The Report of the Oil and Gas Institute in Krakow

The Polish Petroleum and Natural Gas Market

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WICEPREZES RADY MINISTRÓW
MINISTER GOSPODARKI
Janusz Piechociński

Introduction by Deputy Prime Minister, Janusz Piechociński, Minister of Economy, for the yearly publication of "The Polish Petroleum and Natural Gas Market 2013"

Warsaw, 12 August, 2013

Janusz Piechociński – Deputy Prime Minister, Minister of Economy

Dear Sir/Madam,

You are holding another publication which sums up the current situation in the fuel and energy sector – "The Polish Petroleum and Natural Gas Market 2013". I am convinced that you will find important opinions concerning the ongoing changes in the sector. The opinion of experts and representatives of the sector is always valuable for us and taken in consideration in creating new regulations.

Competitiveness in the oil and gas sector, its balanced development and security of supplies are all very important elements of the Polish energy policy. Therefore, we undertake tasks which will help to meet the challenges of modern economy.

In the Ministry of Economy, we prepared proposals of new solutions which are supposed e.g. to facilitate running a business and eliminate barriers in accessing the oil and gas market. We also wish to strengthen the protection of the rights of sensitive recipients. Such regulations were listed e.g. in the draft of Gas Law as part of the so-called "energy tri pack".

Moreover, we prepared amendment of the order describing the principles of independent, safe LPG fuelling. The stations which will introduce such self-service will have to adapt their equipment to the new regulations. Considerable part of the sector representatives have already done that, so the costs of potential conversion will not be a great burden for the fuel stations. The draft of the order was widely consulted with representatives of the oil sector. At present, the process of its notification is coming to an end in the European Commission.

These and other actions of the Ministry of Economy are the response to the most essential needs of the fuel market in Poland. You will read in the publication about all the challenges for the sector. This is an interesting book, not only for specialists in the field of power industry, but also for the people who wish to extend their knowledge on the broadly defined oil and gas sector. Therefore I warmly invite you all to read this year`s edition.

The Economy of Oil and Gas

Natural gas storage and changes in the market

Buy in Summer – Sell in Winter

Jacek Ciborski, Maciej Szumieluk

Transformations in the natural gas market in Poland will have fundamental influence on the storage sector. As a result of liberalization of prices, additional demand for storage capacity will arise. The current investment plans of the Polish Oil & Gas Company (PGNiG) may prove to be insufficient to meet the future demand for gas storage facilities.

Natural gas storage is an inseparable component of stable operation of the gas system. It allows to assess the seasonal differences in demand, guarantee against the effects of disruption in supplies and ensure stable volumes of natural production. Underground storage facilities are particularly essential in countries highly dependent on the import of fuel – they reduce the risk related to technical failures or interrupted supplies on the part of exporter or transit country.

The process of market liberalization and elimination of restrictions in gas transmission between markets opens new market applications for gas storage facilities, which will enable optimization of the costs of gas purchase and price arbitration for turnover companies.

The existence of natural gas storage facilities, their capacity and technical parameters result in the extent of national energy security. By increasing the stability of supplies they reduce in a short time the degree of dependence on external entities. They also improve the stability of supplies in domestic market.

In a closed market of natural gas, the question of stability of supplies and secure operation of the system is the chief justification for maintaining reserves. The process of market liberalization and elimination of restrictions in gas transmission between markets opens new market applications for gas storage facilities, which will enable optimization of the costs of gas purchase and price arbitration for trading companies.

Natural gas storage facilities in Poland

In Poland, there are six natural high methane gas storage facilities of total capacity 1.82 bcm and two facilities of capacity 0.23 bcm which support an isolated low-calorific. The total injection capacity of the installations comes to 22.4 million m^3 daily and they enable withdrawal at the rate of 36.6 million m^3 a day. This volume corresponded to 49% of peak daily demand for natural gas in 2012 (72.2 m m^3).

Total capacity of the facilities could cover 49 days of average daily consumption of gas in 2012, which places Poland in the group of EU member states of the lowest gas consumption coverage index. Lower values are typical only for countries with high volume of domestic production which are supplied from the nearby deposits or which own numerous LNG terminals, e.g. Great Britain, Holland, Belgium. Countries of similar structure of supplies as Poland, even despite having a real possibility of diversification of gas supplies, are featured by considerably higher values of consumption coverage due to storage capacities: Germany – 103, France – 115, Czech Republic – 149 or Hungary – 219 days.

Moreover, dominating systems in Poland are natural gas storage facilities located in depleted hydrocarbon deposits which are characterized by relatively low parameters of injection and withdrawal in relation to their working capacity. The only storage facility built in salt-leached caverns is the one in Mogilno, which on account of high withdrawal capacity, at 18 m m^3 per day, is used to balance the system and cover short-term deficiency of the fuel. For comparison, in the whole European Union there are 142 gas storage facilities of total capacity 83.4 m m^3, out of which only 50% are installations in depleted oil and gas deposits. About 26% of all facilities are located in salt caverns and 18% in aquifer.

The owner of all storage facilities in Poland is PGNiG. To comply with regulations of the European Union, the company was made to isolate a branch of Storage Systems Operator, based on which a subsidiary was established in November 2010 – Operator Systemu Magazynowania Sp. z o.o. In May 2012 it received concession for gas storage and was designated the storage system operator (SSO). At present, all the SSO storage capacities are made available to third parties (TPA principle). SSO is obliged to run their business in a non-discriminatory manner and to make available all information needed for effective access to the system.

Natural gas reserves stored in Poland can be divided into three categories:

- The fuel stored to balance the transmission system – approx. 50 m m^3 capacity reserved for the GAZ-SYSTEM company;
- Obligatory reserves stored by companies importing gas to Poland for resale purposes. At the moment, three companies are obliged to store obligatory reserves, the largest of them is PGNiG – from 1st October 2012 to 30th September 2013 it has to store 883.7 m m^3 of natural gas. Besides PGNiG, the duty to store the reserves covers also the Handen Company and Egesa Energy Group. The remaining importers are exempt from the obligation of storing obligatory reserves. The volume of

obligatory reserves corresponds to 30 days of average daily import[1];

- Natural gas intended for trading purposes, stored trading companies in order to ensure continuity of supplies in the face of large variability of seasonal and daily demand on the part of recipients and limited possibility of satisfying it with immediate supplies from abroad.

The demand for storage capacities remains closely connected with the volume and variability of demand for natural gas. With lower temperatures in autumn and winter the consumption of natural gas increases. Domestic production and import, featured by high degree of linearity, are then insufficient for covering the whole demand for the fuel. Therefore, the demand is balanced by releasing the stocks maintained in gas storage. Higher temperatures reflect in reduced demand for heating, and by the same, lower gas consumption. In the summer, domestic production and import cover the demand entirely and the surplus is injected to gas storage facilities to be ready for the next autumn and winter season.

Demand for storage services and market liberalization

Market liberalization aims to improve competition and – as a result – abandon the price rating. Although it is assumed to be advancing gradually, there is no doubt that the ultimate method of determining the price is to be the supply-demand relation on the market.

Based on the experience of other European Union countries, the creation of common natural gas market and its liberalization open the prospect for a new method of using gas storage facilities. Along with the formation of liquid gas trading markets and shaping the market price of the fuel, arbitration operations will be possible. It will consist in using seasonal and short-term price differential.

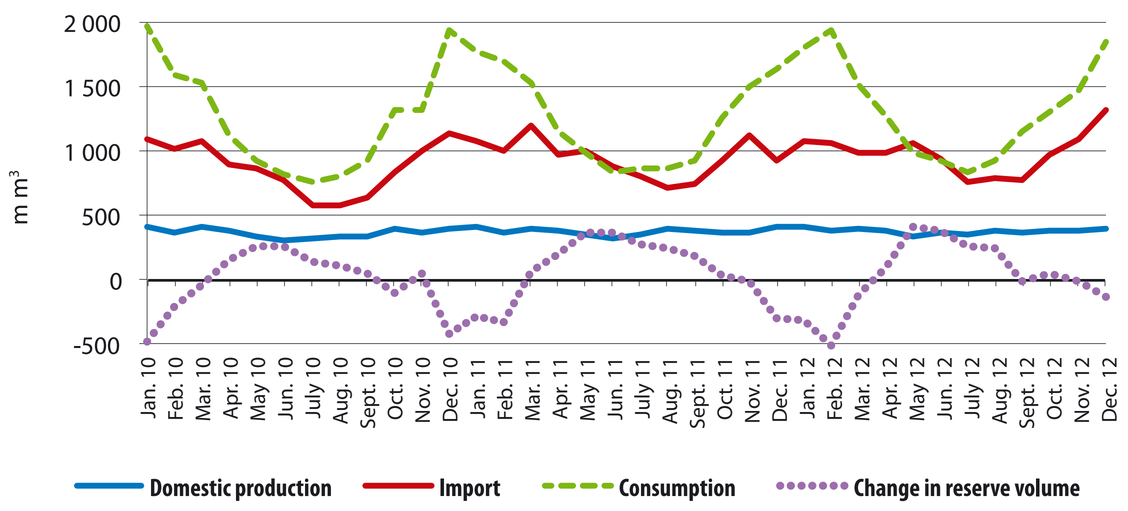


Fig. 1. Extraction, import, consumption and changed volume of natural gas reserves in Poland
Source: Compilation by PwC based on Eurostat information

When analyzing the natural gas prices, as part of spot contracts on the German hub NetConnect Germany in the recent three years, considerable seasonal difference in prices is clearly visible. The differences in the mean gas price in the summer (June–August) and winter months (December–February) in 2012 reached 0.27 eurocent for kWh, i.e. after conversion – about 128 PLN for 1000 m^3. The differential in prices may become a justification for the arbitration operations, which comes down to purchasing the

1 *In compliance with the draft Gas Law of 9th October, 2012, maintaining reserves is the obligation of companies dealing with the resale of natural gas to protected recipients. Also, the method of calculating the reserves volume has changed.*

fuel in the summer months when its prices are visibly lower, storage in the autumn, and then selling it in winter, when – on account of increased demand – the prices of gas are significantly rising.

The extension of cross-border connections and consequently, the access to new gas sources, will enable optimization of the portfolio of import contracts to satisfy the national demand for natural gas. Supplies of the fuel, executed as part of the long-term contract concluded between PGNiG and Gazprom Export, are sufficient to cover the current demand in the summer months but the demand for volumes exceeding this level appears in the winter months, i.e. in the period of high market prices of gas. On account of its oversupply and lower prices, it will be more profitable to purchase in summer. However, before delivery to the market, it will be essential to store the imported fuel.

Investments in the storage facilities in the face of demand for additional capacity

PGNiG, as the only entity which owns natural gas storage facilities in Poland, considering the forecast for increased demand for gas, runs the extension program for its storage capacity up to 3.5 billion m^3 by the year 2020. The new capacities are to be commissioned already this year (Underground Gas Storage (UGS) Wierzchowice – extension from 575 to 1200 m m^3) and in 2014 UGS Husów, UGS Brzeźnica and the first stage of the investment in Kosakowo). Completion of extended Cavernous Underground Storage (UGS) Mogilno is planned for the year 2018.

According to PwC estimates based on the forecast for optimal development of natural gas market prepared by GAZ-SYSTEM for ENTSOG and on the schedule for accessing new storage capacities by PGNiG, it may be concluded that the commissioned investments will ensure appropriate supply of storage capacity in order to secure the market against obligatory and commercial needs; deficiency may appear only about the year 2027. However, the investments do not include the possibility of additional demand that may be reported by the trading companies as a result of liberalization of the market.

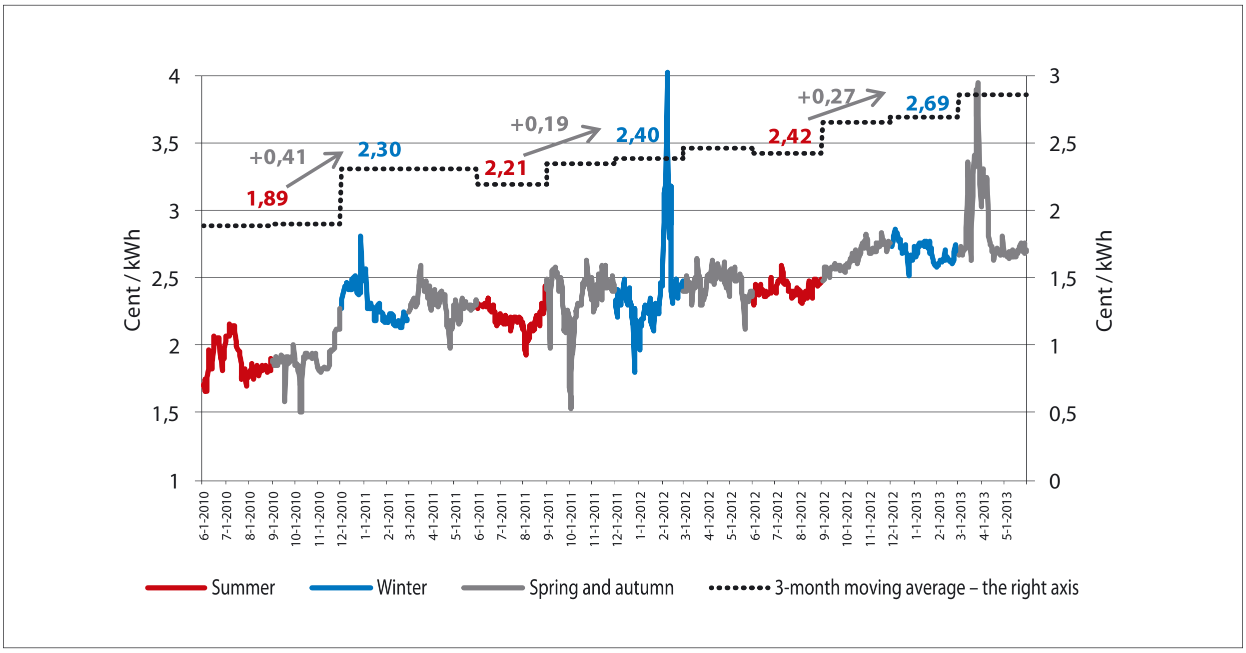


Fig. 2. Seasonal and daily differences in natural gas prices recorded on NetConnect Germany
Source: Compilation PwC based on NetConnect Germany

In connection with considerable price variations over a short time, the storage business may also be based on short-term arbitration, i.e. purchase operations while waiting for a rapid price rise, e.g. when the fuel is scarce. An example may be the situation in the German market in February 2012 or in March 2013.

Considering all the advantages above, which stem from the liberalization of the gas market, we may suppose that it will lead to demand for additional storage capacity.

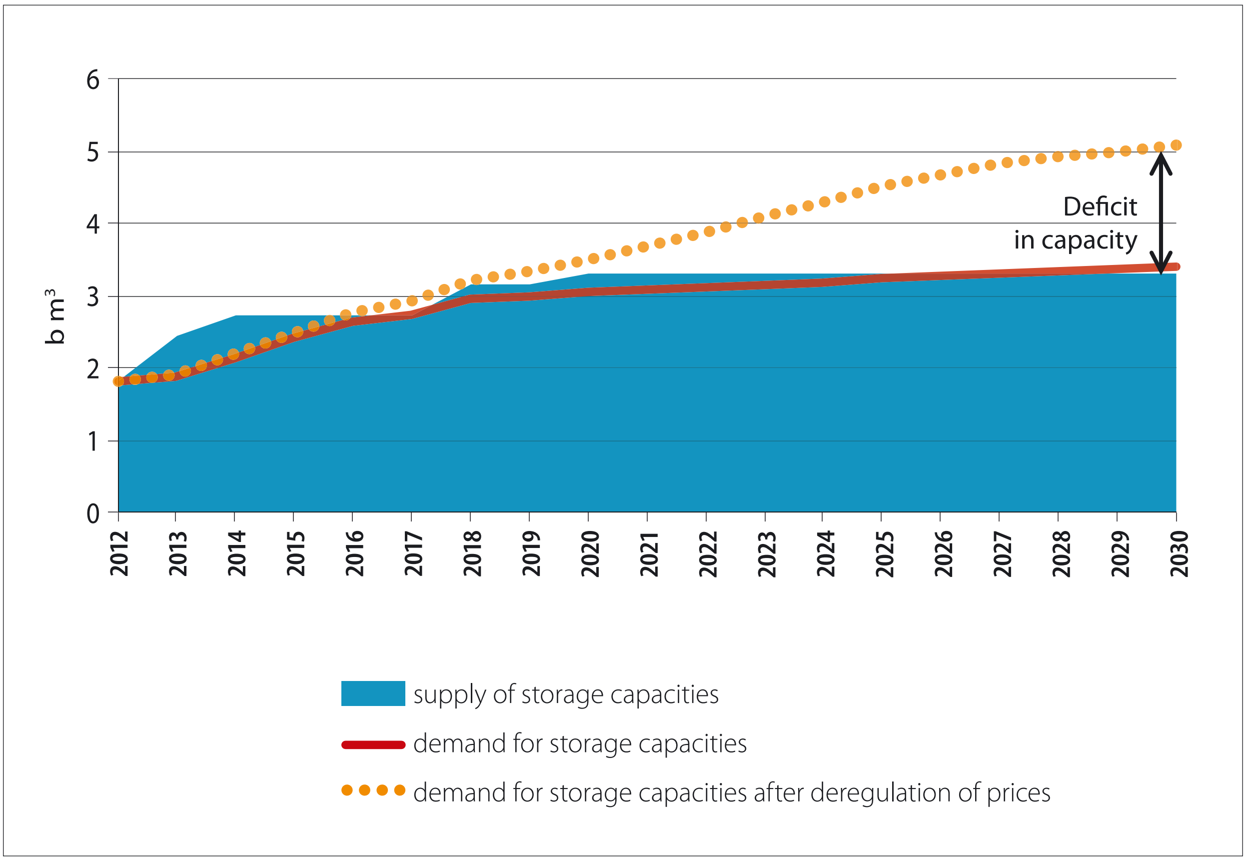


Fig. 3. Supply of PGNiG`s gas storage capacities vs. estimated demand for storage capacities in Poland
Source: Compilation by PwC based on GAZ-SYSTEM and PGNiG information

Considering a new source of demand for storage capacities which results from liberalization, the investments executed by PGNiG may be insufficient for satisfying the entire market demand. Precise estimation of the volume of additional demand is difficult to assess at the moment, as the shape and speed of changes in the gas market are uncertain. Still, on the assumption that the Polish gas market will move towards the model of the German market, we may presume gradual increase in reserves maintained for arbitration purposes. This may bring about deficiency in the market of storage capacities in Poland as soon as in the year 2016. By the year 2030, with the speed of increasing domestic gas consumption assumed by GAZ-SYSTEM, the deficiency may reach the level of 1.76 billion m^3.

Precise estimation of the volume of additional demand is difficult to assess at the moment, as the shape and speed of changes in the gas market are uncertain. Still, on the assumption that the Polish gas market will move towards the model of the German market, we may presume gradual increase in reserves maintained for arbitration purposes. This may bring about deficiency in the market of storage capacities in Poland as soon as in the year 2016.

As opposed to infrastructural investments in the field of transmission, the extension of gas storage facilities is not an indispensable condition for successful market liberalization, but its likely outcome. However, as a result of liberalization of gas prices, creating a liquid wholesale market and a system of fines for unbalanced companies, a model will arise which will enhance the economic attractiveness of maintaining natural gas reserves. When a deficit in the storage capacities occurs, it is the market that will be interested in construction of additional storage capacities.

In this respect, a definition of energy security should be reminded, as contained in the *Energy Law*, according to which it means "*the condition of economy which makes it possible to cover the current and prospective demands of recipients for fuel and energy in the manner technically and economically justified, while observing the environment protection rules*". In view of the fact that increased storage capacity in the market will favourably affect the stability of supplies, a conclusion can be drawn that by the same, it will improve the energy security; but the improvement will not result, as so far, from the intervention of the state, but it will be the effect of the market phenomena. Nonetheless, it is vital to construct an attractive system to stimulate investments.

Currently, the gas fuel storage area is subject to tariffs. The tariffs are approved by the President of Energy Regulatory Office in such a way that they can cover justified business expenses in respect of gas fuel storage and construction, development and modernization of the storage facilities, with guaranteed justified return of involved capital. In *Energy Law* the minimal rate of return on this business was established at 6%. In the recent years, the rates approved by the President of Energy Regulatory Office guaranteed the rate of return of more than 11%. However, considering the extended time of construction of a gas storage facility, and consequently postponed time until the installations generate positive financial flow for investors and a long period of time in which the facilities will be operating, the effective internal rate of return on investments, i.e. the basic index that the investors are guided by when making an investment decision is substantially lower.

Bearing in mind that the rate of return is determined as an administrative decision, the risk should be indicated in connection with maintaining the present rating policy. Moreover, the regulation which specified the minimal rate of return was removed from the storage business in the course of works on the draft *Gas Law*.

Therefore, the question has to be answered how attractive the conditions will prove to be for potential investors interested in operations in the area of gas fuel storage? For it may be possible that in spite of deficiency of capacities on the market, in case of lack of more liberal approach in shaping the prices for storage services, there will be no prospective investors in this sector.

Jacek Ciborski – Deputy Director in Oil, Gas and Chemical team, PwC

Maciej Szumieluk – Associate in Oil, Gas and Chemical team, PwC

Economy and gas

Will Polish industry have to pay more for gas than European competitors?

Mateusz Konieczny, Bartosz Safiejko

The cost of natural gas purchase is for many companies one of the key factors affecting the competitiveness of production. It is generally believed that the Polish enterprises pay more for gas than their European competitors. Is this belief justified? What will the prospective gas prices be like for the Polish industry?

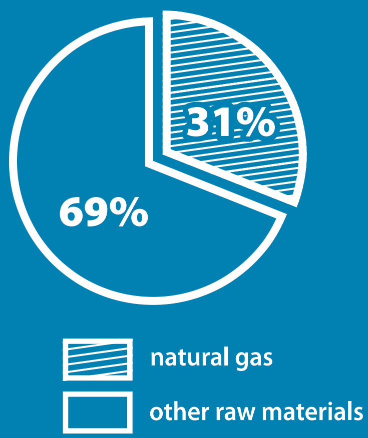
Natural gas is an essential component of the Polish energy balance – it meets approximately 14% of total national demand for primary energy. Over 60% of 15.4 billion m^3 (bcm) of gas consumed yearly in Poland falls to industrial customers. In case of some chemical companies the gas purchase scale is so big that quite often just the costs of gas acquisition determine competitive position of these companies on international market.

