and evaluation of fracture systems and the hydraulic conductivity of rocks are also possible with this method.

The results of microtomography are presented as 3-D images showing the primary framework as well as pore structure of the entire rock sample. After that, the sample is subsampled and detailed, quantitative analysis is carried out in order to determine the number of subtypes of pores within it.

Determination of porosity and pore-size distribution

The most important application of the μCT method is investigating the porosity of rocks in order to evaluate their reservoir properties as well as pore permeability, which determines fluid flow [e.g. Van Geet et al., 2000, 2003].

The direct product of microtomography is shadow images of a 3-D object (Fig. 3) projected at various angles on a 2-D screen (Fig. 4). Each of such images carries information about the reduction of intensity of

Table 1. Colour representation of the volume classes of pores

Pore volume [voxel]	1-9	10-99	100-999	1000-9999	10000-99999	> 100000
pore volume [μ^3]	2.10^{2}-2.10^{3}	2.10^{3}-2.10^{4}	2.10^{4}-2.10^{5}	2.10^{5}-2.10^{6}	2.10^{6}-2.10^{7}	>2.10^{7}
Colour	yellow	blue	red	green	white	violet

** 1 voxel – 216 μm^3*

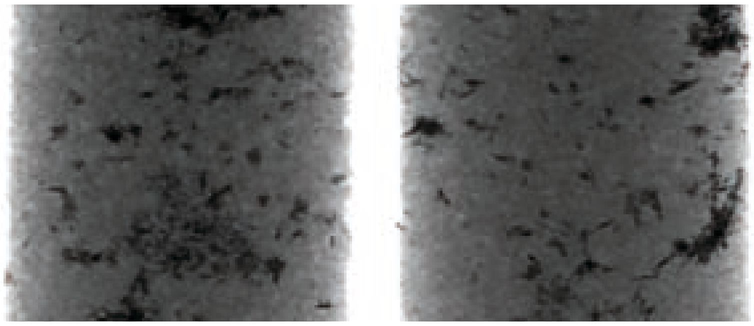


Fig. 3. Sandstone projections (sinograms)

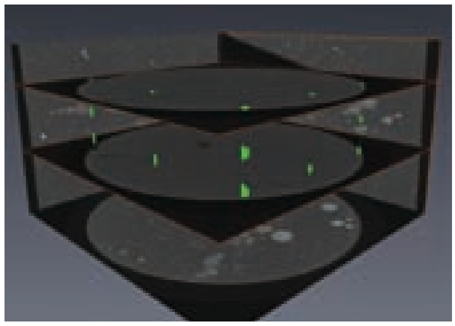


Fig. 4. Cross-sections showing the internal structure of rocks

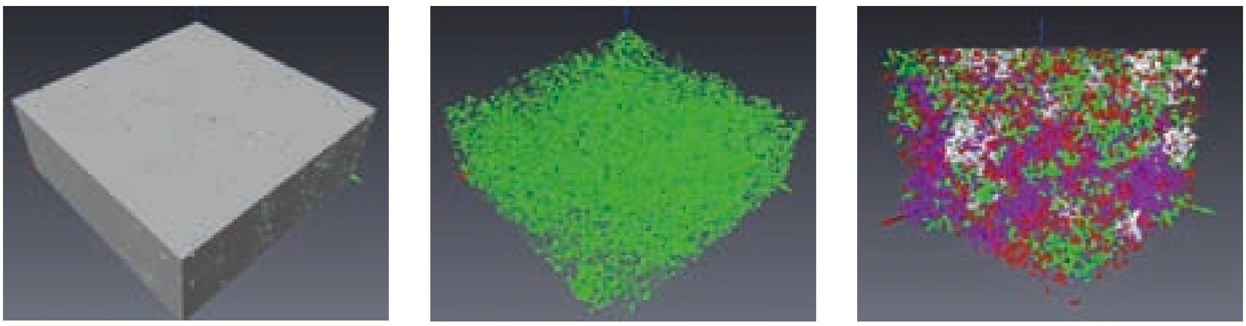


Fig. 5. Three-dimensional reconstruction and visualisation of pore spaces in the whole sample: a – 3-D image of rock framework (without pores), b – pore spaces identified in 3-D, c – 3-D distribution of each volume class

X-radiation inside the 3-D object (Fig. 5). After further data processing, i.e. after reconstructing projections, a spatial image of the sample is created (Fig. 5).

Interpretation of the μCT data involves qualitative and quantitative analysis, and is based on 3-D images. As the first step, spatial visualisation of the original structure of the whole rock sample is done; then analysis of the pore distribution is carried out, and involves dividing the network of pores into subgroups. A subgroup is defined as a network of connected pores not connected with other subgroups. Subgroups are classified according to their total volume and the six largest subtypes of pores are distinguished in each sample (Table 1). The results are presented in two types of graphs. The first graph is a plot of the number of subgroups in each volume class; thus it demonstrates how divided each class is. The second plot shows the distribution of volume classes.

Figure 6 illustrates the 3-D visualisation of μCT data which displays all pore spaces of sandstone samples associated with different porosity; the differences between the analysed samples are significant.

Figure 7 shows an example of μCT analysis (typical of that carried out by the Oil and Gas Institute) of sandstone samples collected from the Upper Rotliegend strata in the area of the Fore-Sudetic Homocline. The samples represent two different depositional systems: eolian (facies A) and lacustrine (facies P).

Sample 1 (Fig. 7A) is an eolian sandstone of facies A2 associated with a porosity coefficient of 9.4%. It has

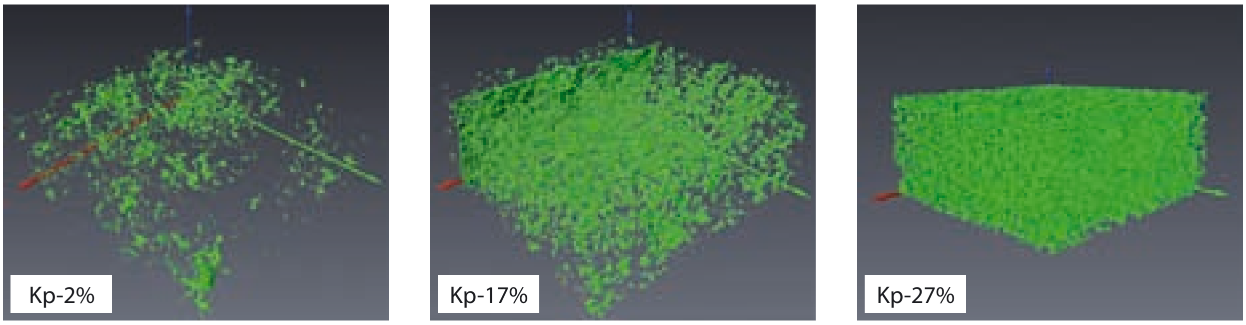
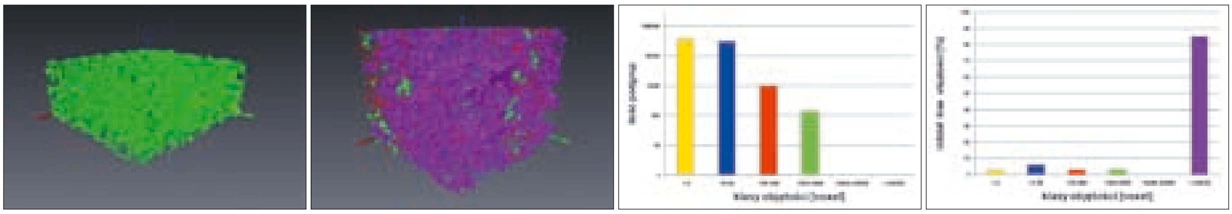


Fig. 6. Visualisation of the internal pore structure of rock (green – pores)

A) Sample 1, well 0-3



Class No.	Volume of the class [voxel]	Pore volume [µm³]	Number of pores in the class	Volume of pores in the class [voxel]	Representation of class by percentage [%]
I	1-9	2.10^2-2.10^3	38 052	269 080	2.8
II	10-99	2.10^3-2.10^4	29 878	552 123	5.8
III	100-999	2.10^4-2.10^5	1 004	278 973	3.0
IV	1000-9999	2.10^5-2.10^6	133	302 794	3.2
V	10000-99999	2.10^6-2.10^7	1	14 188	0.2
VI	>100000	$>2.10^7$	1	8 029 840	85.0
			69 069	9 446 998	100

a very well-developed pore structure. The pores form subgroups described as volume classes I to VI. As much as 85% of the porosity is described as volume class VI, which dominates and represents only one object. The sample has pore connectivity along all of the analysed directions, while the pores are well connected. Due to the low curvature coefficient, the Y and Z directions are preferential (Table 2, Fig. 8).

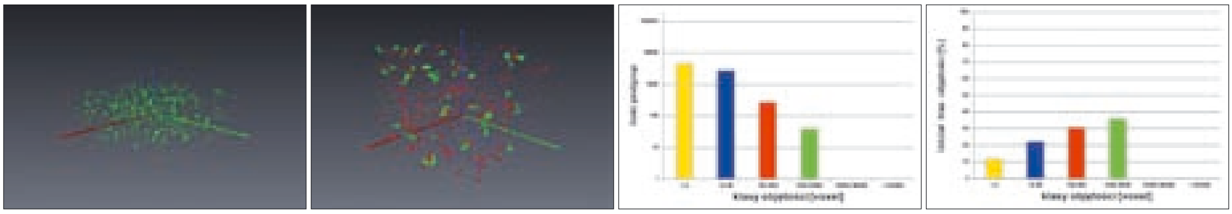
Sample 2 (Fig. 7B) is also an eolian sandstone of facies A2, although it is associated with low porosity formed by evenly distributed pores which belong to classes I to IV. Representation of each of the volume classes decreases starting from class IV, through classes III and II to class I. No pores which would connect the opposite edges of the sample were observed; however, the uniform distribution of pores which belong to classes III and IV suggests that connections invisible at the scanning resolution may exist.

Sample 3 (Fig. 7C) represents deposits associated with sandy playa facies P2 which have a very low porosity coefficient of less than 0.6%. The spatial distribution of pores is highly non-uniform. Animation reveals that at some orientations streaks of higher porosity are apparent and they resemble the distribution of fractures. The pores in this sample belong mainly to classes I to III. There is one subtype of pores described as volume class IV; however, it represents only 0.2% of the whole pore volume. Volume class II is dominant, forming about 63% of the pore structure.

Assessment of pore-channel curvature

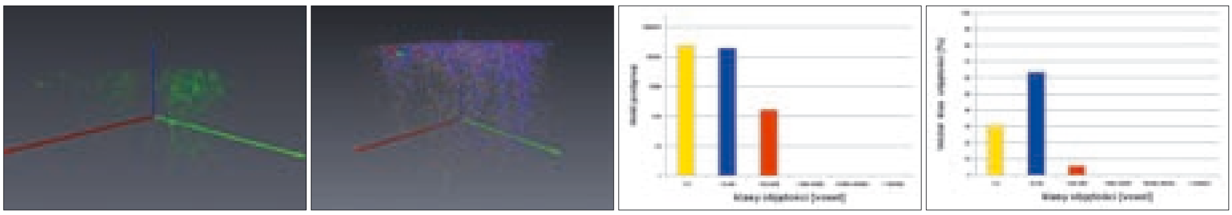
Microfocus X-ray computed tomography can be used to visualise and to quantitatively assess the curvature of all connected pore channels in a sample. Due to the three-dimensional character of the µCT meth-

B) Sample 2, well R-1



Class No.	Volume of the class [voxel]	Pore volume [μm³]	Number of pores in the class	Volume of pores in the class [voxel]	Representation of class by percentage [%]
I	1-9	2.10^2-2.10^3	4 600	31 939	11,7
II	10-99	2.10^3-2.10^4	2 766	60 835	22,2
III	100-999	2.10^4-2.10^5	273	83 154	30,4
IV	1000-9999	2.10^5-2.10^6	39	97 952	35,8
V	10000-99999	2.10^6-2.10^7	0	0	0,0
VI	>100000	>2.10^7	0	0	0,0
			7 678	273 880	100

C) Sample 3, well K-2

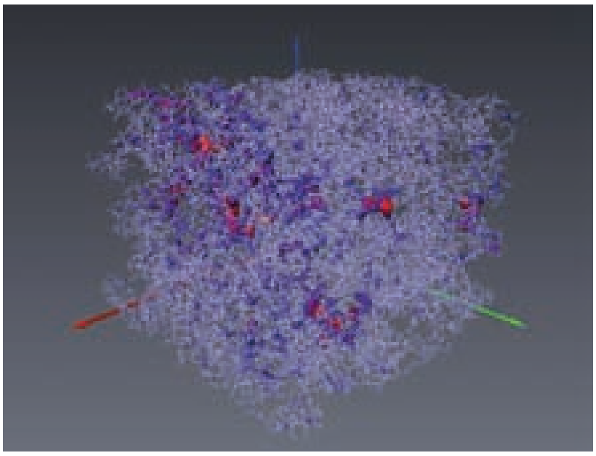


Class No.	Volume of the class [voxel]	Pore volume [μm³]	Number of pores in the class	Volume of pores in the class [voxel]	Representation of class by percentage [%]
I	1-9	2.10^2-2.10^3	24 651	174 269	30.8
II	10-99	2.10^3-2.10^4	19 286	358 560	63.4
III	100-999	2.10^4-2.10^5	163	31 174	5.5
IV	1000-9999	2.10^5-2.10^6	1	1 124	0.2
V	10000-99999	2.10^6-2.10^7	0	0	0.0
VI	>100000	>2.10^7	0	0	0.0
			44 101	565 127	100

Fig. 7. μCT characteristic of samples which have various porosity

Table 2. Results of measuring the pore-channel curvature using the µCT method

Sample	Direction of curvature analysis	Absolute number of voxels from tunnel	Relative number of voxels from tunnel	Average curvature	Maximum curvature	Minimum curvature	Standard deviation
1A	X	8 583	0.043	1.638	2.408	1.318	0.255
	Y	12 147	0.061	1.268	1.895	1.106	0.166
	Z	15 827	0.063	1.291	1.830	1.115	0.146
1B	X	986	0.005	1.568	1.841	1.467	0.078
	Y	11 536	0.058	1.296	1.628	1.101	0.137
	Z	16 254	0.065	1.353	2.370	1.113	0.205



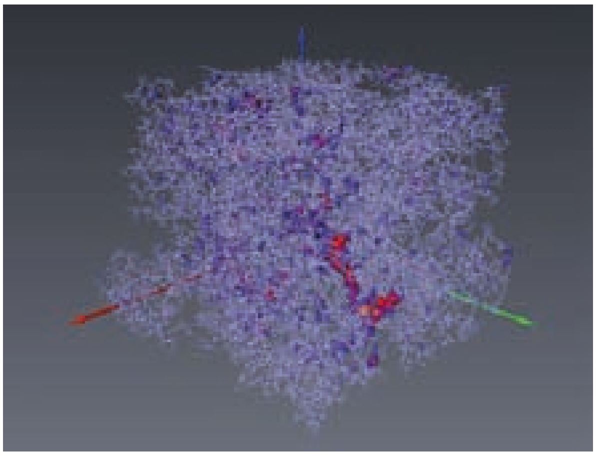


Fig. 8. Example of µCT image of all connected fluid-flow paths in samples 1A and 1B

X axis – red
Y axis – green
Z axis – blue

od, the curvature measurements can be carried out in three orthogonal directions, i.e. X, Y and Z. They provide information about the potential anisotropy in the spatial distribution of pores and possible fluid-flow paths within the reservoir rocks. This parameter is calculated only when there is a connection between opposite sides of a subsample, i.e. when the pore channels are permeable along an analysed direction.

A study of the curvature of pore channels was carried out on three samples shown in Fig. 7. The parameter was determined only for sample 1, and is presented in Table 2. Visualisation of the group of pores described as volume class VI is shown in Fig. 8, and the locations of axes running through the middle of pores are also shown. Here, the colour and thickness of each line reflects the width of the system of pores at each location. Narrow pores are shown with blue, while wide-diameter pores are shown with red and yellow. The curvature coefficient values have a similar distribution in both of the samples, which indicates similar variability of fluid-flow paths in pore spaces within the whole sample. However, connections of channels in subsample 1B are much worse than in subsample 1A. The average curvature of the flow paths for sample 1A is 1.68 in the X direction, 1.27 in the Y direction and 1.29 in the Z direction. For sample 1B it is 1.57 in the X direction, 1.30 in the Y direction and 1.35 in the Z direction.

The remaining two samples (2 and 3) indicate a lack of connections which would allow fluid flow in any of the X, Y and Z directions [Zalewska et al., 2010].

Fracture visualisation and evaluation of their sizes using µCT

Microtomography can be used to visualise, evaluate and characterise fractures. Fig. 9 illustrates the

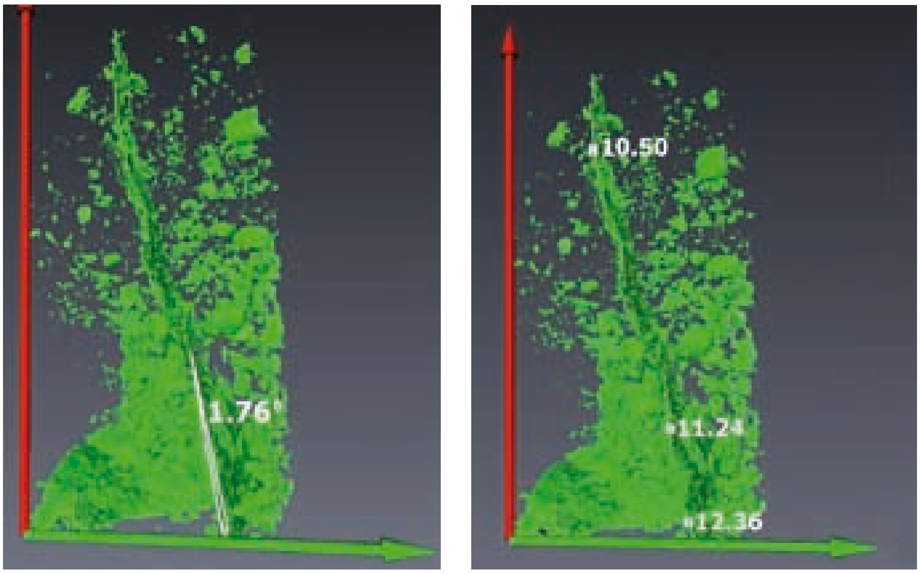


Fig. 9. Microtomography section through fracture in sample 9433:

X axis – red
Y axis – green
Z axis – blue

cross-section through the fracture in a recrystallised limestone sample. A network of very narrow fractures cutting each other was identified. The most apparent fracture has a width varying between 10.50 and 12.36 μm and an angle of aperture of 1.76° [Zalewska et al., 2010].

Other potential applications of microfocus X-ray computed tomography in the petroleum industry

Evaluation of wormholes generated through acidizing carbonate rock samples

Evaluation of wormholes generated by acidizing carbonate rock samples was carried out by the Oil and Gas Institute. It allowed a number of observations about the effectiveness of acid, particularly in 3-D images presented as animations. The animations, which are based on data generated by a microtomography system and created using modern (3-D) software for image processing, were particularly useful in observing changes within rock cores due to injected acid. Fig. 10 presents a comparison of the structure of sample cross-sections before and after injecting acid.

Figure 10 illustrates the location of the wormhole inside the core sample, and suggests an increase in the pore volume, marked as the black area surrounded by the red line. All images on the right show the fully developed wormhole. The whole wormhole is difficult to present in the 2-D image; however, it can be viewed as a 3-D animation available on the website of the Department of Geophysics for Drilling of the Oil and Gas Institute: http://www.inig.pl/ZD/images/sw/video/sw-microCT.html

Figure 11 presents the development of a pore in 3-D. This is done by comparing two major subtypes of pores for every sample before and after the acidizing process. There is a very clear increase in volume of the largest object of class VI. The situation before acidizing is marked with green, while the state after the experiment is marked with semi-transparent violet.

The reconstructed internal structure of the pore network within the rock has been presented as histograms (Fig. 12) which indicate that the pore number within each of the volume classes is similar before and after the process. The number of pores within volume classes I and II is insignificantly lower; the number of pores which belong to classes III to V is higher, while the number of pores of class VI is the same. Plots showing the representation of each of the volume classes indicate an increase in the representation of class VI by 30%.

Analysis of the connectivity of the pore network was carried out. Analysis of the curvature of pores indicated that before the acidizing experiment the network of pores had a diameter below the scanning resolution (20 μm) and did not have any connectivity in any of the analysed directions (X, Y, Z). After the acidizing, a wormhole opened, and created a connection along the Z axis. The average curvature is 1.17, i.e. it slightly deviates from the straight line.

As a result of the first experimental microtomography, a number of observations with regard to the effectiveness of the acidizing process were made, particularly in 3-D images presented as animations. The animations, created from data generated by the microtomography system together with modern soft-

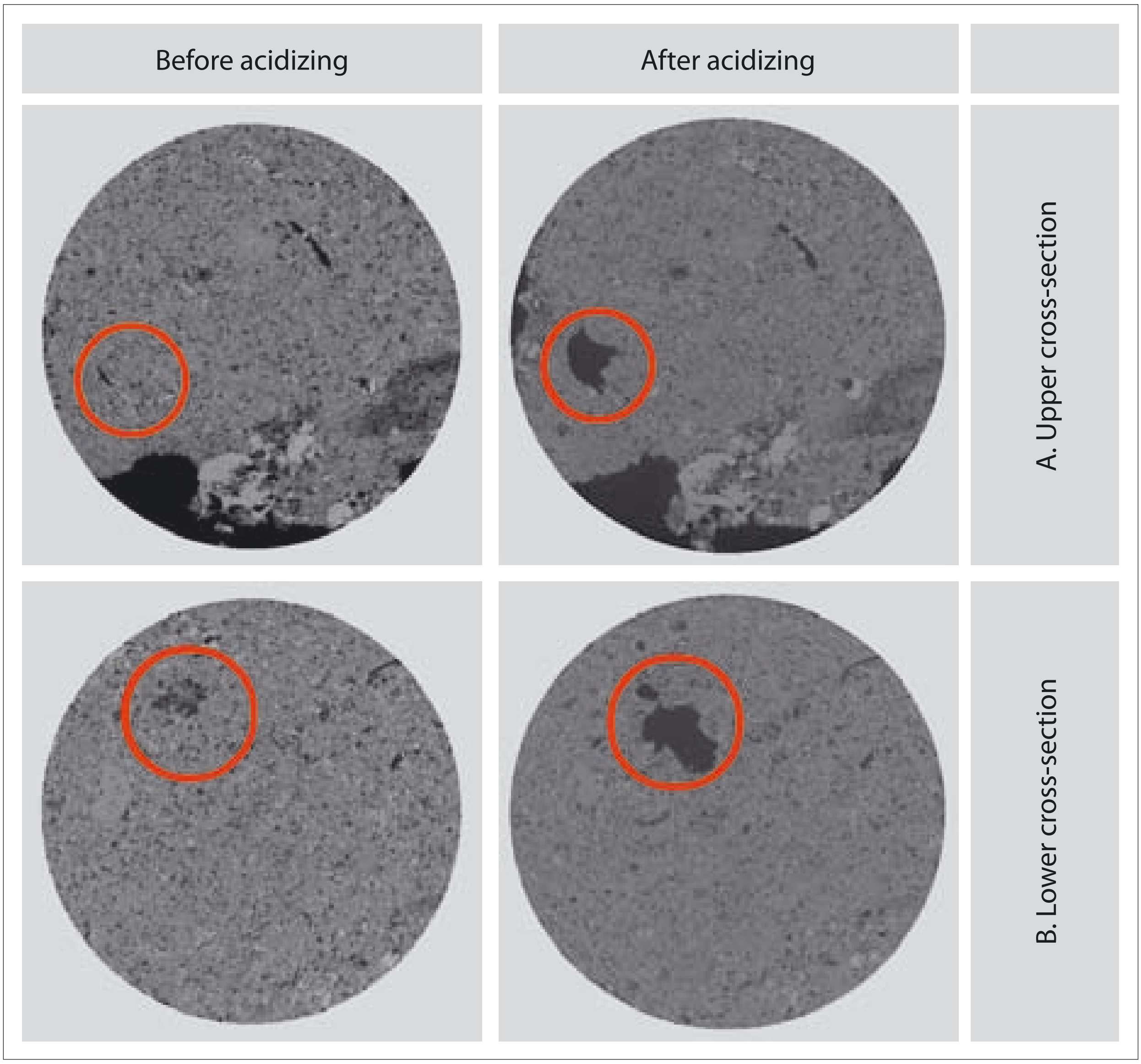


Fig. 10. 2-D images of rock-core sections before (left image) and after (right image) injecting acid

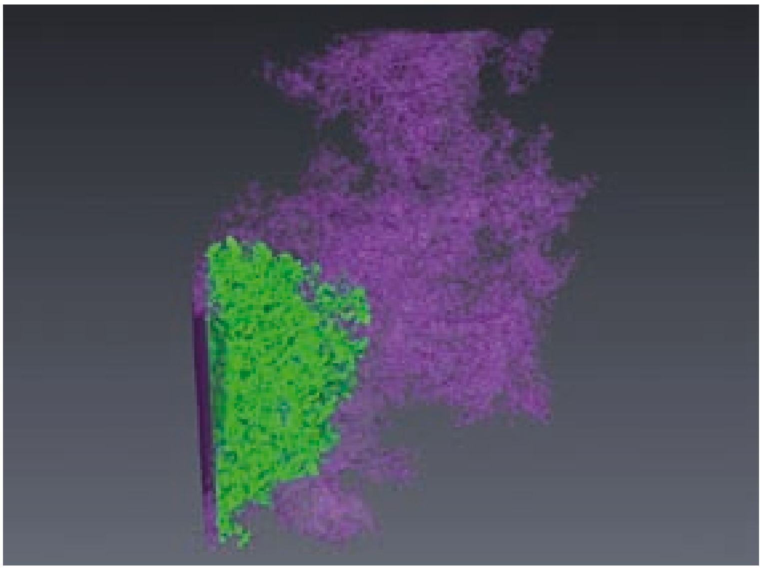


Fig. 11. Spatial visualisation of changes in volume of pore structure: green – before acidizing, violet – after acidizing

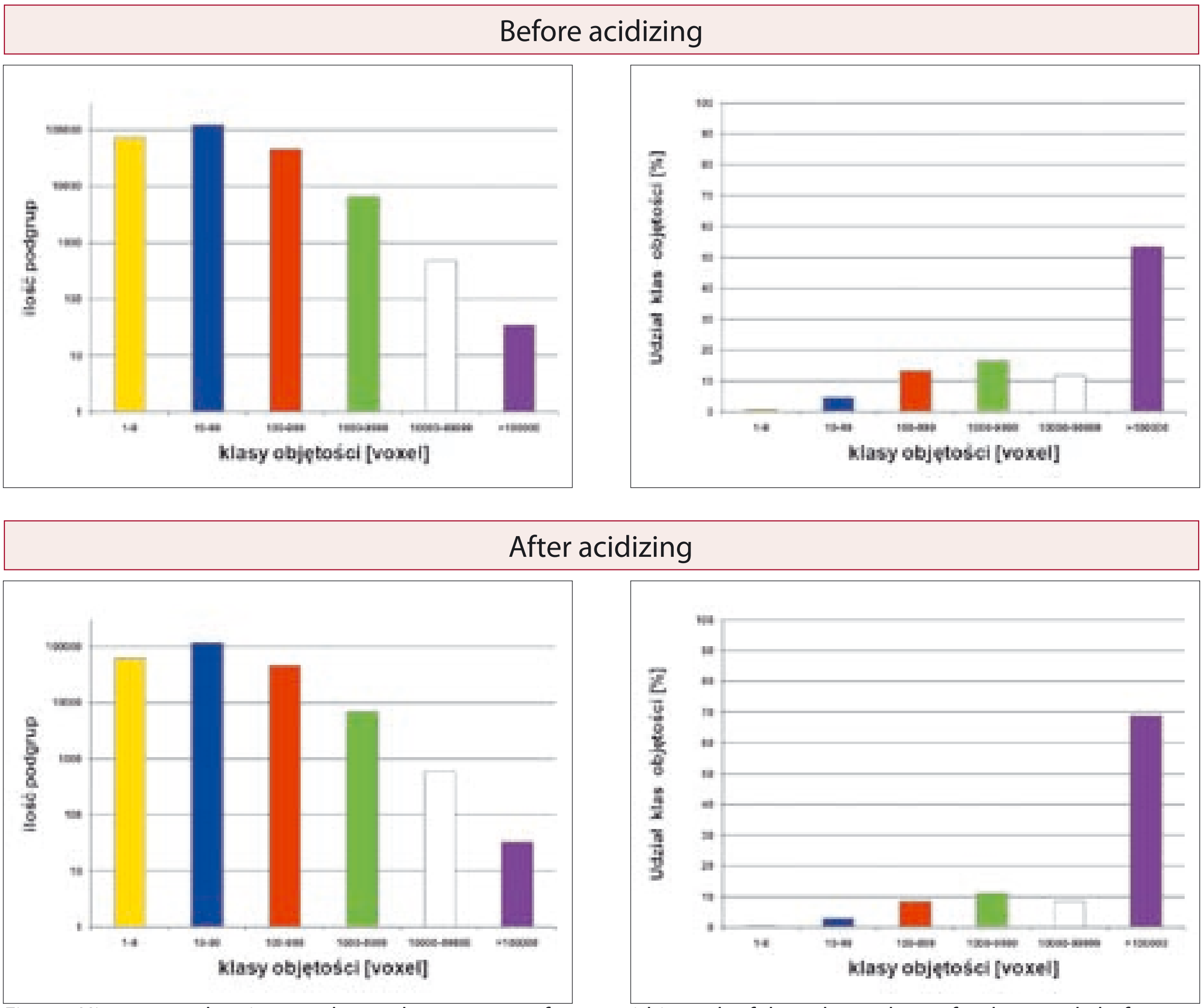


Fig. 12. Histograms showing number and percentage of pores within each of the volume classes for the sample before and after acidizing

ware packages for 3-D image processing, were particularly helpful in identifying changes inside core samples after injecting acid.

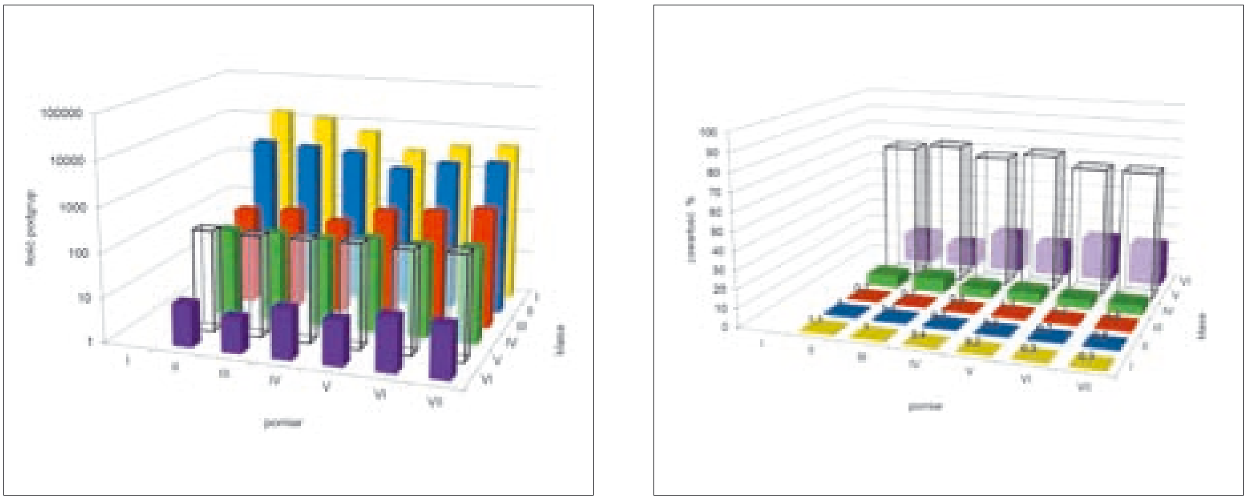
It should be emphasised that until now there was no method for monitoring the migration of acid though pores within rock cores. Thanks to the introduction of the μCT method, such studies are possible. Thus, it is possible to verify theoretical calculations and numerical simulations of the efficiency of the acidizing process [Zalewska et al., 2010].

Testing of the structure of hardened cement paste

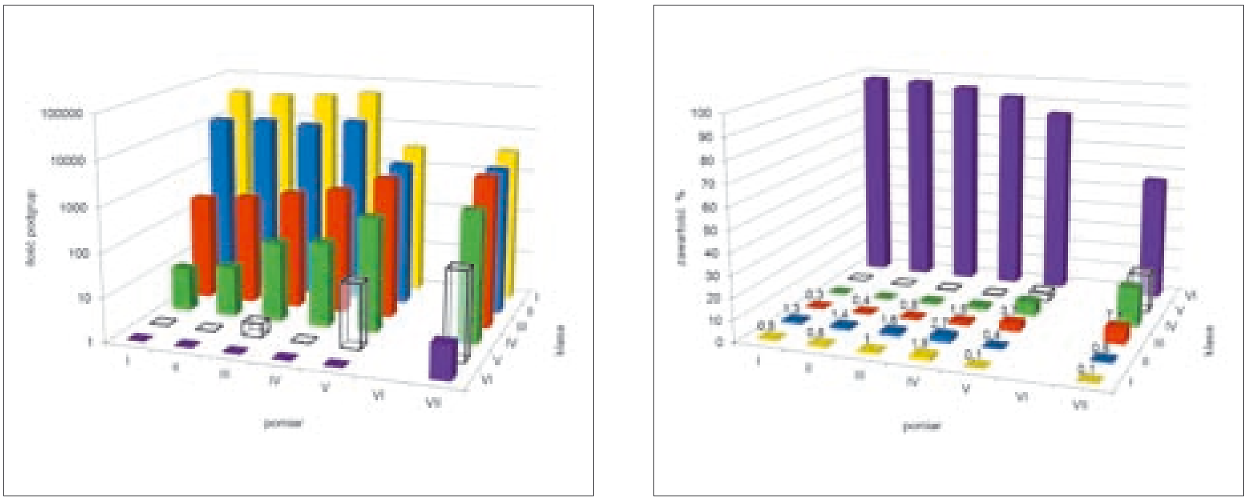
Testing of the microstructure of hardened cement paste of different age (ranging from 20 minutes to 28 days from the preparation of cement mix) was carried out using the μCT method. The results demonstrate the new research potential of the Oil and Gas Institute. The pore structure was imaged using this technique, and pores were classified according to their volume class, as shown in Fig. 13. During the analysis of the sample of cement 2, good correlation between the volume representation of pores which belong to class VI and those belonging to classes III to V (Fig. 13) was noticed. This is because as the cement swells, the largest pores are divided into smaller pores. The conclusion is supported by the fact that the number of pores of classes III to VI has increased with time. When the volume representation of pores of class VI increases, the curvature of channels within the sample also increases (from 1.2 to 2.2) [Zalewska et al., 2010].

The Oil and Gas Institute carries out laboratory testing of rock cores in order to determine their petrophysical properties in the context of their reservoir proper-

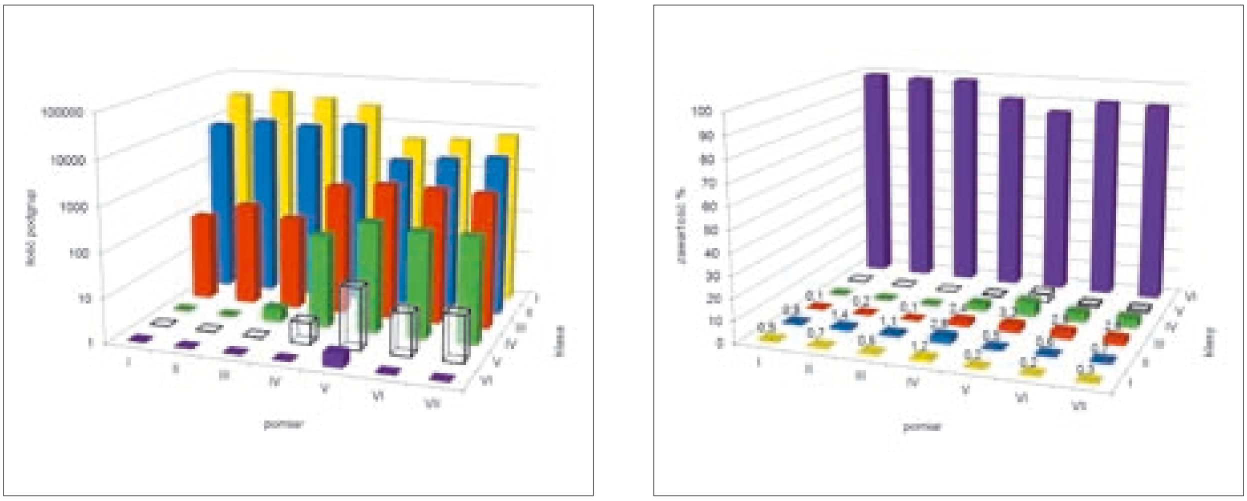
A	B



Cement 1 (basic)



Cement 2 (20% of microspheres)



Cement 3 (10% of microspheres)

Fig. 13. Classification of pores within tested cements (A) according to their number, (B) according to their volume expressed as a percentage

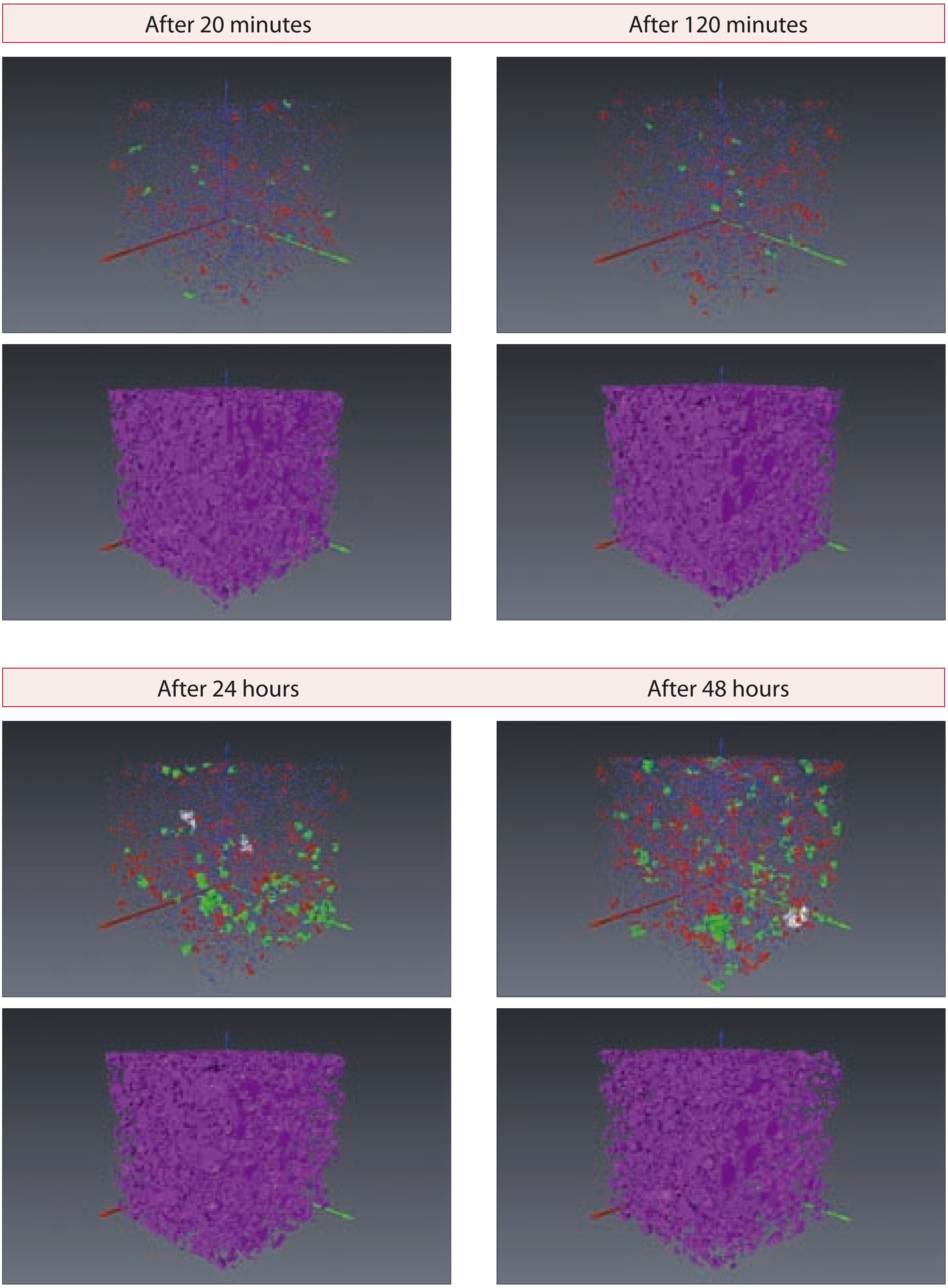


Fig. 14a, 14b. Spatial distribution of pores in the sample of cement 2

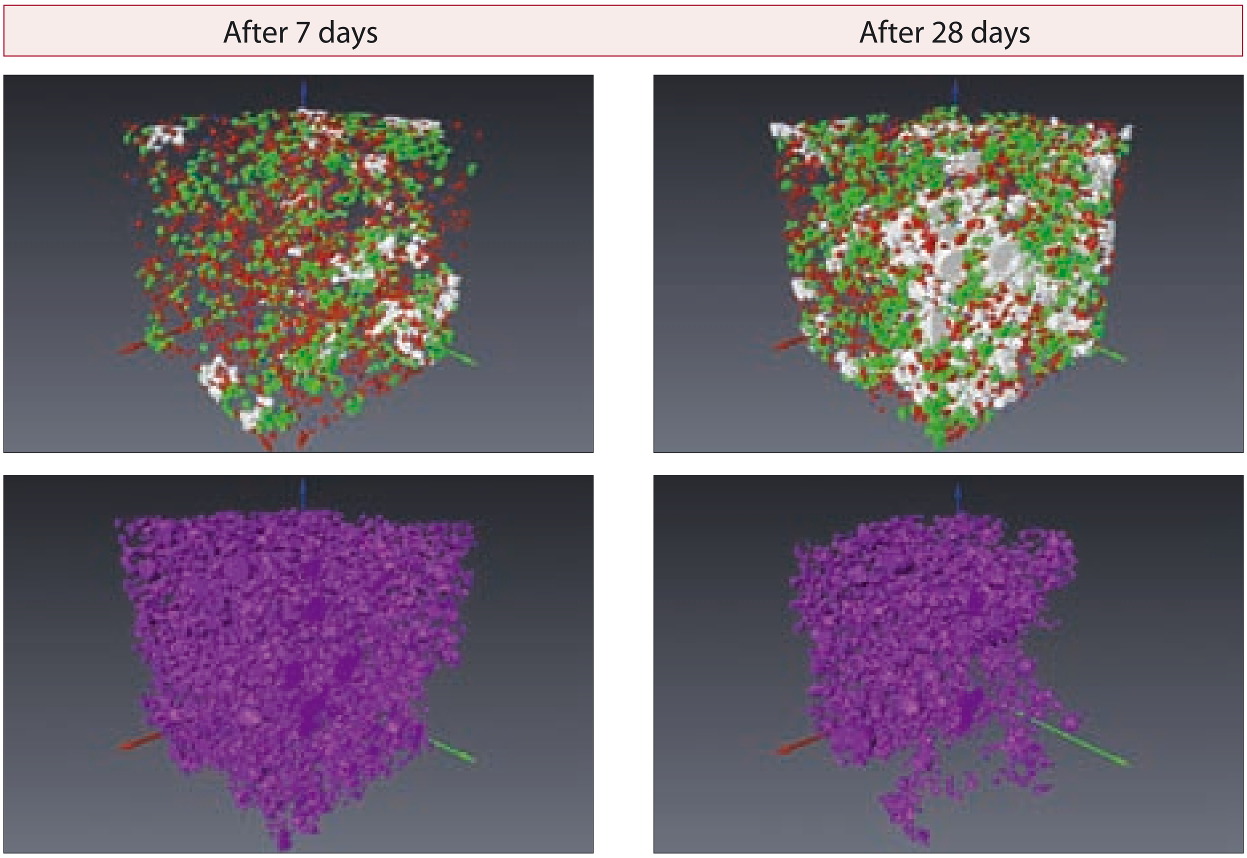


Fig. 14c. Spatial distribution of pores in the sample of cement 2

ties as well as pore permeability determining reservoir fluid flow.

Clastic reservoir rocks, which may have variable structure and texture as well as different cement and pore saturation, used to be analysed using thin sections viewed under a polarised-light microscope. Currently, thanks to X-ray microtomography we can look "inside the rock". This unique and new method is non-destructive, and provides physically realistic images of reservoir rocks with micrometre-range resolution. It can be used to assess qualitatively and quantitatively the spatial distribution of pores and connection between them, and it can also identify and characterise fractures. Such testing can provide data for pore-network analysis in a wide research context; most important, such analysis is based not on an isolated result but on mean porosity values.

A general advantage of using microtomography over the microscopy method is the ability to image fractures in 3-D and to interpret these images with particular attention to fracture orientation, and possibility to identify its changes and fracture aperture. The percentage representation of fracture volume within a rock sample can also be measured, and most important the width of fractures can be precisely determined at any point. This property is of primary importance when we deal with reservoir rocks associated with low porosity and permeability, since their hydrocarbon production rate depends mainly on the number of open fractures. Such studies may also be relevant for the analysis of fracture networks in gas-bearing shale formations.

Microfocus X-ray computed tomography is a unique and promising research tool. Despite its great potential, however, it is not widely known and applied in the Polish petroleum industry. We are therefore hoping that this publication and the information included in it will help geologists who work in hydrocarbon exploration and production to familiarise themselves with the subject of evaluating the petrophysical properties of rocks using 3-D image analysis.

The authors are employed by the Kraków branch of the Oil and Gas Institute

Examples in the literature of application of X-ray microtomography in the petroleum industry

Determination of elastic properties based on µCT images

Arns et al. [2002] first demonstrated that the elastic properties of the Fontainebleau Sandstone can be directly determined based on µCT images. Elastic properties established using digital images of rock cores corresponded very well with those known from laboratory tests carried out on samples having a wide range of porosity levels and in different saturation conditions. Changes in the elastic properties due to changing pore-fluids were consistent with Gassmann's equations.

Evaluation of electrical properties of carbonate rocks based on X-ray microtomography

Youssef et al. [2008] demonstrated that the numerical simulation of petrophysical properties in complex carbonate rocks is difficult, particularly with respect to electrical properties for which spatial distribution of micro-pores is particularly important. Despite that, the author presented modelling of electrical properties based on pore-network models. Based on microfocus X-ray computed tomography images of carbonate rocks, he calculated the porosity and resistivity index. The results were compared with experimental values and showed good correlation.

Literature

1) *Computation of linear elastic properties from microtomographic images: methodology and agreement between theory and experiment. Geophysics. v. 67, p. 1396-1405.*
2) *Hounsfield G.N. 1972. A Method of and Apparatus for Examination of a Body by Radiation such as X- or Gamma Radiation. British Patent No. 1,283,915.*
3) *Hounsfield G.N. 1973. Computerized transverse axial scanning (tomography). Part 1: Description of system. British Journal of Radiology, 46, 1016-22.*
4) *Kayser A., Knackstedt M., Ziauddin M. 2006. A closer look at pore geometry. Oilfield Review, v. 18, no. 1, p. 4-13.*
5) *Van Geet M., Swennen R., Wevers M. 2000. Quantitative analysis of reservoir rocks by microfocus X-ray computerised tomography. Sedimentary Geology, 132, 25-36.*
6) *Van Geet M., Lagrou D., Swennen R. 2003. Porosity measurements of sedimentary rocks by means of microfocus X-ray computed tomography (µCT). Geological Society, London, Special Publications 2003 volume 215: 51-60.*
7) *Wellington S.L., Vinegar H.J. X-ray Computerized Tomography. Journal of Petroleum Technology, 39, p. 885-898, 1987.*
8) *Youssef S., Han M., Bauer D., Rosenberg E., Bekri S., Fleury M., Vizika O. 2008–High resolution µ-CT combined to numerical models to assess electrical properties of bimodal carbonates. SCA2008-37 Konferencja GEOPETROL 2008.*
9) *Zalewska J., Dohnalik M. Niektóre zastosowania rentgenowskiej tomografii komputerowej w geologii. GEOPETROL 2008.*
10) *Dohnalik M., Zalewska J. Rentgenowska tomografia komputerowa w badaniu skał zbiornikowych. GEOPETROL 2008.*
11) *Sikora G., Zalewska J., Dohnalik M. Możliwości rentgenowskiej mikrotomografii komputerowej w rozpoznawaniu, obrazowaniu i szacowaniu wielkości szczelin. GEOPETROL 2008 Konferencja GEOPETROL 2010.*
12) *Zalewska J., Dohnalik M., Poszytek A. Mikrostruktura przestrzeni porowej piaskowców eolicznych określona metodą analizy trójwymiarowych obrazów micro-CT. GEOPETROL 2010.*
13) *Zalewska J., Kaczmarczyk J., Dohnalik M., Cebulski D., Poszytek A. Zastosowanie mikrotomografii rentgenowskiej do oceny własności zbiornikowych skał węglanowych. GEOPETROL 2010.*
14) *Zalewska J., Łykowska G., Kaczmarczyk J. Obraz 3D mikrotomografii rentgenowskiej skał węglanowych. GEOPETROL 2010.*
15) *Zalewska J., Kaczmarczyk J., Dohnalik M. Ocena przestrzeni porowej skał węglanowych w oparciu o dane mikrotomografii rentgenowskiej (micro-CT) i jądrowego rezonansu magnetycznego (NMR). GEOPETROL 2010.*
16) *Kaczmarczyk J., Dohnalik M., Zalewska J. Symulacja przepływu mediów złożowych przez przestrzeń porową skał węglanowych na podstawie obrazów mikrotomograficznych. GEOPETROL 2010.*
17) *Dohnalik M., Kaczmarczyk J., Zalewska J. Ekstrakcja parametrów geometrycznych sieci porowej z obrazów mikrotomografii rentgenowskiej. GEOPETROL 2010.*
18) *Zalewska J., Kut Ł., Kaczmarczyk J., Dohnalik M. Eksperymentalne badania 3D cementów z zastosowaniem mikrotomografii rentgenowskiej (micro-CT). GEOPETROL 2010.*
19) *Zalewska J., Dohnalik M., Kaczmarczyk J., Masłowski M., Biały E. Ocena kanalików robaczkowych w rdzeniach skał węglanowych z wykorzystaniem mikrotomografii rentgenowskiej. GEOPETROL 2010 .*

Oil consumption [million tonnes]

	1965	1971	1981	1991	2001	2010	2011	Change 2011 over 2010	2011 share of total
US	552.1	730.6	735.3	755.4	884.1	849.9	833.6	-1.9%	20.5%
Canada	53.8	73.5	84.2	75.3	90.5	102.7	103.1	0.4%	2.5%
Mexico	14.2	20.7	54.0	74.0	86.6	88.5	89.7	1.3%	2.2%
Total North America	**620.2**	**824.9**	**873.5**	**904.7**	**1061.2**	**1041.1**	**1026.4**	**-1.4%**	**25.3%**
Argentina	22.1	23.5	22.4	20.2	19.5	25.9	28.1	8.2%	0.7%
Brazil	14.9	28.0	52.8	64.9	92.7	118.0	120.7	2.3%	3.0%
Chile	3.3	5.2	5.1	6.8	10.5	14.8	15.2	2.8%	0.4%
Colombia	3.9	5.5	7.5	9.6	10.2	11.4	11.7	2.4%	0.3%
Ecuador	0.7	1.2	3.3	4.7	6.3	10.3	10.5	2.6%	0.3%
Peru	3.6	4.7	6.7	5.4	7.0	8.5	9.2	9.0%	0.2%
Trinidad & Tobago	2.0	2.3	1.7	1.2	1.3	1.7	1.7	-3.5%	^
Venezuela	9.3	10.6	21.1	18.8	28.8	36.9	38.3	3.8%	0.9%
Other S. & Cent. America	21.5	28.6	39.0	39.6	54.6	53.5	53.7	0.4%	1.3%
Total S. & Cent. America	**81.3**	**109.6**	**159.6**	**171.1**	**231.0**	**281.0**	**289.1**	**2.9%**	**7.1%**
Austria	5.6	10.2	11.0	11.6	12.8	12.9	12.5	-3.6%	0.3%
Azerbaijan	b/d	b/d	b/d	8.2	4.0	3.2	3.6	11.9%	0.1%
Belarus	b/d	b/d	b/d	24.1	7.3	7.3	9.0	22.8%	0.2%
Belgium	-	26.9	23.4	25.8	31.0	33.5	33.7	0.7%	0.8%
Bulgaria	3.7	9.9	12.5	4.2	4.2	3.8	3.5	-6.4%	0.1%
Czech Republic	4.0	7.7	11.4	7.1	8.4	9.1	9.1	-0.5%	0.2%
Denmark	10.2	18.4	12.8	9.1	9.8	8.4	8.3	-1.7%	0.2%
Finland	5.7	11.1	12.3	10.6	10.5	10.4	10.5	0.9%	0.3%
France	53.9	102.8	99.0	94.6	95.5	84.4	82.9	-1.7%	2.0%
Germany	86.3	144.0	133.4	133.1	131.6	115.4	111.5	-3.3%	2.7%
Greece	4.4	7.4	11.9	15.8	20.2	18.7	17.2	-7.9%	0.4%
Hungary	3.8	6.7	10.8	8.0	6.7	6.7	6.5	-3.1%	0.2%
Republic of Ireland	2.4	4.5	5.1	4.9	9.0	7.6	6.8	-10.4%	0.2%

Oil consumption [million tonnes]

	1965	1971	1981	1991	2001	2010	2011	Change 2011 over 2010	2011 share of total
Italy	52.3	93.8	95.7	92.4	92.8	73.1	71.1	-2.7%	1.8%
Kazakhstan	b/d	b/d	b/d	21.7	7.7	9.5	10.2	7.6%	0.3%
Lithuania	b/d	b/d	b/d	8.3	2.7	2.7	2.7	0.8%	0.1%
Netherlands	25.3	36.0	36.2	36.6	44.6	49.9	50.1	0.3%	1.2%
Norway	5.1	8.1	8.7	8.6	10.2	10.8	11.1	3.5%	0.3%
Poland	5.4	9.4	16.1	14.9	19.5	26.7	26.3	-1.5%	0.6%
Portugal	2.7	5.4	8.8	11.5	15.8	12.5	11.6	-7.3%	0.3%
Romania	7.1	10.9	16.7	15.6	10.6	8.7	9.0	4.4%	0.2%
Russian Federation	b/d	b/d	b/d	245.3	120.5	128.9	136.0	5.5%	3.4%
Slovakia	2.3	4.4	6.6	4.4	3.2	3.9	3.7	-5.3%	0.1%
Spain	14.2	30.9	50.4	46.9	73.0	72.1	69.5	-3.7%	1.7%
Sweden	18.9	27.5	22.4	16.4	16.2	15.3	14.5	-5.3%	0.4%
Switzerland	8.0	13.3	11.9	13.0	13.1	11.4	11.0	-3.0%	0.3%
Turkey	5.0	9.0	15.4	22.0	29.7	30.2	32.0	5.8%	0.8%
Turkmenistan	b/d	b/d	b/d	5.2	3.8	4.8	4.9	3.9%	0.1%
Ukraine	b/d	b/d	b/d	58.1	13.5	13.0	12.9	-0.8%	0.3%
United Kingdom	74.2	104.3	74.7	82.5	78.4	73.5	71.6	-2.6%	1.8%
Uzbekistan	b/d	b/d	b/d	11.2	6.7	4.3	4.4	0.7%	0.1%
Other Europe & Eurasia	173.6	272.5	442.0	36.6	25.5	30.4	30.3	-0.4%	0.7%
Total Europe & Eurasia	**574.3**	**975.0**	**1149.1**	**1108.4**	**938.4**	**903.1**	**898.2**	**-0.6%**	**22.1%**
Iran	10.0	18.9	29.0	52.5	65.8	89.8	87.0	-3.1%	2.1%
Israel	4.1	5.3	8.1	9.0	12.5	11.2	11.1	-0.8%	0.3%
Kuwait	5.2	4.3	5.8	3.7	12.2	19.0	19.0	0.2%	0.5%
Qatar	^	0.1	0.8	1.5	2.4	7.4	8.0	8.3%	0.2%
Saudi Arabia	19.6	20.6	35.9	57.9	74.7	123.2	127.8	3.7%	3.1%
United Arab Emirates	^	0.1	5.6	19.2	19.7	28.9	30.5	5.6%	0.8%
Other Middle East	8.8	12.6	26.0	38.1	61.5	84.7	87.5	3.2%	2.2%

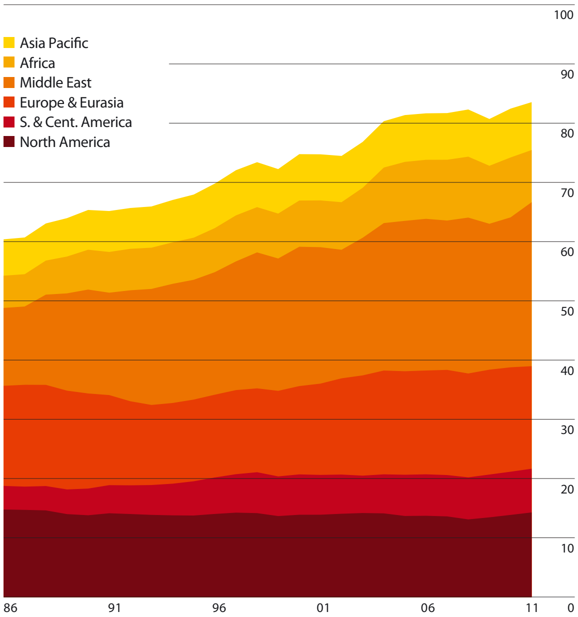
Oil consumption [million tonnes]

	1965	1971	1981	1991	2001	2010	2011	Change 2011 over 2010	2011 share of total
Total Middle East	**47.7**	**62.0**	**111.1**	**181.9**	**248.8**	**364.3**	**371.0**	**1.8%**	**9.1%**
Algeria	1.3	2.3	5.9	9.1	8.8	14.8	15.6	5.3%	0.4%
Egypt	6.9	6.3	15.2	23.4	26.1	36.3	33.7	-7.2%	0.8%
South Africa	5.6	9.4	13.0	16.7	22.5	26.1	26.2	^	0.6%
Other Africa	12.0	19.0	38.7	48.6	62.4	83.4	82.9	-0.6%	2.0%
Total Africa	**25.8**	**37.0**	**72.7**	**97.8**	**119.7**	**160.6**	**158.3**	**-1.4%**	**3.9%**
Australia	16.9	25.8	29.2	30.8	38.1	43.4	45.9	5.7%	1.1%
Bangladesh	-	-	1.6	1.7	3.9	4.9	5.0	2.2%	0.1%
China	11.0	38.4	81.1	121.9	228.4	437.7	461.8	5.5%	11.4%
China Hong Kong SAR	2.1	4.1	6.9	6.3	11.8	17.9	18.1	1.0%	0.4%
India	12.6	20.5	34.0	58.9	107.0	156.2	162.3	3.9%	4.0%
Indonesia	6.1	7.0	21.1	33.6	54.1	65.2	64.4	-1.1%	1.6%
Japan	87.9	219.8	223.8	251.8	247.3	200.3	201.4	0.5%	5.0%
Malaysia	2.0	3.1	8.4	13.9	22.0	26.7	26.9	0.7%	0.7%
New Zealand	2.7	4.1	3.9	4.8	6.1	7.0	6.9	-1.5%	0.2%
Pakistan	3.8	4.3	5.4	11.4	18.3	20.5	20.4	-0.2%	0.5%
Philippines	4.2	8.3	10.2	11.1	16.5	12.2	11.8	-3.6%	0.3%
Singapore	3.8	6.6	10.9	23.7	36.4	60.5	62.5	3.3%	1.5%
South Korea	1.3	9.5	23.9	59.9	103.5	106.0	106.0	-0.1%	2.6%
Taiwan	2.2	7.5	18.0	29.3	44.2	46.3	42.8	-7.5%	1.1%
Thailand	2.3	5.6	11.0	21.9	36.2	45.8	46.8	2.2%	1.2%
Vietnam	1.5	5.1	1.7	2.8	9.0	15.1	16.5	8.9%	0.4%
Other Asia Pacific	3.1	4.8	10.6	9.6	13.9	16.0	16.7	4.5%	0.4%
Total Asia Pacific	**163.5**	**374.6**	**501.8**	**693.3**	**996.5**	**1281.7**	**1316.1**	**2.7%**	**32.4%**
Total World	**1512.8**	**2383.0**	**2867.8**	**3157.2**	**3595.6**	**4031.9**	**4059.1**	**0.7%**	**100.0%**