In search of cheap gas

Recently, a tendency can be noticed to locate chemical plants, especially ammonia production, in regions rich in natural gas – such as Middle East and Africa. It is proper to mention here also the example of the United States where the shale gas boom breathed new life into the American chemical and petrochemical industry. In April 2012, the gas price in Henry Hub reached the lowest level in 13 years (2 USD / MMBtu, that is only approx. 70 USD per 1000 m^3) – the level eight times lower than the historical maximum registered in December 2005 (560 USD per 1000 m^3). The gas price fall contributed, among other things, to lower ethylene production costs from approx. 1000 USD to a little above 300 USD per ton. Chemical companies from the United States experience their renaissance at

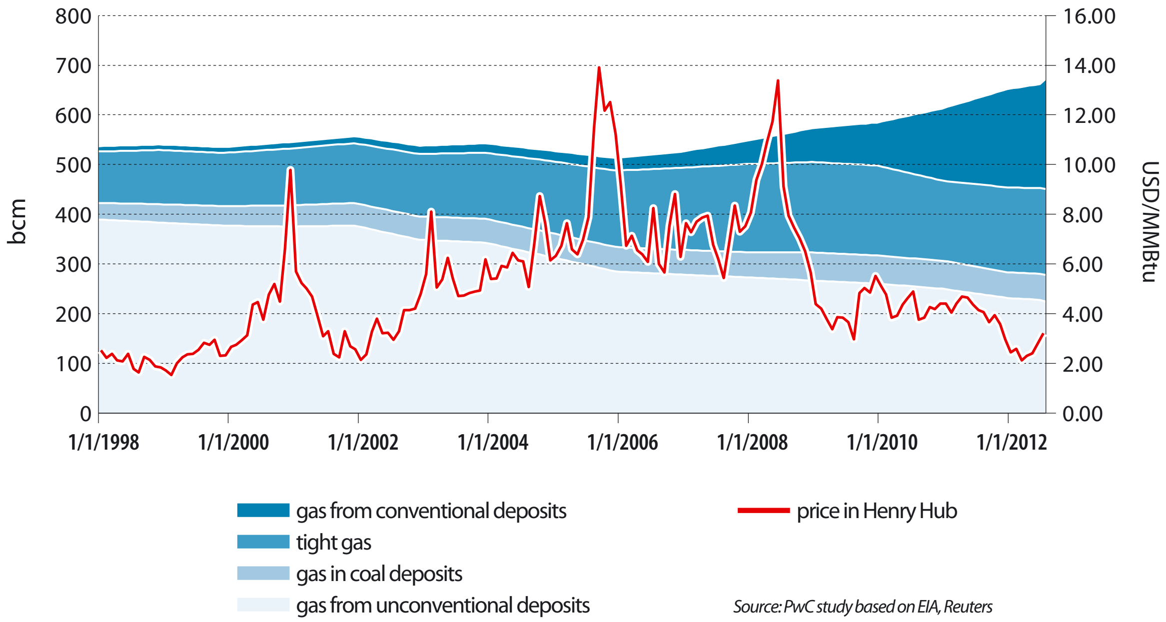
Annual consumption of natural gas by nitrogen production plants is approximately 2.4 bcm, that is over 15% of total domestic consumption. The biggest player in this region is Grupa Azoty – only the plant in Puławy consumes almost 1.0 bcm a year. According to the data for the year 2012, the gas purchase expenses in Grupa Azoty may amount to almost 31% of total raw material purchase costs.

Chart 1. Natural gas purchase expenses in the purchase structure of Grupa Azoty in 2012



Source: Presentation of Grupa Azoty results 2012

Chart 2. Natural gas extraction and average yearly gas prices in the USA [bcm; USD / MMBtu]



Source: PwC study based on EIA, Reuters

present – the evidence, among other things, is the extension of Dow Chemical and Formosa Plastics plants and reshoring of several foreign factories back home.

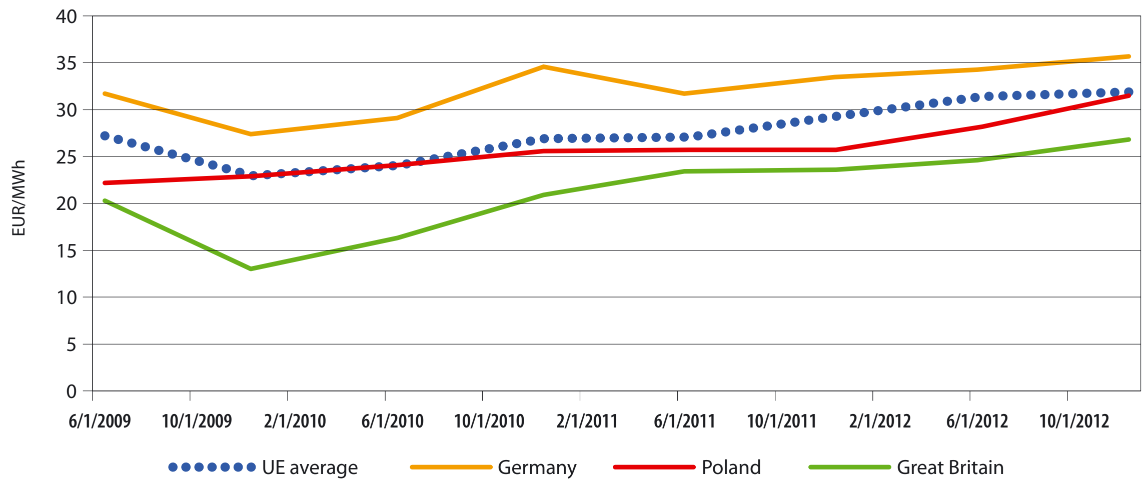
Due to the comparatively small own resources of natural gas and resulting necessity to import considerable quantities of this raw material, the prices for European recipients are at a level several times higher than in the USA. It is generally believed that Poland is among the countries with the highest gas prices in Europe, which is supposed to put the national companies in a disadvantageous position, even in relation to their regional competitors. However, is it a true conviction?

The devil is not so black...

According to the Eurostat, in the recent years (2009–2012) gas prices for big industrial recipients in Poland were approximately 7% below the European average.

There are several key factors due to which gas prices for final recipients in Poland are still at "European" level, despite high costs of import from Russia under the Yamal contract. The first and possibly the most essential one is connected with our own domestic extraction. The extraction cost of natural gas is several times lower in our country than the price paid by Poland for the Russian gas. At present, almost 30% of domestic gas consumption comes from our own deposits – taking these values into account in the price basket has considerable influence on lowering of the average price of gas acquisition. For comparison – in Germany where prices for industrial recipients are as much as 17% higher than the European average, their own extraction covers only 12% of domestic consumption. In turn, in Great Britain where the price level is only ¾ of the European average, demand coverage index by own extraction is over 50%. Therefore, the more gas comes from own deposits, the lower the price for the final recipient.

The second key mechanism which keeps in check the prices of natural gas in Poland is their tariffication, that is the procedure of gas companies' price list approval by the President of the Energy Regulatory Office (URE). In accordance with the principle of energy law, the tariffication is to "protect recipients' interests against groundless level of prices and charges". Consequently, thanks to the decisions of the URE President, considerable rise in the price of imported gas as part of the Yamal contract in the recent years only partially contributed to higher tariffs for final recipients. Although the Polish Oil and Gas Company (PGNiG) suffered because of that, as in the years 2011–2012 it reported loss in gas trading for six consecutive quarters, the Polish industry could pay for gas more or less the same price as its western competitors at that time.



Postponing the introduction of excise duty on natural gas was the third factor in favour of the Polish recipients. This burden already functions in the majority of West European countries and it is a mark-up on gas price from several to a dozen or so per cent. According to the European Union requirements, the excise duty on natural gas will come into force in Poland in November 2013. In justification to the draft amendment to the act the government estimates that it will be equivalent to 3% of average wholesale gas price. Due to the working character of the present arrangements and planned possibility of obtaining exemption by some industrial plants, the real influence of excise on gas price is difficult to estimate at the moment.

In spite of high prices of this raw material imported from Russia and contrary to the general conviction, the nominal cost of natural gas purchase by Polish industrial plants was at similar level to that in Western Europe in recent years. Is it possible, however, that the situation will remain the same in the long run?

The volume of gas extraction in Poland is approx. 4.2 bcm and it has been at stable level for about 10 years. This segment requires constant actions; for example, in the first quarter of 2013 above 60% of investment expenditures of the PGNiG Group was devoted to hydrocarbon exploration and production. However, each zloty spent in this way returns with interest – the cost of gas extraction from own deposits is even several times lower than gas purchase prices abroad, which makes it the cheapest incoming stream in the PGNiG gas price basket.

It can be worse if no action is taken

In the present situation of the Polish gas market, the basis for a long-term maintenance of the current price levels is uncertain. Firstly, with the increasing demand for natural gas in Poland, the share of own extraction in gas balance will gradually diminish. Secondly, it is expected that increasing exploration costs connected with drilling deeper and deeper will have an impact on the increase of unit price of extracted gas. Thirdly, insufficient import infrastructure still does not give Polish customers any real alternative for gas purchase from Russia. It can be stated that unless proper action is taken to implement new extraction projects and develop the infrastructure, the situation of Polish recipients may deteriorate.

The gas price for the final recipients is the outcome of the costs of its acquisition. Due to this, directions of gas supplies are of key importance in price development. By analysing the present situation on the gas market in Poland and its possible future shape, four main directions of gas acquisition can be distinguished.

First direction: domestic extraction

The volume of gas extraction in Poland is approx. 4.2 bcm and it has been at stable level for about 10 years. This segment requires constant actions; for example, in the first quarter of 2013 above 60% of investment expenditures of the PGNiG Group was devoted to hydrocarbon exploration and production. However, each zloty spent in this way returns with interest – the cost of gas extraction from own deposits is even several times lower than gas purchase prices abroad, which makes it the cheapest incoming stream in the PGNiG gas price basket.

Together with exploitation of subsequent deposits, the exploration becomes, however, more and more expensive, because it is necessary to drill deeper wells to reach the lower-situated deposits. Still more expensive is prospecting for natural gas in shale beds, which requires advanced technologies like horizontal drilling and hydraulic fracturing. All this increases the cost of production. Therefore, even if Polish shale gas programme is successful, the gas from unconventional deposits will be much more expensive than the one extracted at present and in extreme case, its exploitation may turn out to be completely unprofitable. To maintain or to strengthen the present influence of own extraction on gas prices in Poland – despite the shale gas programme – exploration for new conventional deposits, easier and cheaper in exploitation, should not be forgotten.

Second direction: Russia – the Yamal contract

In contrast to own extraction, gas imported under the Yamal contract is the most expensive stream of this raw material in Poland. It also has the largest influence on the price development for final recipients – the minimal Yamal gas reception provided for by PGNiG in Poland is approx. 9 billion m^3 annually, that is almost 60% the present Polish demand.

Despite the lack of official information about Gazprom prices for individual recipients it is generally believed that Poland is among the countries who pay the most for the Russian gas in Europe. These opinions are supported by "leaks" from the Russian media (journal *Izviestia*, earlier *Viedomosti* and the *Interfax* agency), according to which in the recent years PGNiG paid for the Russian gas about tens of percent more than importers from Western European countries. Despite the price reduction obtained by PGNiG in December 2012 (estimated in media as 15%) the

situation of industrial recipients has not significantly changed. In spite of relevant fall in the import price, the tariff for industrial recipients has been lowered merely by 3.3%.

Difficult negotiating position of PGNiG doubtlessly has an influence on the high prices of the Russian gas. With limited possibilities of gas purchase from alternative sources, even the greatest Polish player has little chances of changing the conditions imposed by Gazprom. The development of import infrastructure is of key importance from this perspective.

Third direction: cross-border connections (interconnectors)

Supplies from directions other than the eastern one, through gas interconnectors, that is gas pipes joining Polish gas system with systems of other countries, create an alternative for the Yamal contract. From PGNiG's perspective, the existing connections on the German and Czech borders allow to keep the volume of Russian gas import to Poland at the minimum level provided for in the Yamal contract, while the remaining part of demand is covered through available western and southern connections. But from the point of view of final recipients, and especially industrial plants, the planned construction of other interconnectors (with Germany, the Czech Republic and Slovakia) can bring almost only advantages.

Extension of import infrastructure will allow to increase the activity of independent gas suppliers on the Polish market, which will finally give customers the possibility to choose the most profitable offer from several competitive ones. What is more, the access to the German market will let the largest industrial recipients optimize their gas supplies portfolio and take advantage of temporary price reductions in Western Europe, that is to purchase gas directly within immediate (spot) contracts.

The Czech Republic is a superb example of influence of the extension of transmission infrastructure on the dynamics of gas market development, where the construction of cross-border connections in localities Hora Svaté Kateřiny and Waidhaus enabled free flow of gas from and to Germany. This fact, in connection with the liberalization process, resulted in the fall of market share of the earlier monopolist, the RWE company, from 99% to 51% within 5 years, in favour of independent suppliers, which in the final result made gas prices in the Czech Republic closer to those in Western Europe.

The liquefied natural gas (LNG) terminal constructed at present in Świnoujście is the first such investment in this part of Europe. In the initial phase of its functioning it will allow to collect up to 5 bcm of gas annually, which can have significant influence on the shape of the Polish price basket.

Fourth direction: the LNG terminal in Świnoujście

The liquefied natural gas (LNG) terminal constructed at present in Świnoujście is the first such investment in this part of Europe. In the initial phase of its functioning it will allow to collect up to 5 bcm of gas annually, which can have significant influence on the shape of the Polish price basket. So far, the possibilities of gas import to Poland have been strongly limited by the existing network of gas pipes. Construction of the LNG terminal will allow the Polish gas trade to take part in the quickly growing LNG market due to the purchase of gas from such countries as e.g. Qatar, Algeria and Nigeria. Recently, potential export of natural gas surplus from unconventional deposits in the United States has been discussed, which can change the image of the world gas market.

At present, the LNG prices differ considerably depending on the region: in the USA the quotations of liquefied gas prices oscillate around 200 USD/t, while in Europe this is approx. 500 USD/t, and in Asia – because of the quickly growing demand – even 800 USD/t.

The export of gas surplus obtained from shale beds in the United States to Asia and surely to a lesser degree to Europe should be natural consequence of such condition. The first long-term contracts for delivery of American liquefied gas have already been signed. What is important, these contracts move away from LNG price indexing based on quoted oil prices. Contracts for gas supplies from the USA through Sabine Pass terminal to the Korean Kogas plant, British Gas and Spanish Gas Natural, based on the formula of 115% price in Henry Hub can serve as an example.

Construction of the LNG terminal in Poland fits well in the above market trends. Although the Asian countries will rather go first in the queue for American gas (due to large demand and high prices), its appearance on the market will cause redirection to Europe of a part of LNG supplies from outside the USA (Qatar, Nigeria) currently provided for the Asian market. It can give European recipients wider range of suppliers to choose from and in consequence, larger influence on the costs borne for purchase of this raw material. Thanks to the possibility of participation in the LNG market, also the Polish customers might be able to take advantage of these changes.

Future of gas prices for industrial customers

Discussed tendencies will influence the development of prices of individual streams of gas flowing into the Polish market and at the same time on the price for the Polish industrial and individual customers. A factor, which may additionally affect price levels, is the present liberalization of gas market in Poland.

In an ideal scenario, development of gas infrastructure (interconnectors, the LNG terminal) and currently proposed regulatory solutions leading to liberalization of the market will influence the development of recently opened gas exchange, where natural gas from different sources will be directed (own extraction, the Yamal contract, Western Europe, the LNG market). New independent suppliers and biggest industrial plants, active on the exchange will optimize gas purchases, which will influence the shaping of prices of this fuel at the level acceptable for most recipients.

Long-term contracts, which guarantee the stability of deliveries, will still be the trade basis. The example of West European countries shows, however, that the indexation of contracts will, in time, be based on gas exchange quotations and the spot trade will begin to play ever greater role allowing to take advantage of the temporary price reductions on the market. Creation of new storage infrastructure which allows to postpone consumption of fuel purchased at bargain prices, may also turn out to be profitable.

The success of the above described scenario for development of the Polish gas market depends on many factors. It is true, as it was noticed earlier, that prices for industrial recipients in Poland are not much different at present than the average European ones, however, it can be stated with a sufficient degree of certainty, that lack of any actions is the worst possible solution. Implementation of "an ideal scenario" requires from the market participants and regulators a coherent strategy, great effort and making significant investment expenditures. The first steps – such as construction of the LNG terminal, provision of transmission capacity on the borders with Germany and the Czech Republic and implemented at present market liberalization programme – have already been taken. It will depend on the subsequent actions, what price, in comparison to the European competitors, will be paid for gas in the future by the Polish industrial plants.

Chart 4. Average LNG prices in different regions in July 2013 [USD/MMBtu]

Source: PwC study based on Waterborne Energy

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Przedsiębiorstwo Eksploatacji Rurociągów Naftowych „Przyjaźń" S.A.

PERN „Przyjaźń" S.A. is a dynamically developing Group of Companies, which includes five subsidiaries companies besides 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 also includes Międzynarodowe Przedsiębiorstwo Naftowe SARMATIA Sp. z o.o. – a study company established to examine profitability of development of the Euro-Asian Oil transportation Corridor. In total the Group owns over 3.0 million m^3 of storage capacity for crude oil and 1.8 million m^3 for liquid fuels. It also manages the sea terminal handling 34 million tonnes of crude oil per year. It also provides services within transport, handling and storage of crude oil, reloading, blending of fuels as well as laboratory research into petroleum products.

PERN „Przyjaźń" S.A. – dominant company within the Group, is 100% owned by the Treasury. It was established in 1959 in order to transport crude oil from Russia to Poland and East Germany. The Company operates directly a network of over 2.5 thousand km of crude oil and product pipelines.

The Company's basic task is to operate the network of pipelines transporting Russian crude oil for the biggest producers of fuels in Poland and in Germany. This services is provided via „Friendship" pipeline, running from Adamowo (located at the border of Poland with Belarus) to Płock, and then to Schwedt in Germany. Pomerania Pipeline, connecting Płock with Gdańsk, also plays an important role in providing Polish refineries with crude oil, and it allows us to transport crude oil in both directions. Crude oil may be pumped to Gdańsk Naftoport, and then it is exported by tankers. This pipeline also allows us to provide Polish and German refineries with crude oil originating from other directions than „Friendship" pipeline. In consequence this means „sea" supplies, their handling at Naftoport and them pumping crude oil towards Płock.

Besides the network of crude oil pipelines, PERN „Przyjaźń" S.A. also owns a network of product pipelines, used for transporting liquid fuels produced by refineries. This network radiates from Płock towards Warsaw, Poznań and Częstochowa.

An extremely important service – for our country's energy security, provided by PERN „Przyjaźń" S.A. is crude oil storage. The Company owns three tanks farms: in Adamow, Płock and Gdańsk, equipped with tanks capacities from 32 thousand to 100 thousand m^3.

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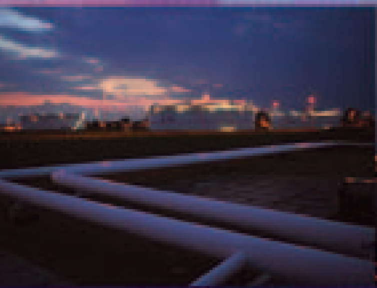
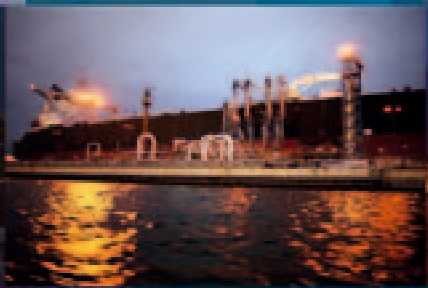

Leader in oil and fuel logistics

Subsidies for the oil and gas sector

How to reach for funds still this year?

Beata Tylman, Tomasz Sajkowski

Shrinking world reserves of easily accessible natural resources and enormous international competition demand constant development from the companies operating in the oil and gas market. Obviously, one of possible scenarios in this case is prospecting for new deposits of raw materials which will ensure long-term profitability. However, their scarce availability requires more and more advanced technologies, which on the one hand will allow cost-effective extraction of deposits unexploited so far, on the other they will optimize technologies for transportation or raw material processing into making the final product.

This development cannot be achieved without research and development activities (R+D) and just such investments are and will soon be the main subject of subsidies both from domestic and international sources.

Sources of state aid for R+D activities

In order to identify the structure of the state aid sources, they can be divided into three main sources available currently and in the near future. They are both national sources, allocated by the National Centre for Research and Development or the National Fund for Environment Protection and Water Management and the European funds which will be available in the framework of the new financial EU prospect, beginning in 2014. These, in turn, will be allocated as part of the Structural Funds (destined to support the regions, including Poland or economic sectors, which are unable, without financial support, to match the average economic level in the EU) and by direct support from the European Commission within the framework of the The EU Framework Programme for Research and Innovation – Horizon 2020. Subsidies for R+D projects are and will be available for all businesses, regardless of their size or origin of capital.

The EU funds for supporting the R+D projects, as part of the current financial EU prospects (2007–2013) are basically distributed at the moment. The analysis of their application and intention may, however, serve as helpful source demonstrating the condition of development of the oil and gas market in Poland.

The results of tests conducted by PwC indicate that by the year 2012, within the framework of the most popular of the present sources of support for R+D works in Poland (activities 1.4 of Operational Programme Innovative Economy), very few projects received subsidies in the chemical, oil, gas and fuels sector, which finally was not very popular comparing to the other sectors and types of projects. Leaders in subsidized investments are companies in the IT sector, which is caused by a large number of enterprises of this type in Poland. It seems however, that in order to compete in international market of oil and gas, the entities operating in Poland must put greater emphasis on development of new technologies which will allow them to become visible in the difficult, international market.

It should also be remembered that subsidies help finance the most innovative projects, therefore the most risky ones. This may be the significant motivating factor for beginning this type of activities. Risk is an inherent part of it; if in the course of execution of R+D project it turns out that its further continuation is groundless, the project may be stopped, whereas the grant – as a general rule – should be paid by that moment.

Table 1. Division of main sources of state aid to support the research and development activities (*Source: PwC's own study*)

National sources	Structural Funds within Operational Programmes 2014–2020	Direct programmes of European Commission
• National Centre for Research and Development (NCBiR) • National Fund for Environment Protection and Water Management (NFOŚiGW)	**Operational Programmes:** • Programme concerning innovation, scientific research and connections with the business zone – Operational Programme Innovative Development (PO IR) • Programme concerning low emission economy, environment protection, prevention and adaptation to climate changes, transport and energy security • Programme concerning the development of competencies and abilities and good governance	• Horizon 2020 – The EU Framework Programme for Research and Innovation

How to prepare a research and development project?

Many Polish businessmen are not aware of the fact that daily work of their engineers – with all the advancement of available technologies, validation of the methods used or enhancing particular solutions, also working on new products, development of new formulas or moving from laboratory scale to industrial one constitute *de facto* the research and development activities for which subsidies can be obtained. On account of that, when preparing a R+D project, the first step should be the definition of what the engineers are really doing and what they intend to achieve/improve/enhance within the nearest 2–3 years (it is a typical period for a completion of most R+D projects).

When this fundamental question is already answered, the companies which are planning to apply for financial support must consider what the possible methods of reaching the assumed objectives are, what risk is related to each of them and which of the methods will be the most cost-effective. The aspect of monetization of the R+D project is the more vital that subsidized projects must be translated into the actual improvement of competitiveness of the business – i.e. expected results of the research project should be attractive and competitive in the market. The time has already gone by (hopefully irretrievably), when subsidies were granted to sophisticated projects with no correlation between expectations and market demand.

Possible effects of subsidized R+D projects

Every entrepreneur who can answer all the questions above, who will calculate expenses, prepare schedule and invent a product/technology whose elaboration will potentially translate into the business profitability, may apply for subsidies for the research and development project which – in turn – may be finalized in several possible ways. This may be e.g. a prototype of new product/technology. Although the prototype itself should not become the source of income for the beneficiary (he will then have to deduct the income from subsidized investment ex-

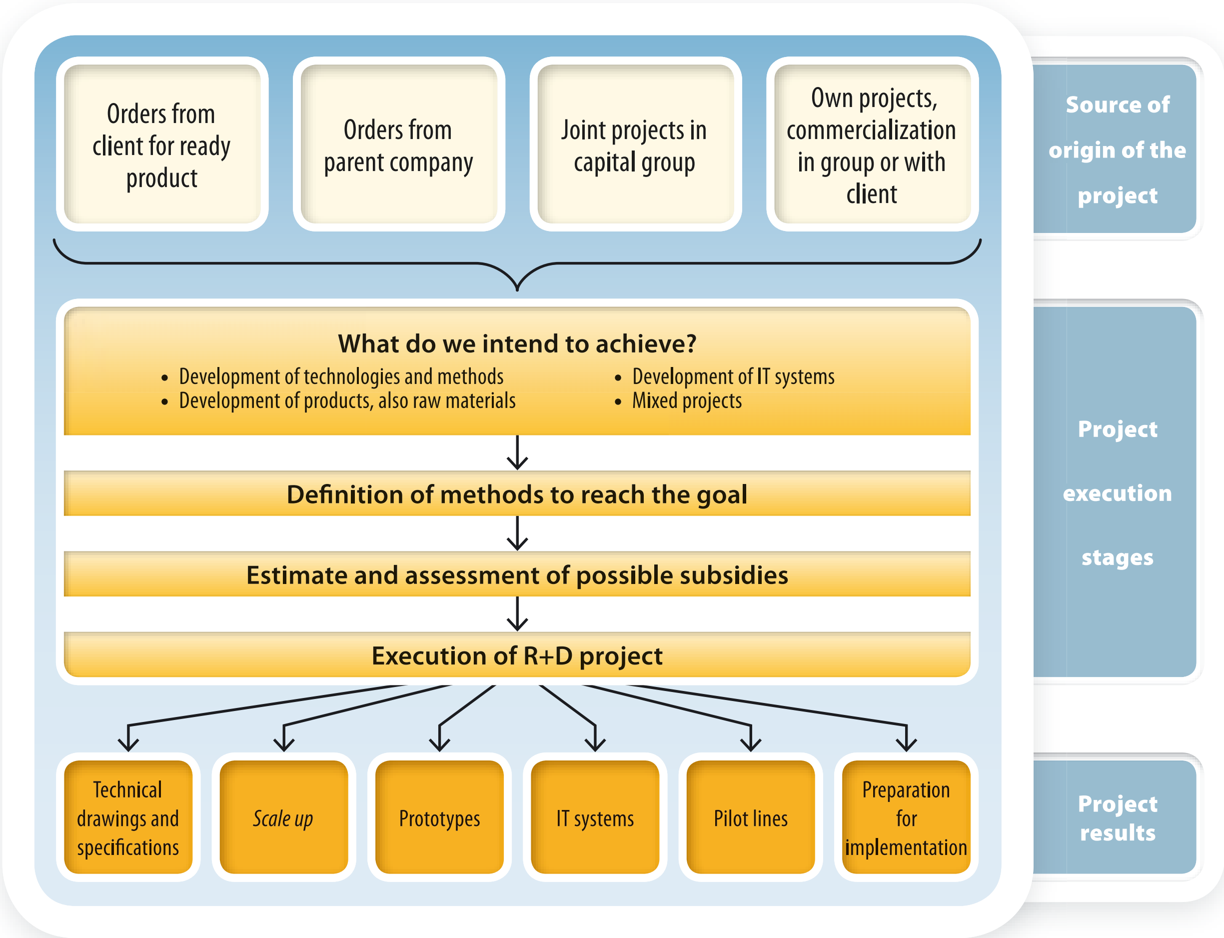

Fig. 1. Construction of research and development projects
Source: PwC`s own study

penses as he is using the prototype), it can be the basis for creating industrial copies of elaborated product. Companies may also, as part of the project, create demonstrational/pilot lines which will allow to test how the new technology performs in the real market situations.

However, completion of the R+D works need not have such material form. As the effect of the project, also technical drawings may arise to facilitate the production of new products /technologies, which – specifically in case of large and costly devices – may be the most cost-effective solution for smaller companies operating on the market.

Although the effects of the projects must be commercialized, the method of realization is to a large extent free. The beneficiary of subsidized project may assume implementation of the new product/technology in his business. It can also be assumed that the effects of the project will be sold to another company – which very often comes true in case of technology elaborated “to order” or in capital groups. Nonetheless, the programmes often set maximum time limits, when technology must be commercialized, which means implemented, e.g. two years following the R+D project completion.

Flexibility of principles of the support schemes – both with regard to the effects of the project and methods of using them – strongly supports applying for subsidies for the research and development projects. The main stages of such operations are presented in Fig. 2.

Available sources of support

By the time the European Union funds for the years 2014–2020 can be used, entrepreneurs in the oil and gas market may count mainly on domestic aids. Among the support tools available recently and in the near future, there are e.g. programmes: GEKON, Demonstrator+ and the programme dedicated to companies operating in the field of prospecting and extraction of natural gas from shale formations – *Blue Gas*.

As a rule, within the framework of programmes listed above, beneficiaries, including entrepreneurs or scientific research consortia may obtain support from 25% of eligible costs even to 100% of incurred expenses. Percentage volume of support depends, on the one hand, on the type of beneficiary (higher funds go to companies in the sector of small and medium-sized enterprises and scientific research units – the expenses of scientific research units can be fully subsidized from state funds) and also on the type of conducted research. These can be divided into industrial research, i.e. research aiming at acquisition of new kind of knowledge and skills (subsidized from 50% to 70%) and development studies, i.e. work aiming at acquisition, merging, shaping and using currently available knowledge and skills (subsidized from 25% to 45%).

As part of executed operations, beneficiaries may also apply for an additional bonus increasing the percentage value of subsidies by 15 percentage points. The requirement in this case is to fulfill the conditions for receiving such a bonus, e.g. by establishing cooperation with a research unit, an enterprise in the sector of small and medium-sized companies or wide distribution of the project results.

Eligible costs in R+D projects

The catalogue of eligible costs in case of research and development projects covers most expenses which can be connected with executed tasks. The subsidies usually cover the following costs:

- costs of employment (gross costs with employer's contributions) of workers executing the R+D projects,
- amortization of purchased or produced research and development apparatus,
- amortization of buildings, lease/use of land,
- purchase of non-material and legal values,
- operational costs (e.g. materials, advisory services, business trips),
- general costs (e.g. administration, media, accounting) – depending on the programme, maximum 8÷15% of total investment costs.

Programme *Blue Gas*

The objective of implemented – jointly by the National Center for Research and Development and Industrial Development Agency – programme *Blue Gas* is "the development of technologies connected with extracting gas from shale in Poland and their implementation in operations of the enterprises in Poland".

Only scientific research consortia whose leader is the entrepreneur interested in implementation of the results of conducted research work may apply for subsidies for research phase and construction of pilot lines. As part of the first *Blue Gas* call for proposals resolved in May, 15 projects obtained subsidies in which – predominantly – PGNiG participated (10). An example of subsidizing four projects in which less recognizable enterprises were the leaders (Baltic Ceramics, Strzelecki Energia, Polymem Ltd., SIM Gdynia Holding) proves, however, the legitimacy of applications for subsidizing also smaller entities operating on the market.

Second edition of *Blue Gas* call for proposals is planned for the fourth quarter of 2013.

Programme GEKON

Another of currently available sources of funding (call for proposals is planned for the fourth quarter of 2013) is the GEKON programme. What is interesting, subsidies in this programme are intended not only for execution of R+D studies but also for implementation of their results (i.e. investment operations) in the economic activities of the enterprise. The most important of the requirements, which are obligatory with applications for funds up to the sum of 10 million PLN (for R+D stage) and to the sum of 20 million PLN (for implementation stage) is the range of projects which must cover ecology-friendly technologies.

Actually, this is one of the few sources which also help large-scale enterprises finance investment operations and develop infrastructure. No wonder that it arouses considerable interest in this kind of funds.

Programme Demonstrator+

The last of the available (according to schedule) sources of funding for the R+D projects is the programme Demonstrator+. Although the decision on organizing another call for proposals in 2014 has not been taken yet (it depends on availability of the funds), the entrepreneurs may consider this tool as potential source of subsidies for large pilot research projects.

Minimum eligible cost of the projects applying for funds is 5 million PLN. Moreover, substantial value of maximum subsidies (100 million PLN) has a great impact on the attractiveness of Demonstrator+ among the Polish entrepreneurs. In the most recent call for proposals enrolment, which terminated in May 2013, 140 applications were collected for total sum of 2.7 billion PLN.

Demonstrator+ provides the possibility of financing a small-scale installation, before it reaches its ultimate, target size. The expenses spent on such installation, including raw materials and supplies used during the project (tests) may also be funded.

Effective use of energy

Besides the research and development projects, entrepreneurs using at least 20 GWh of energy annually may apply for funds for conducting audits of energy process technologies, buildings, internal transmission networks or energy sources. What is essential, as

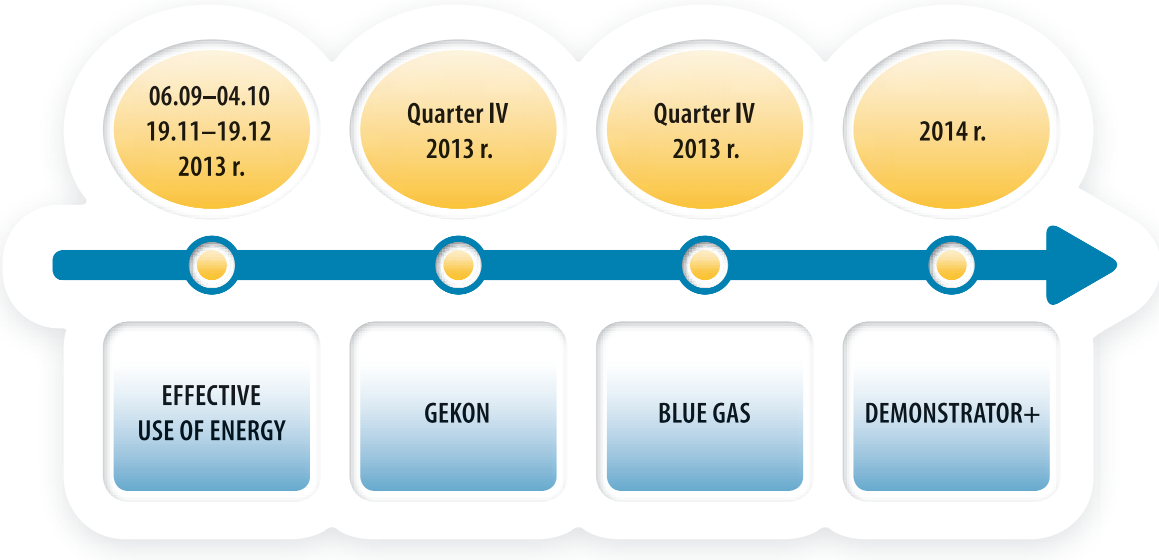

Fig. 2. Schedule for competitions
Source: PwC`s own study

this is a programme organized by the National Fund for Environment Protection and Water Management (NFOŚiGW), when calculating the volume of energy consumption by a specific entity, all its sources and shapes are considered, e.g. electric energy, cool, heat, chemical energy and gas. Funding the services connected with audit may amount to 70% of its costs and may constitute *de minimis* aid (may not exceed 200 thousand euro in a three year period).

The companies which have the results of energy audit (subsidized as part of the Programme or from other sources) which facilitates the possibility of increasing the energy effectiveness of examined area by at least 7%, may also apply for preferential loan for implementation of activities oriented towards improvement of energy effectiveness of the company. In this part of the Programme, the applicants may receive a loan up to 75% of eligible costs of the investment, with interest rate equal WIBOR3M – 100 basis points (but no less than 3.5% a year).

High amount of potential loan (up to 90 million PLN) makes this tool a desired source of financing even for large investments.

Examples of subsidized projects

When quoting the list of beneficiaries of operation 1.4 PO IG which provided subsidies for the largest number of R+D projects so far, several interesting features of the oil and gas projects can be noticed. Average time span for completion of the project is approx. 26 months, and average value of subsidies is about 4 million PLN. However, it must be remembered that there are also projects of small and medium-sized companies which benefit from higher subsidies. In turn, the average value of eligible costs in the R+D projects amounted to 6 million PLN.

The subsidized projects comprise such topic areas as:

1) **New types of fuel** – development of product and production method, e.g. "Innovative technology for producing 2nd generation fuel in the process of waste depolymerization".
2) **New formulas of chemical compounds** – e.g. "Extending the offer by innovative fabric softener".
3) **Extending the product range** – e.g. "Development of innovative fertilizer produced with the use of post-fermentation".
4) **Recycling, repeat use of raw materials and renewable raw materials** – e.g. "Breakthrough in production of polyurethanes: Innovative technology for obtaining oligomerol based on renewable raw materials".
5) **New methods and systems applied in installations** – e.g. "Development of the prototype of installation for monitoring the rate and degree of biocomponent and biofuel ageing".

What next?

If everything goes according to the schedule and promises of the government and European agencies are kept, already in the second half of the year 2014 new call for proposals for subsidizing projects from the EU funds can be expected. There will be both call for proposals organized by the Polish institutions as part of Structural Funds dedicated for Poland and also Pan-European call for proposals organized directly by the European Commission. It should also be kept in mind that – in unison with preliminary assumptions of new principles for fund distribution – the aid for investment activity connected with expansion of plants for large companies will take the shape of preferential loans. In this case, non-returnable subsidies will most likely be available only for research and development operations or possibly, activities associated with environment protection.

In this context, attention should be drawn to the sources of funding the R+D works distributed directly by the European Commission. So far, they enjoyed much less popularity among the Polish companies, which might have been the effect of availability of funds dedicated to Poland and also fear about competition against the European companies or finally the language barriers – all applications for call for proposals organized by the European Commission usually have to be prepared in English.

It is expected, however, that in the years 2014–2020 the last such a huge amount of money dedicated to Poland will be available. After that, our national companies, including these in the oil and gas sector, will have to compete for funds in the European market. So, maybe it is worth learning how to apply and use the possibilities offered to entrepreneurs by Programme Horizon 2020? There will certainly be funds for research and development in the EU, also after the year 2020.

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The article describes the situation for 31 July, 2013.

Amendments to the Geological and Mining Law

An acceleration of oil and gas exploration in Poland owing to changes in law?

Tomasz Barańczyk, Grzegorz Kuś

Information about unconventional gas deposits in Poland as estimated by different institutions is mostly based on outdated geological data. It is estimated that in order to better understand the potential of unconventional deposits in Poland, at least 150–300 prospecting boreholes must be made. With this in mind 48 boreholes made already are definitely not enough.

The exploration, recognition and exploitation of minerals are generally subject to licence at the moment. The requirement to obtain a concession also concerns minerals like hydrocarbons. According to the presently binding Geological and Mining Law, concessions for the exploration, recognition and exploitation of hydrocarbons should be granted based on tender. However, owing to various circumstances (e.g. issuing the concessions under the previous Act of Geological and Mining Law and the issues concerning the so-called "concession priority") the current tenders for concessions for hydrocarbon exploitation are rather exceptions to the rule than the rule itself.

According to the latest version of the draft of changes to Geological and Mining Law as well as some other acts, there will only be one recognition and exploitation concession and exploratory activities will only have to be reported.

In October 2012, with increased interest in exploration for gas from shale formations, the government adopted principles related to changes in the system of concessions in Poland. One of the main demands presented in these principles is the liquidation of exploration concessions. According to the latest version of the draft of changes to Geological and Mining Law as well as some other acts, there will only be one recognition and exploitation concession and exploratory activities will only have to be reported.

As of 1 August 2013, 236 concessions for exploration and recognition of oil and natural gas deposits have been issued in Poland. Of these 107 concerned unconventional deposits.

Acceleration?

According to the estimation of the Ministry of the Environment which prepared the above mentioned draft, thanks to the liquidation of exploration concessions, the geophysical research market will be liberalized, which is supposed to speed up exploration works in Poland. In justification of the draft of the legal amendments of 1 August 2013, the Ministry of Environment indicates directly that *"(…) Exclusion of geophysical research from concession restrictions should lead to an increased availability of the basic geological information obtained in this way, through a simplification in the procedures which grant permission to carry out the works. Furthermore, this regulation ought to further increase the number of entities which carry out the exploration activities (…)"*. Additionally regarding, in estimation of the regulation's effects it is stated that *"(…) deregulation of the legal provisions which concern conducting hydrocarbon exploration should have a positive effect on the development of exploration activity in Poland (…)"*. When the new regulations come into force, the only thing that will be necessary for carrying out exploration operations will be to report a schedule of geological works to the Minister of Environment.

However, according to entrepreneurs *„(…) against the intentions of the project's authors, the suggested solution will not provide an additional incentive for* the *development of exploratory activity in Poland but it will simply cause a significant slowdown in this sector (…)"* (the position taken by PGNiG S.A. during public consultations) and *„(…) conducting costly research does not guarantee the entrepreneur an increased chance to gain the recognition and exploitation concession, especially offshore and it may discourage them to identify new areas. (…)"* (the stand taken by LOTOS Petrobaltic).

It seems that entrepreneurs' fears are justified. First of all, the lack of exploration concessions may cause the exploration works to be conducted only at a minimum level in order to derisk the acreage and increase potential recovery of invested funds. Additionally, because of the reduction in the time of the exclusive right to use the geological information from 5 to 2 years, most likely only such research will be carried out that can be used within 2 years.

In consequence, it is likely that regarding the effect of liquidation of exploration concessions, the anticipated growth in activities in hydrocarbon exploration operations will not take place.

New concessions and NOKE

The liquidation of exploration concessions is correlated with the introduction of recognition and exploitation concessions granted for a period from 10 to 30 years and with the appointment of the National Energy Minerals Operator (NOKE).

Recognition and exploitation concessions are to be granted in tenders organized according to new rules. The tender proceedings will consist of three stages which include a qualification procedure, a tender and the conclusion of a contract for cooperation with NOKE.

The tender criteria, apart from technical issues, are supposed to focus mainly on the amount of remuneration offered by investor for establishing the mining usufruct right. Successful tenderer or tenderers will enter a contract of cooperation with NOKE and each party of the contract will be granted concession.

The institution of NOKE is nothing new in the world. Similar entities operate in many countries, e.g. the Norwegian Petoro or Danish North Sea Fund. However, there are certain fears that participation of NOKE could cause delays in the decision-making process between the parties of the contract on cooperation. Even though in the latest version of the draft law the power of veto was cancelled, nonetheless the introduced procedure of protest can lead to decision inefficiency among members of the cooperation contract. In this context, it is not certain whether the participation of NOKE will constitute a value added for the current holders of exploration and recognition concession who – according to proposed regulations – will be able to decide whether they wish to cooperate with NOKE at the exploitation stage or not.

For current holders of exploration and recognition concession most essential are the temporary regulations which are supposed to grant them exploitation concession without tender proceedings. The appropriate formulation of these regulations is particularly significant in the context of the verdict of the European Court of Justice of 27 June 2013, in which a few of the Polish regulations (some of them already deleted) were considered to be at variance with the Directive 94/22/EC. Until these regulations are finally formulated, most

probably the entrepreneurs who already have exploration and recognition concessions will reduce investments for exploration to the absolute minimum, until they are absolutely sure of the terms on which they can retain the right to obtain the exploitation concession on the principle of priority.

Improvements in environmental procedures

Legislative changes which may stimulate exploration for hydrocarbons in Poland are planned to embrace also the environmental procedures. Less time will be needed for satisfying the environmental procedures and their scope will cover rather than the whole concession area, just the immediate zone around the planned borehole. Moreover, the decision will be necessary later than currently required, i.e. before the drilling begins. Also, the requirement of obtaining new environmental decisions in case of changing the depth of exploratory boreholes is to be abolished.

The above solutions seem to be making the right steps – considering the fact that the average wait time required for receiving an environmental permit for activity related to exploration and exploitation operations is currently a few hundred days. Also, the peculiar situation will be eliminated when deepening of a borehole by 50 m more than originally planned required a wholly new environmental permit.

Simplification of the environmental procedures is likely to have a positive effect on the pace of exploratory activity – obviously on the condition that they will come into effect as soon as possible. Some of the provisions were introduced by modifying the statues for activities which may considerably affect the environment, and became binding on 1 August, 2013. However, the date the major changes in geological and mining law as well as environmental regulations will come into effect is still unknown as the draft has not even been sent to the Sejm yet.

> The legislative changes which may stimulate the hydrocarbon exploration in Poland are planned to embrace also the environmental procedures – shorter time will be needed for satisfying the environmental procedures and their scope will cover rather the whole concession area, just but the immediate zone around the planned borehole.

Summary

It is feared that the proposed legislative changes will not bring a decisive rise of interest in exploratory activity in the near future. However, it seems that the new law should be passed as soon as possible so the entrepreneurs operating in the sector can gain a better understanding of the regulatory environment in which they are operating.