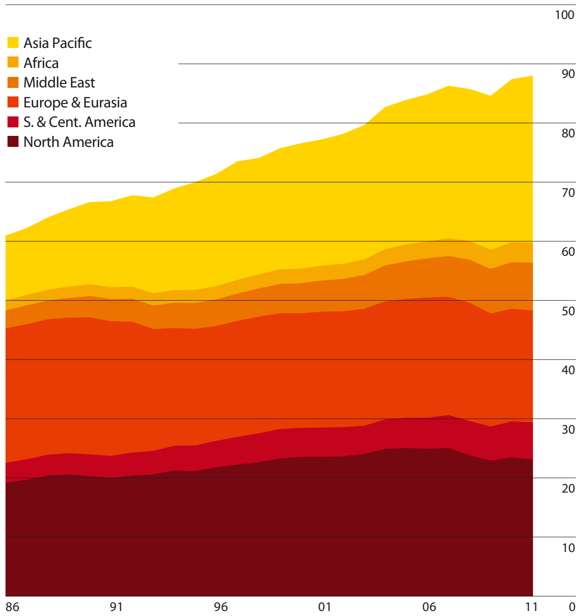
^ less than 0.05

Source: BP Statistical Review of World Energy 2012

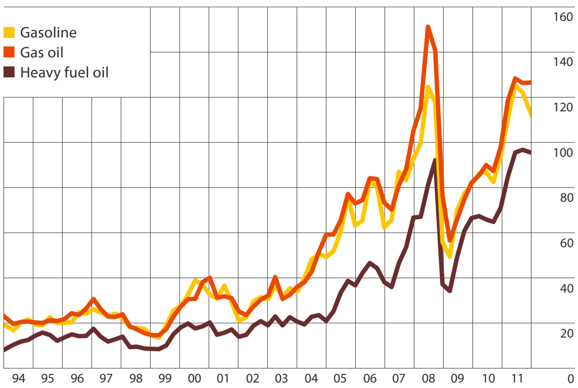
Oil production [m barrels/day]



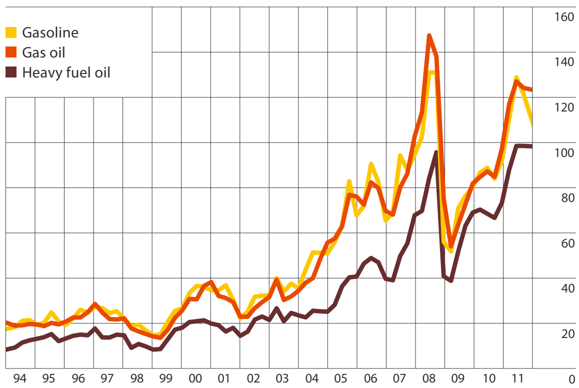
Oil consumption [m barrels/day]



Product prices in Rotterdam [USD per barrel]

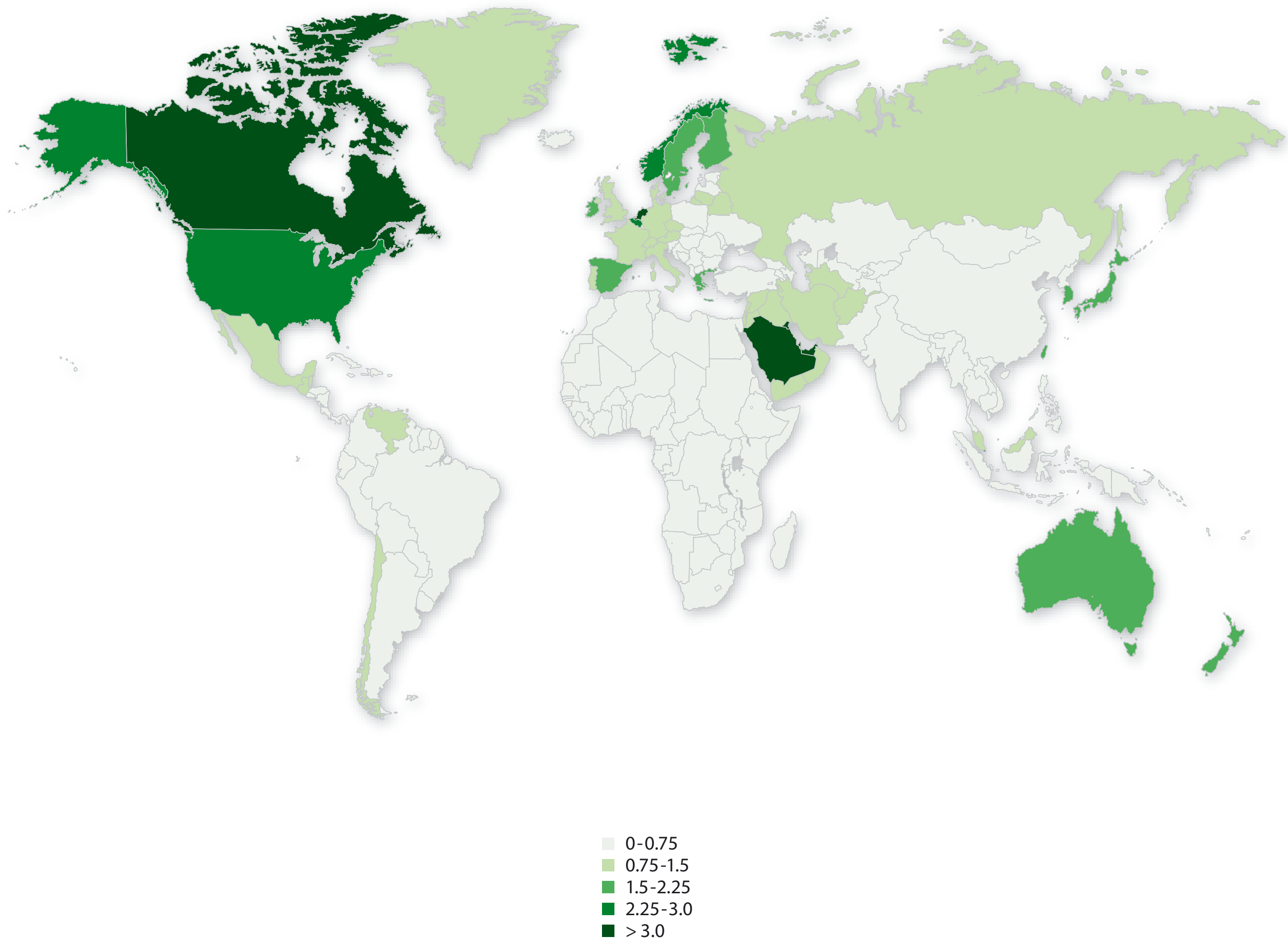


Product prices on the US Gulf Coast [USD per barrel]



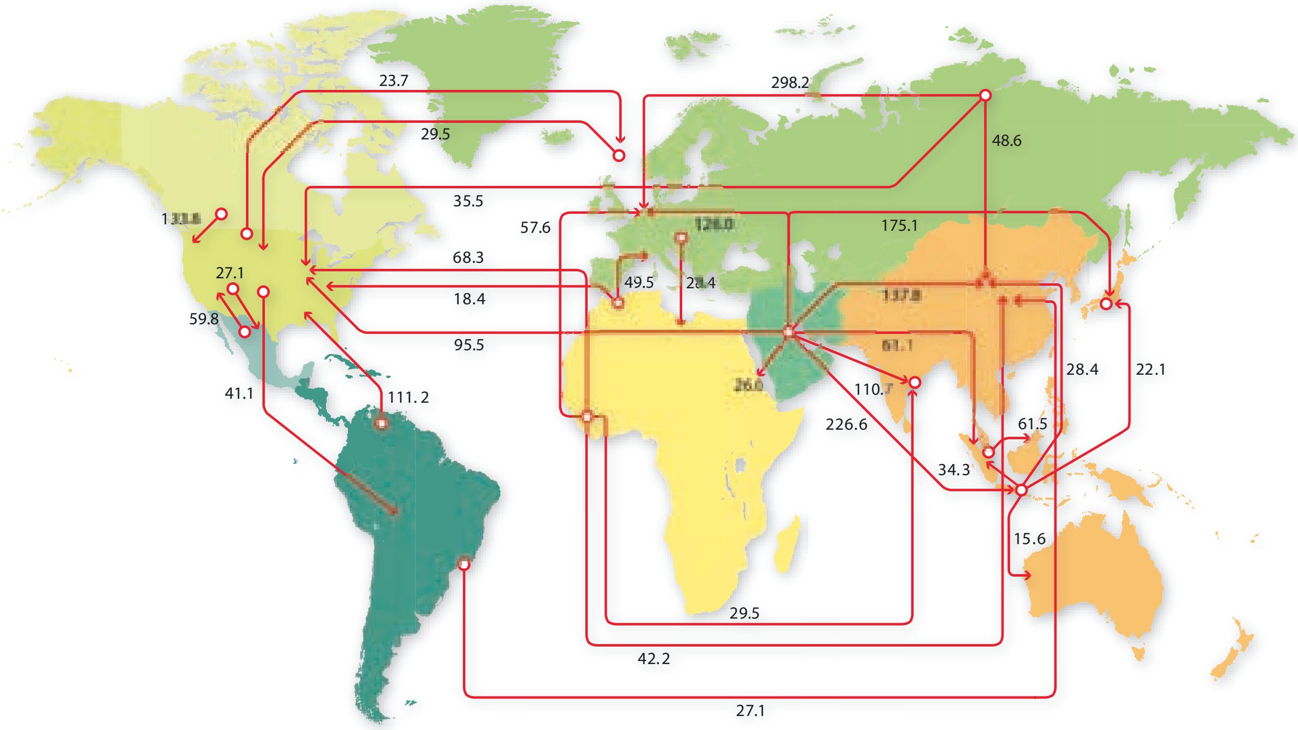
Source: BP Statistical Review of World Energy 2012

Oil consumption *per capita* in 2011 [Tonnes]



Source: BP Statistical Review of World Energy 2012

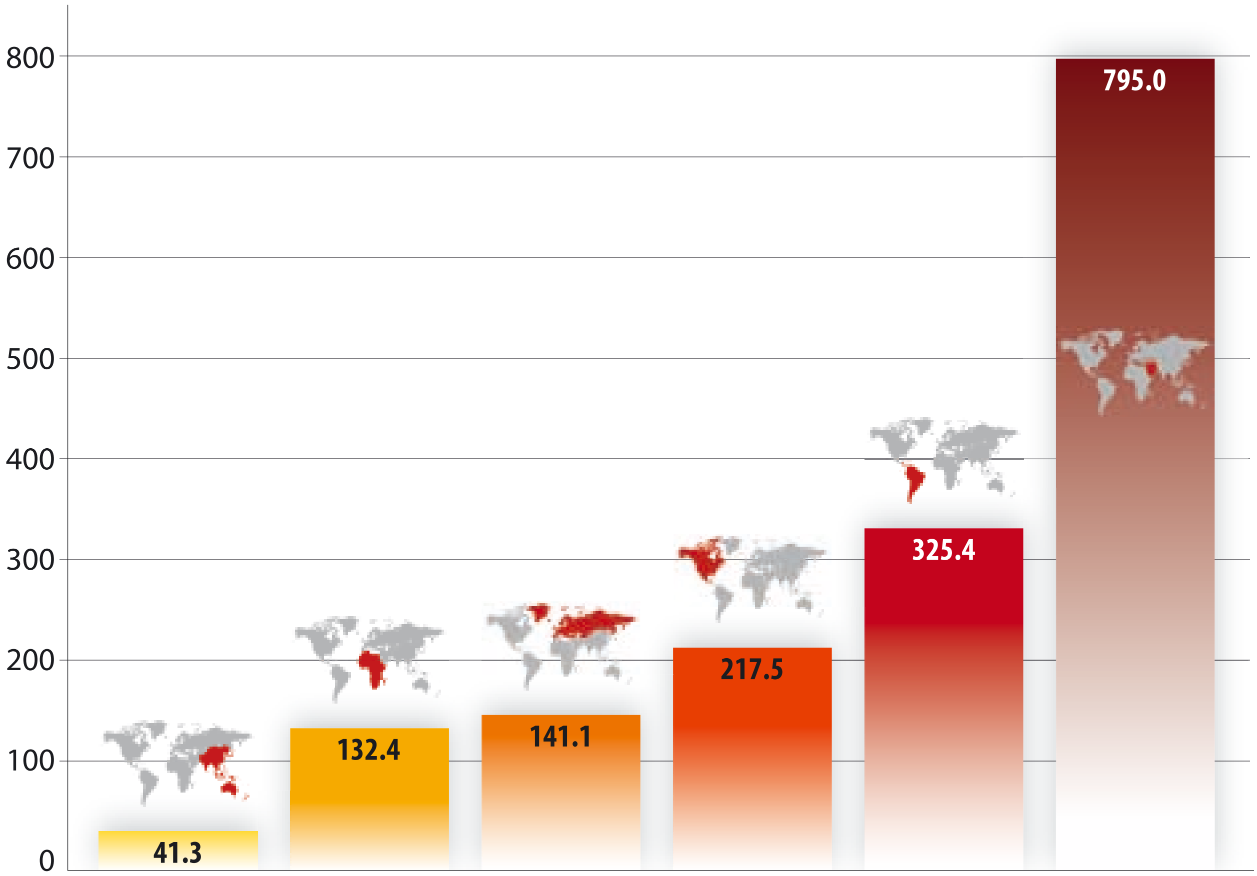
The main directions in oil trade in 2011 [in m tons]



- US
- Canada
- Mexico
- S. & Cent. America
- Europe & Eurasia
- Middle East
- Africa
- Asia Pacific

Source: BP Statistical Review of World Energy 2012

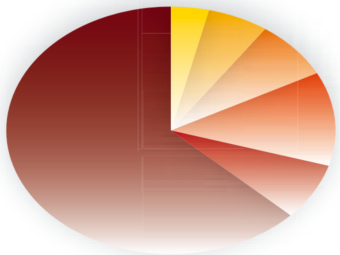
Oil: Proved reserves [in bln barrels] by the end of 2011



Asia and Pacific	41.3
Africa	132.4
Europe and Eurasia	141.1
North America	217.5
South and Central America	325.4
Middle East	795.0

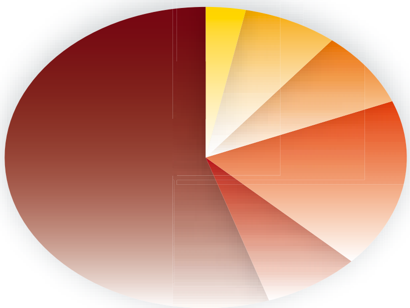
Source: BP Statistical Review of World Energy 2012

Distribution of confirmed oil resources in 1991 – 1032.7 bln barrels total



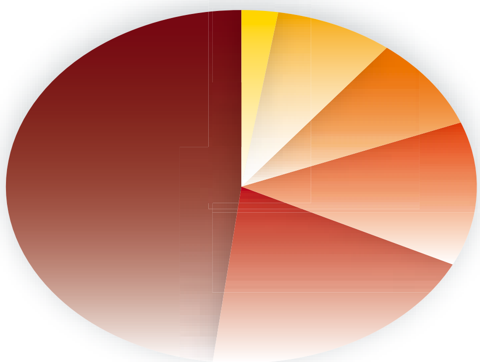
- Asia and Pacific 3.6%
- South and Central America 5.8%
- North America 7.4%
- Europe and Eurasia 11.9%
- Africa 7.2%
- Middle East 64.0%

Distribution of confirmed oil resources in 2001 – 1267.4 bln barrels total



- Asia and Pacific 3.2%
- South and Central America 7.6%
- North America 8.1%
- Europe and Eurasia 18.2%
- Africa 7.8%
- Middle East 55.1%

Distribution of confirmed oil resources in 2011 – 1652.6 bln barrels total



- Asia and Pacific 2.5%
- South and Central America 8.1%
- North America 8.5%
- Europe and Eurasia 13.2%
- Africa 19.7%
- Middle East 48.1%

Source: BP Statistical Review of World Energy 2012

GAS:

exploration, distribution, sales

Joint ventures in the shale gas sector

The most essential thing is cooperation

Tomasz Barańczyk, Konrad Michalak, Jarosław Grzywiński, Grzegorz Kuś

Since exploration concessions – which, considering the exploratory potential – cover the most attractive areas in Poland – have already been granted, the shale gas market enters a more mature phase.

At present, we can expect the appearance of business patterns characteristic for mature markets among the investors already existing in the Polish market and those who only consider going into this business.

particular companies and reports of further gas boreholes make people believe that quite soon we can expect investors to take more active part and estimate potential forms of cooperation, and division of costs and benefits concerning the expected output.

Not to go off course in the race

From the areas of exploration works, more and more information is coming about the deposit potential. As it appears from announcements of particular companies, identification works will be intensified already in 2012. Many international players wish to take the chance and have a share in the benefits from extraction of Polish shale gas. Some of them have decided, for the last few years, to make investments at the early stage of market formation by submitting applications for concession for prospecting and recognition of shale gas. The others refrained from action and observed the investment climate in Poland and decided to wait for initial confirmation that the deposits exist and waited for definition, by the state authorities, of the legislative and tax frames of the business.

There are still many imponderables concerning the new gas law and taxes on hydrocarbon extraction. However, positive statements by representatives of

Reshuffle in the business

Specificity of shale gas deposits requires incurring capital investments on a much larger scale than in the case of conventional gas. Conducting prospecting works is characterized by a high level of uncertainty. This is why, taking as an example the North American market and some ventures in the sector of conven-

> Along with the market development and further capital use in other exploratory boreholes, it can be expected that the significance of cooperation between companies in the market will rise.

tional gas extraction, the concession owners decide to cooperate with other subjects. The main reasons for such cooperation are:

- The desire to minimize and diversify the risk connected with the investment,
- possibility of acquisition of funds, necessary for performing the drilling,
- sharing the experience and *know-how*.

The first of the mentioned factors – risk minimization – concerns all the players in the market. It might turn out soon that only some concessions will offer output conditions which would guarantee the profitability of the project. This is the reason why companies are ready to give up a part of potential benefits from the concession they have, in order to acquire shares in projects located in other regions.

The second reason – acquisition of the capital – is the most important to smaller companies which have been granted concessions but their funds are not sufficient to start the drilling. It is estimated that the cost of making one borehole is higher in Poland than in the USA and costs even about dozen million dollars. Smaller subjects need to cooperate with big players who may help by providing financial resources for the project in return for the share in future benefits.

Another factor – sharing the *know-how* – mainly applies to companies that did not take part in the American shale "boom" a few years ago. An example is the group of Polish energy companies which search for cooperation with American investors in order to develop competence in the field of gas extraction from unconventional deposits.

Along with the market development and further capital use in other exploratory boreholes, it can be expected that the significance of cooperation between companies in the market will rise. What is more, as the size of potential deposits in other concessions was confirmed, it is possible that new subjects will appear,

interested in taking part in the costs and benefits connected with shale gas extraction.

Shale gas "farmers"

The cooperation contracts related to the shale projects development, which have been entered into in Poland so far, varied considerably in terms of concession size, transaction value or the size of the acquired share. Despite the existing differences, most transactions of this type are described with one notion, an expression borrowed from American market – "*farm in*".

In practice, the most common cooperation of *farm-in* type in Poland are:

- contractual joint venture (CJV) based on cooperation contracts – joint operating agreement (JOA),
- special purpose venture (SPV) in the form of limited partnership.

Moreover, the Polish practice resembles the one noticed in the United States, where joint venture contracts based on JOA are the most common kind of cooperation in shale gas sector. However, shareholders should be aware that each and every solution mentioned above has its significant legal and tax consequences.

Cautiousness

Most of the investors are aware of the technical issues connected with the project, such as prospecting and extraction costs, probability of success, gas volume, access to the market, etc. The subject of their concern are the external conditions, typical of a particular country, just like the structure of taxes for transaction, legal potential, social responsibility and balanced development strategies. Furthermore, each side of transaction should persuade their shareholders that the transaction is fair from the financial side (opinion on the price fairness). It ought to be emphasized that the Polish law and its tax regulations are not adjusted to various forms of joint ventures, it does not matter whether it is a cooperation contract (JOA) or limited partnership (SPV). Every cooperation scenario may become a concern to the investors.

Legal approach

From the legal perspective, all deposits in Poland constitute an exclusive property of the Republic of Poland. One of the most key issues for an investor is to enter into a valid and fully enforced mining usufruct contract with the State Treasury. According to such a contract, the investor from the shale sector will have the right to use particular resource deposits whose owner is Poland. The mining usufruct contract will describe precisely all conditions and use of such deposits. The investor may plan prospecting and/or extraction of the designated material. The concession will be issued for a definite period of time, however, for at least 3 years and no more than 50 years.

The Polish mining and geological law which concern the process of granting concessions for prospecting, recognition and extraction of hydrocarbons (also oil and shale gas) establish that the concession and mining usfructe can be granted only to a single subject. At the same time, concession transfer is allowed only as a whole, i.e. selling shares in the concession is not possible. Another issue to be discussed is the ownership of the output gas or the potential need for obtaining permission from antimonopoly office in the case of creating SPV.

Taxes are significant

From the tax perspective, with reference to joint ventures, the key issue is an appropriate structuring of remuneration for granting access to a concession. Usually, one subject has a concession from a certain date and when new partners wish to join, the concession holder expects "a charge for the entry" and payment for the already incurred costs. Often seen in other countries structures with asymmetric division of future costs and incomes (e.g. the subject which transfers rights to the concession will have 60% of income and 30% of costs, and the purchaser 40% of income and 70% of costs) in Poland may lead to substantial limitation in deducting of partial tax costs for the purchaser.

It is worth noting that the foreign subjects which engage in joint ventures in the scope of gas prospecting or extraction in Poland (e.g. as a partner in a company) might be perceived by the Polish tax authorities as having the so-called permanent establishment for tax purposes. As a consequence, they may be obligated to pay income tax in Poland and to fulfill a vast array of administrative and reporting duties. Furthermore, in some situations, depending on the range of conducted activities, it can happen that the foreign subject creates a *fixed place of business* for the purpose of the value added tax (VAT) or the necessity for VAT registration in Poland. The questions of VAT settlement will also appear with reference to current settlements among participants of joint ventures, particularly when one of them is the operator who funds prospecting works with the so-called *cash calls* or by re-invoicing the costs on the others. Additionally, questions concerning VAT settlements may result from the sales patterns related to the material extracted in the future, hence they should be analyzed at the preliminary stage of the joint venture. Worth noticing is the fact that in some cases there might appear duties of paying real estate tax on land and buildings that are used for hydrocarbon prospecting or extraction. In this context, tax payment would jointly charge all the participants of the joint venture.

> Polish mining and geological law which comprises the process of granting concessions for prospecting, identification and extraction of hydrocarbons (also oil and shale gas) establish that the concession and mining use can be granted only to a single subject.

To sum up, through an advanced tax planning and use of existing optimization opportunities, it is possible to secure the tax situation of the *joint venture* participants and to shape their tax charge efficiently.

The authors are employees in the Tax and Legal Department and Business Advisory at PwC

Tomasz Barańczyk – Partner
Konrad Michalak – Vice Director
Jarosław Grzywiński – Senior Lawyer
Grzegorz Kuś – Senior Consultant

Gas Infrastructure

Perspectives for natural gas export from Poland

MATEUSZ KONIECZNY

The stage of prospecting and identification of unconventional natural gas deposits in Poland has been crowned with success. Numerous Polish and foreign entities commence exploitation and extraction of gas. The economy of extraction promotes the development of generative capacity of electric power based on gaseous fuel and the Polish chemical industry strengthens its competitiveness owing to the availability of domestic resources.

Up till now Polish firms, mostly importers and consumers of natural gas have expanded into a new area of operations which comprises dealing in the domestic liberal market and abroad, which makes them active participants of the European natural gas market and brings them real economical benefits at the same time.

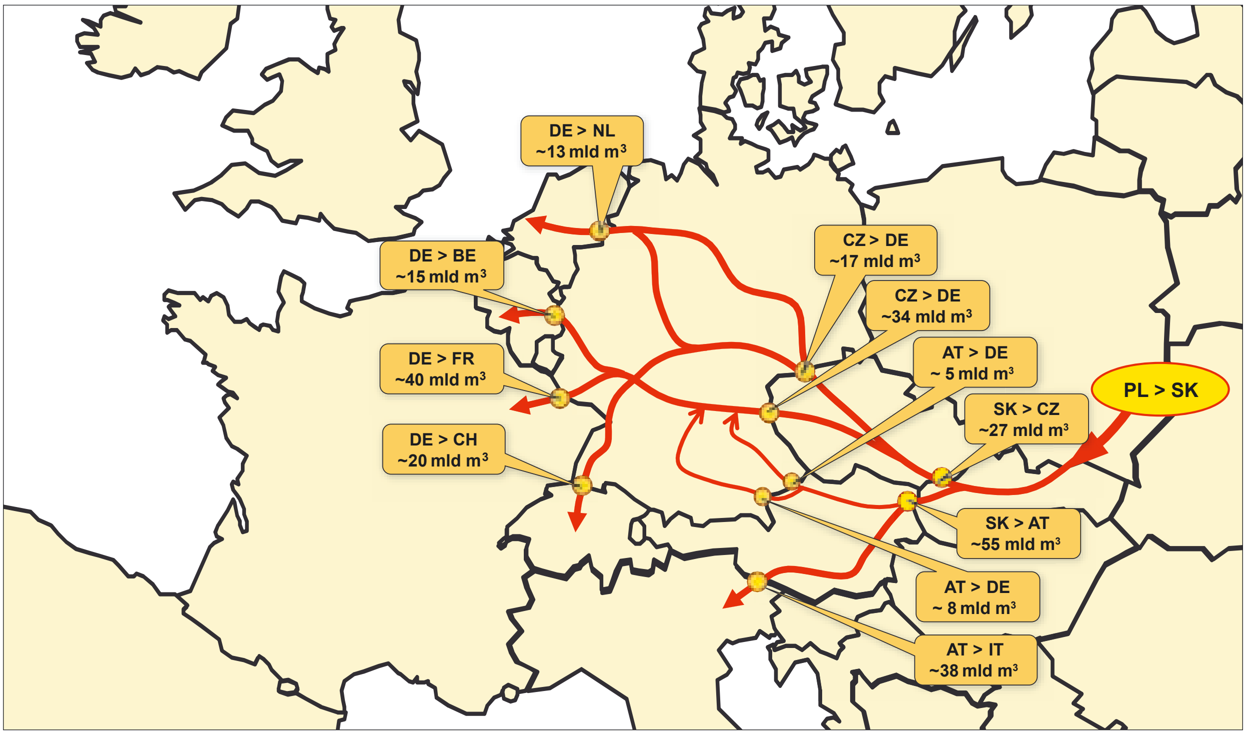
Poland is on the way of transformation from a state dependent from fuel supplies into an entity which is becoming the mainstay of energy security of the region by ensuring supplies of the resources to internal markets of the European Union. Such an image of the Polish natural gas market appears as the consequence of the most optimistic scenarios of development of shale gas exploitation. However, at present, such an optimistic approach may seem to be a rather distant and obscure vision. The degree of identification of unconventional gas deposits does not allow yet to determine reliably the extractable volumes, which makes it impossible to settle the economy of exploitation and define potential increase in domestic gas supply.

On the other hand, the scale of the breakthrough which may be caused by natural gas from shale formations in Poland is large enough for us to become aware of potentially different scenarios related to its extraction. Especially, the fulfillment of the optimistic scenario of the natural gas potential from unconventional deposits kindles the emotions of the branch members, which allows to draw the picture of Poland as a strong player in the European energy market, independent from external suppliers.

What would happen, if our country had surplus of natural gas? Let us think for a moment of a situation in which the perspective of Poland possessing a large surplus of gas exceeding our own demand is a fact. Eventually, the possibility of selling the natural gas outside Poland will be determined by demand for this raw material on global markets and in West European countries, and first of all, by price competitiveness of Polish gas as compared to alternative sources of supplies. This article, however, disregards the aspect of gas prices and focuses on technical possibilities of its export from Poland.

Liquefied natural gas – (apparently) global range

Liquefied natural gas (LNG) has become part of the European gas balance for good. Many years ago, most of the states of the Old Continent with access to the sea invested in terminals which enabled the import of gas in liquid form. Globally, facing considerable distances of sources of natural gas supply to areas of its increased consumption, the LNG has become an effective – with respect to the costs – solution which facili-



Map: Technical transmission capacities of intersystem connections on gas distribution routes from 'Brotherhood' pipeline. *Analysis by PwC on the basis of the ENTSO-G data.*

tates long distance gas transmission. Considering the possibilities of exporting LNG is then a natural direction of analysis for each country possessing the surplus of natural gas.

The global LNG market is divided into three major regions of production and/or consumption:

- **The Atlantic market** (a net importer including mainly the USA and Europe as consumers and Africa and Central America as producers);
- **The Pacific market** (a net importer including basically Japan and South Korea as consumers and Malaysia, Indonesia and Australia as producers);
- **The Middle East region** (a net exporter, including first of all Qatar and Oman as producers)

– supplying the two other areas.