Undoubtedly, legislators should take action and encourage investors to conduct exploratory activities (e.g. through suitable tax preferences). Also, it must be emphasized that all the solutions should be communicated to social partners in a clear manner so that both the investors and society have a complete picture of their future regulatory "environment".

Tomasz Barańczyk – Managing Partner in Tax and Legal Department, PwC

Grzegorz Kuś – Legal Adviser at the oil and gas sector team, PwC

Consequences of government proposal to levy taxes on oil and gas exploration in Poland and for the extractives industry

Counting one's chickens before they're hatched

Tomasz Barańczyk, Grzegorz Kuś, Marek Kilian

The data collected by the American Energy Information Agency on the potential volume of shale gas deposits in Poland in 2011, estimated at approx. 5.3 bcm, provided a strong impetus for commencing large-scale prospecting and identification works.

Not only are the resources of key importance for the development of the extractives industry but also the system of regulations, including taxes. Under the current law, the government take in Poland comprises: corporate income tax for legal entities ("CIT"), real estate tax ("RET"), concession royalty and exploitation fees and the fee for mining usufruct rights. In October 2012, the Polish government adopted assumptions concerning new regulations related to hydrocarbon exploitation. Originally, the new regulations for the sector were to be collected in one specific act. Nonetheless, in the course of legislative proceedings, the issue of taxes for hydrocarbon exploitation (Ministry of Finance) was separated from the legal and regulatory issues (Ministry of Environment). As it was indicated in October assumptions, the planned government take connected with hydrocarbon exploitation should be no more than 40% of the gross profit.

New taxes…

The Ministry of Finance prepared a draft law on special tax on hydrocarbons, amendment to the law concerning the tax on exploitation of some minerals and amendment to some other laws. The original version of the draft law was published on 28 February, 2013, and then modified by subsequent versions: dated 12 June, 2013 and 7 August, 2013. The law is to come into effect starting from 1 January, 2015.

The key aspect of the planned law is to introduce a new special hydrocarbon tax ("SHT") for entities conducting business in hydrocarbon exploitation. The taxable base is to be the surplus of income from exploitation over the expenses incurred in a specific year. Both the catalogue of revenues and eligible expenditures for the SHT were defined in a special way which is different from similar institutions where the application of the tax law is used in the calculation of income taxes. Originally, two tax rates were defined, depending on the accumulated ratio of revenues (i.e. as for the principle of all the tax years, since the date the law became effective) to accumulated expenditures:

- 12.5% – when the value is >1 and < 2 and
- 25% – when the value is ≥ 2.

Such a construction of the SHT was criticized by the sector on account of occurrence of only two significantly different tax rates being used alternatively (no progression typical for tax collected from natural persons). Therefore, in the SHT draft act of 12 June, 2013 (which was also repeated in the latest version of mentioned draft law of 7 August, 2013) regulations concerning SHT rates were modified. Index R was introduced as the ratio of accumulated revenues to accumulated eligible expenditures. Index R is used to help define the tax rates. Three rates have been correlated with it, so that if the R index is:

- < 1.5 – the tax rate is 0% of the taxable base,
- ≥ 1.5 and < 2 – the tax rate is calculated according to the formula (25 × R – 25)/100,
- ≥ 2 – the tax rate is 25% of the taxable base.

The SHT in its present form can be called quasi-progressive. The proposed method of calculating tax rates *de facto* postpones the moment of taxation with the SHT until the R index is 1.5. In the previous version, the entrepreneur would enter the tax threshold of 12.5%, practically from the point the R index exceeded 1.

Essential regulation in the context of determining the amount of the taxable base of the SHT is the mechanism of reference prices. If the price obtained by the taxpayer for supplies of extracted oil or gas is lower than 90% of the reference price (established, i.a. on the basis of stock exchange quotations), revenues from exploitation operations will be calculated according to the reference prices.

The second of the new rates is a tax on the exploitation of certain minerals related to oil and gas, a kind of resource rent – *royalty*. Its rate depends on the technical parameters of the deposit. Depending on the geological conditions, its amount is to be:

- for gas: 1.5% or 3%,
- for oil: 3% or 6%

of the value of extracted natural gas or extracted oil. This value equals to the product of the volume of extracted gas or oil and average price of gas or oil respectively. These volumes announced each month by the Minister of Finance on the basis of the arithmetic mean of intraday quotes for the previous month: (1.) of natural gas – determined at the Polish Power Exchange or (2.) oil – established on the basis of the OPEC Daily Basket Price. Deposits of oil and gas from shale formations should, in principle, be covered by a lower rate (1.5% or 3% respectively) on account of the technical parameters of the deposit.

The law on SHT uses also the "accompanying minerals" which in certain situations will be taxable at the actual delivery price, instead using the average market prices. In relation to the initial proposal of February this year, in subsequent drafts the regulations stated that exploitation from the offshore deposits will be taxed with a *royalty* (1.5% – natural gas and 3% – oil, respectively), regardless of the technical parameters of the deposits.

The draft SHT act imposed restrictions on participating in the exploitation business by granting the right only to corporations. However, in the latest version of the draft law of the SHT of 7 August, 2013 these limitations – in response to criticism by members of the extractives industry and opinions proposed by specific ministries during the course of interministerial agreements – have been deleted. In compliance with the latest version of the draft law of the SHT, the entrepreneurs will be able to run a business connected with hydrocarbon exploitation in any legal form; also natural persons and organizational units which are not legal entities will be able to undertake exploitation operations.

From the perspective of the sector, the matter of key importance is, however, the regulation on suspension of collecting the SHT and *royalty* till the end of the year 2019. Admittedly, keeping appropriate records or filing declarations during the "suspended" period will still be necessary but this change was positively received by entrepreneurs – particularly on account of the fact that it also concerns those entities which are already running exploitation from conventional deposits or from the offshore resources.

…and more fees

Ministry of Environment presented the proposal of the draft act for the modification of the Geological and Mining Law and some other laws ("GML"). The original version of 15 February, 2013 was modified twice – by drafts of 12 June and 1 August, 2013.

The main assumptions of the draft are: introduction of a new concession tender model and the appointment of the National Operator of Energy Resources ("NOKE") – a company, whose goal is to participate in each exploitation concession.

NOKE is to be established by the Bank Gospodarstwa Krajowego and the National Fund for Environmental Protection and Water Management. It was proposed at first that the planned share of NOKE in the profits of the operating consortium would be one of the criteria for the tender for an exploitation concession (i.e. generally the investor who suggested larger share in the profits for NOKE would have a better chance), and its share of expenses will be reduced to at most 5%. Such solution would lead to considerable asymmetry between the share of NOKE in profits and expenses, being de facto an additional quasi-fiscal burden for the licence holders. However, after criticism from the sector, the decision was made to resign from such substantial asymmetry. The newest draft of GML makes the participation of NOKE in the profits and expenses equal to the same level that was limited to a maximum of 5%. In this way, the share in the profits will not be then a tender criteria.

The draft assumes that the exploitation fees for communes, poviats and voivodeships are planned to rise from 2015 at the earliest. The new rates are demonstrated in table 1.

lations. Moreover, the legitimacy of the assumptions made and the correctness of the calculations cannot be verified, particularly that the calculations of some companies in the sector indicate that the value

Table 1. New rates of exploitation fees

Natural gas		Petroleum	
Current rate	**Rate assumed by draft law**	**Current rate**	**Rate assumed by draft law**
6.06 PLN/thousand m^3 (methane-rich natural gas)	24.00 PLN/thousand m^3 (methane-rich natural gas)	35.87 PLN/ton	50 PLN/ton
5.04 PLN/thousand m^3 (other natural gas)	20 PLN/thousand m^3 (other natural gas)		

Furthermore, the allocation structure of funds received from hydrocarbon exploitation fees will be changed. So far, 60% has gone to the commune in which the business is conducted, and 40% was allocated to the National Fund for Environmental Protection and Water Management. In compliance with the new draft, the revenues are to be distributed in the way presented in chart 1.

Consequences of the proposed solutions

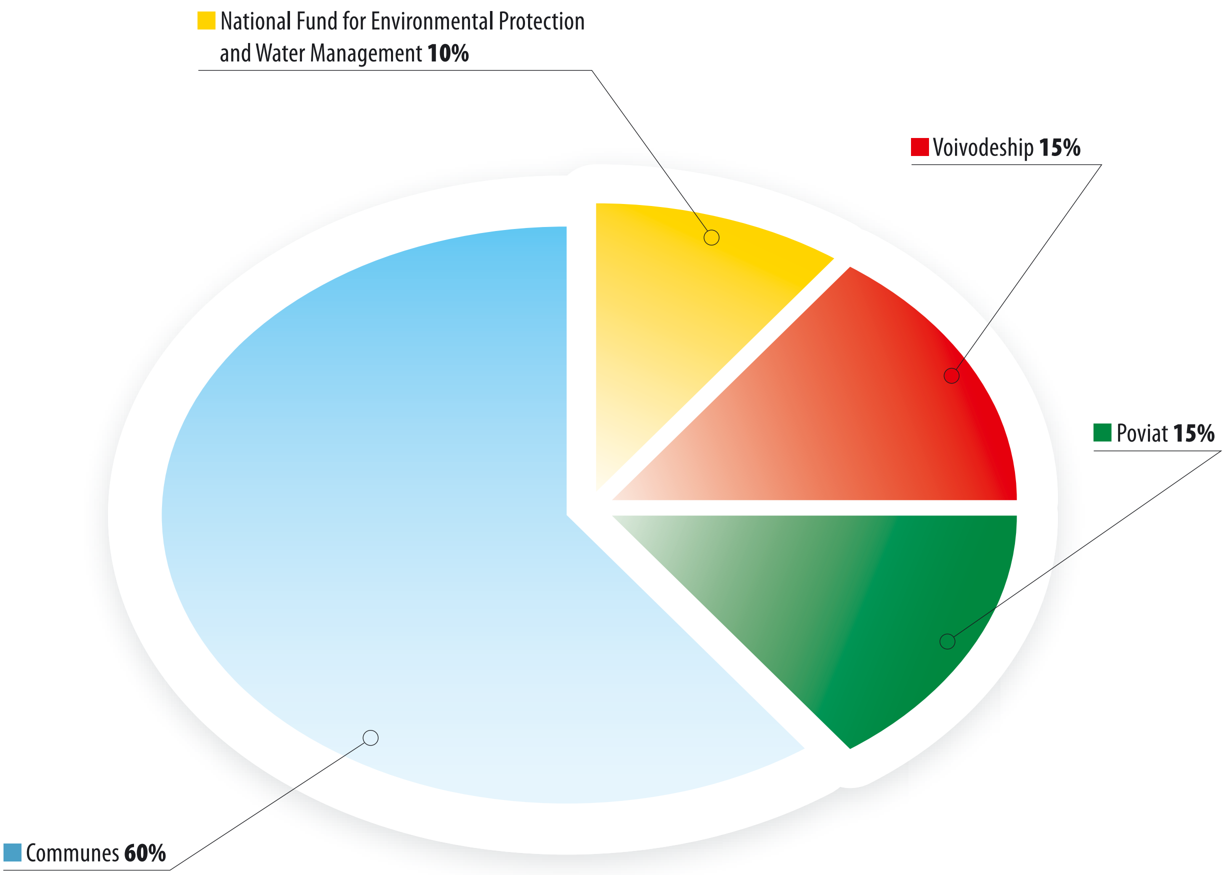
While evaluating the drafts of the new laws in the light of economic rationality, the total amount of government take related to hydrocarbon exploitation should be assessed. Initial estimates of the budget revenue generated from the new taxes on extractives industry have been presented by the Ministry of Finance in the assessment of the effects of the SHT draft law regulations. Conclusions resulting from these calculations are consistent with the assumptions on which they were based: the accumulated government take will not exceed 40% of the gross profits. However, no detailed data has been presented on which the Ministry calculations are based. In the same way, it cannot be verified whether the budget revenues of the SHT and royalty evaluated by the Ministry of Finance in the years 2015–2029 will reach the value of 10. 5 to 17.5 billion PLN – as presented in calculations. Moreover, the legitimacy of the assumptions made and the correctness of the calculations cannot be verified, particularly that the calculations of some companies in the sector indicate that the value of government take may significantly exceed 40% of the gross profits. What is more, the price adopted by the department for 1 MWh of gas oscillates between 91.46–105.90 PLN, whereas now in the market on the next day on the Polish Power Exchange it amounts to approx. 116 PLN. The Ministry did not provide any explanation for its assumptions in relation to the price for 1 MWh of gas, which – in view of the adopted time span for the analysis is of key importance for modeling the fiscal charges. Moreover, it seems that increased gas supply should result in a lower price, as observed in the United States.

The vital issue which will certainly substantially affect the calculation of the government take is the question of indexation (i.e. increasing every year by a certain index) of the expenses of exploitation operations on account of the time passing and the issues connected with the changing value of money in time, as in this type of activity, expenses are incurred at the beginning and the revenues can be collected only after many years. A solution which applies to the indexation is known in the systems in Denmark, the Netherlands and Norway. Whereas the draft law on SHT does not contain analogical provisions.

Summary

Currently, the effect of the new government take on the extractives industry cannot be precisely determined. Undoubtedly, investors will pay more on ac-

Chart 1. Distribution structure for revenues from exploitation fees



count of the new taxes and fees. What must be noted, furthermore, is that the drafts do not include many incentives or tax reliefs which would encourage investors and attract the foreign capital, which appears to be indispensable because of the capital-intensive nature of operations in the area of hydrocarbon identification and exploitation. Certainly a good signal for the sector is the suspension of collection of the new taxes till the end of 2019. This is a particularly essential solution for the entities which are already running exploitation operations from conventional deposits.

It seems also that the regulations relating to conducting exploration and recognition works by several entities should be specified more precisely. The current model of "one concession – one entity" is not profitable for the development of this sector in Poland, which will also affect the volume of the national budget revenue generated from the planned fees. Indeed, the possibility of creating an exploitation consortium with NOKE is planned in which each investor will be granted a concession but this may not be sufficient.

To sum up, the government should, as soon as possible, develop a draft of taxation and systemic regulations concerning the question of hydrocarbon exploitation in Poland. The new regulations should be – on the global scale – competitive enough to ensure not only revenues to the national budget but more importantly, they should ensure that the present investors stay in our country and attract more of them because if the final charges for the sector turn out to be too high, instead of revenue to the budget, Poland will be left with a regulation which is simply "counting its chicken before they`re hatched".

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Marek Kilian – Consultant at the oil and gas sector team at PwC

OIL:

exploration, extraction, sales

Development of hydraulic fracturing technologies in hydrocarbon deposits in Poland

To increase extraction

Elżbieta Biały

Hydraulic fracturing aims at creating a propped fracture in the deposit to provide larger contact area of the borehole with the deposit and to access its parts situated further, at longer distance from the borehole.

Although basic principles of hydraulic fracturing have not changed since the method was used for the first time, for many years many of its variants were introduced with various fracturing fluids, many fracture proppants and also different methods of pumping the fracturing fluids.

> In Poland, the first research works on hydraulic fracturing methods were initiated in the Oil and Gas Institute in 1950s. They became foundations for the stimulation methods used widely today.

What were the beginnings ?

Hydraulic fracturing has been around for more than 65 years. It has been introduced to industry in 1947 in the USA. Since then, it has been one of the most commonly used methods enhancing hydrocarbon extraction. Hydraulic fracturing is an elaborate process combining the aspects of geomechanics, fluid mechanics, deposit engineering and chemistry. Technological fluid, which consists of a carrier of properly selected rheological properties with addition of materials filling the fracture is pumped to selected section of the borehole. The fluid, injected under suitably set high pressure, creates a fracture in the rock structures, whereas the so-called proppant fills it and supports, forming new routes for the gas migrating to the borehole.

In Poland, the first research works on hydraulic fracturing methods were initiated in the Oil and Gas Institute in 1950s. They became foundations for the stimulation methods used widely today. Initially, a great obstacle for wide propagation of intensification treatments in Poland was drilling the well by percussion methods in which the columns of exploitation pipes were sealed with clay. Before stimulation treatments, reconstruction works had to be performed, consisting in cementing the last column of pipes. The treatment packers were practically inaccessible at that time.

The first fracturing was made in Poland in the years 1956–1957 in the mines: Wielopole, Bóbrka and Wańkowa. In order to initiate and direct the fracture in stimulated boreholes, a small torpedo was used, according to the concept by A. Ogrodnik and A. Bania [13]. Subsequent years brought the development of works on compositions of treatment fluids which facilitate transportation of sand to formed fractures (B. Fleszar). The fluids were then made on the basis of bunker oil and naphthenic soap, also condensate, sodium soap and acid-in-oil emulsion (J. Pohl, A. Kwaciszewska) [13]. The preparation of the treatment fluid was quite simple. The equipment used in the treatment consisted of Russian power generators CA 320 used by prospecting companies for cementing operations [13]. Looking through archival material of the Oil and Gas Institute [4], particularly the correspondence related to preparation of technological fracturing projects and reports on executed treatments, it is impossible to overlook the advancement in the field of stimulation. An example may be hydraulic fracturing operations in borehole Łodyna-77. In the year 1961, hydraulic fracturing treatment performed in this borehole was technically unsuccessful, however, subsequent operations – in 1964, and then in 1970 and 1975 – were successfully accomplished, enhancing the daily petroleum output.

Parallel to the works on drilling fluids, proppants were tested with the use of aluminium, silicon, calcium and magnesium, as well as silicic proppants.

In 1976, a sequence of hydraulic fracturing operations were performed, including hydraulic fracturing with simultaneous acid treatment – the operation executed then for the first time in the Polish oil industry. The advantage of this method was – apart from facilitating the deposit patency by forming a fracture – achieving an additional effect due to chemical impact on clay and calcite cementation of the sandstone. For example, in Osobnica-120 borehole in interval 1160÷1125 m hydraulic fracturing was performed combined with acid treatment, with the use of formalin and ammonium acid fluoride. In the gas collector in borehole Ujazd-3, hydraulic fracturing was made in combination with acidation, using acetic acid as acidation agent [8]. In borehole Zatwarnica-3 hydraulic fracturing was made with simultaneous acidation, and in Łodyna-77 borehole – selective fracturing treatment [4]. In the boreholes Słopnice-7 and Słopnice-13 a couple of hydraulic fracturing treatments were made with simultaneous acidation, the outcome of which was enhanced petroleum output and in the borehole Słopnice-21 – increased gas inflow [4]. For the Bogdaj–Uciechów-36 borehole, fracturing technology was developed with simultaneous acidation of basic limestone and Rotliegend by means of hydrophobic acid-in-oil emulsion. In gas boreholes Bogdaj–Uciechów-38, 44, 47, 49 hydraulic fracturing treatments were made with hydrocarbon-based treatment fluids and selected new chemical substances tested in the Institute of Oil and Gas Mining (at present the Institute of Oil and Gas). The hydrofracturing method proved to be a every effective tool for well intensification,

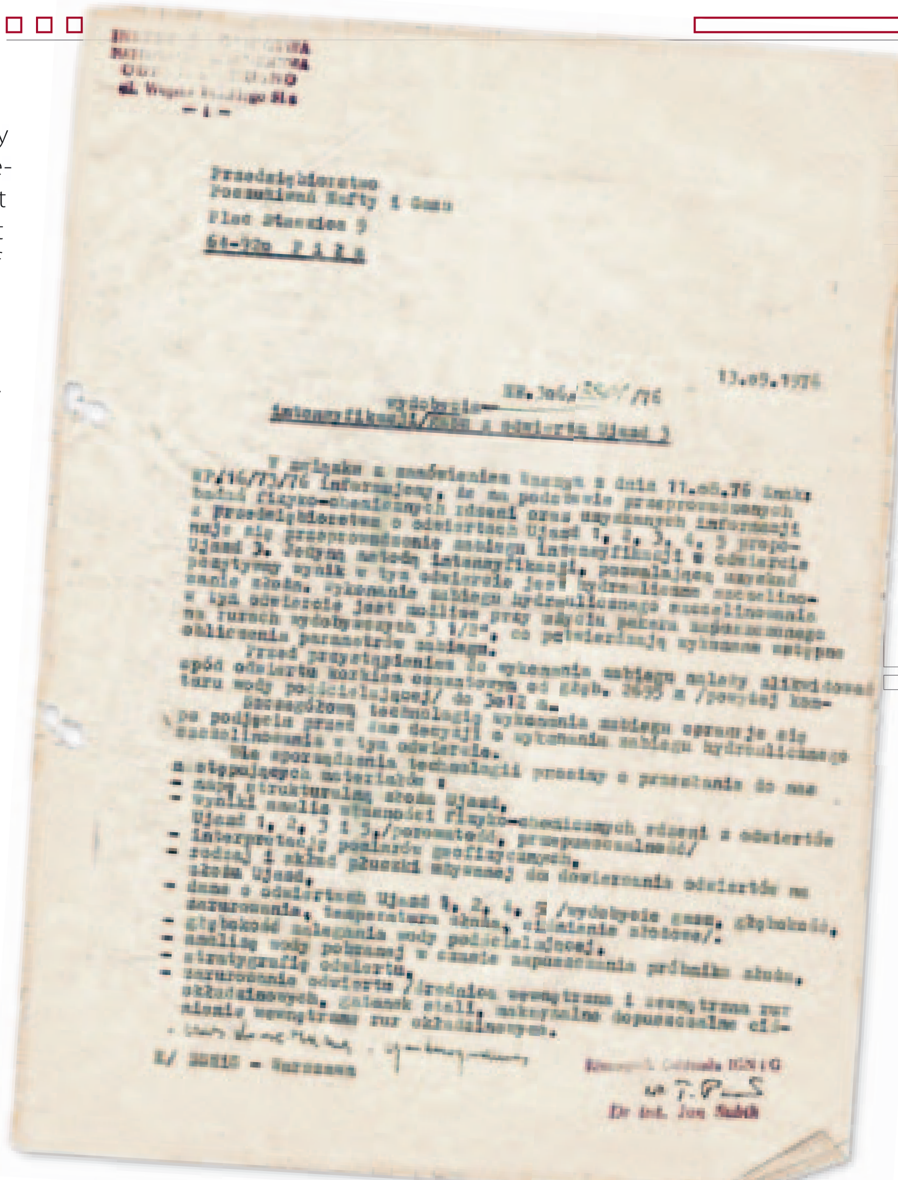

Fig. 1. Letter of the Oil and Gas Institute in Krosno to PGNiG (Polish Oil and Gas Mining) in Piła on intensification of gas extraction in borehole Ujazd-3 (source: archival documents of the KS plant)