The development of American market caused by large scale production of natural gas from shale formations is gradually changing the developed scheme of the LNG market presented above – in the near future the United States will become an exporter of gas exactly due to investments in liquefying terminals. This means that Poland, while considering the construction of its own export terminal, has to be aware that the American market can no longer be perceived as a potential export direction but rather as a potential competition. In fact, it leaves two directions for potential export of the Polish LNG – the European market or the Asian (Pacific) one, which is more distant from Poland than for the producers from the Middle East who also benefit from additional effects of scale due to possession of liquefying installations which are the largest in the world. Thus, the above brief presentation of the context for the LNG markets shows that when analyzing the possibilities of liquefying the gas in Poland, particularly the European market has to be taken into account, especially the Baltic Sea and the North Sea basins.

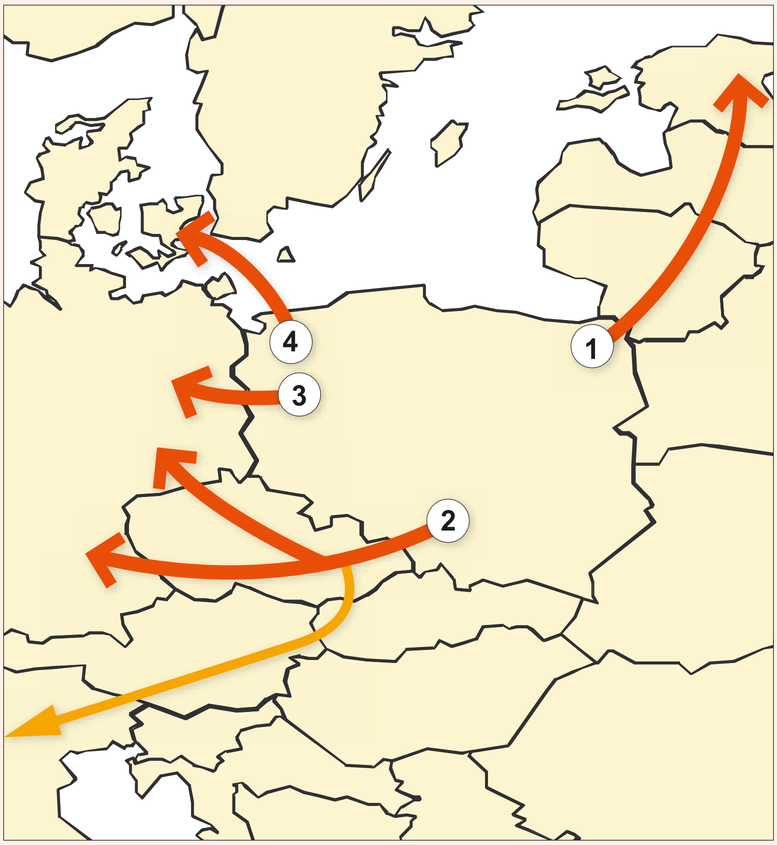
Regardless of the above rationales, in case of having export surplus, Poland should consider first of all the export of gas to the countries of the European Union. The reason is plain – the appearance of Poland in the balance of the natural gas suppliers to the Union market may completely alter the perception of our country in Europe and contribute to considerable strengthening of our position on the international arena.

Another rationale to consider the LNG as a form of export of natural gas from Poland is the possibility of avoiding in this way the limitations of gas transmission infrastructure in Europe. Despite the close network of connections, there are bottle necks in the European mains; mainly the limitations resulting from long term transmission contracts concerning trans-border connections. Meanwhile, regasification terminals in Europe have substantial surpluses of non-contracted capacity. In 2010 not utilized capacity of import terminals amounted to about 55% of their total capacity estimated at that time at approximately 170 billion m[3].

Alternative gas pipeline export routes

The extensively discussed possibility of connecting Polish natural gas transmission system with 'Brotherhood' gas pipeline does not exhaust the Polish possibilities of constructing export gas pipelines. Among alternative projects which can aid this objective, the following should be listed:

- Connection with Lithuania – currently analyzed by the GAZ-SYSTEM and Lietuvos Dujos. This connection is intended to facilitate the export of up to 4.5 billion m³ of natural gas to the Baltic states.
- Connection with the Czech Republic – there is a possibility of converting into export function of the existing connection near the city of Cieszyn, which was to function originally as a source of gas supplies to Poland.
- Connection with Germany – up till now, conceptual infrastructural projects concerning the German mains were focused on the possibilities of connecting Poland to the Berlin gas ring which is fed from the East via Mallnow (Yamal gas pipeline), currently also by 'Opal' gas pipeline (onshore extension of the Nord Stream pipeline)and from the West via 'Netra' gas pipeline (supplying gas coming from the North Sea, however this route will eventually be most probably replaced by the stream from the 'Opal' gas pipeline).
- Connection with Denmark – the 'Baltic Pipe' project to link Poland with the Norwegian 'Skanled' gas pipeline via Danish territory, which was analyzed a few years ago gains a new meaning in the context of Polish export demands. Considering gradual depletion of the Danish deposits, this country will soon become a net importer of natural gas and may be interested in renewal of the project in order to secure its own import demands.



Potential alternative export connections of the Polish transmission system. *Source: PwC analysis*

While talking about the possibilities of exporting the LNG, the question of economy of its transport in Europe remains still open. The advantage of LNG over conventional transmission via gas pipelines is achieved only in case of appropriate distances. On the other hand, at present the countries like Norway, Algeria or Egypt, which are located relatively close to the European markets effectively place in them the volumes of their own LNG. Nonetheless, the economy of transport within Europe, especially in relation to the transmission infrastructure, requires thorough analysis.

Gas from the East – the potential of gas transmission infrastructure in the region

The present shape of transmission infrastructure in Poland does not provide the possibility of exporting natural gas from Poland. The transmission system was constructed with the intention of importing gas from the East and current investment projects aim at diversification of supplies to our country. Creating the possibilities of export of natural gas will require new investments. Assuming that the main objective of construction of export infrastructure should be providing the access to possibly largest number of target markets, an interesting option is connecting the Polish system with existing transit channel of the Russian gas running through Slovakia ('Brotherhood' pipeline). Analyzing the Russian export policy relating to the Northern gas pipeline Nord Stream and plans of its further extension, it should be assumed that in the near future the meaning of 'Brotherhood' pipeline measured by the volume of the Russian gas supplied to Europe will be decreasing. In the context of expected drop in pumped volumes, substantial technical transmission capacity (total capacity at output points of Slovak pipelines is about 82 billion m³) as well as access to the key markets in Europe, connecting Poland to this pipeline has a tremendous potential.

Natural gas flow distribution, which up till now has reached Europe via Slovakia demonstrates that by connecting to this transmission channel Poland will gain access to almost all key markets of Western Europe. Until the construction of the Nord Stream, Russia was able to supply natural gas via 'Brotherhood' gas pipeline to Germany, Italy, Austria, Slovakia, the Czech Republic and by extended European gas pipeline network also to France or Benelux countries. This gas pipeline also provides direct access to the physical hub in Baumgarten, which enables concluding spot and short term gas sale transactions.

Table 1. List of estimated capital expenditures for infrastructure projects (pipeline vs. LNG)

	Liquefying terminal (greenfield)	Liquefying terminal (on the basis of regasification terminal)	Intersystem gas pipeline
Source	Data by CB&I	Plans to convert import terminal Sabine Pass in the USA (Stage I)	Preliminary feasibility study for import connection Poland - Slovakia
Capacity	about 6.8 billion m³	about 12.2 billion m³	3 billion m³
Level of capital expenditures	3,75 billion USD	5,4 billion USD	750 m PLN
Capital expenditures per unit	1.875 billion PLN/billion m³	about 1.50 billion PLN/billion m³	0.25 billion PLN/billion m³

Source: PwC analysis on the basis of ChemLog, GAZ-SYSTEM and CB&I data and press releases.

Remarks: estimated data – they do not take into account the value of money in time. The calculation is based on the assumption that outlays estimated for the project of connecting Poland and Slovakia are adequate also for the export function of the gas pipeline. The scale effect of infrastructure was disregarded. It should be remembered that outlays for the investment with capacity other than the one indicated in the table will not change linearly, so the comparison of outlays per unit should be treated only as indicative.

How much may it cost us?

One of the major economical criteria defining profitability of any venture is the level of investment outlays; when considering the possibility of export, this aspect cannot be neglected.

In 2010, as part of the European Union program ChemLog, tentative feasibility study was prepared for

Electric power – alternative way of natural gas export

Apart from the possibilities of natural gas export in its natural form presented in this article, an interesting alternative has to be pointed out, i.e. export of gas in the form of electric energy, for generation of which it has been used.

According to the data of Energy Market Agency[1], in 2011 the total export of electric energy from Poland amounted to over 12 TWh (which was ab. 7.1% of total output). In the structure of net power generated in Poland in distribution into types of fuel, natural gas makes up at present only 3%[2]. An attempt to relate this contribution to the volume of energy export in order to estimate the equivalent of natural gas which was used in this way, in today's reality will produce a very low result.

Taking into account that the scope of this article is limited and we narrow the discussion to the terms of natural gas market changed by unconventional gas, we can assume a substantial increase in generative power based on this fuel. Aggregation of published investment plans into new generative powers based on gas fuels in Poland points out to their joint potential of about 6.5 GW[3]. If all the investment plans are accomplished, it will not change the fact that natural gas will still play substantially smaller role in the structure of generative output than traditional coal fuels.

However, if we take into consideration the flexibility of operation of gas units and assume that the leading criterion deciding on energy export is the possibility of fast application of price arbitration among markets, it is just gas blocks that will provide the possibility of almost immediate reaction to the changing market conditions.

Export of natural gas in the form converted into electric energy should be perceived only as an interesting idea and potentially a kind of slight complement to the export of gas itself. On the other hand, if, for the purpose of this article, we assume that the total volume of last year's export of electric energy was based on gas units, then, after conversion into natural gas equivalent the export would exceed 1 billion m^3.

1 Source: The Energy Market Agency S.A. Monthly bulletin – Statistic Information about electric energy, December 2011

2 Source: the PwC and ING. Attractiveness of gas-fuelled power generation investments. May 2012

3 Source: the PwC and ING. Attractiveness of gas-fuelled power generation investments. May 2012

construction of new interconnectors joining the Polish system with neighbouring countries[1]. Among the analyzed investments was the project of connecting Poland with 'Brotherhood' gas pipeline. Initial technical analysis showed technical possibility of such connection and total investment outlays were then estimated at about 750 million PLN[2]. It must be noted that this analysis was made with the assumption that the gas pipeline will have an import function and technical Poland-oriented capacity was meant to be about 3 billion m^3 annually. Modification and adaptation of this project to export demand will presumably change the results of the calculations, while the analysis mentioned permits the assumption of potential expense amounts related to the investment. Additional verification of the costs of discussed investment may be provided by the results of tentative feasibility study for the connection Poland – Lithuania published by GAZ-SYSTEM at the beginning of July 2012[3]. According to the results of initial analysis, a total unit cost of constructing one kilometer of this pipeline will amount to about 4 million PLN, whereas for the mentioned above analysis of the connection with Slovakia this cost was 4.4 million PLN per 1 kilometer, so there is no substantial discrepancy here.

For the execution of investment comprising the construction of a terminal for liquefying natural gas, the data may be quoted after international firm CB&I[4] which specializes in projecting and execution of investments in the LNG segment. According to the data, a unit cost of the greenfield investment in a liquefying terminal amounts to about 1.875 billion PLN for liquefying capacity of 1 billion m^3 of natural gas.

A natural gas liquefying terminal in Poland could be located at the site of currently constructed re-gasification terminal. Then, the cost of construction of liquefying installation will certainly be lower than the one indicated above. It results from the fact that some infrastructure which is already prepared for regasification purposes can be adapted for liquefying function – especially harbor infrastructure (piers, breakwaters) and LNG tanks. An example of utilizing the existing infrastructure of regasification terminal is the project of converting the Sabine Pass installation

1 Source: Chemical Logistics Cooperation in Central and Eastern Europe. Feasibility Study. Cross-border gas pipeline for improving the logistics in Central and Eastern Europe. November 2010. Polish Chamber of Chemical Industry.

2 Investment outlays were estimated on the basis of 180 m EUR for the connection Strachocina – Velke Kapusany. The amount in PLN, at the rate: 1 EUR = 4.20 PLN.

3 Source: Gas Interconnection Poland – Lithuania (GIPL). Results of Business Case Analysis. GAZ-SYSTEM and Lietuvos Dujos. July 2012.

4 Source: CB&I. Current State & Outlook for the LNG Industry. Rice Global E&C Forum. September 2011.

Small scale liquefying installations and re-export of LNG

Among the possibilities of exporting gas in liquefied form, apart from the presented large scale liquefying installation, the construction of a small scale liquefying installation and re-export of LNG from Swinoujscie should be mentioned.

The idea behind these solutions is an assumption that our objective is not to compete in the global markets but only the management of the local potential located within the basins of the Baltic and the North Sea. By the potential of this region one should understand the demand from existing and planned satellite regasification terminals located chiefly in the Scandinavian countries as well as in the Baltic states. (Lithuania, Latvia and Estonia).

- Small scale liquefying installation – the concept of constructing LNG producing installation with capacity adapted to demand in the region which would give the possibility of liquefying and export of natural gas located in the territory of Poland
- Re-export of LNG – the concept based on the lack of own liquefying infrastructure. The LNG volumes arriving in Swinoujscie could be reloaded to smaller vessels and then directed to satellite regasification terminals. In this case, there would be no physical transfer of natural gas extracted in Poland, but with regard to trade balance, Poland would be an exporter of natural gas.

Both indicated solutions are beneficial in their diametrically lower investment outlays for their execution in comparison to a large liquefying installation, yet with much lower export potential.

in the USA where estimated outlays for the liquefying capacity of 1 billion m^3 of natural gas amounts to 1.5 billion PLN.

The possibility of utilizing the infrastructure which is being currently constructed in Swinoujscie will not change the fact though, that construction of a liquefying terminal will be much more capital consuming than gas pipeline investments.

Conclusions: which is the right way?

Historical conditions resulted in the fact that gas pipeline infrastructure in Central and Easter Europe was oriented to transmission of the Russian gas from the East to the West, mostly to German and Italian recipients. Paradoxically this feature, which has been usually pointed out as the key weakness of the transmission system in our area, may become the source of benefits for Poland in the discussed context.

Relatively small scale of investments in connecting the Polish transmission system to the 'Brotherhood' pipeline in Slovakia would provide Poland with access to practically entire European market with substantial potential of available free transmission capacity, assuming that the role of the principal transit channel for the Russian gas will be taken over by the Nord Stream (potentially with the South Stream gas pipeline). Alternatively, assuming smaller export demands of Poland, the projects such as connections with German or Czech system can be considered, which also enable transmission to the Western markets, even though on a smaller scale.

Export direction by sea in liquefied form – in spite of expected larger investment outlays and consequently larger unit transportation cost to European recipients – still constitutes an interesting alternative for the lack of barriers resulting from long term reservation of transmission capacity in transmission systems in Europe and access to global sale markets.

The time for selection of optimal export routes will come at the time when uncertainty related to the future of unconventional gas will change into solid data concerning its potential of exploitation. This information will then allow Poland to undertake economically rational investment decisions. Regardless of the fact, in which direction goes the possibility of gas export from Poland, a great chance for Poland has to be emphasized in case of shale gas success – the meaning of Poland on political map of Europe will be growing in direct proportion to the volume of exported gas.

The author is a Manager
at the PwC Business Advisory

The development of gas sector based on the European Union resources

Record investments

The security of energy and fuel supplies is one of the EU priorities. It depends mainly upon the diversity of acquisition sources. This is the reason why the European Commission is focused on investments in this sector.

In the current EU cohesion policy, the member states have allocated 3% (i.e. about 11 billion euro) of the budget for the power industry sector. The Polish power sector received 20% of this sum. Almost 7.5 billion PLN[1] of the EU resources were collected for this purpose as part of **Operational Programme Infrastructure and Environment** (OPI&E) which is governed by the Ministry of Regional Development. The sum of 4.1 billion PLN was allocated for investments in energy security of the country, out of which 2.7 billion PLN were intended only for the gas sector.

One of the key investments carried out within Operational Programme Infrastructure and Environment is the **construction of LNG terminal in Swinoujscie[2]**, which will increase the supply of natural gas in Poland by half. The investment is to be completed by the middle of the year 2014. The Polskie LNG Company received for this purpose 456 million PLN[3] from the Programme. In order to complete a part of the project, the company received also the EU funds from the so-called Recovery Plan. As a result, Poland will be able to receive about 5 billion m^3 of natural gas annually[4] by sea (after regasification), which is about 1/3 of the annual gas consumption in the country. Further, gas will be transmitted by pipeline or tankers (rail or road transport).

The construction of LNG terminal in Swinoujscie – the only one in this part of Europe – along with the investments (carried out by GAZ-SYSTEM S.A. company) which aim at expansion of natural gas transmission system are part of the EU plans concerning the construction of North-South corridor in Middle-East Europe. This corridor – by using internal gas pipeline systems of Poland, Czech Republic, Slovakia and Hungary, and interconnectors – is to link LNG terminal in Swinoujscie with LNG Adria terminal in Croatia.

Owing to the EU financial support, **by the year 2014 there will be about 1000 km of high pressure transmission gas pipelines in Poland.** For the con-

1 *Out of which about 2.9 billion PLN in OPI&E was meant for investments in acquisition of energy from renewable sources and effectiveness in energy sector.*

2 *The name of the OPI&E Project: The Construction of Liquefied Natural Gas Regasification Terminal in Swinoujscie – unloading and regasification installation.*

From www.polskielng.pl: LNG (Liquefied Natural Gas) is a fuel produced from natural gas after removing pollution and then changing the state of matter under the influence of pressure and very low temperature – about minus 160°C (-270°F). Due to liquefaction, a very clean, colourless and odourless fuel is received, without toxic or corrosive properties. LNG contains mainly methane and small amounts of other hydrocarbons. LNG undergoes the process of regasification, which is another transformation into gas through heating the material in liquid state. During this process, the gas volume becomes about 600 times bigger.

3 *Total cost of construction of the LNG terminal is about 3.5 billion PLN.*

4 *Currently Poland uses about 14 billion m^3 of gas annually.*

Gas pipeline Wloclawek-Gdynia, the hub in Wiczlino (photo: GAZ-SYSTEM S.A.)

struction of seven gas pipelines co-funded by OPI&E, the total estimated investment outlays will be about 3.8 billion PLN. GAZ-SYSTEM S.A. company received about 775 million PLN from the Programme. Consequently, the capacity of the transmission system and the possibility of transmitting gas fuel on a larger scale will increase. Gas pipelines subsidized by OPI&E comprise: **Szczecin-Gdansk, Szczecin-Lwowek, Rembelszczyzna-Gustorzyn, Gustorzyn-Odolanow, Jeleniow-Dziwiszow, Polkowice-Zary, Wloclawek-Gdynia**.

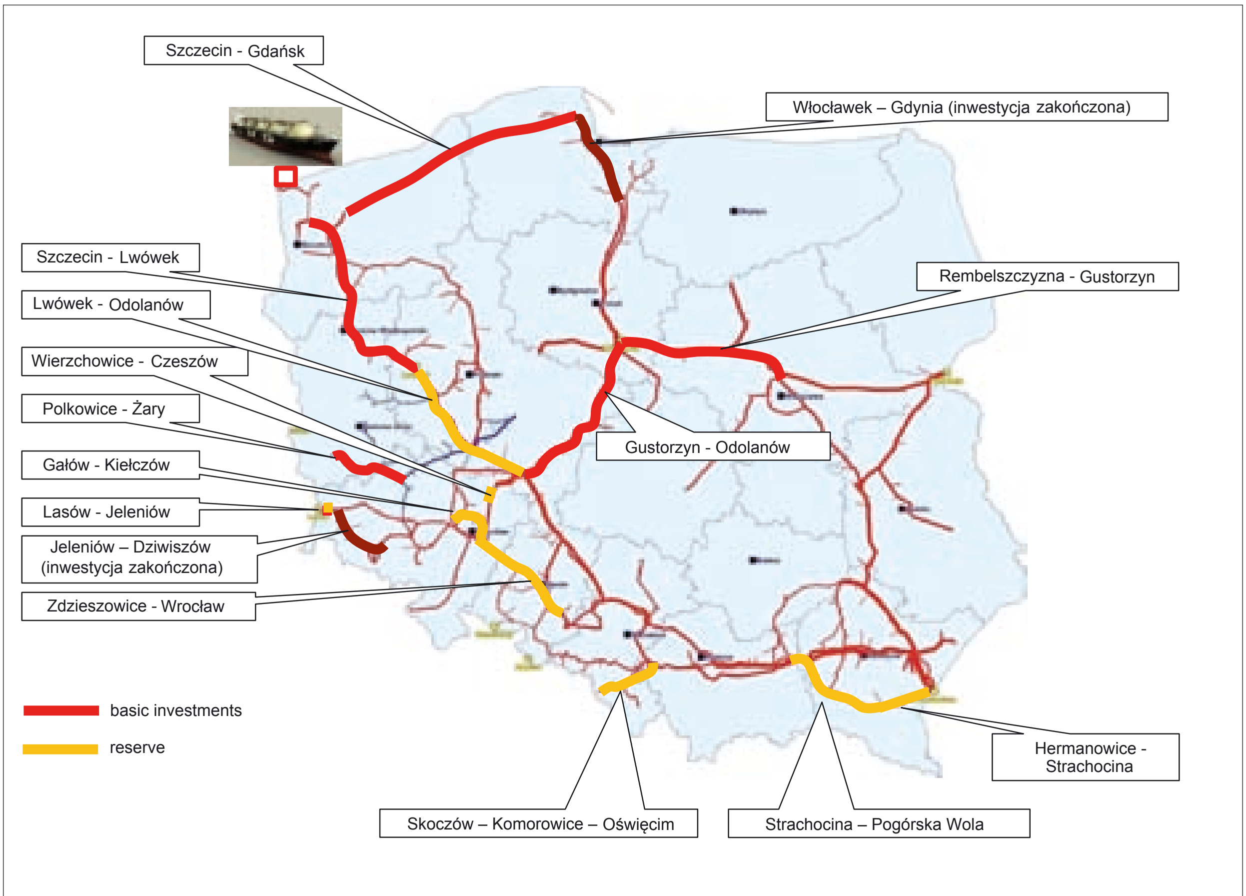
With the funds of the European Union Operational Programme Infrastructure and Environment the transmission and distribution network of natural gas and gas storage are being developed. Also, the LNG terminal in Swinoujscie is under construction. Until now, 35 investments in the gas sector in the country were subsidized, the total sum of which was 2.3 billion PLN. The projects in energy sector are very time-consuming because of their complexity and the effect on the environment. However, all the investments will be completed by 2015.

Construction of these pipelines ensures better security of gas supply to consumers, it will create opportunities for gas market development by increasing the capacity of transmission system and appropriate conditions for expanding the distribution network.

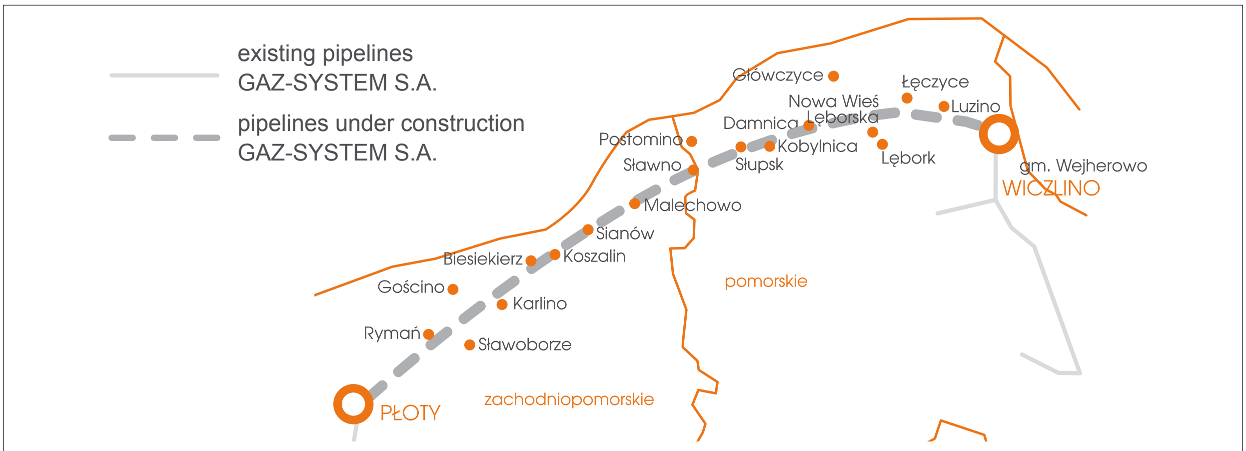
– *As a part of strategic investment programme of the* GAZ-SYSTEM S.A., *it is essential to execute projects connected with adaptation of the grid to receive gas from the LNG terminal in Swinoujscie which is under construction. Owing to regulations of a special law concerning the construction of LNG terminal, it was possible to speed up considerably the pace of accomplishment of our investments connected with expansion of Polish transmission system. We consider also other investment projects which would integrate the transmission infrastructure in our part of Europe. We will make every effort to take into account the need for further transmission system expansion in Poland, also in the new financial perspective for 2014-2020* – says **Rafał Wittmann** – the Manager of Development and Investment Department GAZ-SYSTEM S.A.

Until now, GAZ-SYSTEM S.A. has finished the construction of two transmission gas pipelines **Wloclawek-Gdynia** and **Jeleniow-Dziwiszow** of total length of 128.7 km. It was built with the EU funds of total sum of 65 mln PLN. The biggest gas pipeline supported by OPI&E is the Szczecin-Gdansk[5] section whose

5 *The project is carried out in four stages: Ploty-Karlino, Karlino-Koszalin, Koszalin-Slupsk and Slupsk-Wiczlino.*



The investments of Gaz-System Company co-funded by OPI&E. Source: GAZ-SYSTEM S.A.



Range of the investment "Szczecin-Gdansk Gas Pipeline". Source: GAZ-SYSTEM S.A.

length is 265 km and it is subsidized with the sum of 226.88 million PLN. By the end of 2013 the pipeline will meet the demand for gas in provinces: Western-Pomeranian, Pomeranian, Kuyavian-Pomeranian and Greater Poland, and it will also ensure cooperation with the underground gas storage reservoirs.

In the future, this gas pipeline will cooperate with **cavernous underground gas storage in Kosakowo** which is also subsidized from OPI&E. Moreover, as part of the Programme, the underground gas storage in **Wierzchowice** and **Strachocin** is expanded. The Polish Oil and Gas Company (PGNiG SA) received about 673 million PLN from OPI&E for carrying out these investments, which makes up almost half of the construction costs. Thanks to the EU financial support, the ability to store gas in the country will rise by over 50%, i.e. by 905 million m^3 (by the middle of 2014). The expansion of single gas storage in

Underground Gas Storage in Strachocina (photo: PGNiG SA)

Wierzchowice will produce the active storage capacity by 625 million m³.

In 2011 the expansion of underground gas storage in Strachocina was completed. It is the first finished project among the investments carried out by PGNiG SA in the Operational Programme Infrastructure and Environment. The project was subsidized with the sum of 62.68 million PLN. In effect, the active store capacity increased by 120%, up to 330 million m³. The project is a part of PGNiG SA long-term investment plans in the area of Strachocina, comprising the expansion of storage facility to the capacity of 1.2 billion m³.

– *PGNiG SA received subsidies from OPI&E for the construction of three natural gas storage facilities. The execution of these projects will increase the energy security of the country by providing gas supply to consumers in the case of failure in the gas supply system, and it will contribute to a better balancing of seasonal irregularity in gas demand for the country economy* – says **Joanna Zakrzewska**, the PGNiG SA press spokesperson.

Investing in underground gas storage is a crucial element of gas system infrastructure development. It will enable strategic reserves of natural gas, which is unusually important in the case of Poland which is currently highly dependent upon the import of this fuel. Storage facilities will help to balance the seasonal irregularity of gas consumption by consumers or the short-term local fluctuation in its consumption.