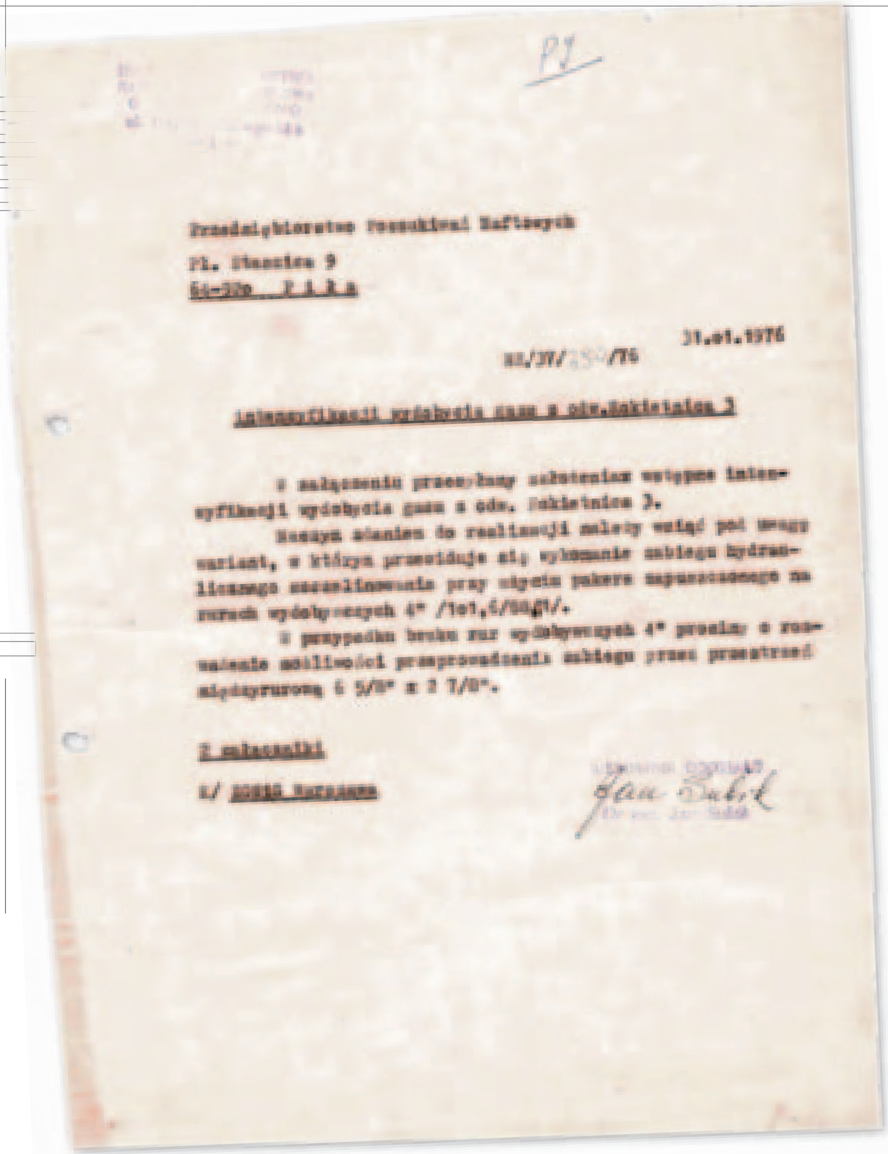

Fig. 2. Letter of the Oil and Gas Institute in Krosno to PGNiG in Piła on intensification of gas extraction in borehole Rokietnica-3 (source: archival documents of the KS plant)

The aim was achieved and the authors of the project suggested several compositions for the operating fluid for hydraulic fracturing of deposits situated at great depth [14].

The years 1979–1983 were for the Institute of Oil and Gas Mining a special period of laboratory research concerning the petrophysical properties of core samples, mainly from the deposits in Przemyśl, Lubaczów and Husów. The test results were used in the development of optimal intensification methods for extracting gas from the Carpathian Foreland and they were implemented in industry. At that time, the Institute`s cooperation with industry became closer, particularly with the treatment team in Sanok. Works were begun on the selection of stimulation methods for shallow Carpathian deposits and the Foreland. In the result, drilling was recommended to perform hydraulic fracturing with the use of fracturing fluid based on synthetic polymers. The industrial test was carried out in the Hanka-32 borehole. Also, innovative research for the Polish petroleum industry started to develop compositions for blockators for temporary isolation of created fractures and their application in fracturing [15]. Selective hydraulic fracturing with blockators was used in gas collector in shale formations in the Husów-83 borehole. It was the first intensification treatment both in the Husów deposit (1979) and in Poland.

In the years 1984–1986, works were continued on the application of domestic polymers to fabricate fluids for stimulation treatment of the wells which facilitated access to high thickness layers.

At the beginning of 1990s, tests were carried out in the Oil and Gas Institute on treatment fluids resistant to high temperatures (up to 130°C) for hydraulic fracturing with addition of Polish synthetic polymers: Rokrysol WF-2 and Gigtar S and 3. Industrial tests with these fluids were performed in the boreholes Grochowice-35 and Daszewo-19K [6]. Works were also continued on technology of hydraulic fracturing operations for the deposits of indigenous Miocene (borehole Przemyśl-116 – 1992). The chief goal of the stimulation with Giktar P polymer and peroxide was to obtain vertical fractures. ACF power generator was used for making the drilling fluid and the treatment was to be performed by

though, failures occurred as well, e.g. the stimulation operations in the Miocene deposits in the vicinity of Przemyśl.

Seeking the composition

With increased number of very deep boreholes, it was necessary to elaborate a composition of the fluid used in their stimulation, which would correspond to these conditions. Besides resistance to high temperature, the fluids were supposed to have the right properties: they had to be able to create a fracture, carry the sand, have low filtration and consist only of chemical substances produced in Poland.

the Extraction Intensification Group from the Institute of Oil and Gas Mining (PGNiG) in Sanok Branch. However, during the works, a series of problems arose impossible to solve at that time. First of all, they resulted from the lack of good quality equipment and absence of uniform methods for description of the fracturing fluids. Despite the efforts made to elaborate standardized methods in the entire oil industry to measure the properties of fracturing fluids, they did not bring expected results in the new developing fluid chemistry. The result was diversity of testing methods in various laboratories, which substantially hindered the definition of fluid properties, specifically when considering the fact that applied research methods may considerably change the properties of treatment fluids and, by the same, affect the designed treatment technologies. Identical situation related to examination of mechanical properties of rock [5]. In spite of the difficulties, in the years 1993–1994 several new compositions for fracturing fluids were worked out which featured low resistance of the flow through the extraction pipes, higher viscosity and lower filtration to the deposit.

Photo 1. Workstation for proppant conductivity tests (source: KS Plant`s own materials)

Period of technological transformation

The year 1995 was a watershed in Poland in respect of development of stimulation methods. The introduction of free market economy marked the end of politics aiming at economic self-sufficiency. Technological transformation period was initiated in the Polish oil mining. Many modern devices were then purchased for conducting field works and laboratory research, as well as the software – also, the one necessary for stimulating extraction. The Extraction Intensification Centre at PGNiG SA in Sanok was provided with modern equipment which permitted to perform world-class intensification treatments. This equipment became a chance for performing bigger treatments, in more difficult and more complicated deposit conditions. Moreover, there was radical change in the system of financing scientific research in Poland. Research projects of many years` standing, oriented at solving particular economic problems were replaced with a system of competitions for research projects and commissioned and target projects. Introduction of competitiveness in research resulted in increased requirements from industrial employers. To meet the requirements, after years of stagnation in funding research, major investment was necessary in research infrastructure. At that time, Laboratory for Stimulation of Extraction was created at the Oil and Gas Institute, equipped with unique research apparatus for conducting tests and designing stimulation treatments.

The Laboratory for Stimulation of Extraction could boast of having such devices as:

- workstation for testing proppant conductivity (Photo 1),
- workstation for testing rheological treatment fluids (Photo 2).

Owing to the apparatus, it was possible to provide full characteristics of fluids and proppants necessary for optimization of the fracturing process, covering such examination as:

- simulations of fluid flow in hydraulic fracturing treatments on a semi-commercial scale (Photo 3),
- rheological examination of fluids for hydrofracturing operations,
- testing the filtration of fracturing fluids in static and dynamic conditions,
- flowback tests,
- proppant tests,
- tests of conductivity of hydraulic fracture, depending on the proppant and treatment fluid used,
- selection of agents to regulate the rheological properties of fluids (surfactants, polymers, etc.).

Photo 2. Workstation for rheological examination of fluids for hydraulic fracturing (source: KS Plant`s own materials)

Due to modern apparatus, also the problem of unification of research methods was solved – all the tests on proppants and fracturing fluids started to be made according to standards used by stimulation laboratories all over the world.

Cooperation of the Extraction Intensification Centre and Laboratory for Stimulation of Extraction at the Oil and Gas Institute, transformed in 2004 into Plant, permitted to apply the new technologies in hydraulic fracturing operations. They used fluids worked out on the basis of cross-linked linear polymers [2]: first of all: guar, hydroxypropyl guar (HPG), carboxymethyl hydroxypropyl guar (CMHPG) and carboxymethyl hydroxyethyl cellulose (CMHEC). Application of such fluids requires appropriate technology and suitable equipment. Those technologies were used in many countries for many years; in Poland, the main obstacle for using them was the lack of appropriate laboratory and operational equipment. Only opening the borders to the West European countries and investments made at that time enabled adaptation of these technologies to the Polish oil industry.

Following the modernization of technological base, detailed analysis was made of the deposits and the bores selected for extraction intensification [10]. The first operations of hydraulic fracturing with the new equipment were performed in May 1996 in gas borehole Jaszczew-32a, with preceding mini-fracturing test. Based on that, essential physical and mechanical parameters necessary for designing the proper hydraulic fracturing operation were described. In the result, considerable increase in gas extraction was achieved: from 11 nm^3/min before the treatment to 233 nm^3/min after the operation [9]. Another successful hydraulic fracturing in which modern technology was used was the operation in borehole P-8 performed in one of the neighbouring countries, where the deposit temperature 98°C exceeded the limit of applicability of HPG. Preparation of appropriate fracturing fluid was quite a challenge. Finally, imported chemical agents were used. Fracturing treatment brought increased gas output from 40 m^3/min before – to 160 m^3/min after the treatment [1].

In the course of five years after modernization of the Plant of Hydrocarbon Extraction Stimulation and the Extraction Intensification Centre at the Oil and Gas Mining Institute in Sanok, many successful

Photo 3. Fragment of research workstation for stimulation of fracturing fluid flow on semicommercial scale (source: KS Plant`s own materials)

fracturing treatments were made. Subsequent years brought considerable advancement in this technology, as well as the technology of hydraulic fracturing in horizontal boreholes [7].

Simultaneously, in the Plant of Hydrocarbon Extraction Stimulation research works were continued for industry, commissioned by the Committee of Scientific Research, which facilitated the application of more and more technologically advanced fracturing fluids and modifications of the fracturing process itself. The works were aimed at enhancing the effectiveness of hydraulic fracturing treatments. Another area of research were the works connected with testing the proppants. According to the API procedures, tests were carried out of proppant agents commonly used by the Oil and Gas Mining Institute – quartz sand BM; results of the tests were used in designing hydraulic fracturing operations. Works were also undertaken to improve the strength parameters of sand by resin bonding [11].

By the end of 1990s and in subsequent years, the government policy was directed to every aspect of environment-friendly activities. Modifications were introduced in legal regulations, which obliged all Polish entrepreneurs to apply the principles of sustainable development of conducted business. On account of that, also in the area of stimulation, extremely important became tests on the influence of chemicals used in fracturing fluids on the natural environment. As a result of undertaken tests, a data bank was created on toxicity of the agents used in exploitation [12], which contained both information provided by producers and distributors and results of tests carried out in the Oil and Gas Institute. All the tests are performed according to uniform methodology, interpreted according to clearly defined principles and documented in standardized form so that their comparison is possible in the ecological aspect. This is a great change in the approach to safety of applied agents in comparison with the fracturing treatments performed previously.

Current directions for development

At present, stimulation operations in the Polish oil mining are developed on the basis of modern world technology. Decisions concerning stimulation treatments are preceded by various laboratory tests and anticipated effects of these treatments are confirmed by computer simulations. Cooperation with

By the end of 1990s and in subsequent years, the government policy was directed to every aspect of environment-friendly activities. Modifications were introduced in legal regulations, which obliged all Polish entrepreneurs to apply the principles of sustainable development of conducted business. On account of that, also in the area of stimulation, extremely important became tests on the influence of chemicals used in fracturing fluids on the natural environment.

international chemical companies working for the oil industry allows to apply the latest state-of-the-art chemical agents. Thanks to that, Polish stimulation matches the performance of western companies.

Along with the development of the plans of gas prospecting in shale, new challenge appeared before the Polish stimulation related to elaboration of new independent technological solutions in the field of stimulation operations in unconventional natural gas deposits. The know-how in our country is still insufficient and based only on the knowledge of the American companies, which have great experience in this domain. Uncritical or mechanical transfer without considering the specific Polish geological conditions may lead to false decisions. Therefore, elaboration of new technologies, materials and procedures leading to optimization of technologies, parameters and methodology for planning the stimulation treatments in unconventional natural gas deposits in Poland has the key importance for economy. A great chance for developing independent technological solutions for stimulation of shale gas deposits is provided by the government programs, such as: "Blue Gas – Polish Shale Gas", Innotech and other projects executed in cooperation between oil companies and research units.

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Methods of separation of oil fractions with the help of modern distillatory system with a rotating band

Distillation with a rotating band

JERZY KUŚNIERCZYK

The oil extracted directly from the deposit is not intended for immediate use for technological reasons. Valuable fractions can be separated from it with the use of proper methods.

In order to be isolated, crude oil distillation should be conducted. It is done by heating a sample to a defined temperature in which components contained in the petroleum precipitate forming gases and then, the gases are condensed again into a liquid phase. Precise separation of individual fractions is quite a complicated task, however, it is essential nowadays. Crude oil refining is conducted on an industrial scale in refineries.

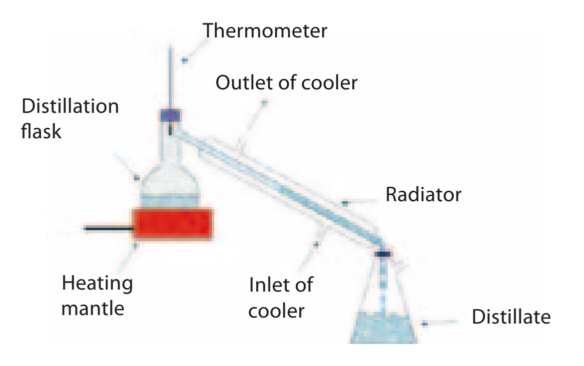

Fig. 1. Simple device used in the distillation process

The distillation process

Distillation consists in separation of a liquid mixture (petroleum in this case) by vaporization of individual components and then their condensation. It is applied to isolate specific components from the studied mixture of hydrocarbons. In the distillation process diverse temperatures are used in which condensation of oil components takes place. The main product obtained in the distillation process is called distillate, however, the residue of this process is the so-called depleted liquid [1].

In laboratory conditions determination of the oil fraction composition is done with the use of normal Engler's distillation. To do this, a laboratory set is used (fig. 1), whose main components are: standardized distillatory flask, thermometer with the measuring range 0÷360°C and the Lebieg's radiator. Water is used as the cooling factor [2].

Equipment for oil distillation

Detailed studies on oil distillation are conducted in the Department of Oil and Gas Reservoir Testing at the Oil and Gas Institute. The distillation system (fig. 3) applied in the presented device consists in separation of successive fractions of the studied sample on theoretical shelves resulting from the length of the distillation column – it is the main unit of the device.

Fig. 2. Testing equipment

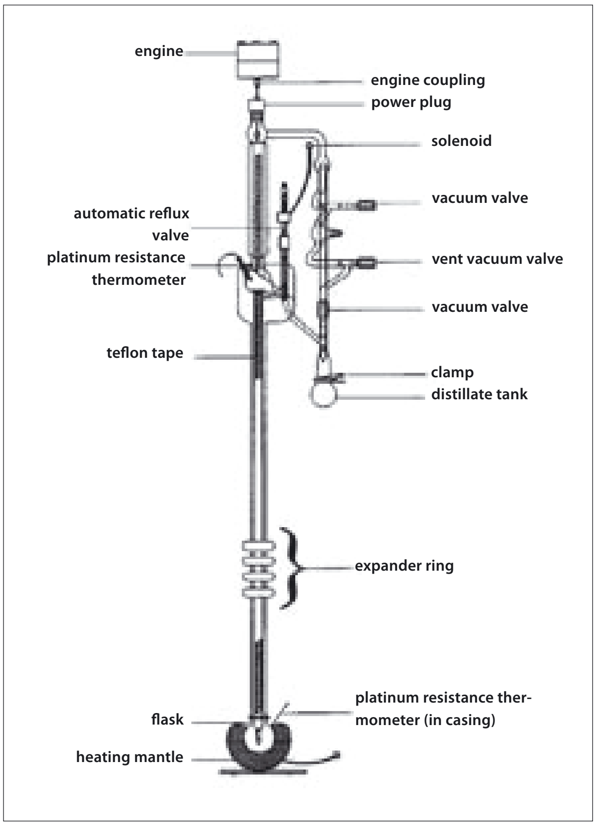

Fig. 3. Diagram of the distillation column

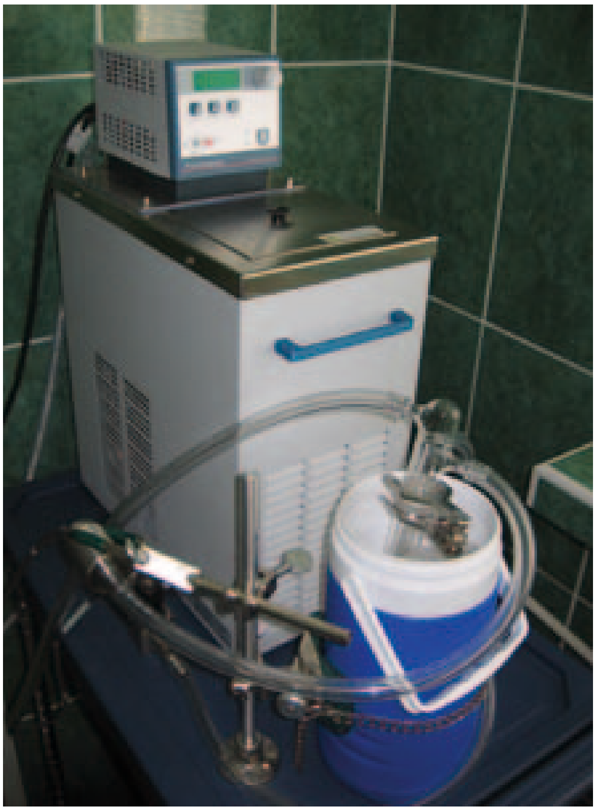

Fig. 4. Cryostat and a trap with dry ice

Fig. 5. Vacuum pump

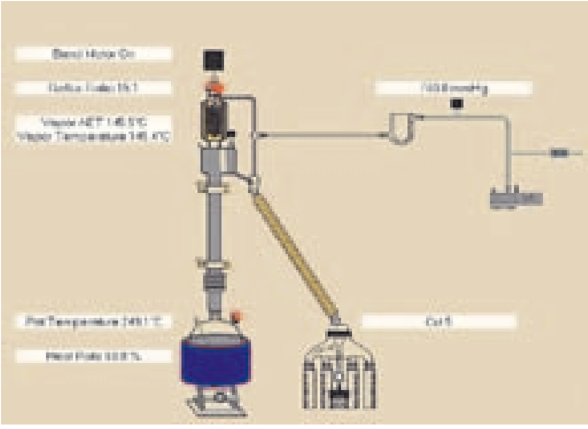

Fig. 6. Visualisation of the distillation process

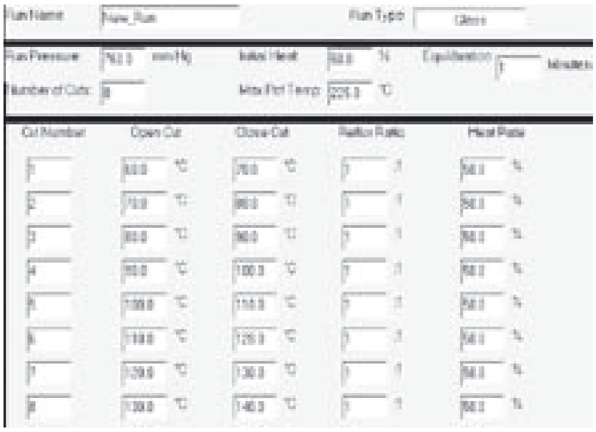

Fig. 7. View of the distillation control panel

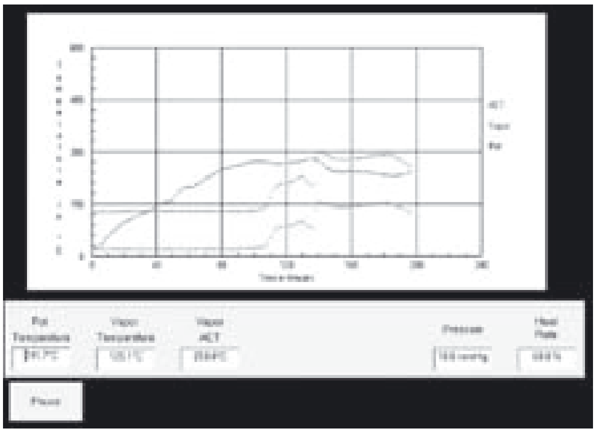

Fig. 8. Visualization of the temperature change

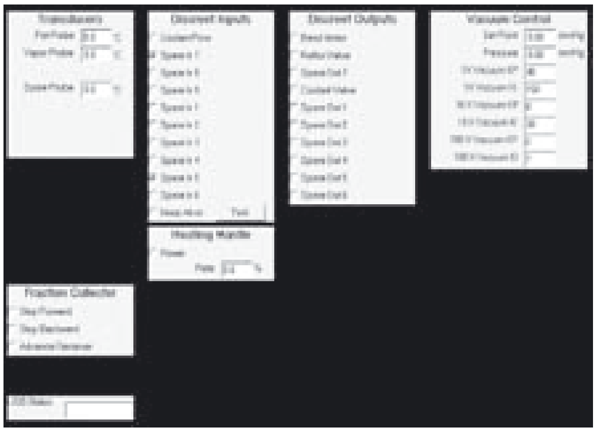

Fig. 9. Manual control panel

Inside, there is the so-called rotating band, thanks to which distillation of the studied sample is done. This band has a spiral shape and it runs through the whole length of the column, it is set in motion by an engine placed over the device [3].

The whole device consists of several basic parts:

- distillation system, composed of:
  - heating element (heating mantle),
  - boiler
  - mixer
  - check valve
  - automatic fraction receiver
  - rotating band
  - distillation column
- support frame
- controller with a control computer
- circulatory bath with a cryostat
- vacuum pump [3].

A closed circulation cryostat is used for cooling the vapors liberated during distillation (fig. 4). Its temperature ranges from –10°C to + 55°C. The applied controller makes it possible to fluently control parameters and programme a few stages of cooling or increasing the temperature. A “trap” with dry ice has been used to catch the lightest fractions of the sample which were not collected in the condenser.

The set includes also a vacuum pump. It is used to regulate the distillation pressure ranging from the atmospheric pressure (760 mm Hg) to the pressure of even 0.1 mm Hg. The distillation pressure is controlled by a special valve. The manner of the connection of described elements was shown in figure 5.

Controlling the distillation process

The whole distillation process is controlled by a computer equipped with a specialist programme. Thanks to it, almost each parameter can be changed at any moment of conducted study. There is a possibility to introduce and save various distillatory programmes which can be recovered later. Figures 6 and 7 show the view of the control panel during distillation: figure 6 illustrates the process with insight into

Fig. 10. Vapour condenser

Fig.11. Automatic fraction receiver

the study parameters, while figure 7 shows the view of the control panel before the study.

The temperature variability can be viewed as a function of time during the sample distillation process (fig. 8). The chart shows three parameters, namely: the temperature of the sample in the boiler (blue), temperature of the sample in the condenser at atmospheric pressure (green) and temperature of the sample in relation to the distillation pressure (red). Distillation pressures and the present power of the heater are given on regular basis. There is also a possibility of manual control of some parameters by the system, even during the test (fig. 9).

During the study, the oil in the flask at the bottom of the distillatory column is brought to the boil. Vapours which precipitate at that time heat the whole column on their way to its upper part where they become condensed. Some vapours flow down into the flask again, while the remaining part is distilled. Automatic check valve controls the volume of collected fraction. The temperature in the condenser should be sufficiently low to condense the vapours and sufficiently high not to cause the distillate crystallization in the condenser [3]. After the sample has passed through the condenser (fig. 10), it goes to the automatic fraction receiver (fig. 11). It is divided into eight identical cylinders in which the volume of individual components is taken down. There is a rotary funnel through which the distillate flows down to the other measuring cylinders.

Results of conducted study

Chart 2 shows results obtained in the oil distillation process with the use of rotating band system.

Studies were conducted on samples of storage reservoir oil. As results from the conducted study, each time approximately 50% of the whole sample volume was distilled.

Summary

The rotating band used in the equipment produces better and more precise separation of individual

Chart 1. Results of oil distillation for sample no. 1

No.	Collected fractions	Range of boiling points [°C]	Distillate volume [%]	Total distillate [cm³]	Density in temp. 20°C [g/cm³]
1	C_5	below 36.5	2.25	4.5	0.6424
2	C_6	36.5÷69.2	3.25	11.0	0.6915
3	C_7	69.2÷98.9	6.00	23.0	0.7286
4	C_8	98.9÷126.1	6.00	35.0	0.7378
5	C_9	126.1÷151.3	5.75	46.5	0.7598
6	C_{10}	151.3÷174.6	5.25	57.0	0.7782
7	C_{11}	174.6÷196.4	4.50	66.0	0.7879
8	C_{12}	196.4÷216.8	4.25	74.5	0.8000
9	C_{13}	216.8÷235.9	3.50	81.5	0.8112
10	C_{14}	235.9÷253.9	3.25	88.0	0.8191
11	C_{15}	253.9÷271.1	2.50	93.0	0.8298
12	C_{16+}	over 271.1	53.50	200.0	0.9231

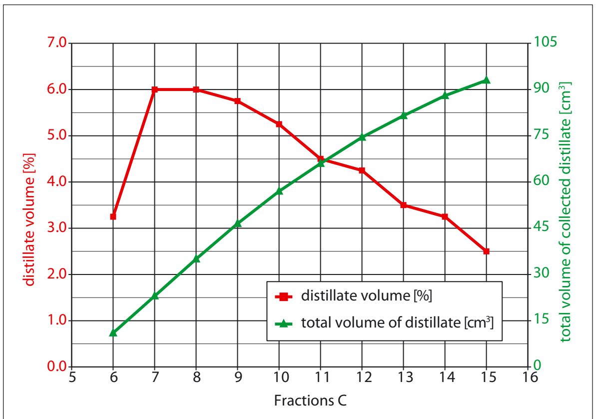

Fig. 12. Change in the volume of distillate collected during the study

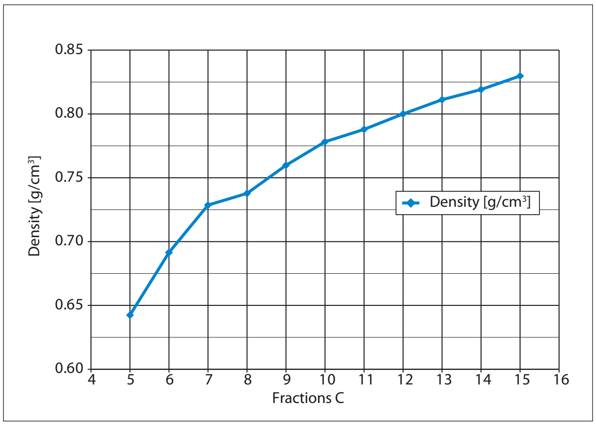

Fig. 13. Density of individual fractions at temperature 20°C

oil fractions, while the vacuum pump coupled with a sensor keeps the set negative pressure and at the same time increases the range of distillation temperatures. The small amount of oil needed to conduct distillation (max 250 cm³) is a great advantage of this device. This is an especially important advantage, as often only oil samples taken from the depth probes are available; on account of limited volume of the sample, traditional distillation is difficult or impossible.

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Chart 3. Results of oil distillation for sample no. 2

No.	Collected fractions	Range of boiling points [°C]	Distillate volume [%]	Total distillate [cm³]	Density in temp. 20°C [g/cm³]
1	C_5	below 36.5	3.00	6.0	0.6328
2	C_6	36.5÷69.2	1.50	9.0	0.6785
3	C_7	69.2÷98.9	8.00	25.0	0.7265
4	C_8	98.9÷126.1	8.00	41.0	0.7431
5	C_9	126.1÷151.3	6.75	54.5	0.7734
6	C_{10}	151.3÷174.6	6.50	67.5	0.7827
7	C_{11}	174.6÷196.4	5.25	78.0	0.7962
8	C_{12}	196.4÷216.8	4.50	87.0	0.8182
9	C_{13}	216.8÷235.9	4.25	95.5	0.8328
10	C_{14}	235.9÷253.9	4.00	103.5	0.8477
11	C_{15}	253.9÷271.1	3.75	111.0	0.8634
12	C_{16}	271.1÷287	3.25	117.5	0.8750
13	C_{17}	287÷303	3.00	123.5	0.8834
14	C_{18+}	over 303	38.25	200.0	0.9456

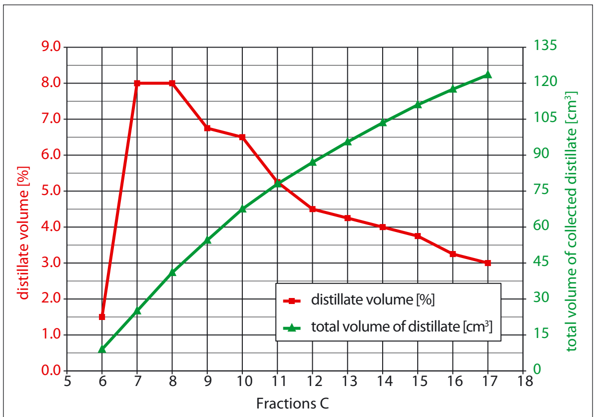

Fig. 14. Change of distillate volume collected in the study

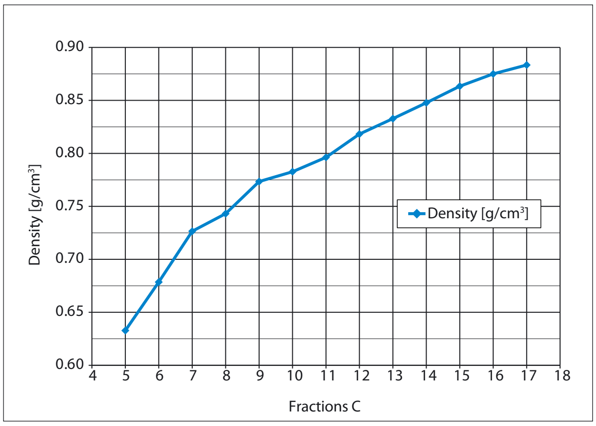

Fig.15. Density of individual fractions at temperature 20°C

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Deposit simulations

Ants, fish, birds and deposit simulations or what we can learn from animals

Piotr Łętkowski

There are many problems whose solution is doomed to failure when using classical methods. Some of them emerged as theoretical problems but their effective solutions have essential practical value in many fields of science and technology.

An example of such a problem is e.g. the problem of a travelling salesman. It consists in finding the shortest possible way between the specific number of cities (Fig. 1) – with assumption that he visits each of them once – and then comes back to the starting point. For five cities there are exactly 12 possible ways of visiting all the cities, but for twenty, the number of possible solutions is about six million. In practice, we deal with the problem of travelling salesman e.g. in logistics, when designing the ICT network and integrated circuits.

Another example is the "backpack problem". Its name comes from optimized selection of the items in such a way that their overall value is the biggest and they also could be placed in a "backpack". With a given set of elements of specific weight and value, only such of them should be selected for which the sum of their value is possibly the greatest and the sum of weight does not exceed the set value (capacity of the backpack). The backpack problem can be found in real life in economy and theory of operational tests.

Towers of Hanoi and the age of universe

The difficulty in finding the solution to presented problems is determined by their computational complexity, i.e. minimal number of operations necessary to find the solution. The concept of computational complexity may be presented in more detail using the example of the so-called Tower of Hanoi (Fig. 2). In fact, the Tower of Hanoi is a game for kids which consists in rebuilding, while preserving the shape, a tower made of discs of different diameter; while making shifts, additional column can be used with general assumption that it is not allowed to put a disc with bigger diameter on a smaller one or shift several discs at the same time.

It is obvious that the number of disc shifts necessary to complete the tower depends on the number of discs. But what is the relationship? It turns out that its formula is $2^n - 1$, where n is the number of discs. 15 shifts are sufficient for stacking four discs. However, for ten discs there are already 1023 shifts and for 20 – the number of shifts is 1 048 576. However, if $n = 64$, the number of shifts is 18 446 744 073 709 551 615 (18.5 trillion). Assuming that we will make one shift a second, the completion of the tower would take us about 584 billion years. For comparison, it must be remembered that the age of the universe (since the Big Bang) is estimated at about 13.7 billion years. Just like the problem of the travelling salesman and the backpack problem, the Tower of Hanoi is an example of task whose computational complexity increases really fast with increasing number of elements.

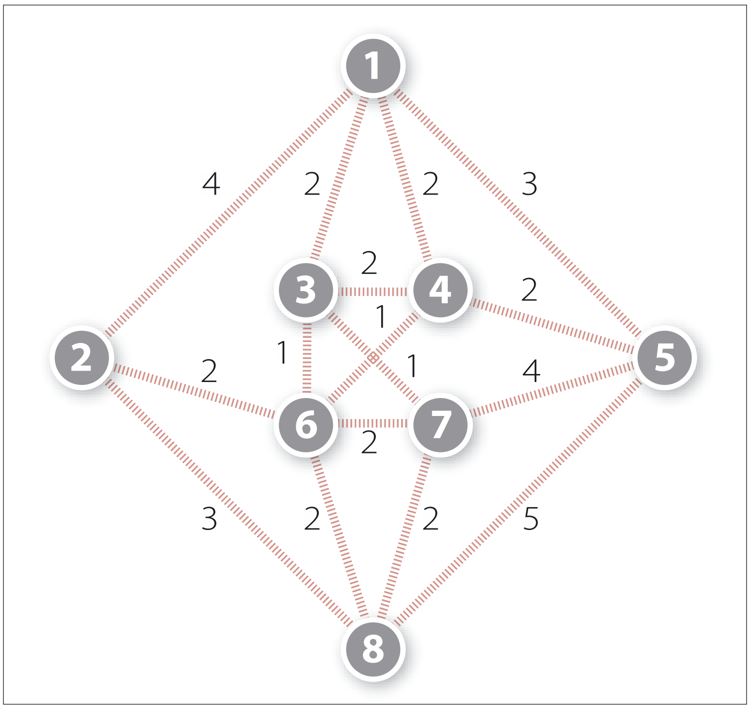


Fig. 1. Graphical representation of the travelling salesman`s problem

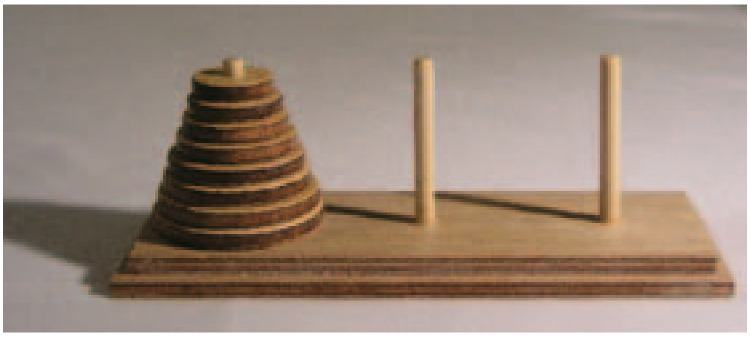


Fig. 2. Children's toy – Tower of Hanoi

Problems of this type are called in the theory of computational complexity the NP-hard problems. It is clearly visible that solving any of presented issues with the method of checking each possible solution is not a good idea. Classical methods of solving optimization problems are no good either. It results from the fact that they require detailed description of the problem, so the best thing would be if it had the form of a function. For NP-hard problems such function does not exist or its description is impossible. It can only be stated that one solution is better than the other, e.g. one route is shorter than the other (the travelling salesman's problem).

Another reason is the volume of the searched set of solutions (that is the number of all possible solutions). It is so enormous that classical methods simply cannot cope with it. The last, but no less important reason for pointlessness of the classical methods for the NP-hard problems is the fact that in case of finding a "good" solution these methods are not able to improve it, they simply "come to a halt". A good description of this situation is walking down the stairs according to the principle – "I am moving only downstairs". If we come across a valley on our way down – we will not be able to get out of it.

Inspiration from nature

The weak spot of the classical methods of optimization with reference to presented problems resulted in searching for methods which would operate according to other principles. In search of inspiration, attention was directed to the world of nature and it turned out that evolution already solved such problems.

An example may be the optimization method inspired by observation of the animals' behaviour, particularly those living in large social communities, i.e. ants, birds and fish. Probably the best documented example are the ants; a colony of these insects makes up a complex and well organized social system which fulfills many functions: from food supplies for the colony to its defence. However, when observing single ants, no symptoms of deliberate action can be noticed. Just the opposite; when watching a colony of ants, there is an impression that the ants are moving randomly. What is more, to some extent that is true. How come then that the ants find the food at a long distance from the colony and they are transporting it to the formicary?

It turns out that ants, while starting their search for food, move about randomly. When one of them finds the food, it comes back to the formicary leaving a trace consisting of pheromones. If another ant finds that trace, it stops moving at random and follows the trace towards the food. The more ants find the pheromone path, the stronger it becomes and the more insects it attracts. However, after some time, the pheromones vanish, so their power decreases. The longer the route from the formicary to the food, the more time the pheromones take to disappear.

Shorter, better routes are preferable as they ensure stronger pheromone signal. Evaporation of pheromones is a positive effect for it allows to find the shortest possible way, i.e. optimal route. If the phero-

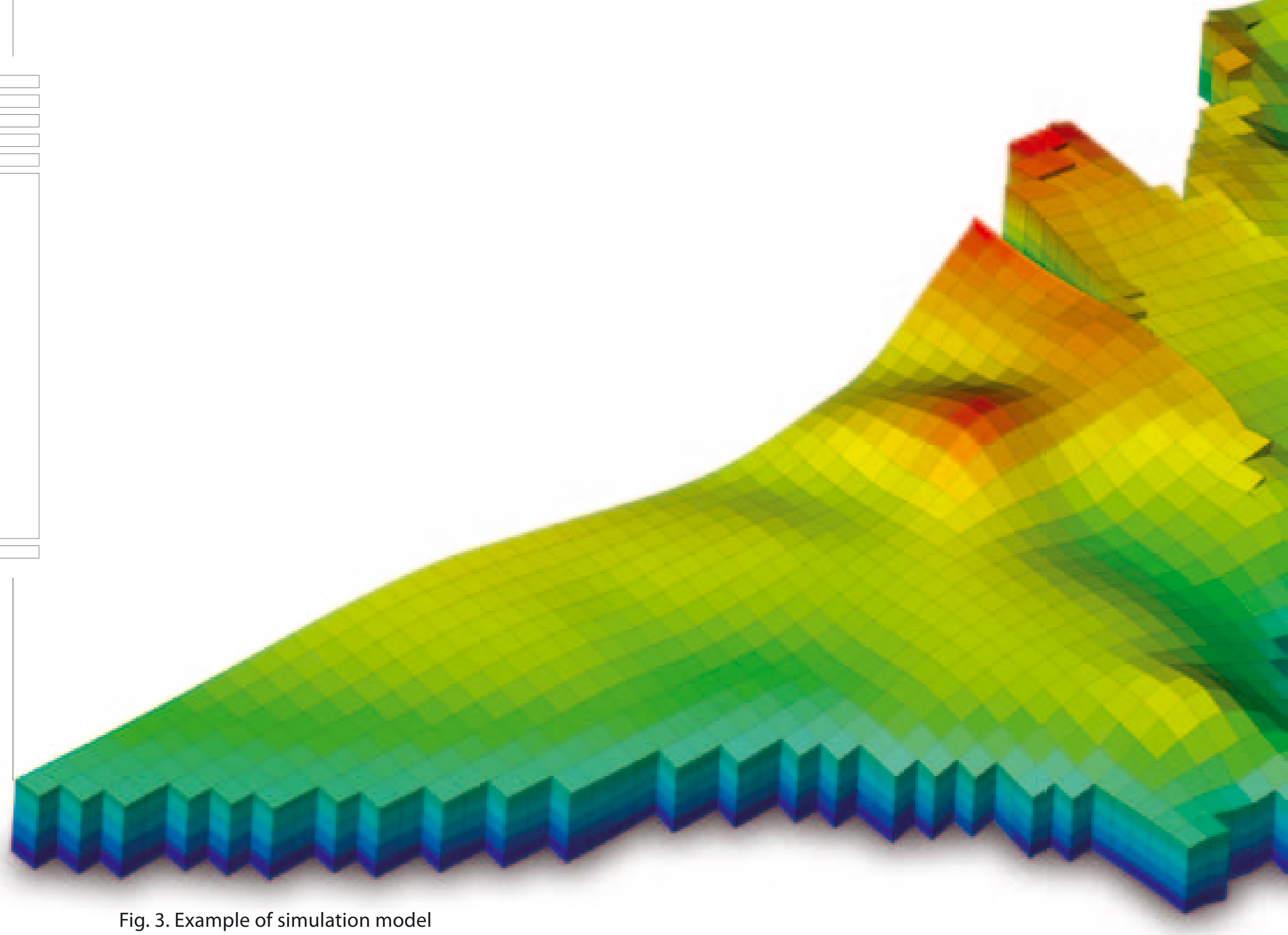


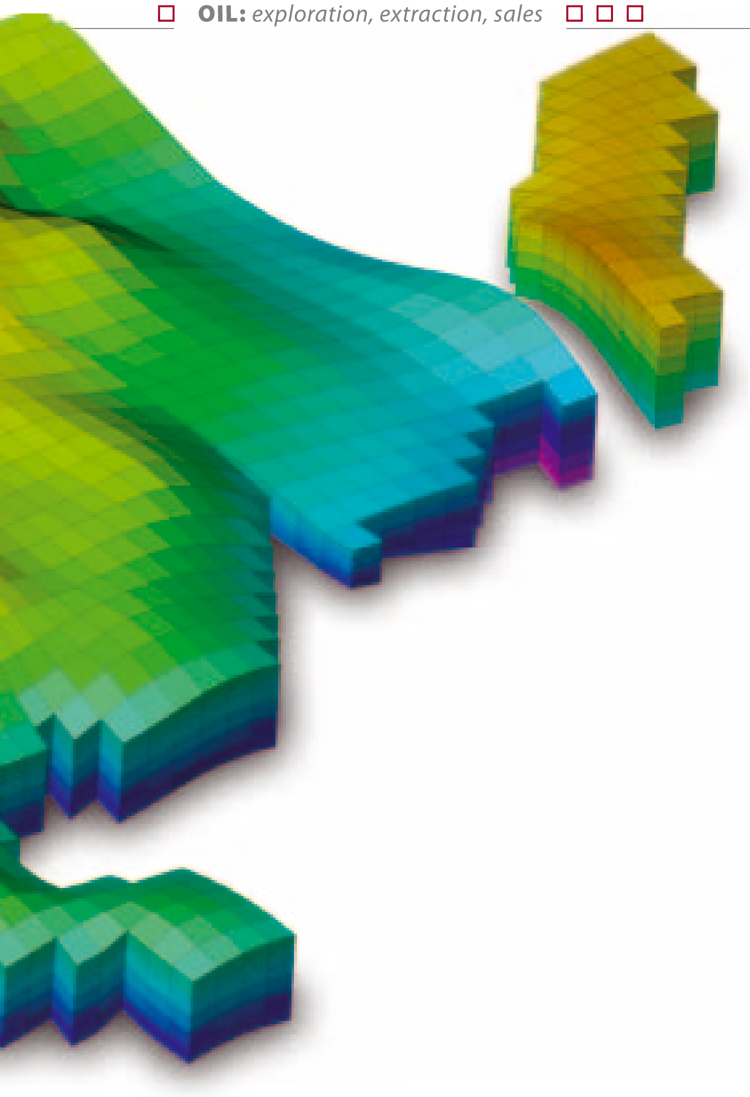
Fig. 3. Example of simulation model

mones did not vanish, each subsequent route would have the same power of "attracting" the ants, which eventually would not permit to find the optimal road. If one ant finds the right (short) way, the other ants will follow this particular route, leaving also the aromatic trace, which will be intensified. Finally, all the ants will move along the same route, best of all, and the remaining paths will be forgotten.