Moreover, **natural gas distribution networks** are built or modernized with the financial help of OPI&E

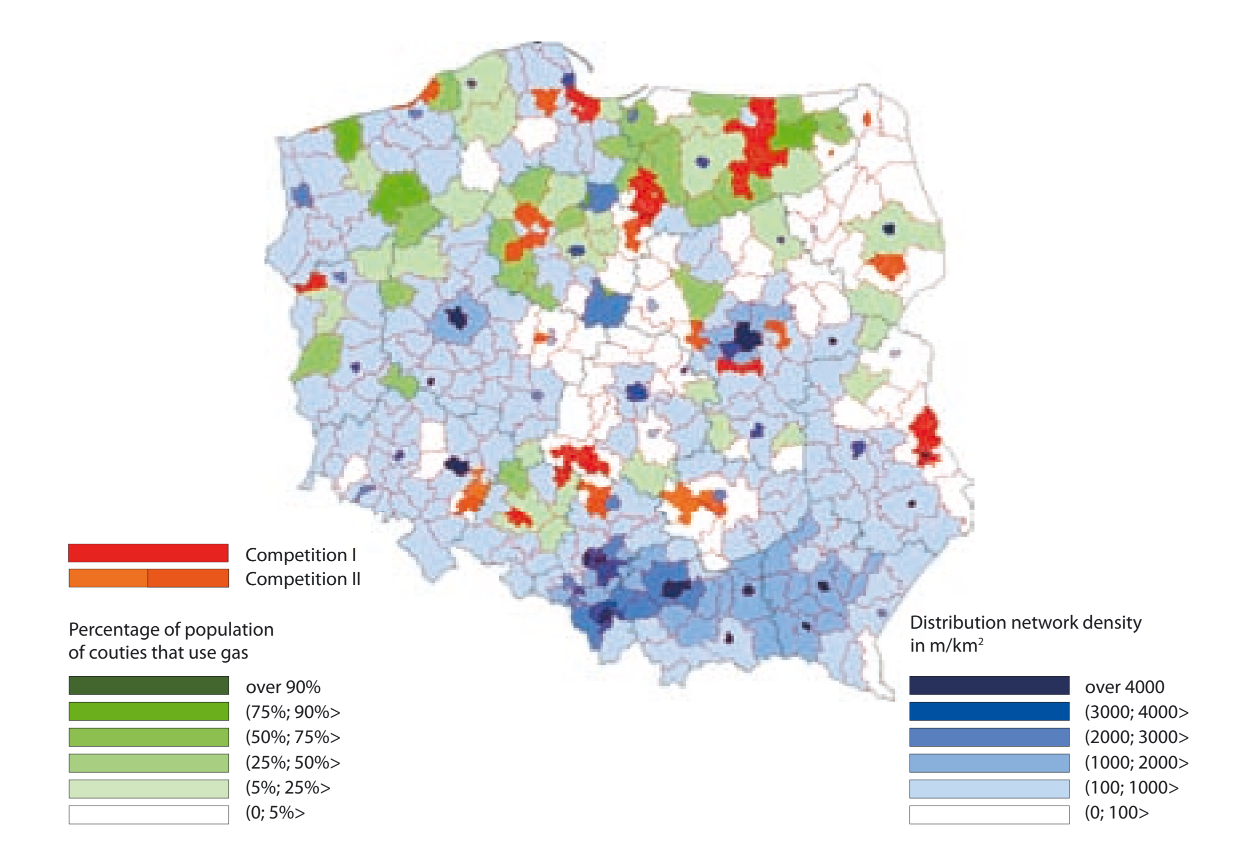
Investments in gas sector in Poland are carried out on a scale which can be compared only to the Polish post-war rebuilding period. In five years` time, owing to the EU funds only, within the OPI&E, the distribution and transmission network will be built and it will be approximately 2700 km long. It is worth noting that on average, 1000-2000 km of network were usually built in Poland within 10 years. In comparison to years 1970-2000 the pace of expansion of transmission and distribution gas pipelines is three times faster.

Location of underground gas storage in the country. Source: PGNiG SA

in areas which have not been gasified yet. By the year 2015, more than 1.7 thousand km of distribution gas network will be subsidized from OPI&E. As a result, about 100 thousand people will have access to gas. Beneficiaries of the subsidies are mostly regional gas companies.

The map „Natural gas distribution network" demonstrates that within the OPI&E (red) projects are carried out not only in areas with no networks (white spots), but also in places where the necessity for conversion from using gas fuel is seen (from LPG to natural gas) and in regions where heating with solid fuel or oil is avoided, which will have a positive impact on the environment. These projects, mostly carried out in North-Eastern Poland, are quite interesting, as on account of the lack of transmission network, the LNG regasification stations will be used and gas will be distributed by the already existing or the newly built distribution network. Therefore, there is a link to another great OPI&E Project – *Construction of liquefied natural gas regasification terminal in Swinoujscie*, from which liquefied gas will be supplied.

– *Further development of transmission investments and gas storage is unusually important for energy security of Poland and other European Union countries* – says **Adam Zdziebło**, Vice Minister for Regional Development. *Although the project package of cohesion policy regulations for 2014-2020 primarily presented by the European Commission does not propose any support for the gas sector from Regional Development European Fund. Poland has taken action to include the transmission and distribution network and also the underground gas storage in the cohesion policy. However, we realize that inclusion of such a record in regulation projects will be very difficult* – emphasizes the minister.



Natural gas distribution network. Source: the Oil and Gas Institute.

***

Operational Programme Infrastructure and Environment is the biggest programme carried out by a member state in the history of the European Union – it is worth 37.7 billion Euro, out of which 28.3 billion Euro comes from the EU funds. In Poland more than 1700 investments worth 168 billion PLN are carried out, and 87 billion PLN were received from European Funds. By the year 2015, a few hundred biggest investments in the most important sectors of Polish economy – transport, environment, energetics, health, culture and higher education – will be financed from the Programme.

The significance of this Programme for the country is shown in the number of projects which are counted among the so-called investments of the future. The ventures involve such sectors as transport, energy and water-sewage. Among 40 biggest investments in Poland which are to be finished until 2015, more than a half is funded by the Operational Programme Infrastructure and Environment.

More detailed information about gas investments co-funded by the Operational Programme Infrastructure and Environment is provided by the Oil and Gas Institute which serves as an implementing institution for activity 10.1 *Transmission system development of electric energy, natural gas and oil, and construction and re-structuring of natural gas storage* and activity 10.2 *Construction of natural gas distribution systems in non-gasified areas and modernization of the existing distribution networks*.

Contact: Centrum FEDE INIG (European funds for energy sector), kawa@inig.pl

Material prepared by Ministry of Regional Development (Managing Authority Operational Programme Infrastructure and Environment)
www.pois.gov.pl

INFRASTRUCTURE AND ENVIRONMENT
NATIONAL COHESION STRATEGY

MINISTRY OF REGIONAL DEVELOPMENT

EUROPEAN UNION
COHESION FUND
EUROPEAN REGIONAL DEVELOPMENT FUND

Gas consumption [billion m³]

	1965	1971	1981	1991	2001	2010	2011	Change 2011 over 2010	2011 share of total
US	432.7	617.1	549.5	553.9	629.7	673.2	690.1	2.4%	21.5%
Canada	22.7	38.8	50.7	67.7	88.2	95.0	104.8	10.3%	3.2%
Mexico	8.4	10.6	24.9	29.2	41.8	67.9	68.9	1.5%	2.1%
Total North America	**463.8**	**666.5**	**625.1**	**650.8**	**759.8**	**836.2**	**863.8**	**3.2%**	**26.9%**
Argentina	4.2	6.5	12.1	20.7	31.1	43.3	46.5	7.5%	1.4%
Brazil	^	0.1	0.9	3.2	11.9	26.8	26.7	-0.3%	0.8%
Chile	0.6	0.7	0.7	1.5	7.3	4.7	5.3	11.7%	0.2%
Colombia	0.9	1.4	3.4	4.1	6.1	9.1	9.0	-0.8%	0.3%
Ecuador	-	0.1	0.1	0.3	0.3	0.5	0.5	-	‡
Peru	0.4	0.5	0.8	0.4	0.4	5.4	6.2	15.2%	0.2%
Trinidad & Tobago	1.2	1.8	2.9	5.7	11.6	22.6	22.0	-2.7%	0.7%
Venezuela	6.8	7.5	14.9	21.9	29.6	32.4	33.1	2.3%	1.0%
Other S. & Cent. America	^	0.1	0.4	0.8	2.3	5.4	5.2	-4.6%	0.2%
Total S. & Cent. America	**14.2**	**18.5**	**36.0**	**58.5**	**100.7**	**150.2**	**154.5**	**2.9%**	**4.8%**
Austria	1.8	3.4	4.8	6.8	8.6	10.1	9.5	-6.0%	0.3%
Azerbaijan	n/a	n/a	n/a	14.7	7.5	7.4	8.2	9.6%	0.3%
Belarus	n/a	n/a	n/a	14.0	15.7	19.7	18.3	-7.2%	0.6%
Belgium	0.1	5.2	9.1	9.7	14.6	18.8	16.1	-14.8%	0.5%
Bulgaria	0.1	0.3	3.8	5.0	3.0	2.6	2.9	14.5%	0.1%
Republic	0.3	1.0	3.5	5.9	8.9	9.3	8.4	-9.3%	0.3%
Denmark	-	-	-	2.3	5.1	5.0	4.2	-16.2%	0.1%
Finland	-	-	0.7	2.6	4.1	3.9	3.6	-10.0%	0.1%
France	5.5	12.4	27.2	30.6	41.9	46.9	40.3	-13.9%	1.2%
Germany	2.9	19.8	54.9	62.9	82.9	83.3	72.5	-12.9%	2.2%
Greece	-	-	-	0.1	2.0	3.7	4.5	24.3%	0.1%
Hungary	1.1	3.2	8.0	9.6	11.9	10.9	10.2	-6.8%	0.3%
Republic of Ireland	-	-	1.3	2.1	4.0	5.2	4.7	-10.5%	0.1%

Gas consumption [billion m³]

	1965	1971	1981	1991	2001	2010	2011	Change 2011 over 2010	2011 share of total
Italy	8.1	13.9	25.3	46.2	65.0	76.1	71.3	-6.2%	2.2%
Kazakhstan	n/a	n/a	n/a	12.8	8.2	8.2	9.2	13.0%	0.3%
Lithuania	n/a	n/a	n/a	5.4	2.8	3.1	3.4	9.0%	0.1%
Netherlands	1.4	22.0	32.0	38.6	40.0	43.6	38.1	-12.7%	1.2%
Norway	-	-	1.0	2.4	3.8	4.1	4.0	-2.1%	0.1%
Poland	1.6	6.4	9.2	9.3	11.5	15.5	15.4	-1.0%	0.5%
Portugal	-	-	-	-	2.6	5.0	5.1	1.8%	0.2%
Romania	15.3	24.8	37.8	24.7	16.6	13.6	13.8	2.0%	0.4%
Russian Federation	n/a	n/a	n/a	418.2	366.2	414.1	424.6	2.5%	13.2%
Slovakia	0.3	1.0	3.5	5.4	6.9	5.6	6.2	12.3%	0.2%
Spain	-	0.4	2.3	6.1	18.2	34.6	32.1	-7.2%	1.0%
Sweden	-	-	-	0.7	0.7	1.6	1.3	-19.1%	‡
Switzerland	-	0.1	1.0	2.0	2.8	3.3	2.9	-12.8%	0.1%
Turkey	-	-	-	4.1	16.0	39.0	45.7	17.3%	1.4%
Turkmenistan	n/a	n/a	n/a	9.3	12.5	22.6	25.0	10.4%	0.8%
Ukraine	n/a	n/a	n/a	117.8	68.8	52.1	53.7	3.0%	1.7%
United Kingdom	0.8	18.2	45.4	56.6	96.4	94.0	80.2	-14.6%	2.5%
Uzbekistan	n/a	n/a	n/a	36.0	49.6	45.5	49.1	7.9%	1.5%
Other Europe & Eurasia	116.6	199.1	385.2	24.2	15.3	16.2	16.6	2.7%	0.5%
Total Europe & Eurasia	**155.9**	**331.2**	**655.9**	**986.4**	**1014.2**	**1124.6**	**1101.1**	**-2.1%**	**34.1%**
Iran	7.3	9.7	5.7	22.7	70.1	144.6	153.3	6.1%	4.7%
Israel	0.1	0.1	^	^	^	5.3	5.0	-6.0%	0.2%
Kuwait	1.3	2.1	4.7	0.5	10.5	14.5	16.2	11.5%	0.5%
Qatar Katar	0.1	1.0	4.2	7.6	11.0	20.4	23.8	16.4%	0.7%
Saudi Arabia	0.6	1.3	11.3	35.2	53.7	87.7	99.2	13.2%	3.1%
United Arab Emirates	-	1.3	6.2	20.4	37.9	60.8	62.9	3.5%	1.9%
Other Middle East	0.8	1.7	3.6	11.8	23.7	44.0	42.7	-3.0%	1.3%

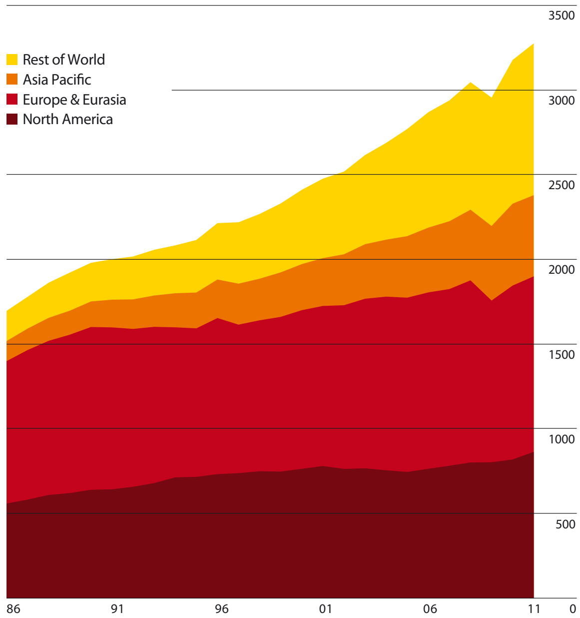
Gas consumption [billion m³]

	1965	1971	1981	1991	2001	2010	2011	Change 2011 over 2010	2011 share of total
Total Middle East	**10.2**	**17.3**	**35.7**	**98.3**	**206.8**	**377.3**	**403.1**	**6.9%**	**12.5%**
Algeria	0.8	1.1	14.8	20.0	20.5	26.3	28.0	6.5%	0.9%
Egypt	^	0.1	2.4	9.1	24.5	45.1	49.6	10.0%	1.5%
South Africa	-	-	0.2	0.3	1.2	3.9	4.3	8.9%	0.1%
Other Africa	0.2	0.6	6.4	10.6	17.6	31.5	27.9	-11.6%	0.9%
Total Africa	**1.0**	**1.8**	**23.9**	**40.0**	**63.8**	**106.9**	**109.8**	**2.7%**	**3.4%**
Australia	^	2.6	12.1	16.2	22.0	25.7	25.6	-0.4%	0.8%
Bangladesh	-	-	1.6	5.3	10.7	19.9	19.9	-0.1%	0.6%
China	1.1	3.7	12.7	15.9	27.4	107.6	130.7	21.5%	4.0%
China Hong Kong SAR	-	-	-	-	3.0	3.8	3.1	-20.4%	0.1%
India	0.2	0.7	2.1	13.4	26.4	61.9	61.1	-1.2%	1.9%
Indonesia	0.5	1.3	7.0	19.5	31.0	40.3	37.9	-5.9%	1.2%
Japan	1.7	3.7	24.1	50.8	74.3	94.5	105.5	11.6%	3.3%
Malaysia	-	0.1	1.3	11.6	25.2	31.9	28.5	-10.5%	0.9%
New Zealand	-	0.1	1.0	4.7	5.9	4.3	3.9	-10.0%	0.1%
Pakistan	1.8	3.5	7.8	13.2	22.7	39.6	39.2	-1.2%	1.2%
Philippines	-	-	-	-	0.1	3.1	3.6	16.0%	0.1%
Singapore	-	-	-	-	0.9	8.4	8.8	4.4%	0.3%
South Korea	-	-	-	3.5	20.8	43.0	46.6	8.3%	1.4%
Taiwan	0.2	1.1	1.6	3.1	7.3	14.1	15.5	10.1%	0.5%
Thailand	-	-	0.3	8.1	24.8	45.1	46.6	3.3%	1.4%
Vietnam	-	-	^	0.1	2.0	9.4	8.5	-9.2%	0.3%
Other Asia Pacific	0.2	0.5	2.2	2.4	3.8	5.3	5.7	7.3%	0.2%
Total Asia Pacific	**5.8**	**17.3**	**73.9**	**167.7**	**308.4**	**557.9**	**590.6**	**5.9%**	**18.3%**
Total World	**650.9**	**1052.7**	**1450.5**	**2001.6**	**2453.6**	**3153.1**	**3222.9**	**2.2%**	**100.0%**

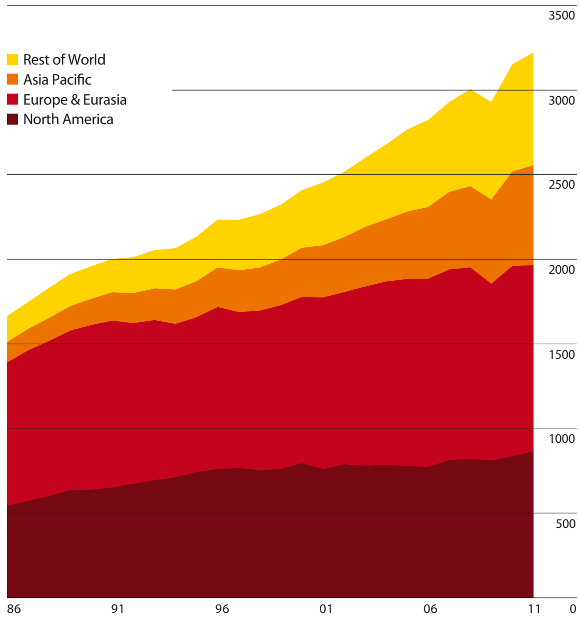
^ less than 0.05
‡ less than 0.05%

Source: BP Statistical Review of World Energy 2012

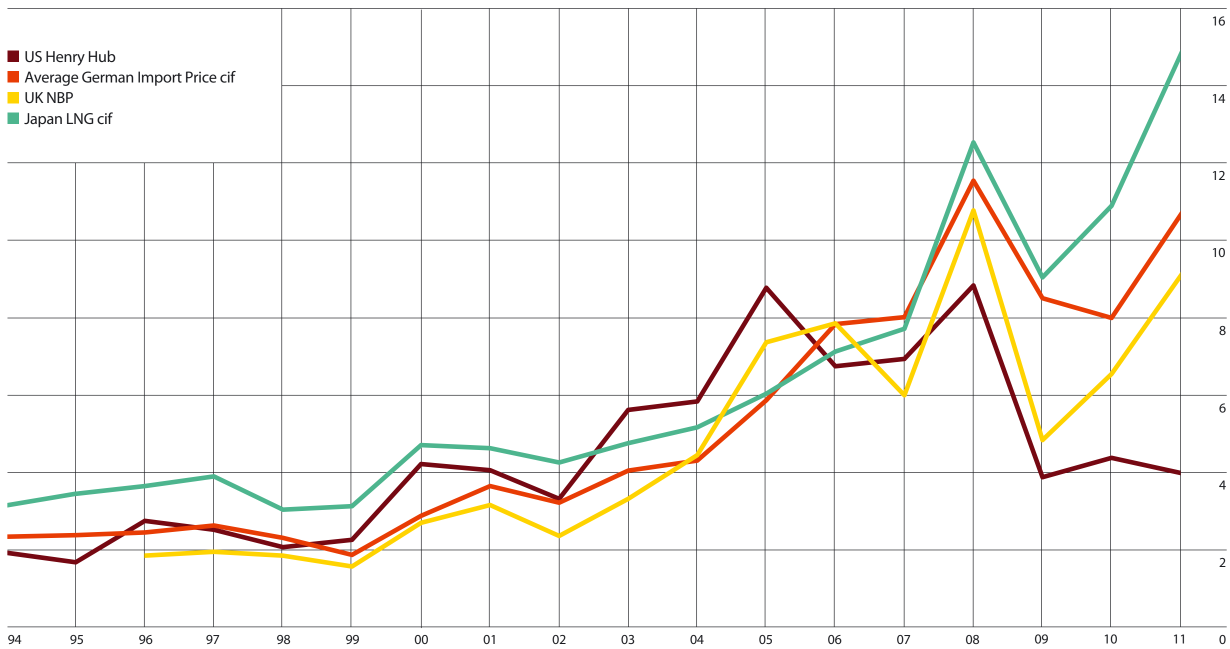
Gas production [billions m³]



Gas consumption [billions m³]

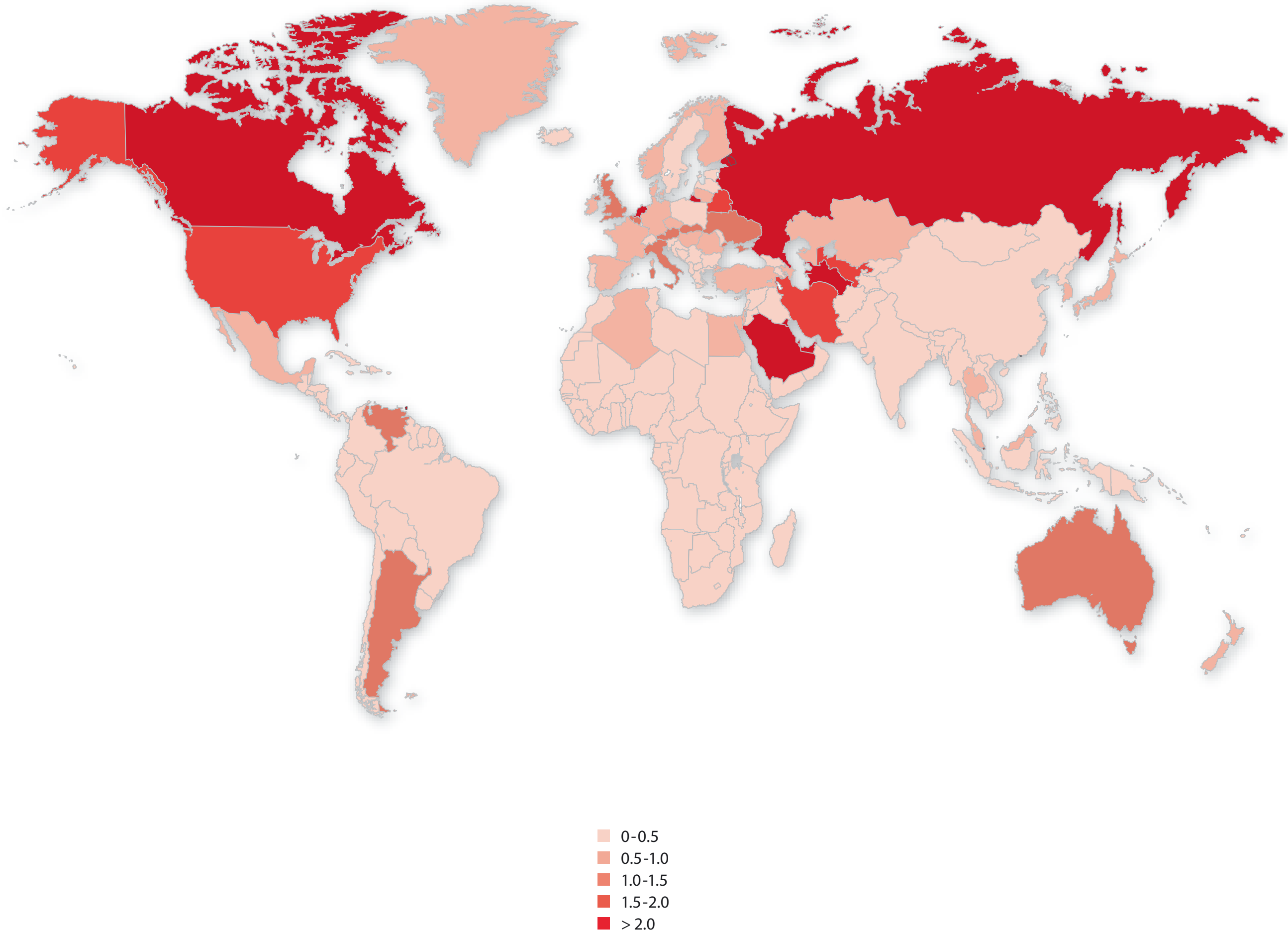


Gas prices [USD for MMBtu]



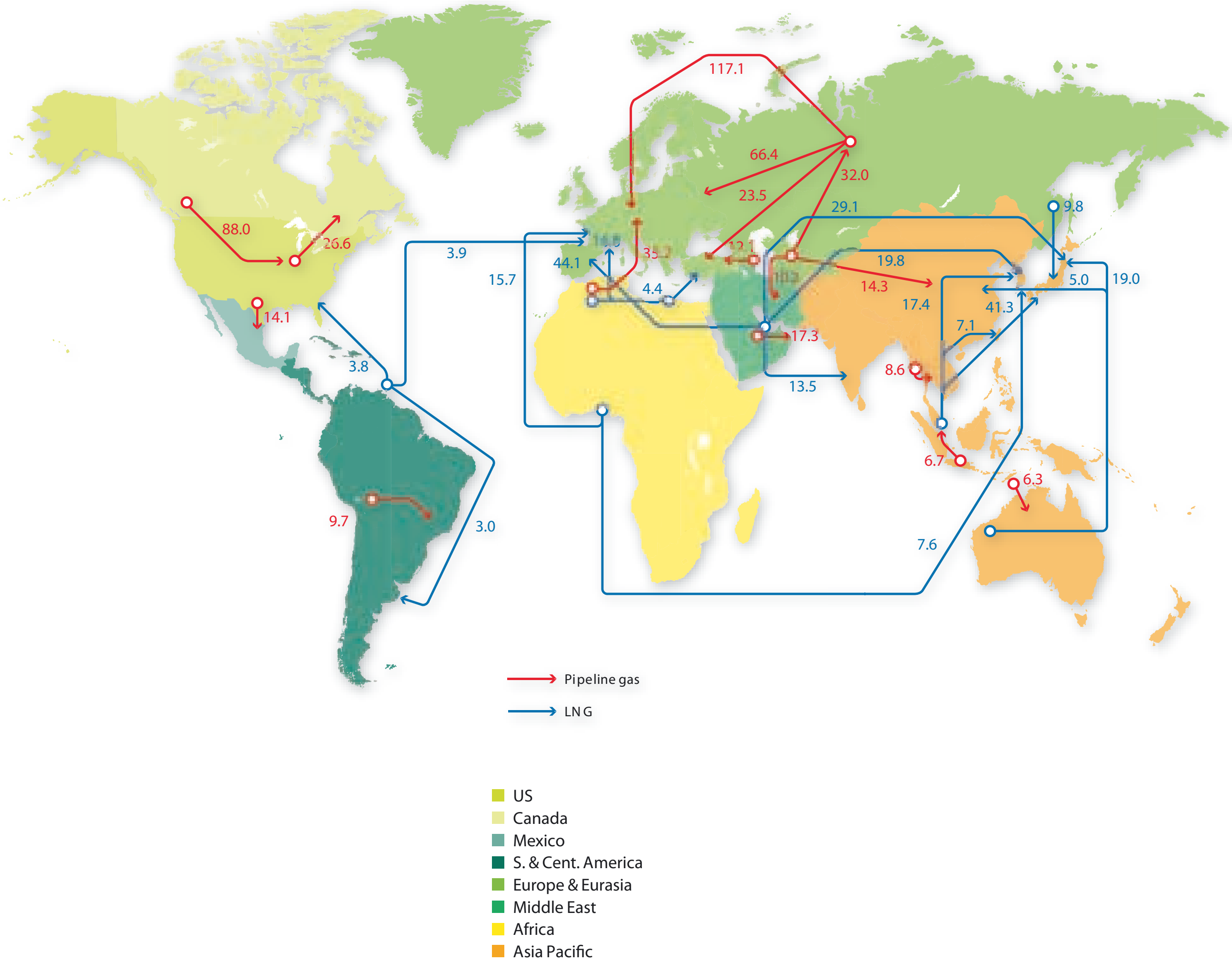
Source: BP Statistical Review of World Energy 2012

Gas consumption *per capita* in 2011 [Tonnes oil equivalent]



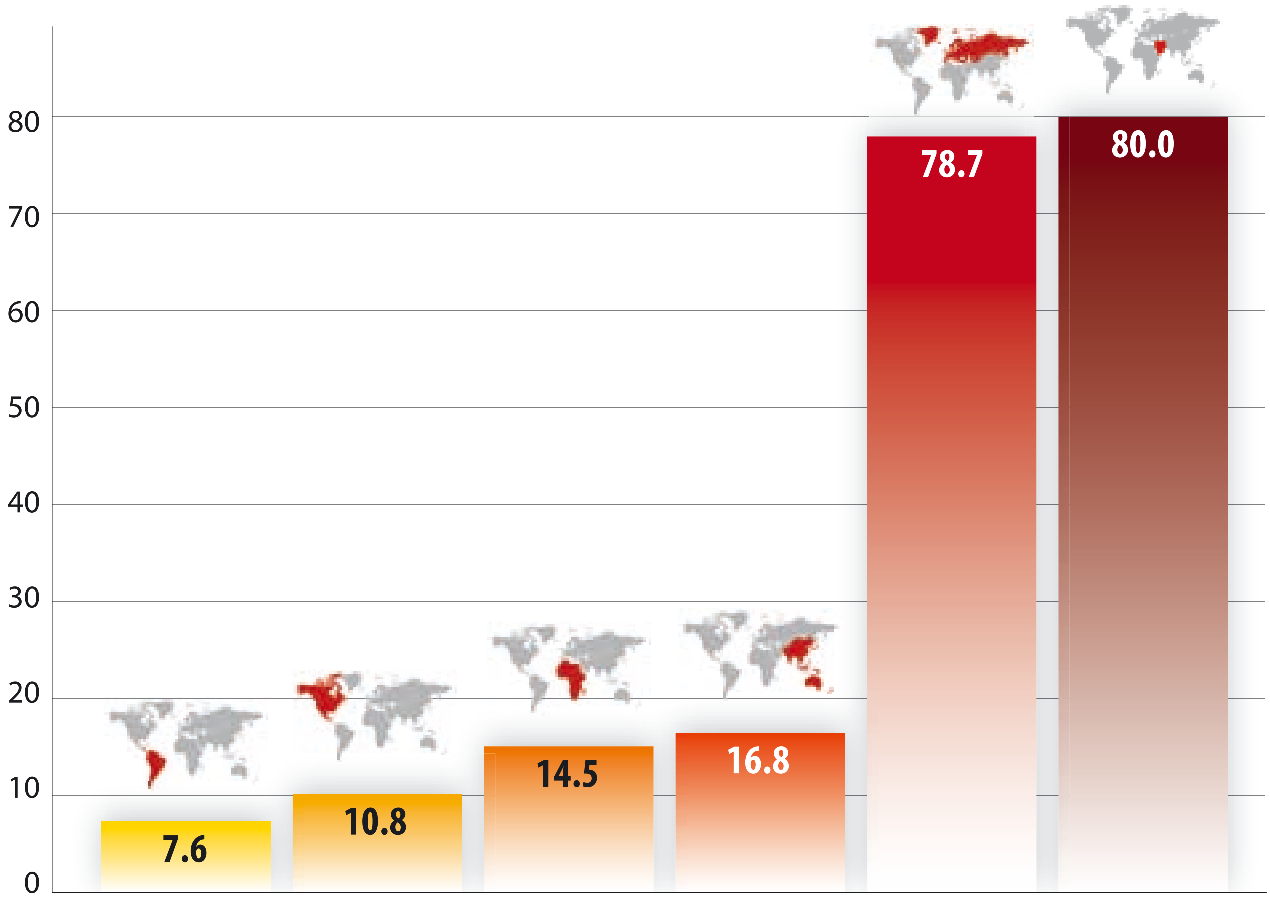
Source: BP Statistical Review of World Energy 2012

The main directions in natural gas trade in 2011 [in bilions m^3]



Source: BP Statistical Review of World Energy 2012

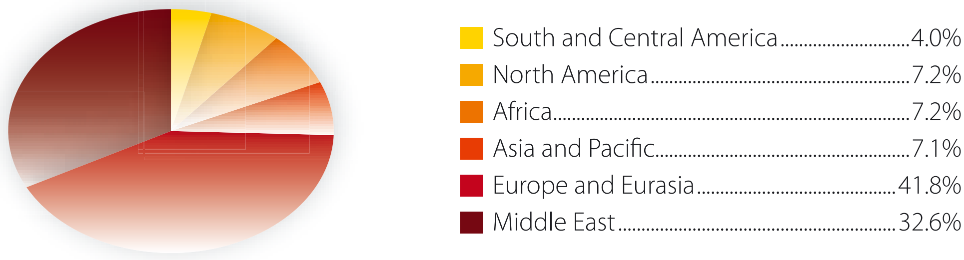
Natural gas: Proved reserves at end 2011 [in trillion m³]



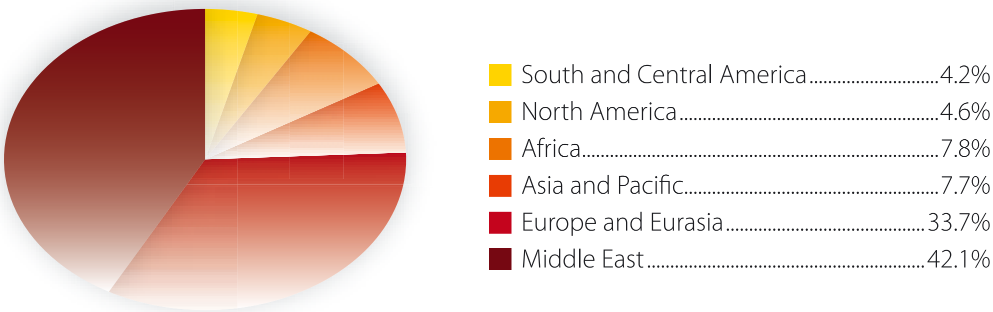
- South and Central America 7.6
- North America 10.8
- Africa 14.5
- Asia and Pacific 16.8
- Europe and Eurasia 78.7
- Middle East 80.0

Source: BP Statistical Review of World Energy 2011

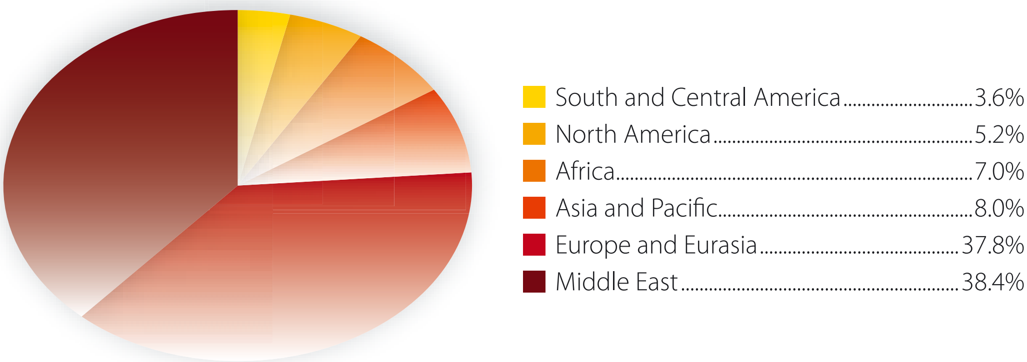
Distribution of confirmed natural gas resources in 1991 – 131.2 trillion m³ total



Distribution of confirmed natural gas resources in 2001 – 168.5 trillion m³ total



Distribution of confirmed natural gas resources in 2011 – 208.4 trillion m³ total



Source: BP Statistical Review of World Energy 2011


20
40
60
80
100
120
GREEN

Ecology

in the oil and gas industry

Sustainable development issues of the biofuel market

Biofuels – a chance or threat to the natural environment?