The conclusion from presented observation is as follows: the basis for functioning of complex communities such as ants is not an individual intelligence but sharing the experience with other community members. In other words, solving complicated problems does not require multifaceted behaviour of individual specimen. Organisms which are governed by a simple rule and exchange information are a sufficient example. Such uncomplicated behaviour linked with the mechanism of sharing the knowledge is often called collective intelligence or swarm intelligence.

On the basis of the method of ants' behaviour described above, in the year 1992, Marco Dorigo proposed a technique of solving problems by searching for the right routes in graphs, called the ant algorithm [1]. Nowadays, the method is used successfully in many fields of science and technology, from engineering through medicine and economy to image analysis.

Another example of application of the swarm intelligence is the so-called *Particle Swarm Optimization* (PSO). The idea of PSO has its roots in simulations of simplified community system represented by a flock of birds and shoal of fish. The application of simple rules ensures synchronized and grade-separated traffic which makes impression of the conduct of one organism. The movement of a shoal of fish or flock of birds is the outcome of activity of all individuals keeping an optimal distance from the neighbours, while also following the leader. Examination of the PSO was begun with an attempt to graphically simulate the behaviour of such groups. It turned out, however, that created mathematical model may also be used as optimization method. The authors of this technique of optimization, presented in 1995, are Eberhart and Kennedy [2].



But what does this have to do with deposit simulations?

As it was already mentioned, the NP-hard problems are encountered in many fields of science and technology. One of the examples is deposit engineering, namely simulation engineering. Nevertheless, in order to present the problem, it must be explained what the deposit simulation model is.

Simulation model is a mathematical description of the deposit, i.e. a porous rock filled with oil, gas and water – deposit fluids under pressure. What is necessary in deposit description is the knowledge of its geometry, properties and physical laws describing such systems. Geometrical model is simply a set of hexagonal blocks arranged in layers. The properties are described by assigning numbers to each block which corresponds to various properties, e.g. porosity or permeability. If the presented system is complete with appropriate physical equations describing the conduct of fluids in the deposit rock, then a model will arise which will allow to reconstruct the processes occurring in the real deposit. Simulation models are applied e.g. in forecasting the extraction or projects for deposit expansion.

At the time of the actual deposit exploitation, a series of quantities are measured, e.g. pressure in the boreholes, volume of extracted fluids, etc. If the model is correct, after considering the volume of actually extracted deposit fluids, the pressures in the boreholes should be consistent with reality. Briefly speaking: the mathematical and physical model presented above is appropriate only if it reconstructs the real conditions. Unfortunately, construction of such a model is not an easy task due to the fact that the information on the basis of which it is built concerns no more than 2% of the deposit volume. The construction of simulation model consists then in "guessing" e.g. the properties of the deposit rock between the boreholes. The mathematical and geostatistical methods are applied here, as well as the seismic techniques (3D seismics), however, not much is known about the deposit and the model constructed in this way is not credible – it does not reconstruct the real deposit conditions.

The only method of model verification is the introduction of suitable changes that would help obtain required consistence with reality. This process is called *history matching* and in practice it consists in multiple repetition of the procedure: calculations (simulation) – analysis of the results – modification of the model, until a satisfactory conformity of measurements and results is achieved and modification of the model is done "by hand", on prior analysis of the results of the previous simulation. On account of complexity of the problem, the knowledge, experience and plenty of time are indispensable components of model verification. It sometimes happens that obtaining satisfactory matching requires a few hundred tests, which – with average time of a single simulation lasting between 2 and 10 hours may take months to complete.

History matching – NP-hard problem

Simulation models often have several hundred thousand blocks. In each block, the quality sequence is defined (porosity, permeability, conductivity, capillary pressure, relative permeability, etc.). Moreover, the zones of deposit rock discontinuity are described (the so-called faults), contacts of deposit fluids and their properties, the properties of aquifer and many other qualities. This means that the number of possible combinations of these parameters is difficult to determine. Surely, general form of the flow equation is well known but they are nonlinear equations, resolved many times in the course of simulation; it is not possible to draw any conclusions from their forms. The only thing that can be relied upon is information of this type: "model no. 125 gives better results than model no. 111".

We are dealing then with an extremely intricate physical system, defined by a large number of numerical parameters and described by a complicated system of nonlinear differential equations.

Calibration is an attempt to solve the reverse problem. It means that attempts are made to modify the input data in such a way (e.g. properties of deposit rock) as to obtain the target values on the output (e.g. borehole pressure). Furthermore, it is impossible to solve calibration in an explicit way, namely, various combinations of model modification may produce very similar results and it is often difficult to decide which solution is better. In other words, we have to tackle a NP-hard problem.

Algorithms based on swarm intelligence performed well in the problem of history matching. Using the analogy of formicary, it can be claimed that the simulation model is an "ant" looking for the best solution, i.e. such combination of parameters for the system of deposit rock–deposit fluid which best reconstructs the actual situation of the deposit.

At the first stage, each of many models – ants – is generated at random in defined ranges of parameter values. Optimization consists in iterative modification of each of the models in order to obtain the model which best reflects the actual deposit conditions. This process is conducted according to random distribution with set parameters. One of them is the rate of pheromone evaporation, mentioned before. If it is too low, good solutions are long remembered, which practically means that the solution will be found soon but it will probably be at most "satisfactory". If the rate of pheromone evaporation is high, good solutions will soon be forgotten, i.e. the optimization process will take longer and will have more random character. On the one hand, this parameter must be selected so as the whole process does not take too long, on the other – obtained solution can accurately simulate the real deposit features.

It is obvious that the swarm algorithm will not do all the work. As the swarm intelligence techniques operate on many solutions, often several solutions are obtained in the outcome of calibration, out of which the best must be chosen for further analysis. What is more, the optimization process depends indeed on the value of control parameters; their selection has the key importance for its effectiveness. The values of the parameters are selected by the trial and error method; it often requires conducting many tests.

There is no doubt that applications which support the process of history matching, by providing possible solutions, may successfully be used for testing hypotheses, while reducing also to minimum the scope of operations performed by the engineer.

Summary

Swarm algorithms demonstrated their effectiveness in deposit engineering, both in theoretical discussion and the actual deposits [3, 4]. They are also used more and more widely in commercial applications to support the process of history matching. On account of random incidence, they effectively search the set of solutions. They are easy in implementation and they may be combined with each other and with other optimization methods. Then, hybrid algorithms come into being which are linking the assets of the methods used. All that makes the swarm algorithms a promising direction of tests aiming at creating more and more effective optimization algorithms.

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LCA – tool for assessment of influence of conventional motor fuels on global warming

How to produce more ecological fuels?

Delfina Rogowska

One of the priorities of the European Union is the reduction of greenhouse gas emission. It was expressed by signing the Kyoto Protocol and also by stimulating the activities of enterprises by issuing appropriate legal acts (directives).

Emission in the energy sector is anticipated to fall by 85% by the year 2050 [1]. This goal can be reached by a few methods – both by intensification of power generation from renewable sources, improvement of energy efficiency and direct reduction of emitted greenhouse gases. The last method found expression in directive 2009/30/EC, commonly called the FQD Directive.

One of the most essential changes introduced is increasing the maximum content of biocomponents in motor fuels and also making the fuel suppliers liable for reduction of greenhouse gases in the life cycle. According to the details contained in article 7a paragraph 2: *"Member states shall require suppliers to gradually reduce the greenhouse gas emission in the whole life cycle per unit of energy generated from fuel and energy supplied by up to 10% by 31 December 2020, compared with the fuel baseline standard referred to in paragraph 5 (b) of the FAQ directive".*

What is essential, reduction of greenhouse gas emissions is referred to emissions generated in the whole life cycle. The directive neither specifies the methodology for calculation nor refers to standardized methods.

The LCA methodology

The principle of evaluation of the product in the life cycle is currently the generally applied methodology for measuring the influence of this product on the environment. The standardized methodology described in the PN-EN ISO 14040 [3] and PN-EN ISO 14044 [4] standards is used for this purpose. Life cycle includes successive and connected with one another stages of the product system: from receiving or producing this raw material from natural resources to its final liquidation and the evaluation of life cycle means collection and evaluation of inputs, outputs and potential influence of the product system on the environment in the period of its life cycle.

In practice, when evaluation of the life cycle of a given product is performed, its influence on the natural environment is considered in procurement of the raw materials for production of the tested product, and then its production, distribution, sale, use and also – after it has been used – its utilisation. Calculations can be done for one or several categories of influence. As a result of such a systematic review, the amount of environmental burdens can be defined at each stage of the life cycle. Finally, this knowledge can be used to manage production in such a way as to avoid shifting of the burdens among individual stages of the life cycle. Such an approach allows to evaluate total influence of the product on the natural environment. The above mentioned and also the universality and clearness of this methodology made it a popular tool for evaluation of all kinds of products.

Before the research, the basic questions to be determined are: adoption of a functional unit and

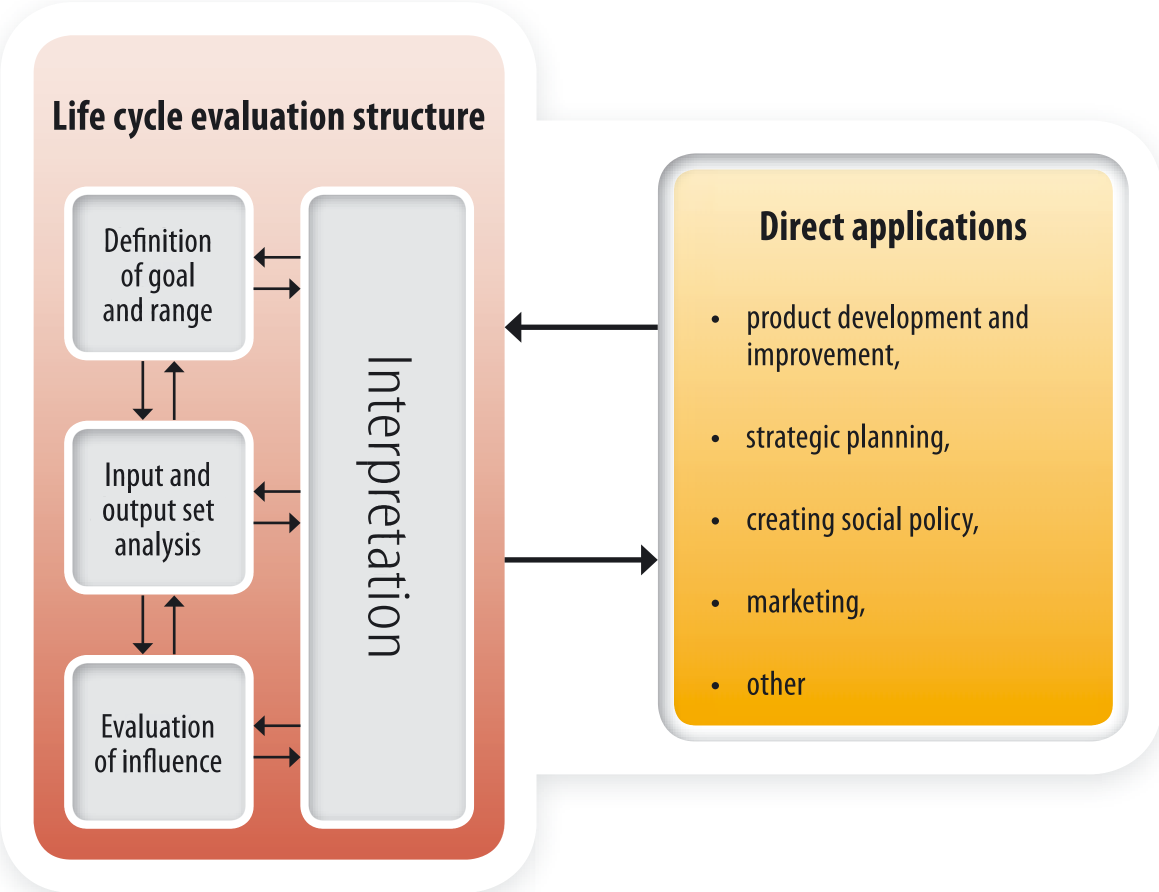

Fig. 1. LCA Phases

setting the limits for the calculation system. The function unit is a quantitative effect of the product system applied as a reference unit. The purpose of determining the functional unit is to define the reference quantity to standardized input and output data.

However, the system limits specify which individual processes should be included in the test and how detailed the examination of these processes should be.

When the system limits are set, the following should be taken into consideration, i.e.:

- materials procurement,
- inputs and outputs,
- distribution and transportation,
- production and use of fuels, electric energy and heat,
- use and service of products,
- elimination of the process wastes and residues,
- recovery of used products (including renewed use, recycling, energy recovery),
- production of supplementary materials,
- production, service and excluding the basic equipment from exploitation,
- additional operations (e.g. the lighting, heating).

When more than one product is made in a given production process, it is essential to adopt proper allocation procedure. Allocation, according to the definition given in [4], means distribution of the input and output process streams or product system between the tested product system and one or several other product systems.

Standard [3] recommends conducting LCA tests in four phases:

- definition of the target and range
- phase of analysis of input and output set,
- influence evaluation phase,
- interpretation phase.

The stages of evaluation described above are presented in figure 1.

Life cycle of motor fuels

Methodology given in standards [3, 4] is universal and widely applied for all products. Its application for oil products requires adaptation.

The life cycle of motor fuels runs according to the pattern shown in figure 2.

house gas emissions, sewage, noise etc. The FQD Directive is concentrated on one phenomenon only: global warming. Therefore, it obliges motor fuel producers to monitor and limit greenhouse gas emissions.

As shown in figure 2, the life cycle of motor fuels is composed of several separate components (oil ex-

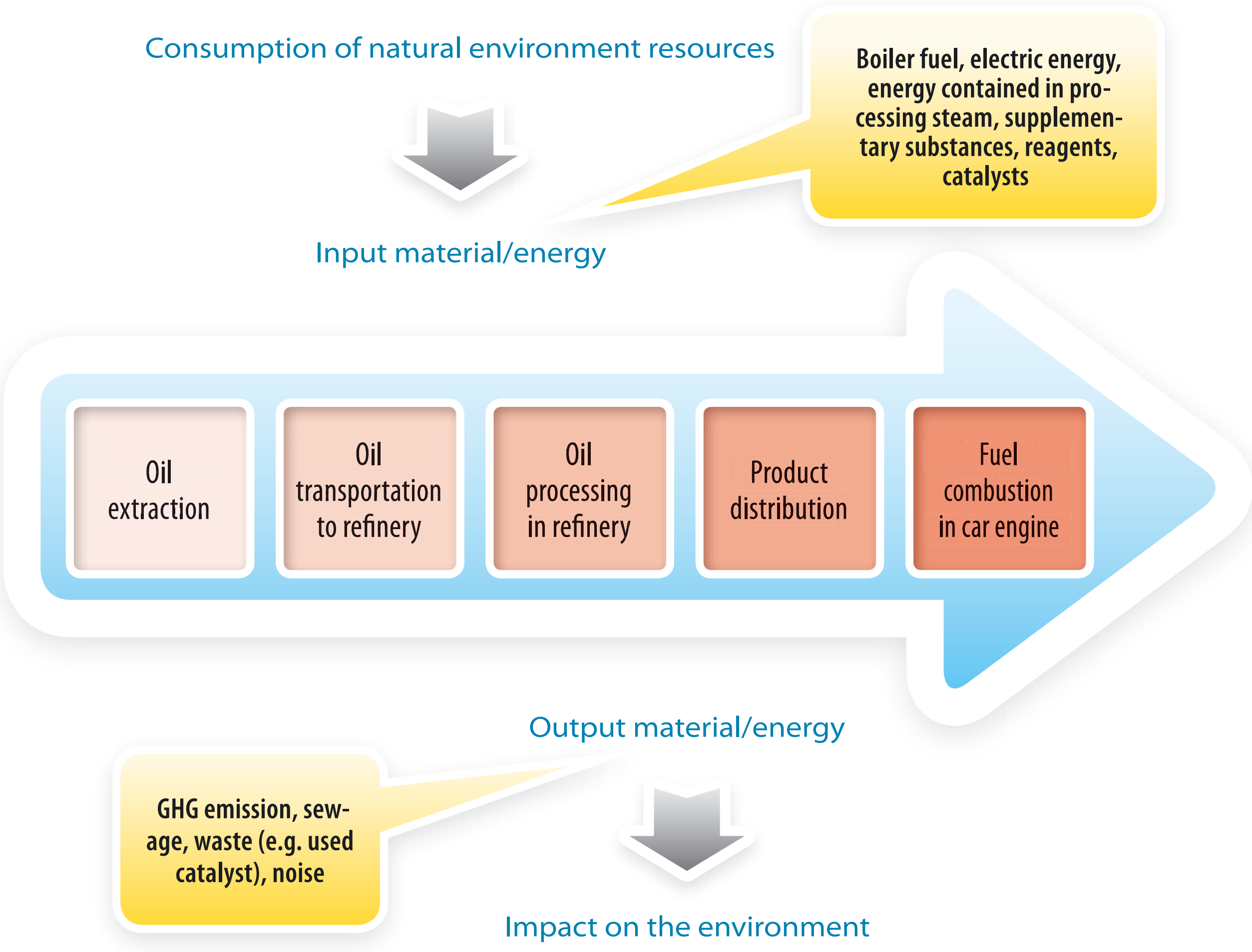

Fig. 2. Life cycle of motor fuels

Life cycle of hydrocarbon motor fuels begins at the moment of oil prospecting and exploration. The next stage is its transportation to the refinery and then processing into motor fuels. When the products are ready, they are distributed to filling stations, to the final consumer. Life cycle ends at the moment the fuel is burnt in a car engine, thanks to which there is no problem with utilization of the consumed product.

Each stage requires making use of the natural environment supplies and it also generates green-

traction, processing in refinery, etc.). In practice, each of these stages is treated as a separate computing system for which the GHG (greenhouse gas) emission factor is defined in reference to the energy contained in fuels. Such approach makes it possible to compare "emissivity" of individual stages for different production pathways.

Depending on the production pathway, the emission share at individual stages can vary, however, its largest part is always attributed to the combustion stage in the vehicle engine. Figure 3 shows in a schematic way the GHG emission distribution in the life cycle of low-sulphur fuel oil [5].

The fuel combustion stage in the car engine makes up almost 80% of all the emission generated in its life cycle, while the next positions are occupied by oil processing (11%) and extraction and transportation (10% of emission).

fuel mass unit, volume or even energy used during production. The adoption of the kgCO_{2eq} / MJ unit of energy contained in fuel allows to compare greenhouse gas emissions in the life cycle of different fuels, e.g. conventional fuels and biofuels or diesel fuel and CNG (LNG) used for driving trucks. So, the decision on adopting the functional unit must be justified by the purpose of the test. Due to the fact that fuels are energy carriers, calculation of greenhouse gas emissions with reference to energy contained in fuel is fully justified.

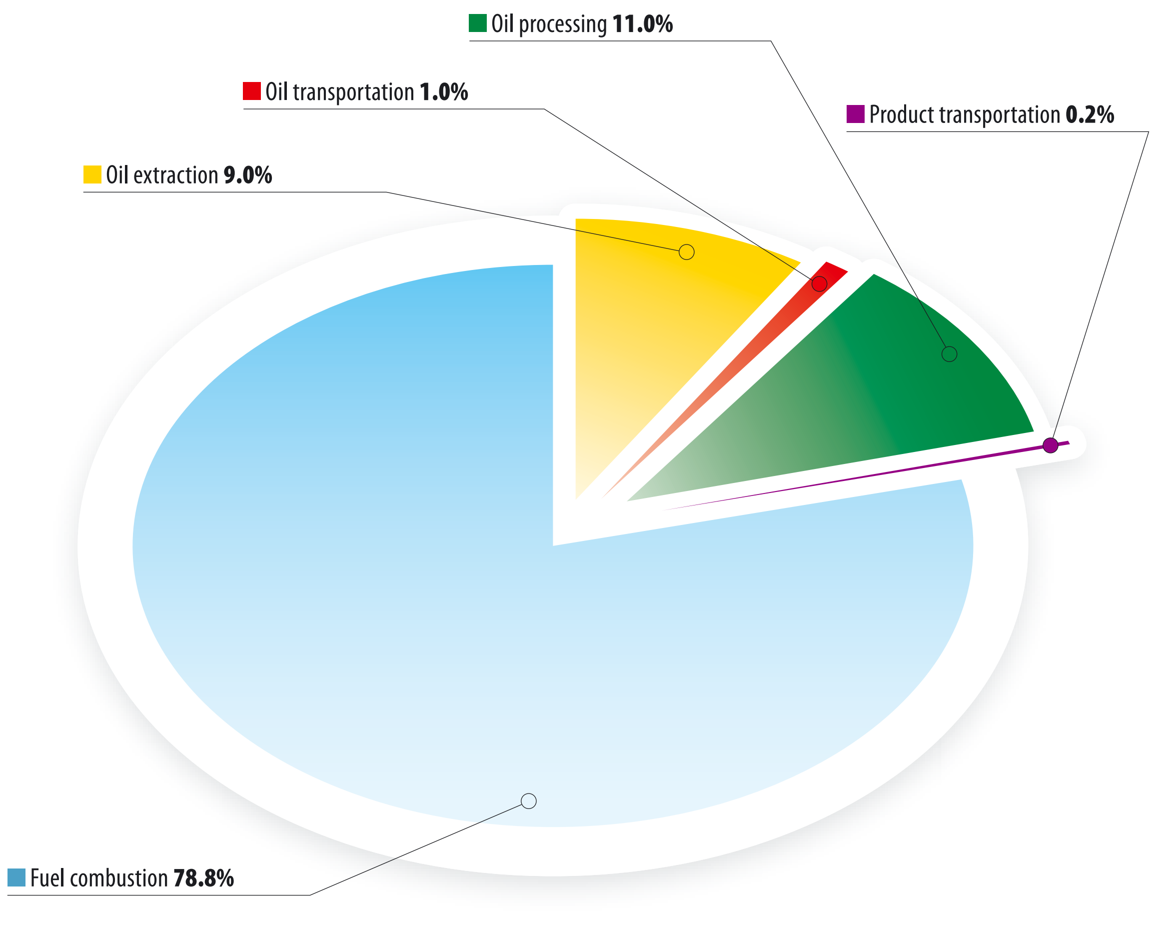

Fig. 3. The GHG emission distribution in the life cycle of low-sulphur diesel oil

Functional unit

In case of evaluation of the influence of motor oils on global warming, the functional unit is the reference of emitted volume of greenhouse gases (expressed as equivalent of carbon dioxide – CO_{2eq}) to a fuel unit. The FQD Directive demands that these values should be referred to the energy contained in fuel. However, depending on the purposes of the LCA studies, the CO_{2eq} quantity may be referred to

Limits of the system

An extremely important element of the analysis is defining the system limits: setting the computing

system. Inclusion of individual processes or their exclusion is conditioned both by significance of specific processes and the purpose for which the work is done. In case of motor fuel production, the limits of the computing system for the whole life cycle of motor fuels include:

- oil extraction,
- its transportation to the refinery,
- oil processing in the refinery,
- distribution of finished products,
- fuel use in the car engine.