Delfina Rogowska, Arkadiusz Majoch

Currently, there are numerous discussions in the world concerning the influence of human activity on global warming and climate change. Although opinions on legitimacy of limitation of GHG emission vary, global-scale actions are taken which aim at reduction of greenhouse gas emission. One of the tools which, among other things, is supposed to achieve this goal are biofuels, used for powering car engines.

In case of conventional engine fuels, the emission of greenhouse gas occurs not only at the moment of fuel combustion in the engine – it is also generated during oil processing in a refinery and its extraction or transport. This is the reason why the LCA method (Life Cycle Assessment described in the PN EN ISO 14044:2009 norm) is used for estimating the influence of petrol or diesel fuel on the environment. In view of the necessity of laws which would stimulate the GHG emission reduction, the European Parliament and Council Directive 2009/30/EC of 23 April 2009, among other things, introduces the requirement of GHG emission (which is counted in the fuel life cycle) reduction by maximum 10% by 31 December 2020. This goal might be achieved also due to the use of biofuels.

Biofuels reduce not only the greenhouse gas emission, but also the dependence upon the fossil fuels and they have an influence – owing to the cultivation of plants which are intended for their production – on country land activation. The development of this industry branch should contribute to an increase in innovation and economic activity. It is expected then that apart from achieving goals of ecological nature, some positive changes of economic-social nature will also be noticeable. However, biofuel production also contributes to generating the greenhouse gas emission. Fig. 1 demonstrates schematically the GHG emission generated at particular stages of the life cycle for conventional fuels and biofuels.

Greenhouse gas emission at the stage of oil extraction is generated mainly by combustion in torches and direct emission of deposit gas to atmosphere [1], unintentional and uncontrolled emission which occurs on valves, device gaskets and apparatus [1] connected with machine and device work. Crude oil processing in a refinery to produce petrol and other products also requires incurring energy expenditures, and as a consequence – generates greenhouse gas emission, just like transport and ready fuel distribution, though this stage is not that essential. However, the most significant is the last stage in petrol life cycle – combustion in a car engine.

Biofuels are perceived as a method for reduction of greenhouse gas emission generated in production and use of conventional fuels. However, their production also requires energy expenditures and it is inevitably connected with greenhouse gas emission. The assessment of this value and determination of other aspects of the influence of increased biofuel

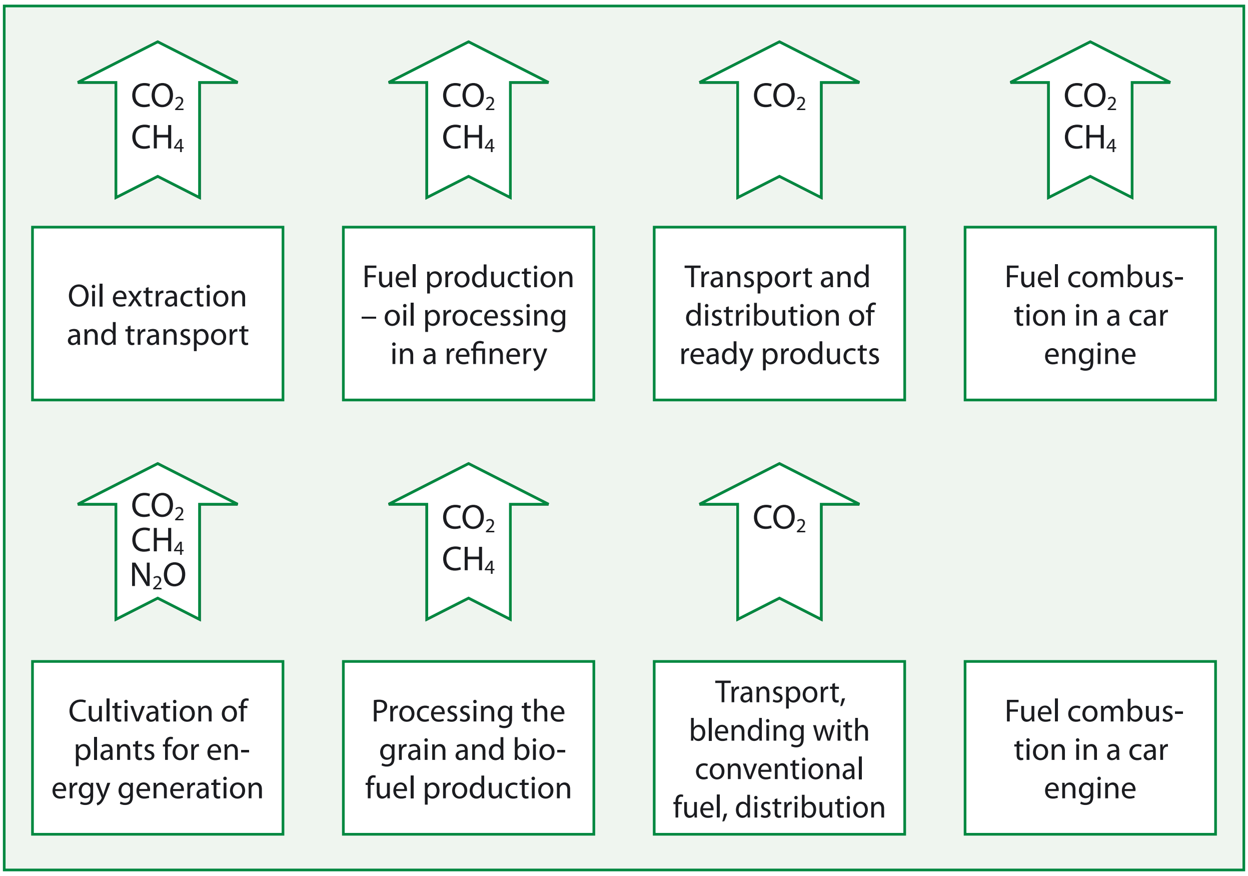


Fig. 1. GHG emission in a life cycle of conventional fuels and biofuels

production on natural environment is taken into account when estimating environment-friendly biofuel properties.

GHG emission in biofuel life cycle

The biofuel production cycle – from the agricultural producer to biofuel manufacturer – is often called "the supply chain". The GHG emission distribution in particular links is different, depending on the material type and production technology. Ordered by the European Commission, JEC Consortium estimated the GHG emission at particular stages [2]. On the basis of achieved by [2] values, the diagram (Fig. 2) presents the distribution of the GHG emission in the life cycle of selected paths of biofuel production.

In Fig. 2, particular biofuel production paths were marked on the x-axis:

1. FAME from rape oil, oilseed cake and glycerine, considered in allocation on energy basis.
2. Ethanol from sugar beets, sugar beet pulp, considered in allocation on energy basis, disregarding biogas from distilling extract.
3. Ethanol from sugar beets, sugar beet pulp, considered in allocation, allocation on energy basis, including biogas from distilling extract.
4. Ethanol from wheat, natural gas as fuel, DDGS taken into account in allocation on the basis of energy.
5. Ethanol from wheat, natural gas as fuel, with the use of turbine and cogeneration, DDGS taken into account in allocation on the basis of energy.
6. Ethanol from wheat, brown coal as fuel with the use of cogeneration, DDGS taken into account on the basis of energy.
7. Ethanol from wheat, straw as fuel with the use of cogeneration, DDGS taken into account in allocation on the basis of energy.
8. Ethanol from sugar cane (allocation not required, biogas excess not examined).
9. Ethanol from corn, natural gas as fuel with the use of turbine and cogeneration, DDGS taken into account in allocation on the basis of energy.

In the case of FAME obtained from rape oil, ethanol from rye and corn, it has been assumed that the route of grain transport from the agricultural producer to the processing plant is 50 km, while in the case

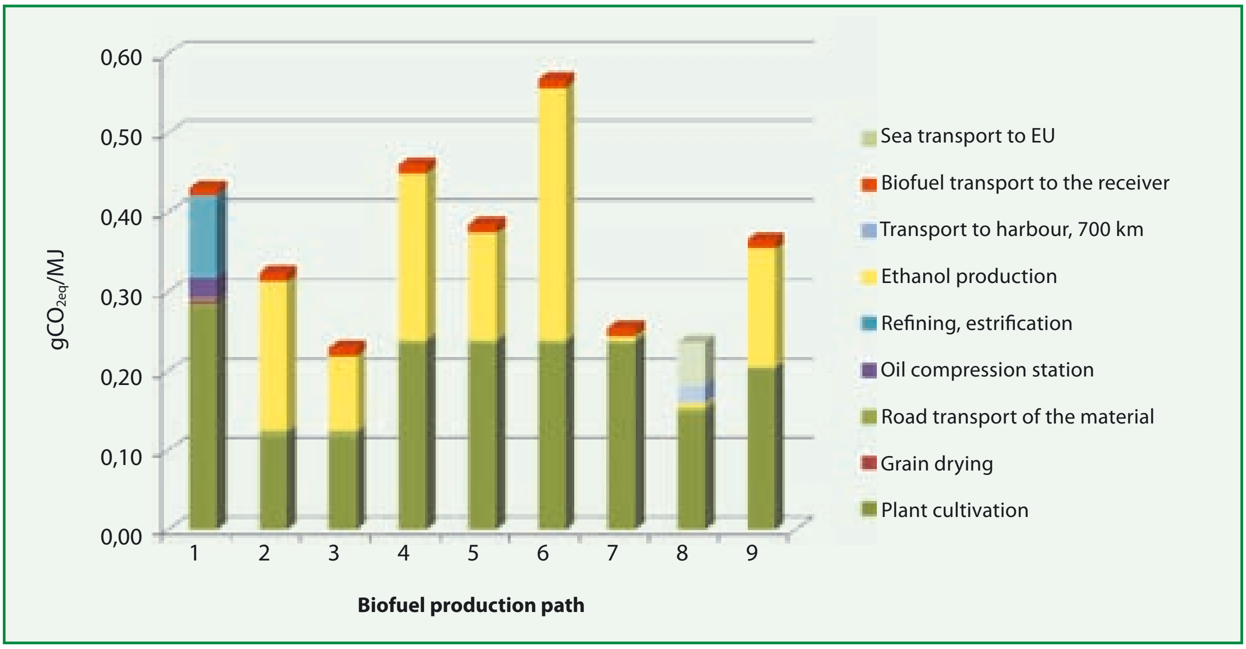


Fig. 2. Distribution of GHG emission in the life cycle, for selected paths of biofuel production

of ethanol from sugar beets the distance is 30 km. For ethanol produced from sugar cane, the transport to sea harbour has been taken into account (the distance of 700 km has been assumed) and sea transport and distribution in the EU area (10 186 km to a harbour in Europe and 150 km to storage reservoirs and 150 km from storage reservoirs to the receiver).

According to Fig. 1, the first link of the chain where the greenhouse gas emission appears is the plant cultivation intended for energy purposes; for domestic biofuels these are e.g. rape, rye or corn. The emission arising at this stage results not only from combustion of fuels which are used for powering machines and agricultural equipment, but it is also brought with chemicals and fertilizers, mainly N_2O emission [3]. The contribution of this volume is significant, sometimes it constitutes more than 50% of total emission in a life cycle. The calculations disregard carbon dioxide which is assimilated by the plants and the one which is released to the atmosphere as a result of biofuel combustion.

In the case of ethanol from sugar cane, the emission generated during transport by sea – also to the harbour, is a significant item. Despite that, this ethanol is characterized by relatively low GHG emission index. The highest emission value was found for ethanol produced from wheat, with the use of brown coal as boiler fuel.

For particular biofuels, the GHG emission generated at the stage of biomass processing – biofuel production, is varied depending on applied technology, boiler fuel and on the method of using other products generated in this process. If they are treated as by-products, their further management is defined and executed, and GHG emission arising in the process is allocated to them as well (by the same, it results in reduced emission attributed to the biofuel). The GHG emission is not ascribed to waste products.

The values obtained in calculations are compared to the emission generated also by conventional fuels in the life cycle. In this way, the **estimation of degree of ability to reduce greenhouse gas** of biofuels is possible in relation to fossil fuels.

ILUC

The view on biofuels presented above, despite relatively high extensiveness, does not give a full image of the influence of biofuels on the natural environment. With growing demand for biofuels, also increased acreage for energy plants cultivation is needed. Moreover, despite systematic rise in crop productivity per hectare, it seems essential to map out new areas for cultivation of plants for food purposes, which results in changes in the ecosystem. This phenomenon is called the ILUC (Indirect Land Use Change) and concerns the changes in the use of lands in any location, as a consequence of actions promoting the development of RES. Relocation of agricultural production for food purposes to another area, changing its natural ecosystem to agricultural areas might be an example [4, 5].

Indirect influence of changing the land use on emission is quite difficult for quantitative estimation. According to the authors of report "*Bioenergy, Land Use Change and Climate Change Mitigation*" [4], changes in the way of land use which accompany mainly deforestation and expanded production for food purposes, make up about 15% of global GHG emission.

Another vital aspect, apart from the land use change, is the degradation of areas of high natural value, protected areas which are habitats of wild animal and bird species, and areas with high biological diversity. These changes are difficult, or even impossible to determine with measurable values.

Sustainable development criteria – RED directive

Having been introduced to the above mentioned issues, the following reflection appears: it is necessary to find the "golden rule", something like a compromise between the need for increasing the biofuel contribution and preservation of the air and areas of great natural interest. This task has been undertaken by the European Commonwealth by implementing the European Parliament and Council Directive 2009/28/EC of 23 April 2009 concerning the promotion of energy from renewable sources which changes and – as a consequence – overrules the directives 2001/77/EC [6]. This Directive is often referred to as "RED", meaning: Renewable Energy Directive. The Directive assumes that the contribution of renewable energy source in the Commonwealth, by the year 2020, will amount to 20% of final gross consumption, including 10% in the transport sector. On the one hand, the directive has a great importance for increased energy security, technological and innovative development support and it should contribute to higher employment and the possibility of regional development, especially in the rural and isolated areas [6]. On the other hand, by introducing regulations which stimulate biofuel production, it was also necessary to define restrictions for natural environment protection. That is why the 17th article of the RED directive introduces "*the sustainable development criteria*" (SDC).

> With growing demand for biofuels, also increased acreage for energy plants cultivation is needed.
>
> Moreover, despite systematic rise in crop productivity per hectare, it seems essential to map out new areas for cultivation of plants for food purposes, which results in changes in the ecosystem.

On account of a high diversification of biofuel market in Europe, the European Commission in the Announcement [7] elaborated the necessity for meeting SDC for biofuels and bioliquids which are:

1. counted towards the national general target on the strength of the Directive concerning renewable energy sources[1];
2. used in order to fulfill the duty of using energy from renewable sources[2];
3. covered by financial support promoting the use of biofuels and bioliquids[3];
4. counted towards the target specified by the Directive concerning fuel quality, with reference to greenhouse gas emission (only biofuels)[4];
5. covered by investments and/or operational help in accordance with EU directives concerning the country's support of environment protection (concerns biofuels only);
6. considered as a part of regulations which concern vehicles powered with alternative fuel and included in the Directive concerning the reduction of CO_2 emission from passenger cars (concerns bioethanol E85 only)[5].

Sustainable development criteria according to RED can be divided into two areas: the first concerns the ability of biofuel to reduce greenhouse gas emission in the life cycle when compared to the fossil equivalent, while the other concerns the protection of areas where plants are cultivated for biofuel production. The criteria were defined in five main points, quoted below after RED [6].

The above mentioned regulations mean that in practice only those biofuels will be used which demonstrate the ability to reduce greenhouse gas emission

1 Article 17 act 1 letter a). Results from the notion of "final energy use" in accordance with the directive (EC) no. 1099/2008 biofuels used in international air transport are counted in this category (offered for sale in one of the member states), but not used any more in the sea transport.

2 Article 17 act 1 letter b) – according to the definition included in article 2 act 1 of the directive concerning renewable energy sources.

3 Article 17 act 1 letter c) – usually: as part of the national plan of support.

4 Article 7a Directive concerning the fuel quality.

5 Article 6 of (EC) directive no 443/2009.

I. Reduction of greenhouse gas emission with the use of biofuels and bioliquids by at least 35%.

Beginning with the 1st of January 2017, the reduction of greenhouse gas emission resulting from the use of biofuels and bioliquids, considered for the purposes described in section 1 letter a), b) and c) of RED directive, is at least 50%. From the 1st of January 2018 the greenhouse gas emission reduction reaches at least 60% for biofuels and bioliquids produced in installations which began production on the 1st of January 2017 or later.

II. Biofuels and bioliquids do not originate from materials obtained from areas of high biodiversity, i.e. areas that in January 2008 or later had the following status, independently of the fact whether they still have it or not:

1. primeval forests and other forested soils, i.e. forests and other forested land with native species, with no clearly visible marks of human activity, where the ecological processes have not been significantly disturbed;
2. areas designated for:
   - purposes of environment protection, either enacted or ordered by proper authorities; or
   - the protection of rare, endangered or seriously endangered ecosystems or species acknowledged as such by international agreements or contained in registers prepared by intergovernmental organizations or International Environment Protection Union, on condition that they are acknowledged according to article 18 section 4, second paragraph, unless there is evidence that production of these materials does not violate the purpose of environment protection;
3. grass-covered areas of a high biodiversity, that is:
   - natural – grass areas which remain grass areas if no human intervention occurs and which preserve natural species composition and ecological features and processes; or
   - artificial – grass areas which cease to be grass areas without human intervention and which are rich in species and are not degraded, unless there is evidence that crops of materials are necessary in order to keep their status of grass-covered areas.

III. Biofuels and bioliquids do not originate from materials obtained from areas rich in carbon element, that is areas which in January 2008 had one of the following statuses, but do not have it any more:

1. marshy areas, that is areas covered or soaked with water constantly or for a considerable period of time during the year;
2. areas constantly forested, i.e. areas of more than one hectare with trees higher than five meters and whose tree crowns cover the area of more than 30%, or trees which can reach the values in situ;
3. areas which cover more than one hectare with trees higher than five meters and whose tree crowns cover between 10% and 30%, or trees which can reach the values in situ,
   unless there is evidence that the area before and after transformation has such an amount of carbon element that having applied the methodology described in part C of annex V of the RED directive, conditions could be met which concern the reduction of greenhouse gas emission.

Regulations of this section will not be used, if – at the time of obtaining the material, the area had the same status as in January 2008.

IV. Biofuels and bioliquids are not produced from materials obtained from areas which were peat bogs in January 2008, unless there is evidence that at the time of cultivation and harvesting of these materials there was no reclamation of the previously non-reclaimed soils.

V. Agricultural materials cultivated in the Commonwealth and used for biofuel and bioliquid production, are obtained in accordance with requirements and standards described in regulations specified in the "Natural environment" in part A and in item 9 of annex II to the Council directive (EC) no. 73/2009 of 19th January 2009 which enacts common regulations for direct support systems for farmers as part of common agricultural policy and enacting specific direct support systems for farmers (Journal of Laws L 30 of 31.1.2009, page 16) and also, in accordance with minimum requirements concerning good agricultural culture principles in keeping with environment protection, as defined in article 6 section 1 of this directive.

at appropriately high level and those produced from plant materials, the cultivation of which was not harmful for the natural environment. Directive 2009/28/EC, apart from a set of requirements, imposed on the economic entities the requirement of submitting appropriate information and conducting its independent audit. By the same, the necessity of biofuel certification appeared which would confirm the conformity with sustainable development criteria according to the RED requirements.

Biofuel certification

The RED Directive, among other things, requires certification systems which would confirm the compliance of material origin, technology and goals with the sustainable development criteria. Detailed regulations concerning biofuel certification were published in the European Commission announcement which appeared in June 2010 [10]. According to the present legislation, it is the duty of economic entities to prove that the particular biocomponent/biofuel meets the sustainable development criteria. There are three ways to meet the criteria:

- by providing data to the proper national authority in accordance with the requirements which were established by the member state (as a part of the "national system");
- by using "voluntary system" accepted for this purpose by the European Commission;
- in accordance with conditions of bilateral or multilateral agreement signed by the Union with third countries, accepted by the Commission for this purpose.

The Polish "national system" is in progress of drawing up; the requirements of the RED directive will be implemented when the amendment to the act concerning biocomponents and liquid biofuels comes into force. However, the last year noted a significant development of voluntary certification systems approved by the European Commission.

Voluntary certification systems

The essence of every acknowledged system is the emphasis on the compliance with requirements related to the natural environment and good agricultural practice in agricultural production for energy purposes and preservation of biological diversity.

The equivalence of compliance with requirements may be executed by means of certification process by entities which approve of the system in which system procedures had been implemented. The basic element of such procedures is the requirement of action transparency and flow of information, considering the basic group of interested parties. Also, the qualifications of auditors have been defined, usually confirmed, among other things, by completed courses with regard to norms PN-EN ISO19011: Guidelines concerning auditing of management systems [8]. The certifying units and auditors play one of the most important roles in implementation of the RED directive and certification of companies by analyzing the proofs presented by the businessman stating that the biofuel fulfills the SDC. The audit is carried out on the principles of: impartiality, independence, competence, and granting the certificate is based on the audit report.

The auditors accepted and appointed, in the certification procedure estimate the compliance level of the future system participant; the statement of inconsistency with sustainable development criteria leads to refusal to grant the certificate. The indicator for such conduct are defined inconsistency categories (serious, small). Serious inconsistencies have to be corrected, otherwise the certificate in the procedure of supervision over the system might be suspended for a defined period of time, and eventually – withdrawn.

In audit procedures it is required to estimate a part of the system participants' activity which is directly contained in the sustainable development criteria; procedures being drawn up constitute guidelines for each party (system participants) on how to obtain and estimate the conditions for producing biocomponents and biofuel in accordance with requirements of proper country regulations. In Poland such regulations are presently at the stage of elaboration by the Ministry of Economy and are currently available in the form of *The project of the act on biocomponents and liquid biofuels and some other acts*. Especially it concerns the estimation of risk in case the requirements are not fulfilled, and consequently, the possibility of cases of inconsistency which prevent granting or retaining the certificate. The preferred method of granting the certification is the audit by a third party. Additionally, it is also indicated that this process should be carried out on the principles of confidentiality, objectivity and impartiality, in accordance with the norm PN EN ISO45011: General requirements concerning units which deal with product certification systems [9]. In case of this requirement, the key issue is referring to the estab-

lished statistic test as part of certification procedure and identification of the chain flow of materials, products, waste and other streams, crucial for the estimation of compliance with the said criteria.

All the entities which appear in the biofuel supply chain are subject to compliance with the SDC requirements. The first link of this chain is, as already mentioned, the agricultural producer. Depending on accepted specific solutions in a particular voluntary certification system, the farmer is either a certified entity, or is only subject to the audit. In the other case, audit is performed when grain storage is certified (the first collecting point) – the next link in the chain.

It is acceptable to make estimations according to three methods. The first involves making the audit mainly with smallholders and organization of producers and cooperatives. Certification is the only way of including to the system of many smallholders and their contribution in the market of products covered by certification system, which can considerably reduce the certification costs.

The second method is multilateral certification which covers the whole chain and which begins from the agricultural producer; including also middlemen, manufacturers, subjects who buy and store and producers. It is worth noting that such a chain must be managed top-down and needs to have implemented rules and procedures of internal audit. In such a case, the certificate is granted to one of the entities and covers all the defined participants registered in different locations. The certificate might be owned by a company which purchases and stores the material and which has signed contracts with the remaining participants of the system.

The last method is the group audit (concerning agricultural producers) in which the procedure begins from the purchase centre or middleman and the others are taken into account in the audit depending on relations which result from contracts and agreements.

It is required that the audit of the supervision unit should be carried out at least once, in regular time intervals. The decision concerning the entitlement for using the certificate should be made public. The last requirement for biofuel certification is obligatory acceptance of certificates issued by other recognized EU systems, which would speed up the procedure, especially with a wide geographical range of the flow of certified materials and products.

It is essential that the above issues: of biofuel certification, requirements of collecting samples during the audit and the verification level, consultations with the interested parties, procedures of submitting remarks, are not mentioned in the RED Directive or have been marked as potential solutions. Many of these issues have been specified in announcements and decisions which accompany the Directive [10, 11, 12]. The analysis of documents makes one aware of the complexity of biofuel certification problems in accordance with SDC.

Introducing the requirements of selected certification system to a company and the necessity to carry out certification generates additional costs. It is worth pointing out that in the scope and content of the above mentioned aspects, the market character of the requirements can be found in accordance with the sustainable development criteria and these aspects can be perceived in categories of influence on competitiveness of certified materials and products. The significance of biofuel certification is vital for the internal organization of the company which is the system participant, but should also be easily identified in a market. Introducing certification system in the external area ought to make the product distinct because of meeting the market requirements or compliance with the binding law. On the other hand, it is expected that the system will be associated with receiving a price bonus whose main beneficiaries are the first entities in the product life chain, i.e. agricultural producers.

Summary

Presented material does not provide an explicit answer to the problem presented in the title of the article: are biofuels a chance or a threat to the natural environment? The biofuel market development creates opportunities for activation, especially in the rural areas, it should be the stimulus for innovation, it should create a new sector with many new jobs. Also, the fact of reduced dependence upon fossil fuels cannot be ignored. On the other hand, it is necessary to avoid excessive exploitation of the natural environment.

The definition of sustainable development criteria have been formed in order to avoid the natural environment degradation with the assumed increase in biofuel production. Is it possible to achieve? Each EU member country implements the RED decisions and as a result, it requires that all biocomponents used for fuel production should meet the relevant requirements. It gives the Directive a global range because it imposes on the providers even from outside Europe the duty to prove they meet the SDC. The Directive was published three years ago and is systematically implemented in all the countries, in Poland as well. It covers numerous areas comprising agricultural production and biomass conversion to fuel products. Considering the fact that such approach to biofuels is relatively new, it cannot be ruled out that as a result of gained experience it will be necessary to make corrections in the RED regulations.

Sustainable development criteria do not cover all the issues connected with biofuels. Those concerning the quality or compatibility with car engine elements and powering system have been omitted.

Essential for biofuel success in Europe are also economic and social aspects. High manufacturing costs, increased due to certification process make the biofuels less competitive in relation to conventional fuels.

To sum up, the chance of development of the biofuel market cannot be explicitly denied, whether in Poland or in Europe. The activities carried out at present should stimulate the development and the search for new, more environment-friendly paths for biofuel production.

The authors are research workers of the Oil and Gas Institute in Krakow

Literature

1) *Carbon Intensity of Crude Oil in Europe Crude. Energy – Redefined LLC, 2010, http://www.theicct.org/pubs/ICCT_crudeoil_Europe_De2010.pdf*
2) *http://re.jrc.ec.europa.eu/biof/html/input_data_ghg.htm*
3) *DRAFT prEN 16214-4Sustainably produced biomass for energy applications - Principles, criteria, indicators and verifiers for biofuels and bioliquids - Part 4: Calculation methods of the greenhouse gas emission balance using a life cycle analysis.*
4) *Göran Berndes (Chalmers University of Technology) Contributing authors: Neil Bird (Joanneum Research) and Annette Cowie (National Centre for Rural Greenhouse Gas Research)" Bioenergy, Land Use Change and Climate Change Mitigation" Report for Policy Advisors and Policy Makers, IEA Bioenergy: ExCo:2010:03.*
5) *http://www.ifqc.org/WhatsNewDetails.aspx?NewsId=4452*
6) *Directive of the European Parliament and the Council 2009/28/EC of 23 April 2009 on promoting the application of renewable energy sources which changes and overruling the directive 2001/77/EC and 2003/30/EC (Official Journal of the European Union no. L 140/16 of 9.06.2009).*
7) *Commission Announcement concerning practical implementation of the EU system of sustainable development criteria of biofuels and bioliquids and binding estimation principles with reference to biofuels of 19.06.2010 (EU Official Journal C 160/8 of 2010).*
8) *PN-EN ISO19011: Directives concerning audit management systems.*
9) *PN EN ISO 45011 General requirements concerning the units which manage the product certification systems.*
10) *The Commission Announcement concerning voluntary systems and standard values in the system of sustainable development criteria for fuels and biofuel (EU Official Journal C160/1 of 2010).*
11) *The Commission Announcement concerning practical implemention of the EU system of sustainable development criteria of biofuels and bioliquids and binding estimation regulations with reference to biofuels 2010/C 160/02.*
12) *The Commission directive of 10 June 2010 concerning regulations which concern estimating the carbon resources in the ground for purposes of annex V to RED directive 2010/335/UE.*

BRENNTAG

Chemical products for oil and natural gas industry

BRENNTAG

The offer of Brenntag Polska

Brenntag Polska is the largest distributor of chemicals in Poland. Our products are used in nearly all branches of industry. Our offer comprises standard and speciality chemicals, plastic and rubber, and technical support to aid the effective business of our clients, such as management of returnable and non-returnable packages, collection of industrial waste and its chemical utilization, packaging to bulk containers, and many other things.

Brenntag Polska is one of many companies of the Brenntag Group, the world leader in distribution of chemicals, which gives us direct access to sources of materials and worldwide technologies and a strong position in relations with our suppliers.

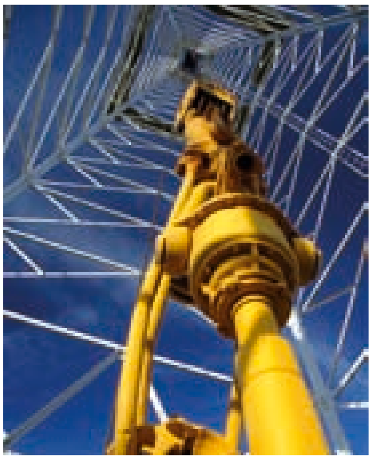
As part of services rendered, we can make available to you 15 storage facilities which are located in different parts of Poland, and our team which will perform reliable technical expertise in each of the presented fields. Brenntag and its Oil and Gas branch can provide you with all chemical solutions, whether they are products for making the drilling fluids, fluids for heating and cooling installations or chemicals used in extraction.

Our strong international structure ensures our clients the widest choice of products in the market at attractive prices and advantageous terms for cooperation.

Responsible for technical support of the oil and gas sector in Poland is the Oil and Gas Technology Division of Brenntag Polska whose team are competent and obliging partners, always ready to help with respect of offered technology and products.

Apart from assistance in selection of necessary materials and technology, our specialists will provide you with professional technical support, both at the stage of implementation and standard exploitation of the systems which make use of our products. The technical team are at your disposal and ready to assist you with reference to product application, solving the issues related to the system operation, monitoring strategies and area verification studies.

The tasks of our team involve preparing the reports of corrosion monitoring and coordination of requirements concerning laboratory tests. Brenntag Polska own the essential base: logistic infrastructure and technical equipment, including analytical and research labs and highly professional staff.



BRENNTAG

We recommend our website with interesting information about Brenntag Polska and extensive presentation of our offer with product specification. Registered users can also take advantage of the online tools which facilitate fast communication with our team and ensure monitoring of financial operations as part of our cooperation.

The offer of Brenntag Polska contains a variety of special products to eliminate problems encountered in the oil business.

The product range comprises:

- Inhibitors and dispersants of paraffin and asphaltenes
- Corrosion inhibitors – continuous and batch treatment
- Hydrate inhibitors
- Organic sediment inhibitors
- Demulsifiers – continuous and batch treatment
- Hydrogen sulphide neutralizers
- Dispersants of asphaltenes and iron sulfates
- Foaming agents
- Biocides

Another range of products offered by Brenntag Polska are those used in drilling:

- Thickeners
- Protective colloids
- Weighting materials
- Deflocculants
- Lost circulation materials
- Clay Inhibitors
- Hydrogen sulphide and oxygen neutralizers
- Anti-foaming agents
- Surfactants
- Functional additives

Further information on our offer can be found on our website **www.brenntag.pl** in section: Oil and Gas – Products.

Biodegradable oils and lubricating greases

Ecology in the national railways

ANNA ZAJEZIERSKA

The legal orders introduced in the recent years and increased ecological consciousness and environment-friendly policy result in wider use of biodegradable agents in economy: for lubricating machines and devices operating in water intake areas, forest areas, national parks and other places where contamination cannot be allowed. They may also be applied in machines and devices greased through, from which used oil cannot be collected; these oils are irretrievably lost, polluting the environment.

It is estimated that in Europe, where consumption of lubricating greases amounts to 4.5 million Mg (tons), about 600 thousand Mg gets into soil or groundwater. In the United States, with global lubricating grease consumption at the level of 9 million Mg, about 1.5 million Mg [1, 2] is irretrievably lost. However in Switzerland, which is the leader in respect of natural environment protection, out of 60 thousand Mg of used lubricating greases almost 40 thousand undergoes the recycling process, and only 4 thousand Mg is irretrievably lost [1, 2].

Currently, the use of biodegradable lubricating greases, apart from traditional areas, is extended to new areas of economy; these greases are introduced in industry, road and rail transport.

Currently, the use of biodegradable lubricating greases, apart from traditional areas, is extended to new areas of economy; these greases are introduced in industry, road and rail transport.

The progress which takes place in the field of alternative lubricating greases is also observed in establishing the new criteria which should be taken into consideration when formulating final products, i.e.: biodegradability, bioaccumulation, toxicity, ecotoxicity, emission to the atmosphere [1, 2]. In publications, it is even suggested that the consumer`s consciousness should be urgently changed, and the consumer should rather use the notion of "environmental acceptable lubricating grease" [1].

In the long-term, modern solutions, in friction pair of machines and devices, in the applications in which it is justified, alternative lubricating greases should be applied, like the "for-life-lubrication". It is suggested that these lubricants should be used in the so-called "life cycle" by collecting the used oils to put them through the recycling process by means of fractioning distillation, and their chemical composition should be changed in technological processes and directed – as secondary material – to blending and distribution and repeat exploitation [1].

Fig. 1. Exploitation of biodegradable oil developed by the Oil and Gas Institute, used in rail vehicles exploited by PKP Cargo S.A.

Components of biodegradable lubricating greases

For production of biodegradable lubricating greases the following oil types are used:

- ester oils of natural origin, mainly rape oil, soya oil and sunflower oil;
- synthetic esters, mainly esters of dicarboxylic acid and esters of monoalcohols, esters of low molecular monocarboxylic acids and polyalcohol esters [1-4].

The most significant are the lubricating greases which are produced with the use of rape oil characterized by appropriate anti-wear and anti-seizing properties, high temperature of ignition and high level of biological degradation. However, it has a low thermal stability connected with the content of polyunsaturated acids in the oil composition and it has worse low-temperature properties, compared to mineral oils and synthetic ester oils.

In the case of components used as plastic grease thickeners for biodegradable greases, most of the conventional thickeners are allowed, i.e. fatty acid metal salts. However, it is recommended to use calcium salts and modified bentonite (aluminium silicate) as compounds related to those existing in natural environment (soil) [5-8]. Apart from the mentioned thickener types, the literature describes also biodegradable greases produced with the use of vegetable oils and polyurea thickeners [9]. Thickeners' biodegradability is dependent upon their chemical composition. Metallic salts of high molecular fatty acids are completely biodegradable. In the case of non-organic thickeners, only organic hydrophobe, which constitutes 10-20% of the thickener mass, undergoes biodegradation [2, 8].

Additives contained in biodegradable lubricants have to meet the criteria of biodegradability and non-toxicity, and components whose biodegradability is below 70% can be used in limited amount and their consumption should not exceed 5% [1-2].

As corrosion inhibitors in biodegradable greases, the most commonly used are esters of alkyl succinate acid (biodegradability over 80%) and calcium sulphonate (biodegradability over 60%). In the case of lubricating additives, the most distributed and permitted by requirements of international organizations for environment protection are products based on selected natural materials, sulphured in conservative conditions

Table 1. Biodegradable greasing oil for the railway – typical quality parameters

Quality parameters	Biodegradable oil	Research methods
Kinematic viscosity in temperature 40°C [mm²/s]	463	PN-EN ISO 3104:2004
Flow temperature [°C]	–21	PN-ISO 3016:2005
Anti-wear properties in testing in 4-ball apparatus, wear mark diameter [mm]	0.35	PN-EN ISO 20623:2010
Anti-wear properties in testing in 4-ball apparatus, welding load [N]	2500	PN-EN ISO 20623: 2010
Anticorrosive properties	pass	PN-ISO 7120: 2011
Biodegradability in water [%]	87.1	CEC L-33-A-94

(sulphur content 12-15%), characterized with biodegradability of 80% and compounds of sulphur and phosphorus [6, 9-11].

As oxidation inhibitors, analogous compounds are used to those applied in conventional plastic greases, i.e. additives like aromatic amines (diphenylamine derivative) and sterically hindered phenols [6, 9]. Both compound types are classified as WGK-1 and WGK-2 agents which in the case of soaking into soil pose small or medium threat to groundwater.

Biodegradable lubricating greases in the national railways

In the recent years in the national railways, growing interest can be observed in the use of biodegradable lubricating greases in lubricating the suspension systems. During the vehicle exploitation on the rails, especially rail curves, the elements of wheel units are subject to mechanical wear and tear. Constructional solutions include the use of steel rims, which after reaching the specific condition are subject to periodic changes.

In order to reduce the wear and tear of elements and to increase the inter-renovation mileage, the wheel rim lubrication with oils and plastic greases is used. These lubricating greases are applied through greasing through systems and they are soaking in the soil and groundwater. Introducing biodegradable lubricants instead of previously used conventional oils and greases enables environment-friendly actions in the new branch of national economy. Such solutions are used for a few years now, in the leading natural-environment-care countries, i.e. in Germany and in Scandinavian countries.

For a few years, in the Oil and Gas Institute, research projects are carried out, connected with biodegradable lubricating greases. By anticipating environment-friendly actions of the Polish legislation to the scope of research works, also lubricating greases were included of high extent of biological degradation, considering also quality parameters required by the national railway (the Oil and Gas Institute`s cooperation with PKP Cargo S.A. concerning e.g. product quality requirements). As a result of works executed in the framework of own resources and a project co-financed by the European Union from the European Regional Development Fund, biodegradable lubricating greases technology was developed which was intended for the national railway for wheel rim lubricating of rail vehicles suspension systems: biodegradable greasing oil and semi-fluid plastic grease. The following were used as greasing oil components: the natural ester oil and selected refined additives from the group of additives allowed by the European legislation for application in biodegradable lubricating greases.

Biodegradable oil is characterized by increased anti-wear properties due to which it limits the mechanical wear of rail vehicle wheel rims. Favourable functional oil parameters which influence the exploitation durability of suspension systems are also good rheological

Fig. 2. Location of Rolling Stock Factory PKP Cargo S.A. which uses biodegradable greasing oil developed by the Oil and Gas Institute

properties which are maintained in a wide temperature range and they enable oil exploitation throughout the whole season, and also high level of biological degradation. Typical properties of biodegradable oil for the railway are introduced in Table 1.

Innovative character of technological solution of producing biodegradable greasing oil for the railway became certified by obtaining a patent PL 206.170 by its creators.

Experimental oil batches were directed to exploitation testing in wheel units of PKP Cargo S.A. locomotives. During two years of observed exploitation carried out in the whole season comprising summer and winter conditions, good oil exploitation properties were confirmed, i.e. mechanical wear reduction in steel wheel rim elements. It enabled the extension of the inter-renovation periods of rail vehicles and obtaining substantial economical effects. Having obtained positive results of exploitation research, the quality of biodegradable greasing oil became accepted and it is allowed in rail vehicles which are used by PKP Cargo S.A.

Currently, PKP Cargo S.A. the amended Greasing Instruction which involves diesel and electric locomotives, advises to use the biodegradable oil developed by the Oil and Gas Institute, instead of previously used

Table 2. Biodegradable grease for railways – typical quality parameters

Quality parameters	Biodegradable grease	Research methods
Penetration in temperature 20°C [mm/10]	421	PN-EN ISO 2137:2011
Liquefaction temperature [°C]	93	PN-ISO 2176:2011
Resistance to water	pass	DIN 51 807 cz. 1
Penetration in temperature -20°C [mm/10]	227	PN-EN ISO 2137:2011
Anti-wear properties in testing in 4-ball apparatus, wear mark diameter [mm]	0,55	PN-EN ISO 20623:2010
Anti-friction properties in testing in 4-ball apparatus, welding load [N]	2500	PN-EN ISO 20623: 2010
Anti-corrosive properties	pass	PN-ISO 7120: 2011
Biodegradability in water [%]	75	CEC L-33-A-94
Biodegradability in soil (100 mg grease/1000 g soil) total mineralization [days]	80	Manometric respirometry Method C.4-D

conventional mineral oil which was produced with the use of petroleum.

The production of biodegradable greasing oil was opened in the Oil and Gas Institute in Oil Technology Department. Refined oil is produced continuously and the confirmation of its good practical qualities are orders for the Oil and Gas Institute from companies subordinate to PKP Cargo S.A.

Biodegradable semi-fluid grease

Another kind of greasing system construction which is currently used in railway suspension systems is the semi-fluid grease. The research on technology of biodegradable grease production was carried out with the use of calcium 12-hydroxystearate as a thickening factor. In order to obtain the required rheological properties in low temperatures which determine good pumping of the product in greasing systems, the composition of vegetable oil and synthetic ester oil was used. Positive exploitation test results permitted this product to be accepted by the Polish railways. The developed grease, apart from good anti-wear properties, is also characterized by low friction resistance and good starting properties. Its additional value is the high level of biological degradation which is described according to soil and groundwater. Technology of grease production is protected by patent no. P 394.099.

At present, biodegradable grease is on the offer of products manufactured in the framework of low-burden production at the Oil and Gas Institute in the Oil Technology Department.

The developed biodegradable grease is also succesfully used in public transport as an agent which reduces noise emitted by rail vehicles exploitation, especially on rail curves and tracks located near housing estates.

Summary

Railway transport is one of the fundamental sectors of national economy: Polish National Railways have now a rolling stock of about two thousand electric and diesel locomotives. Issues connected with this sector's ecology focus on the improvement of fuel use effectiveness and possibilities of alternative fuel use. The European Union legislation supported relevant actions by introducing biofuel Directive 2003/30/EC.

In the European Commission there are currently discussions on biodegradable lubricating greases for railways. So far, the Commission Announcement appeared to European Parliament and Council about the ecological transport COM (2008) 433 and the application to the European Commission and European Parliament concerning components used for engine power of vehicles exploited in agriculture and forestry COM (2007) 840.

In this respect, the subjects of works and research carried out by the Oil and Gas Institute are in accordance with the strategy which results from the future instructions and directives of the Union legislation. These are prospective and anticipating actions in the scope of production and use of biodegradable lubricating greases in the national economy.

The author is research worker at the Oil and Gas Institute

Literature

1) Stempfel E.M. *Practical Experience with Highly Biodegradable Lubricants, Especially Hydraulic Oils and Lubricating Greases*. NLGI Spokesman, 62, 1, 8–22 (1998).
2) Korff J., Cristino A. *Requirements for Environmentally Acceptable Greases According to "Blue Angel Regulation"*. NLGI Spokesman, 64, 8, 22-28 (2000).
3) Szalajko U., Fiszer S., Klomfas J. Die *Schmiereigenschaften der semisynthetischen Öle, gewonennen auf der Basis des Rapsöls. Tribologie – Schmierungstechnik*.48, 2, 78–88 (1997).
4) *Industrial Lubrication and Tribology. Product review. Alternative lubricant base stocks*. 49, 2, 78–88 (1997).
5) Stempfel E.M, Schmid L.A. *Biodegradable Lubricating Greases*. NLGI Spokesman, 55, 25–33 (1991).
6) Fessenbecker A., Korff J. *Additive für ökologisch unbedenklichere Schmierstoffe*. 9 International Colloquium „Ecological and Economicae Aspects of Tribology". Esslingen, January 1994. Ed. W. Bartz, 1994 11.12 – 1 – 11.12 – 14.
7) Kyriakopulos C. *Aluminium Complex Greases Formulated with Biodegradable Base Oils*. NLGI Spokesman, 59, 2, 10-23 (1995).
8) Loderer D. *Lifetime Lubrication of Rolling Bearings with Rapidly Biodegradable Lubricating Greases*. NLGI Spokesman, 59, 2, 16 -20 (1995).
9) Roehrs I., Rosrucker T. *Performance and Ecology – Two Aspects for Modern Greases. NLGI Spokesman*, 58, 12, 474 – 483 (1995).
10) Korff J., Fessenbecker A. *Additives for Biodegradable Lubricants*. NLGI Spokesman, 57, 3, 107–113 (1993).
11) Norrby T., Kopp M. *Environmentally adapted Lubricants in Swedish forest industry – a critical review and case study. Industrial Lubrication and Tribology*, 52, 3, 116–124 (2000).

Ethanol fuel E85 – the challenge for traditional oil-derivative fuels

The future for motorization – directed towards E85?

MARTYNIKA PAŁUCHOWSKA

The crisis in oil supplies in the seventies of the previous century became one of the principal reasons for applying ethanol in fuels in the countries of North and South America.

In the USA, since the eighties of the previous century, the application of ethanol and other oxygen compounds has been imposed by obligatory programme of introducing them to fuels in order to improve emission from engines. The document from 1992 of the U.S. Department of Energy – *Energy Policy Act* (EPAct) [1] determined goals concerning energy security of the country and improvement of the quality of natural environment [2]. According to this document, ethanol fuel E85 is considered in the USA as alternative fuel. It is used to propel *flexible fuel vehicle* (FFV) engines, available in the American market in a wide range of models. This fuel consists nominally of 85% of ethanol and 15% of petrol.

> The FFV vehicles adapted for combustion of ethanol fuel E85 are currently widely available in the USA and Brazil. In the European Union the market of these vehicles is at the stage of accelerated development. The number of manufacturers who expand their offers by the FFV models is growing gradually.

The content of petrol in the ethanol fuel E85 enables the engines of FFV vehicles to work properly in low temperatures, as opposed to 100% of ethanol, which generates problems in similar conditions. Monitoring of the quality of ethanol fuel E85 performed in the years 2007–2009 in the USA demonstrated that its properties did not fulfill specification requirements in respect of minimal and maximal content of ethanol and minimal vapour pressure [3, 4, 5]. They consisted in determination of marginal content of ethanol in fuel E85 for particular climatic class. The minimal ethanol content in E85 was determined to be 68% (*V/V*) and maximal – 83% (*V/V*). The promotion of using the ethanol fuel E85 in the USA is based on financial incentives constructed so as to make the cost of this fuel and petrol comparable in calculation per one kilometer.

The application of ethanol fuels to propel car engines in Brazil is common. This country has the greatest experience in production of petrol including ethanol, being the world leader in production of fuel ethanol. In the Brazilian market, fuels are sold for spark-ignition engines in which ethanol content is 24% (*V/V*) – E24 or 100% (*V/V*) – E100, and ethanol is added to petrol according to requirements of the federal law, with per-

Table 1. The flexi fuel vehicles available in the European Union countries [12]

COUNTRY	FFV VEHICLE BRAND (data from the beginning of 2009)
Austria	Ford, Renault, Saab, Volvo
Belgium and Luxembourg	Saab, Volvo
Denmark	Ford, Saab
France	Cadillac, Citroen, Dacia, Ford, Hummer, Jeep, Lotus, Peugeot, Renault, Saab, Volvo
Germany	Ford, Saab, Skoda, Volvo
Ireland (Ire)	Citroen, Ford, Renault, Saab, Volvo
Italy	Ford, Saab, Volvo
Holland	Cadillac, Chrysler, Citroen, Dodge, Ford, Hummer, Mitsubishi, Peugeot, Saab, Volvo
Poland	Ford
Spain	Citroen, Ford, Peugeot, Renault, Saab, Volvo
Sweden	Audi, Cadillac, Chevrolet (NAV), Chrysler, Citroen, Dacia, Ford, GM (NAV), Mitsubishi, Nissan, Peugeot, Renault, Saab, Seat, Skoda, Volvo, VW
Switzerland	Cadillac, Chevrolet (NAV), Chrysler, Citroen, Ford, GM (NAV), Renault, Saab, Volvo
The UK	Citroen, Ford, Renault, Saab, Volvo
Generally in Europe	**Audi, Cadillac, Chevrolet (NAV), Chrysler, Citroen, Dacia, Dodge, Ford, GM (NAV), Hummer, Jeep, Lotus, Mitsubishi, Nissan, Peugeot, Renault, Saab, Seat, Skoda, Volvo, VW**

centage content determined by the Minister of Agriculture [6, 7].

In the European Union, for many years, the use of energy from renewable sources in road transport has been promoted. Therefore, fuel manufacturers have been encouraged to increase the content of ethanol originating from renewable sources in fuels for vehicles equipped with spark-ignition engines. The European Directives RED [8] and FQD [9] issued in 2009 accepted increased ethanol content in traditional petrol by 10% (*V/V*) and it also facilitated construction of vehicles equipped with engines with flexible fuel combustion – called *flexible fuel vehicles,* which use for propulsion both lead-free petrol and ethanol fuel E85.

In order to render the development of FFV vehicles possible in the European Union and to ensure their basic functionality, the European Committee for Standardization CEN elaborated a standardizing document CWA 15293:2005 [10], in which necessary quality minimum for ethanol fuel E85 was determined so as it could be introduced to the market. However, very soon the FFV vehicles became subject to increased requirements of exhaust gas emission standard Euro 5, which came in force in September 2009 [6]. Due to this fact, the requirements included in CWA turned out to be insufficient to conform to the European emission standards. Therefore, the next step was the elaboration of technical specification CEN/TS 15293:2011 [11] published in February 2011, which changed some margins of quality coefficients, implementing limits for additional parameters. The differences in relation to the original document i.e. the CWA concern:

- stricter requirements for octane numbers and sulphur content;
- changed requirements for parameters such as the content of higher alcohols (C_3–C_5), contents of ether, water, non-organic chlorides, phosphorus;
- introduction of climatic classes regulated by the range of vapour pressure related to the content of ethanol in fuel;
- introduction of additional quality parameters such as density, content of copper, sulphates and electric conductivity;
- removal from specification of parameters such as appearance, content of lead free petrol, temperature at the end of distillation and residues after distillation.

The FFV vehicles available in the European Market

The FFV vehicles adapted for combustion of ethanol fuel E85 are currently widely available in the USA and Brazil. In the European Union the market of these vehicles is at the stage of accelerated development. The number of manufacturers who expand their offers by the FFV models is growing gradually. Prices of these vehicles are determined at the level of corresponding vehicles, fueled with traditional petrol. The FFV vehicles are available in the European market in a wide range of models: from small, passenger cars through light and heavier vans [12].

The market of cars sold in the European Union is continually growing and in 2008 the number of FFV vehicles amounted to 79 thousand; the largest number was sold in Sweden (about 60 thousand), which places this country in a position ahead of Germany, Holland and France in respect of popularity of the FFVs [12]. Availability of brands and models of the FFV vehicles in the EU differs among the member countries and depends on the market. Table 1 presents collectively, which brands of the FFV vehicles are currently available in the EU countries.

Legal regulations on pollutant emission in passenger vehicle exhaust fumes in the EU

The policy of reducing pollutants originating from the road transport sector, which is responsible for 12% of total CO_2 emission in the European Union [13], concerns emission of exhaust gas components such as nitrogen oxides NO_x, carbon oxide CO, unburned hydrocarbons HC, particulate matter PM and emission of carbon dioxide CO_2 as greenhouse gas component GHG. The schedules of limiting harmful components of exhaust gases in respect of NO_x, CO, HC, PM specify the Euro emission standards. The plan for reducing CO_2 was presented in the ordinance of the European Parliament and Council (EC) no 443/2009 of 23 April 2009 which determines the emission standards for new passenger cars as part of integrated approach of the Community to the reduction of CO_2 emission from light transport vehicles [14].

Table 2. European standards concerning the emission of harmful components of exhaust fumes from light passenger cars with spark-ignition engines [15, 16, 17]

Standard	Euro 4	Euro 5	Euro 6
Date of introduction:	January 2005	September 2009	September 2014
Maximal permissible value of emission of harmful components of exhaust fumes from light passenger cars with spark-ignition engines, g/km			
Carbon oxide – CO	1.0	1.000	1.000
Unburned hydrocarbons – HC	0.100	0.100	0.100
Nitrogen oxides – NO_x	0.08	0.060	0.060
Particulate matter – PM	-	0.005*	0.005*

* it concerns only engines with direct fuel injection

Table 2 presents other requirements of European standards in respect of emission of harmful components of exhaust fumes such as CO, HC, NO_x and PM from light passenger vehicles with spark-ignition engines.

Average CO_2 emission from new cars has dropped rapidly in the last 10 years. First of all, it has been due to more advanced vehicle technologies, construction of engines and exhaust gas cleaning systems, as well as improvement of the fuel quality, mainly by reducing the content of sulphur to less than 10 mg/kg.

The new Union principles [14] concerning emission of CO_2 from passenger cars are some of the most demanding regulations related to protection of the environment in the automobile industry. The said legal act determines the necessity of reduction of CO_2 to 130 g/km for average new automobile class by means of further advancement in technology of constructing engines. Continued emission reduction to the target of 120 g CO_2/km is to take place in the result of continuous improvement of automobile technologies and also utilization of bio-fuels fulfilling the criteria of sustainable development [14].

The key items of the above ordinance for passenger cars are [14, 18]:

- reduction of CO_2 emission by new automobiles to 120 g/km, in which the reduction of 10g/km is to originate from increased content of bio-fuels;
- the schedule of reaching the above objective is as follows:
  - » 65% of new cars will conform to the requirements in 2012,
  - » 75% in 2013,
  - » 80% in 2014,
  - » 100% in 2015;
- implementation of ecological innovations by the vehicle supplier or manufacturer which enable its individual target reduction of CO_2 emission by up to 7 g CO_2/km;
- preferential credits for purchasers of vehicles which emit less than 50 g CO_2/km;
- niche automobile manufacturers (from 10 thousand to 300 thousand cars) may apply to the European Commission for deviation from the rule which cannot be higher than 25% when compared to reduction in average, individual CO_2 emission in 2007;
- the average CO_2 emission of a new car in 2020 cannot exceed 95 g/km, after precise evaluation of determined goal;
- proposition of flexible scale of imposing penalties for ignoring the requirements of CO_2 reduction; the manufacturers who exceed the target by more than 3 g/km will pay 95 Euro for each gram. Smaller fees of 5 Euro and 25 Euro are forecast for exceeding the limit by 1–3 g/km;
- after the review which will consider the evolution of the number of new passenger vehicles registered in the Community and all the changes in control procedure of measuring individual levels of CO_2 emission, the targets of carbon dioxide emission may be corrected and will be reviewed every three years.

According to the Directive (EC) no 443/2009 dated 23 April 2009 [14], the use of some alternative fuels may ensure meaningful reduction of CO_2 emission at all stages of the fuel chain. Therefore, this Directive includes regulations which promote using vehicles propelled with alternative fuels in the European market, including FFV vehicles. Article 6 of the Directive establishes target individual levels of CO_2 emission for vehicles propelled with alternative fuel and it promotes the use of ethanol fuel E85 for propelling vehicles with spark-ignition engines. Therefore, it is proposed that the individual level of CO_2 emission for each vehicle which can be adapted for using ethanol fuel E85 – which in turn fulfills requirements of relevant regulations of the Community and also the European specification – will be diminished by 5% by 31 December 2015. However, this reduction can be implemented only when in the a particular member country in which the vehicle is registered at least 30% of filling stations can offer ethanol fuel and it will fulfill the criteria of sustainable development determined for biofuels in Directives RED and FQD.

Sources of emission of harmful substances when using ethanol fuel E85

Even though the E85 is alternative fuel, its use and storage also causes emission of toxic chemical pollutants and greenhouse gas. This kind of pollution is the topic of regulations mentioned above. Emission of pollution to the air occurs due to evaporation of fuel and its combustion in automobile engines. However, the emission caused by ethanol fuel E85 is generally smaller when compared to traditional petrol [19].

Emission due to fuel evaporation

Air pollution by emission of chemical compounds owing to evaporation of ethanol fuel E85 or petrol can occur due to penetration of vapours, ventilation of the tank, fuel leakage or vapour escape.

Penetration of vapours may result through construction materials of the fuel system. However, this kind of emission occurs more frequently in petrol featured by lower content of ethanol then in fuels E5 and E10 [19].

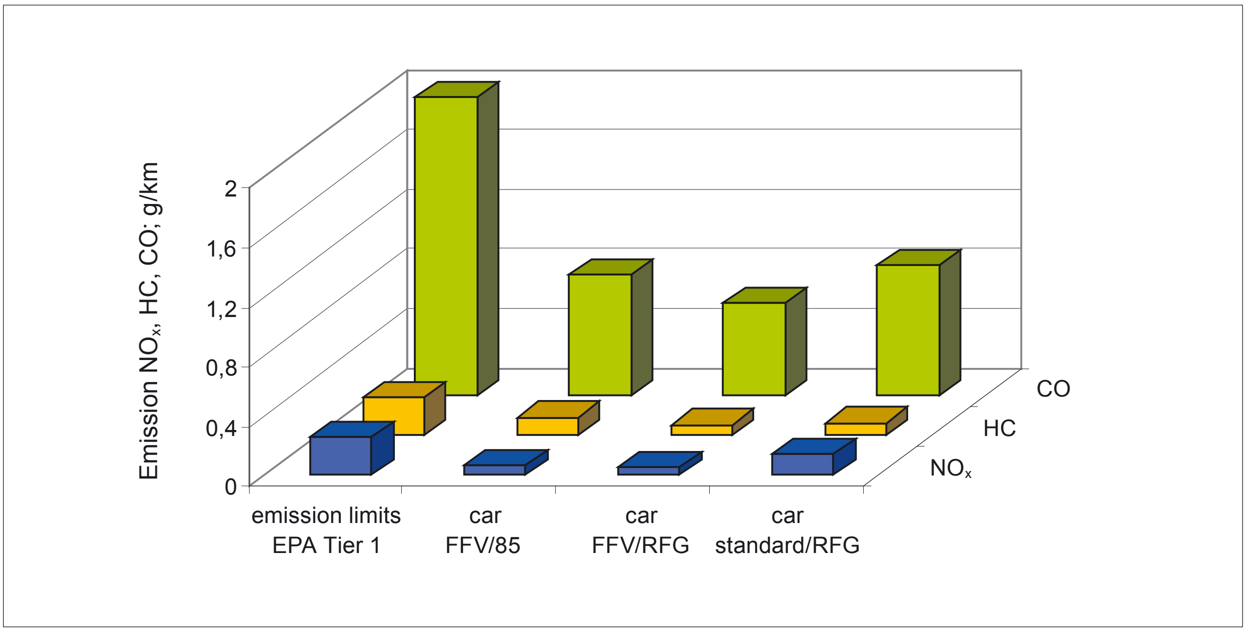


Fig. 1. Comparison of NO_x, HC and CO emission from cars

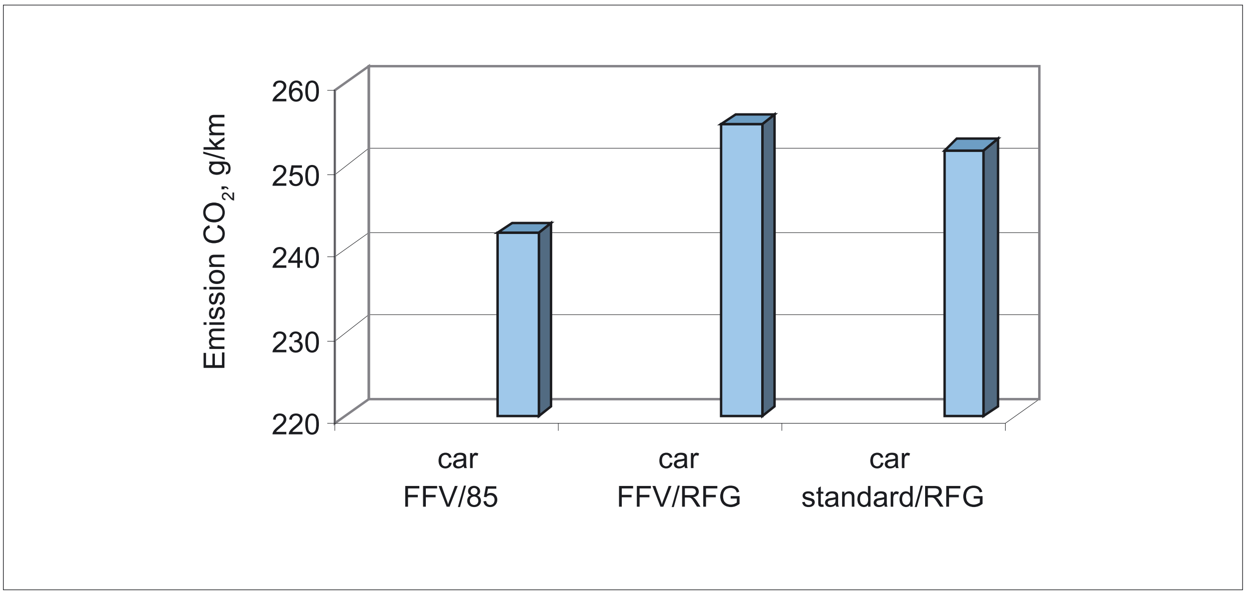


Fig. 2. Comparison of CO_2 emission from cars

Ventilation of the fuel tank takes place when fuel vapours escape from the tank during refueling and also when petrol evaporates in high ambient temperature. Starting from the beginning of 2000, ventilation of the tank is controlled by on-board vapour reclaiming unit installed in automobiles fuelled with E85 or petrol [19].

Vapour may also originate from fuel leakage or vapor escape. This sort of emission is less common in FFV vehicles on account of continual improvements in sealing materials applied in these vehicles [19].

Emission due to fuel combustion

Harmful air pollution due to fuel combustion in a car engine is emitted from an exhaust system after passing through a catalytic exhaust gas cleaning system. Reduction of harmful emission to the air comprises NO_x, CO, HC and other toxic compounds formed in the air, caused by exhaust fumes e.g. formaldehyde, 1,3-butadiene and others, also CO_2.

At the same time, numerous comparative studies are conducted of emissions of harmful substances

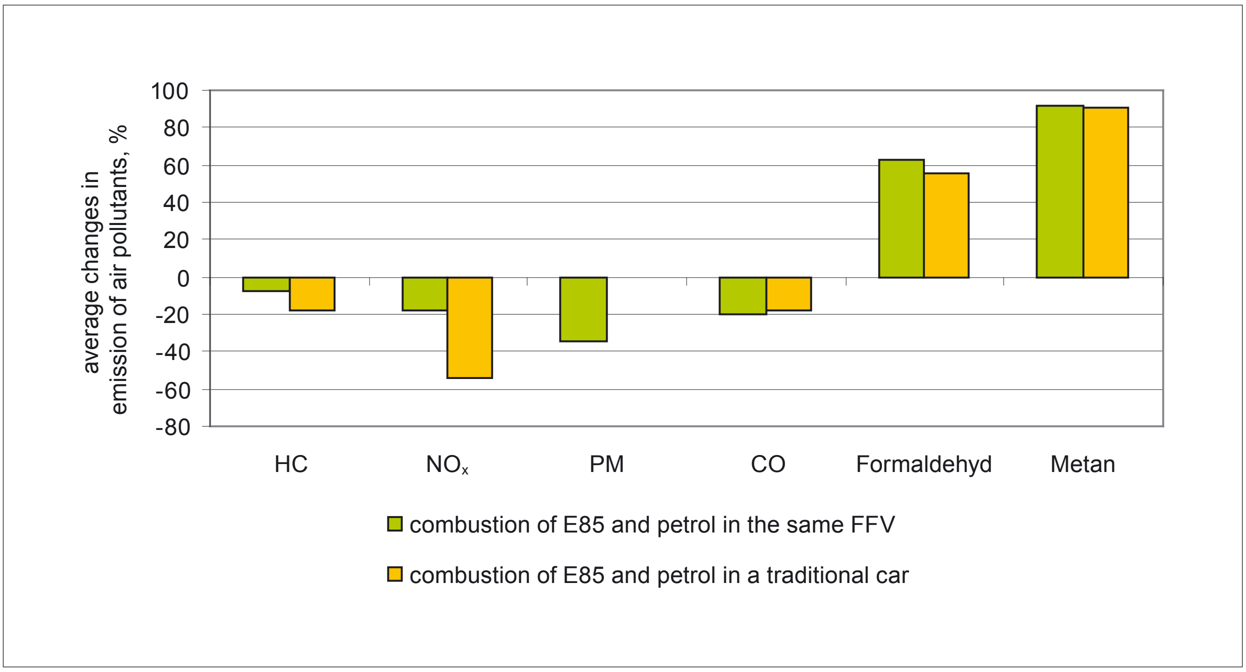


Fig. 3. Comparison of average changes in emitting air pollutants caused by ethanol E85 and petrol

originating from combustion of ethanol E85 and traditional petrol. The National Renewable Energy Laboratory in Ohio studied the emission and fuel consumption in FFV vehicle – Ford Taurus (1996) propelled with ethanol E85 and petrol, reformulated with 2.7% (*m/m*) oxygen content [20].

Fig. 1 and 2 [20] present comparison of emissions of nitrogen oxide (NO_x), hydrocarbons (HC) and carbon oxide (CO), as well as carbon dioxide (CO_2) originating from a FFV fuelled with E85 or reformulated gasoline (RFG) and from a standard car fuelled with reformulated gasoline (RFG).

A standard car fuelled with reformulated gasoline, even though it fulfilled requirements of the standard EPA Tier 1, it featured higher emission than a FFV car. The CO_2 level was distinctly higher in case of fuelling the FFV engines with ethanol E85 than with reformulated engine gasoline.

Research studies executed in respect of influence of fuel combustion on air pollution on fleets of various car models do not always present convergent and unambiguous findings due to a large number of variables. However, in 2008 the National Renewable Energy Laboratory (NREL) in the USA conducted studies concerning detailed data analysis from studies relating it to binding emission requirements [21]. These studies compare emission changes in FFV vehicles fuelled with ethanol E85 with FFV vehicles fuelled with petrol or cars fuelled with petrol, but not compatible with ethanol E85. The results of this analysis [21] demonstrated that the average emission of carbon dioxide CO_2 form combustion of examined fuels in all types of examined vehicles was either diminished or no statistically significant difference between combustion of ethanol E85 and petrol was found. Differences were noticed in emission of other toxic compounds created due to fuel combustion in engines. Thus, vehicles FFV propelled with ethanol contributed to increased content of formaldehyde, acetaldehyde and methane formation in the air. Fig no. 3 [19] demonstrates results of the findings.

> The energy for car transport obtained from renewable sources constitutes only a small percentage nowadays, however, contribution of alternative fuels in the overall volume of engine fuels is growing.

Emission of GHG in the life cycle of ethanol E85

The emission of greenhouse gases GHG related to production and application of ethanol fuel consists of emissions obtained in evaluation of life cy-

cle of the product (E85), beginning with location of the farmland to combustion of the fuel in a car engine.

Research studies conducted at the Argonne National Laboratory in the USA demonstrated that emission of greenhouse gas GHG formed due to production and use of ethanol E85 produced from corn plantations was from 17% to 23% lower in relation to 1 mile (1.6 km) than the emission of the same gases due to production and use of traditional 'regular' type petrol [19]. It was also proved that application of ethanol E85 can diminish the consumption of oil by 70%. The American Environmental Protection Agency is running works on implementing an additional variable into estimation of the general volume of greenhouse gas GHG emission generated from fuels based on ethanol obtained from corn, i.e. intermediate land utilization, which will affect the final gas emission.

Summary

Introduction of ethanol E85 into the market is growing both in the United States and in Europe. It is preceded by expensive research in vehicle technologies, construction of engines, determination of quality parameters appropriate for correct operation of all the systems installed in automobiles. This depicts specific and inevitable changes which are progressing in the world energy balance. The energy for car transport obtained from renewable sources constitutes only a small percentage nowadays, however, contribution of alternative fuels in the overall volume of engine fuels is growing.

The energy policy adopted by the Polish Government to be executed by 2030 means growing integration of the Polish liquid fuel, natural gas and electric energy markets with the European systems, which necessitates searching for and increasing the energy security and also increasing the reserves of all fuels, both liquid and gaseous [22]. In Poland, owing to already existing installations producing fuel ethanol there is a possibility to produce ethanol fuel E85. Construction of automobile market is the question of actions and decisions of the entities operating in it, as car models adapted to ethanol fuel E85 are already manufactured. In view of the assumptions of the government energy policy, the enforced Kyoto Protocol and possibilities of trading with surplus of reduced greenhouse gas emission, there are possibilities of investing in fuel distribution network and creating advantageous financial mechanisms promoting such fuels.

The author is a research worker at the Oil and Gas Institute in Krakow

Literature

1) *Document of U.S. Department of Energy – Energy Policy Act of 1992 (EPAct).*
2) *Handbook for handling, Storing and Dispensing E85, U.S. Department of Energy, April 2002.*
3) *CRC Report No. E-79-2; Summary of the study of E85 Fuel in the USA, Winter 2006–2007, May 2007,http://www.crcao.com/reports/recentstudies2007/E-79-2/E-792%20E85%20Summary%20Report%202007.pdf*
4) *CRC Report No. E-85; National Survey of E85 Quality, November 2009 http://www.crcao.org/reports/recentstudies2009/E-85/E-85%20Final%20Report%20_120609_.pdf*
5) *Flash Report U.S. ASTM Update; Winter meeting of D02 Committee '09, Dec. 16, 2009 http://www.ifqc.org/FlashReports.aspx*
6) *http://www2.petrobras.com.br/portal/ingles/produtos_servicos.html*
7) *http://www.greencarcongress.com/2005/05/japan_and_brazi.html*
8) *Dyrektywa Parlamentu Europejskiego i Rady 2009/28/WE z dnia 23 kwietnia 2009 w sprawie promowania stosowania energii ze źródeł odnawialnych zmieniająca i w następstwie uchylająca dyrektywy 2001/77/WE oraz 2003/30/WE (Dz.U. UE nr L 140/16 z 9.06.2009 r.) – dyrektywa RED.*
9) *Dyrektywa Parlamentu Europejskiego i Rady 2009/30/WE z dnia 23 kwietnia 2009 r. zmieniająca dyrektywę 98/70/WE odnoszącą się do specyfikacji benzyny i olejów napędowych oraz wprowadzająca mechanizm monitorowania i ograniczania emisji gazów cieplarnianych oraz zmieniająca dyrektywę Rady 199/32/WE odnoszącą się do specyfikacji paliw wykorzystywanych przez statki żeglugi śródlądowej oraz uchylająca dyrektywę 93/12/EWG (Dz.U. UE nr L 140/88 z 5.06.2009) – dyrektywa FQD.*
10) *CWA 15293:2005 – Automotive fuels – Ethanol E85 – Requirements and test methods.*
11) *CEN/TS 15293:2011 – Automotive fuels – Ethanol (E85) automotive fuel – Requirements and test methods.*
12) *Available FFV Models. Available FFV brands (beginning of 2009) http://www.best-europe.org/Pages/ContentPage.aspx?id=589*
13) *Dyrektywa Rady i Parlamentu Europejskiego 98/69/EC z 13 października 1998 r. regulująca zasady przeciwdziałania zanieczyszczeniu powietrza przez gazy spalinowe z silników pojazdów samochodowych i nowelizująca Dyrektywę Rady 70/220/EEC (& 2002/80/EC) dla wszystkich pojazdów.*
14) *Rozporządzenie Parlamentu Europejskiego i Rady (WE) nr 443/2009 z dnia 23 kwietnia 2009 r. określające normy emisji dla nowych samochodów osobowych w ramach zintegrowanego podejścia Wspólnoty na rzecz zmniejszenia emisji CO_2 z lekkich pojazdów dostawczych.*
15) *Rozporządzenie (WE) Nr 715/2007 Parlamentu Europejskiego I Rady z dnia 20 czerwca 2007 r. w sprawie homologacji typu pojazdów silnikowych w odniesieniu do emisji zanieczyszczeń pochodzących z lekkich pojazdów pasażerskich i użytkowych (Euro 5 i Euro 6) oraz w sprawie dostępu do informacji dotyczących naprawy i utrzymania pojazdów.*
16) *Dyrektywa Rady i Parlamentu Europejskiego 98/69/EC z 13 października 1998 r. regulująca zasady przeciwdziałania zanieczyszczeniu powietrza przez gazy spalinowe z silników pojazdów samochodowych i nowelizująca Dyrektywę Rady 70/220/EEC (& 2002/80/EC) dla wszystkich pojazdów.*
17) *Dyrektywa Komisji 2002/80/WE z dnia 3 października 2002 r. dostosowująca do postępu technicznego dyrektywę Rady 70/220/EWG odnoszącą się do działań, jakie mają być podjęte w celu ograniczenia zanieczyszczania powietrza przez emisje z pojazdów silnikowych.*
18) *European Automobile Industry Report 09/10, ACEA, www.acea.be*
19) *Alternative & Advanced Technology Vehicles, http://www.afdc.energy.gov/afdc/vehicles/emissions_e85.html; Content Last Updated: 28.01.2011; U.S. Department of Energy – Energy Efficiency and Renewable Energy; Alternative Fuels and Advanced Vehicles Data Center.*
20) *Campbell E.; Setting a Fuel Quality Standard for Fuel Ethanol Tender 18/2004, IFQC, June 2004 na podstawie International Energy Agency: "Biofuels for Transport – An International Perspective", April 2004.*
21) *Yanowitz J., McCormick R. L.; Effect of E85 on Tailpipe Emissions from Light-Duty Vehicles; Journal of the Air & Waste Management Association, February 2009.*
22) *Polityka energetyczna Polski do 2030 roku, Ministerstwo Gospodarki, Załącznik do uchwały Nr 202/2009 Rady Ministrów z dn. 10 listopada 2009.*

Selected aspects of polygeneration systems

Modern and effective refrigeration

On 21 February 2004, Directive 2004/8/EC (1) of the European Parliament and EU Council of 11 February, 2004 came into force. This document imposes on the member states the obligation to implement mechanisms of promoting cogeneration on the basis of demand for heat in internal energy market and saving the primary energy. Poland ratified the Kyoto protocol and – in compliance with the European Union directives – undertook to reduce the emission which accompanies burning, simultaneously increasing production of combined heat and power to 30% by the year 2012. In view of the above fact, the application of co- and trigeneration solutions became a real response to the demand in the energy market.

Production of refrigeration to satisfy the living or technological needs is one of the most energy-intensive technologies; it also has a great impact on degradation of natural environment due to emission of greenhouse gas and gases which deplete the ozone layer. The offers presented currently by producers of combined technologies are, first of all, more environment-friendly, they use the primary energy more efficiently, and the use of waste energy to produce coolness has little influence on the greenhouse effect, several times smaller than technologies based on compressors which have been popular so far.

Increased use of primary energy

Refrigerating technologies based on absorption use the heat from burning fuels such as natural gas, fuel oil, biogas, with COP at level 1.4, but they also use directly steam, exhaust fumes, hot water and geothermal water.

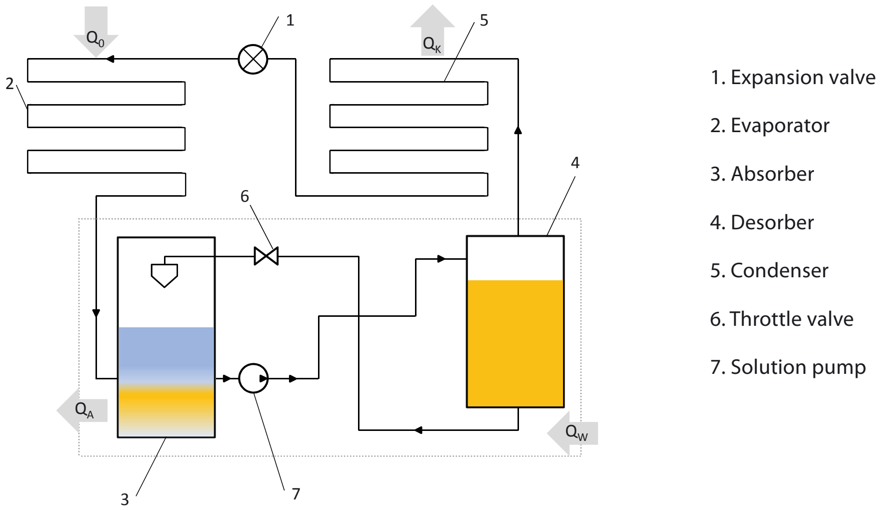
In combined heat and power systems for production of heat, cooling and electric energy, e.g. in the system of power generators propelled by gas engine and the use of waste heat from engine jacket water cooling, producers are already capable of increasing the use of primary energy (e.g. natural gas) to about 85-88%, where, for comparison, the efficiency of classical power station is just a little over 30%.

In so far as the technology of cogeneration systems which use gas engines or turbines is already well-known, much less popular are advanced technologies of generating and transforming energy on the basis of refrigeration technology and systems used in polygeneration sources.

At present, the prevailing trend is the application in cooling systems of both small absorption devices powered by gas which are usually designed for heating purposes in homes, and absorption and adsorptive units powered by heat, such as hot water, steam and exhaust fumes, of high power, used in industry.

The absorption chiller is a system of heat exchangers and mass, combined in series. By combining the exchange processes, the working medium in the gas phase is absorbed in lean solution (low concentration of the working medium). The process of absorption is exothermic, therefore the absorber must be cooled down. Rich solution of the absorber is pumped to the desorber where also the powering heat of the process is supplied. In the process of boiling, steam escapes from the working medium and reaches the surface condenser. In the evaporator, the working medium evaporates at the expense of received heat (e.g. from generated chilled water), and the steam from the working medium travels to the absorber where it is condensed on the surface of the liquid absorbent (absorption).

mide chillers ($LiBr/H_2O$). In the branch of lithium bromide chillers there are several types of units:
- absorption chillers powered by exhaust fumes or discharge water, used in CCHP/BCHP trigeneration systems with turbines



Schematic diagram of absorption chiller

Technologies and refrigeration systems

At present, three main refrigeration technologies are used:
- Lithium bromide absorption chillers powered by hot water, steam or exhaust vapours. These devices are available in capacities from 100 kW to 8000 kW and they are capable of producing chill and hot water. These technologies are designed for use in industry, trade and public utility;
- Ammoniac absorption chillers powered by gas, with the possibility of using a microturbine and powering the chilling system by means of waste heat. Technologies based on ammoniac absorption chillers produce chill, heat and chill or electric energy, heat and chill;
- Silica gel adsorption chillers in which the cooling medium is water and adsorbent of water steam which emerges in the evaporator is silica gel – xerogel formed from saturated silica compounds (i.e. silicon dioxide).

The most advanced branch among those three discussed technologies is the application of lithium bro-

which occur in units with low and high temperature exhaust fumes and with or without an additional gas burner;
- lithium bromide absorption chillers powered directly by natural gas, fuel oil or biogas, providing chill water, heating water and hot utility water and using a gas or oil burner as the source of heat;
- lithium bromide absorption chillers powered by hot water, providing chill water and using hot water of temperature exceeding approximately 70°C as the source of energy;
- lithium bromide absorption chillers powered by steam, providing chill water, using steam at pressure of about 0.01 MPa to 0.8 MPa as the source of energy, used mainly in industry;
- lithium bromide heat pumps – powered by waste heat of parameters:
  - » 20-70°C for first category absorption heat pumps HRH-I,
  - » 65-130°C for second category absorption heat pumps HRH-II.

The primary thermal energy that can be used in these units may be: steam, hot water, hot oil, exhaust fumes, natural gas, biogas, etc. The sources of waste heat may be, e.g. cool water of temperature 40°C or geothermal water of low-parameters. The capacities offered in these units range from about 200 kW to 40 MW.

Lithium bromide absorption chiller powered directly with natural gas, fuel oil or biogas. Source: www.reachabletek.com

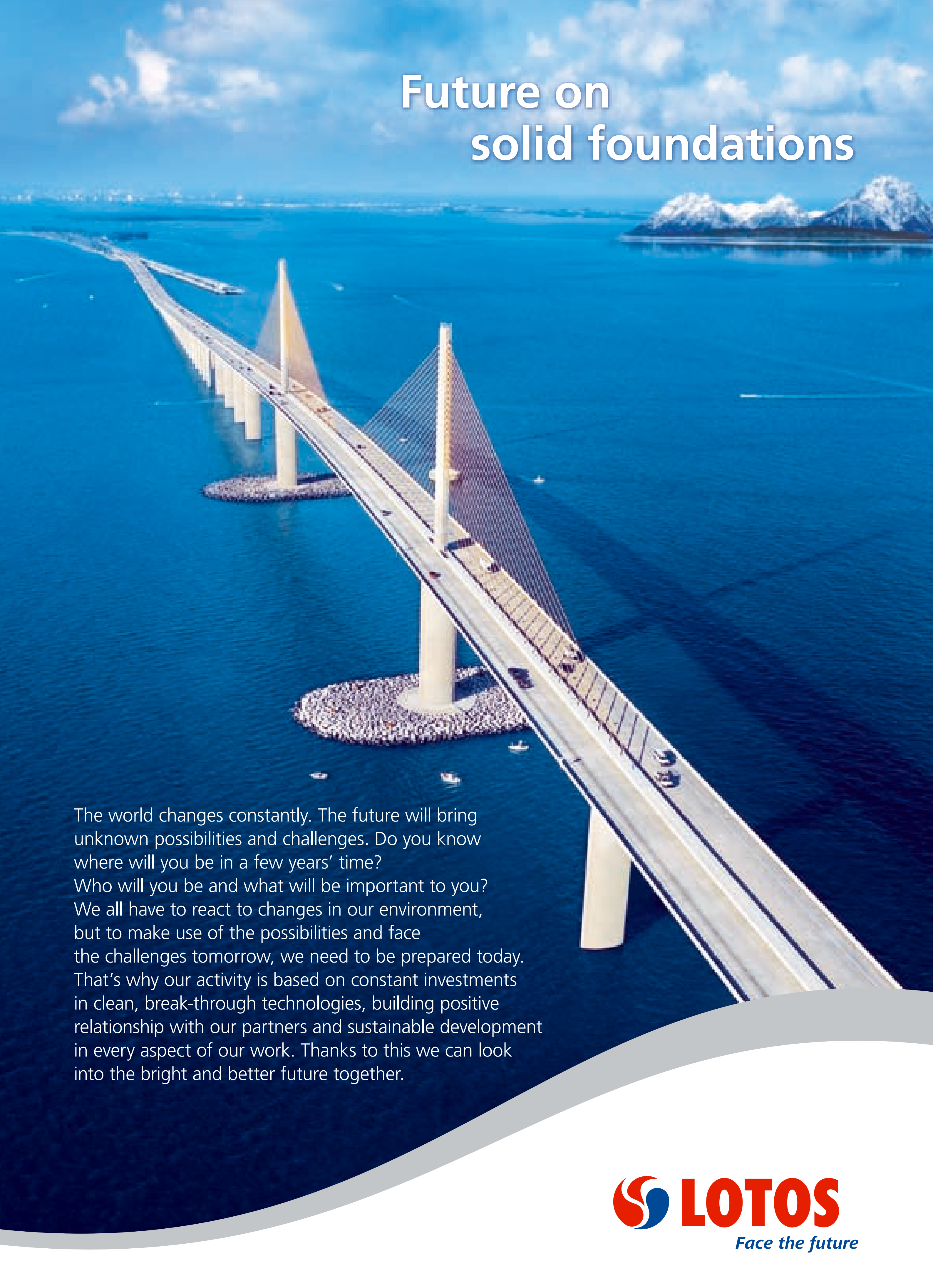
Modular solutions

For units using ammonium hydroxide as the cooling medium (H_2O/NH_3), an interesting solution is the modular solution powered by natural gas or biogas in trigeneration systems. Integrated devices which combine the source of powering (microturbine) and refrigerator, may be installed in the area of any complex to ensure continuous cooling, heating and electric powering. The system pipe installations may be connected with already existing cooling systems and electric installation – with the main power source of the complex or connected to the single electric energy, water and gas reception points. Direct connection to the outlet of the turbine exhaust fumes simplifies the system design and it also eliminates the demand for intermediate heat exchangers and other devices which increase the cost of the installation and reduce its efficiency. An absorption chiller cooled by air is used in this type of solution. It reduces the cost related to maintenance of the cooling tower or water treatment. The modules can run parallel, increasing also the capabilities of the unit and providing an opportunity of increased flexibility of the system operation.

Adsorption chillers are produced in cooling capacities ranging from 35 kW to 500 kW per unit and they are capable of producing chill water for technology or air-conditioning in temperatures from +5°C to +21°C. Low-parameter hot water from 60°C to 95°C can be used to power the devices, so they enable the use of communal heat distribution network in summer or hot water from technological processes.

Energy sale prices, besides the price of fuel purchase, determine the basic extent of cost-effectiveness of constructing polygeneration systems. This concerns mainly the electric energy. The most favourable situation occurs in case of systems which satisfy their own needs, replacing by the same the energy purchased from the network, as the purchase price is much higher than prices of selling the energy to the network. In Poland, the expense of economic use of the environment are still quite small. This results in the fact that the highly efficient energy systems which make use of relatively clean fuels, bear the costs of emission, but considerably lower than obsolete coal-based systems. However, the advantages of using this type of solutions are substantially longer performance of the combined system and reduced fixed costs related to e.g. its operation. These factors affect the economic aspect of these solutions.

Rafał Górecki
PGNiG Technologies S.A.


Future on
solid foundations
The world changes constantly. The future will bring unknown possibilities and challenges. Do you know where will you be in a few years' time?
Who will you be and what will be important to you?
We all have to react to changes in our environment, but to make use of the possibilities and face the challenges tomorrow, we need to be prepared today.
That's why our activity is based on constant investments in clean, break-through technologies, building positive relationship with our partners and sustainable development in every aspect of our work. Thanks to this we can look into the bright and better future together.
LOTOS
Face the future