Depending on the purpose of the research work, the range of individual processes at each stage should be considered. Individual model processes in the LCA motor fuel test can be e.g. oil extraction, its purification and transportation to refinery, and at the processing stage – e.g.: atmospheric distillation system, vacuum distillation system, hydrocracking or reforming system in the refinery, fuel loading at the terminal, fuel transport by railway, storage in fuel base, etc. The range of individual processes should be thoroughly considered for each of these stages; e.g. when extracting oil, the decision should be made on inclusion or exclusion of prospecting stage and, in each case, it should be established if the greenhouse gas emissions resulting from production of machines, devices, elements of equipment are included in the computing system.

Another essential issue is the changed volume of GHG emissions connected with the changed way of using the land on which production is conducted, especially if green areas were intended for production (forests, farmlands, wasteland, etc.). Inclusion of these processes into the computing system is important in evaluation of new investments. In refining industry, as well as in other production plants, supplementary services, e.g. flares, wastewater treatment plants, are indispensable for proper functioning of the unit. Although they are not units directly producing the fuel components, their services are essential, that is why they also should be included into the computing system. Adoption of proper allocation procedure for arising emission for the oil products is a separate issue. The emission generated in connection with production of purchased raw materials and components cannot be disregarded either, however, disputable remains the emission coming from catalyst production or emission from production of supplementary materials used in the processes; in this case the research worker should evaluate the significance of the influence of mentioned elements on the final results. Considering the question of comparative studies for different products, it is essential that the assumptions and exclusions should be – for all evaluated products – at the same level of significance.

The system limits, except the individual processes, should include the set of inputs and outputs. Inputs should include input material and input energy. Input material is e.g. petroleum sent for processing or fuels designed for distribution, while the input energy is e.g. the energy used during oil extraction, transportation and product distribution.

Obviously the obtained goods are the output of the processes but also byproducts (sulphur, acetone on phenol installation), waste, sewage, and emitted greenhouse gases or hydrocarbons. The GHG emission sources should be identified separately for each stage of the motor fuel life cycle. During the extraction phase the essential sources of GHG comprise: field gas combustion in turbines, burning processes in the flare and field gas discharge to the atmosphere [6]; while during oil processing in refinery it is the boiler fuel combustion, electricity and heat production or regeneration of process catalysts. At the fuel distribution stage the GHG emission sources depend on the implemented logistic system.

Usually the data are aggregated in inventory tables prepared on the basis of material and energy balances of individual unit processes.

The GHG emission allocation

Except for motor fuels, many products and materials are produced from oil for further syntheses. Hence, the emission generated during oil extraction and production must be "allocated" to the received products. The allocation procedure is used for this purpose. Energy consumption allocation (and in consequence the GHG emission) in oil refineries should be done in accordance with the rules given in the ISO 14041 standard, i.e. at the level of individual refining processes, if it is possible. Allocation can be done based on physical quantities (mass, volume, energy content in obtained products) or economic ones (e.g. profit share in the sale of individual products). In case of motor fuels, the recommended way is the GHG emission allocation based on the energy content in individual products. It is not an easy task, especially at the stage of distribution of finished fuels, where the filling stations – except for fuels – usually offer other goods and services (sale of goods, fast food, car wash etc.).

In the test prepared by the Centre for Transportation Research, Energy Systems Division and Argonne National Laboratory [7], methodology was prepared based on published data on energy and mass balance for the United States refineries with a simple oil processing pattern and it was applied in allocation of total energy consumption in a refinery for different oil derivatives. This method consists in counting the energy consumption during individual refining processes, by monitoring the streams of mass and energy consumption during production of each product in the course of refining.

Energy consumption connected with individual refining process was distributed by way of coefficients to product streams with the help of:

- share of mass components of these products,
- amount of energy contained in them,
- market value of each product stream.

Advantages of the LCA techniques evaluation in case of motor fuels

Implementation of evaluation methodology for the life cycle of motor fuels in an individual supplier allows to obtain full knowledge in the field of:

- total energy consumption in individual processes and operations of the motor fuel production cycle used for its generation,
- GHG emission generated in individual processes and operations of the motor fuel production

cycle and GHG emission rates in gCO_{2eq} / MJ of energy contained in petrol (diesel fuel, LPG),
- the GHG emission value connected with production of the individual components of petrol and diesel fuels,
- the emission value connected with production of the unit amount of hydrogen.

Making calculations of the actual GHG emission in the fuel life cycle in refineries allows producers to obtain full knowledge in the field of energy consumption and the GHG emission in each process and each operation with reference to normalized amount of energy contained in fuel. On this basis it can be assessed which process "brings in" the highest emissions and actions can be planned leading to reduction of the GHG emissions. Analysis of all sources of GHG emissions can be done related to production of defined fuel components and solutions can be developed for reduction of greenhouse gas emissions.

Calculation of the actual emissions in the field of oil extraction and transport and distribution of produced fuels allows to enable diversification of oil supplies and used refinery fuels and optimisation in the range of transportation logistics and selection of the means of transporting the finished products.

Reduction of the greenhouse gas emissions is not possible in practice without incurring investment expenditures, hence the GHG emission system in the product life cycle should be integrated with the management system and system of optimisation of motor fuels in such a way as to achieve the most optimal effect, i.e. to achieve the largest reduction of greenhouse gas emissions at minimisation of the costs.

Application of the LCA methodology is extremely profitable when introducing new products (alternative fuels) on the market. Obtained results provide the knowledge about complex influence of the product on the natural environment. Conducted studies also allow to estimate ecological advantages resulting from the replacement of one fuel with another. Such approach was used for the assessment of biofuels. According to the 2009/28/EC directive [8], only those biofuels will be recognised as satisfying the obligatory increase in energy from renewable sources for which reduction of greenhouse gas emissions in the life cycle in relation to conventional fuels is at least 35%. This threshold will be raised to 50% in 2017 and from the year 2018 – for new biofuel production installations – to 60%.

Summary

Due to complexity of the process of motor fuel production, the application of the LCA methodology is quite complicated as it requires the cooperation between independent economic operators acting on the fuel market, collecting detailed data for individual processes and also doing numerous calculations. However, making such an analysis allows to identify the most emissive (which is often equivalent for the most energy consumption) processes in relation to obtained normalized energy contained in fuel. This knowledge, especially in connection with the economic data, may subsequently serve to optimise production management. At present many refineries implement integrated management systems, taking into account material purchase and product sale. Inclusion of the LCA analysis into these systems would allow to produce more ecological fuels.

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7) WTT APPENDIX 2, November 2008.. *Description and detailed energy and GHG balance of individual pathways*, WELL-THIS-TANK Report, version 3.0, November 2008 http://ies.jrc.ec.europa.eu/uploads/media/WTTapp2V30181108.pdf - access: November 2011.
8) European Parliament and Council directive 2009/28/EC of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC.

Oil consumption [million tonnes]

Country	2004	2005	2006	2007	2008	2009	2010	2011	2012	Change 2012 over 2011	2012 share of total
US	936.5	939.8	930.7	928.8	875.4	833.0	847.4	837.0	819.9	-2.3%	19.8%
Canada	100.8	99.9	99.4	102.3	101.2	95.2	101.3	105.0	104.3	-0.9%	2.5%
Mexico	88.5	90.8	89.7	92.0	91.6	88.5	88.5	90.3	92.6	2.3%	2.2%
Total North America	**1125.9**	**1130.5**	**1119.7**	**1123.1**	**1068.2**	**1016.8**	**1037.3**	**1032.3**	**1016.8**	**-1.8%**	**24.6%**
Argentina	19.4	20.7	21.7	24.0	24.7	24.0	26.0	27.5	28.2	2.3%	0.7%
Brazil	92.0	94.2	95.8	101.8	108.6	109.1	118.3	122.2	125.6	2.5%	3.0%
Chile	11.5	11.8	13.2	17.0	17.8	17.4	15.4	17.5	17.9	1.9%	0.4%
Colombia	10.3	10.5	10.7	10.7	10.8	11.1	11.9	12.5	12.7	1.0%	0.3%
Ecuador	7.2	7.9	8.3	8.5	8.7	8.9	10.3	10.5	11.0	3.6%	0.3%
Peru	7.3	7.1	6.9	7.1	8.0	8.1	8.5	9.2	9.6	3.2%	0.2%
Trinidad & Tobago	1.2	1.2	1.4	1.7	1.8	1.7	1.9	1.6	1.6	0.2%	*
Venezuela	27.2	28.8	30.3	30.4	34.8	35.2	35.8	35.6	36.6	2.5%	0.9%
Other S. & Cent. America	59.6	58.8	59.5	60.1	57.8	57.0	58.2	58.7	59.0	0.2%	1.4%
Total S. & Cent. America	**235.8**	**241.0**	**247.7**	**261.3**	**272.9**	**272.5**	**286.1**	**295.4**	**302.2**	**2.0%**	**7.3%**
Austria	13.9	14.0	14.2	13.4	13.4	12.8	13.4	12.6	12.4	-1.2%	0.3%
Azerbaijan	4.5	5.4	4.8	4.5	3.6	3.3	3.2	4.0	4.2	5.4%	0.1%
Belarus	7.1	7.1	8.1	7.3	8.3	9.4	7.3	9.0	9.1	1.1%	0.2%
Belgium	33.5	33.5	33.4	33.7	36.8	32.2	33.5	32.3	30.6	-5.4%	0.7%
Bulgaria	4.3	4.8	5.0	4.8	4.8	4.3	3.9	3.8	3.8	0.1%	0.1%
Czech Republic	9.5	9.9	9.8	9.7	9.9	9.7	9.1	9.0	9.1	0.2%	0.2%
Denmark	9.0	9.4	9.6	9.7	9.5	8.5	8.4	8.1	7.6	-6.3%	0.2%
Finland	10.6	11.0	10.6	10.6	10.5	9.9	10.4	9.7	9.1	-6.2%	0.2%
France	94.0	93.1	93.0	91.4	90.8	87.5	84.5	83.7	80.9	-3.6%	2.0%
Germany	124.0	122.4	123.6	112.5	118.9	113.9	115.4	112.0	111.5	-0.7%	2.7%
Greece	21.3	21.1	22.1	21.7	21.3	20.1	18.0	17.0	15.4	-9.5%	0.4%
Hungary	6.3	7.4	7.8	7.7	7.5	7.1	6.7	6.4	6.0	-7.7%	0.1%

Oil consumption [million tonnes]

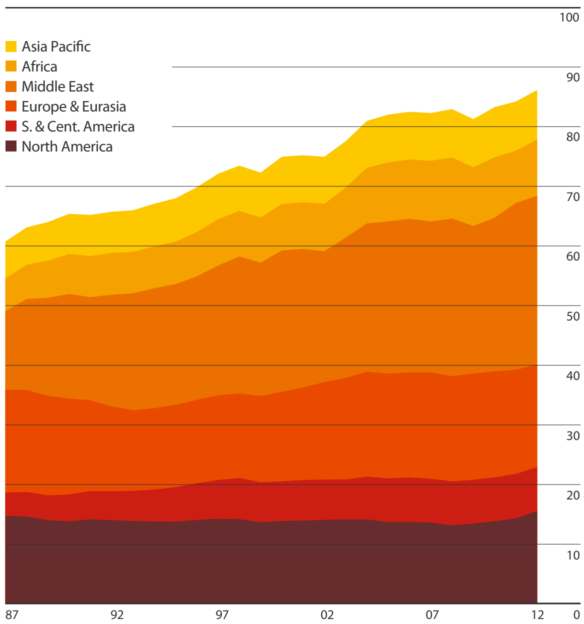
Country	2004	2005	2006	2007	2008	2009	2010	2011	2012	Change 2012 over 2011	2012 share of total
Republic of Ireland	8.9	9.3	9.3	9.4	9.0	8.0	7.6	6.7	6.2	-7.7%	0.2%
Italy	89.7	86.7	86.7	84.0	80.4	75.1	73.1	70.5	64.2	-9.2%	1.6%
Kazakhstan	9.5	9.8	10.3	11.3	11.0	8.9	9.3	11.6	12.8	10.2%	0.3%
Lithuania	2.6	2.8	2.8	2.8	3.1	2.6	2.7	2.6	2.6	-1.2%	0.1%
Netherlands	47.1	50.1	50.8	50.7	47.3	45.9	45.9	46.1	44.1	-4.5%	1.1%
Norway	10.0	10.2	10.5	10.7	10.4	10.6	10.8	10.6	10.8	1.3%	0.3%
Poland	21.6	22.4	23.3	24.2	25.3	25.3	26.7	26.6	25.1	-5.8%	0.6%
Portugal	15.4	16.0	14.4	14.4	13.6	12.8	12.5	11.6	10.9	-6.2%	0.3%
Romania	10.9	10.5	10.3	10.3	10.4	9.2	8.8	9.1	8.8	-3.6%	0.2%
Russian Federation	126.2	126.1	130.3	130.0	133.9	128.2	134.3	143.5	147.5	2.5%	3.6%
Slovakia	3.2	3.8	3.4	3.6	3.9	3.7	3.9	3.9	3.5	-9.3%	0.1%
Spain	78.5	79.3	79.3	80.3	77.9	73.5	69.6	68.5	63.8	-7.2%	1.5%
Sweden	16.2	16.1	16.5	16.0	15.7	14.6	15.3	14.5	13.8	-4.8%	0.3%
Switzerland	12.0	12.2	12.6	11.3	12.1	12.3	11.4	11.0	11.2	1.6%	0.3%
Turkey	30.8	30.9	32.7	33.5	31.9	31.6	31.8	30.7	31.5	2.3%	0.8%
Turkmenistan	4.3	4.3	4.1	4.6	5.1	4.6	4.5	4.7	4.8	3.3%	0.1%
Ukraine	14.3	13.7	14.2	15.6	14.9	13.4	13.0	12.9	13.2	1.9%	0.3%
United Kingdom	81.7	83.0	82.3	79.2	77.9	74.4	73.5	71.1	68.5	-4.0%	1.7%
Uzbekistan	7.7	5.0	5.0	4.6	4.5	4.3	3.6	3.8	3.9	2.1%	0.1%
Other Europe & Eurasia	29.7	30.8	31.5	32.5	33.1	32.6	32.8	32.8	32.8	-0.3%	0.8%
Total Europe & Eurasia	**958.3**	**962.0**	**972.1**	**956.4**	**956.7**	**910.6**	**904.7**	**900.3**	**879.8**	**-2.5%**	**21.3%**
Iran	76.9	80.7	86.5	88.6	92.2	93.5	88.3	85.6	89.6	4.3%	2.2%
Israel	12.0	12.2	11.9	12.4	12.2	11.4	10.9	11.5	13.6	17.8%	0.3%
Kuwait	17.8	19.5	17.7	17.9	19.0	20.3	21.7	20.4	20.9	2.5%	0.5%
Qatar	3.4	4.0	4.5	5.2	6.0	6.0	6.9	7.8	8.0	2.5%	0.2%
Saudi Arabia	88.3	88.2	92.4	98.1	106.8	115.8	123.5	124.4	129.7	3.9%	3.1%

Oil consumption [million tonnes]

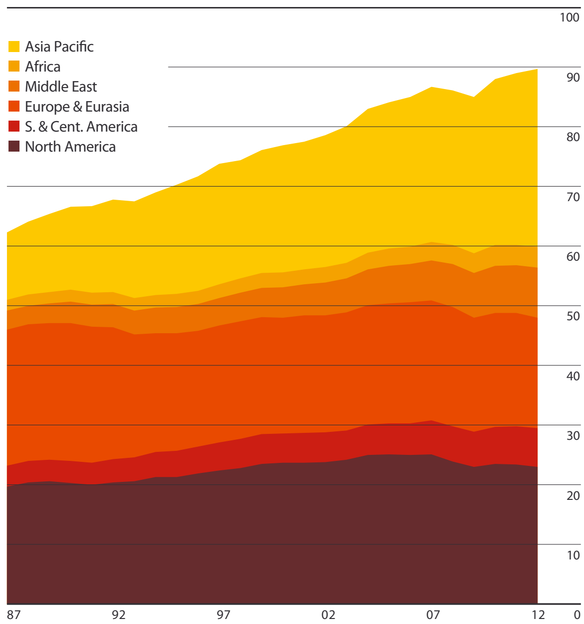
Country	2004	2005	2006	2007	2008	2009	2010	2011	2012	Change 2012 over 2011	2012 share of total
United Arab Emirates	23.9	24.5	26.3	28.2	29.4	28.1	30.0	31.8	32.6	2.2%	0.8%
Other Middle East	60.5	63.5	59.3	60.0	68.6	71.3	74.6	77.1	81.4	5.3%	2.0%
Total Middle East	**282.7**	**292.7**	**298.6**	**310.3**	**334.1**	**346.4**	**356.1**	**358.7**	**375.8**	**4.5%**	**9.1%**
Algeria	10.6	11.0	11.5	12.9	14.0	14.9	14.8	15.5	16.7	6.9%	0.4%
Egypt	26.8	29.8	28.7	30.6	32.6	34.4	36.3	33.7	35.2	4.4%	0.9%
South Africa	24.7	24.6	25.3	26.2	25.3	24.7	26.1	26.2	26.9	2.6%	0.7%
Other Africa	69.7	73.1	72.9	75.7	80.5	82.1	86.4	82.7	87.7	5.8%	2.1%
Total Africa	**131.8**	**138.5**	**138.4**	**145.4**	**152.5**	**156.0**	**163.6**	**158.0**	**166.5**	**5.1%**	**4.0%**
Australia	39.5	40.7	42.1	42.4	43.2	42.9	43.7	46.1	46.7	0.9%	1.1%
Bangladesh	4.2	4.3	4.3	4.2	4.1	3.8	4.2	5.3	5.6	6.3%	0.1%
China	318.9	327.8	351.2	369.3	376.0	388.2	437.7	459.4	483.7	5.0%	11.7%
China Hong Kong SAR	15.4	13.8	15.0	16.1	14.6	16.6	17.9	18.1	17.9	-1.2%	0.4%
India	119.5	121.9	128.3	138.1	144.7	152.6	155.4	163.0	171.6	5.0%	4.2%
Indonesia	60.5	59.5	57.8	59.3	58.7	60.6	65.2	71.1	71.6	0.4%	1.7%
Japan	245.5	248.8	239.6	232.6	226.3	202.2	204.1	204.7	218.2	6.3%	5.3%
Malaysia	25.5	25.0	26.6	29.2	28.8	28.3	28.4	29.1	29.8	2.1%	0.7%
New Zealand	7.0	7.0	7.1	7.2	7.2	6.9	7.0	7.0	7.0	-0.1%	0.2%
Pakistan	16.0	15.3	17.6	19.3	19.4	20.8	20.6	20.8	20.0	-4.2%	0.5%
Philippines	15.9	14.8	13.3	14.1	12.3	13.1	13.2	12.8	13.0	0.7%	0.3%
Singapore	39.4	43.2	46.5	50.5	53.7	57.3	62.9	65.7	66.2	0.4%	1.6%
South Korea	104.6	104.6	104.7	107.6	103.1	103.7	105.0	105.8	108.8	2.5%	2.6%
Taiwan	48.9	49.3	48.6	50.4	45.1	44.3	46.3	42.8	42.2	-1.8%	1.0%
Thailand	43.5	44.3	44.4	44.4	44.3	47.2	47.1	50.5	52.4	3.6%	1.3%
Vietnam	12.5	12.2	12.0	13.3	14.1	14.1	15.1	16.5	16.6	0.7%	0.4%
Other Asia Pacific	14.1	14.2	14.5	15.2	14.7	16.7	16.7	18.0	18.3	1.3%	0.4%
Total Asia Pacific	**1130.8**	**1146.9**	**1173.6**	**1213.3**	**1210.5**	**1219.3**	**1290.5**	**1336.6**	**1389.4**	**3.7%**	**33.6%**
Total World	**3865.2**	**3911.6**	**3950.1**	**4009.7**	**3994.8**	**3921.6**	**4038.2**	**4081.4**	**4130.5**	**0.9%**	**100.0%**

* less then 0.05

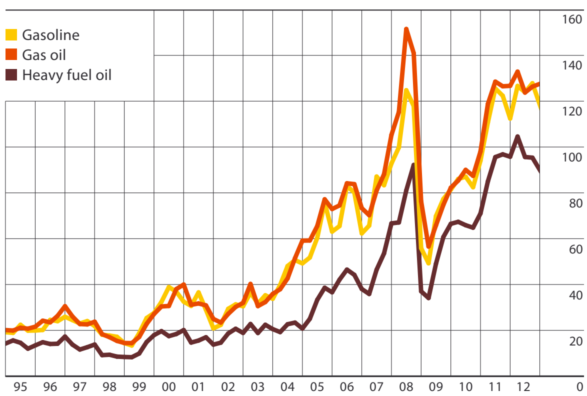
Oil production [m barrels/day]



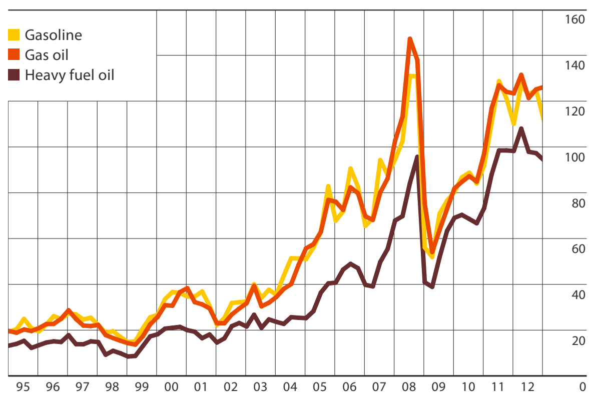
Oil consumption [m barrels/day]



Product prices in Rotterdam [USD per barrel]

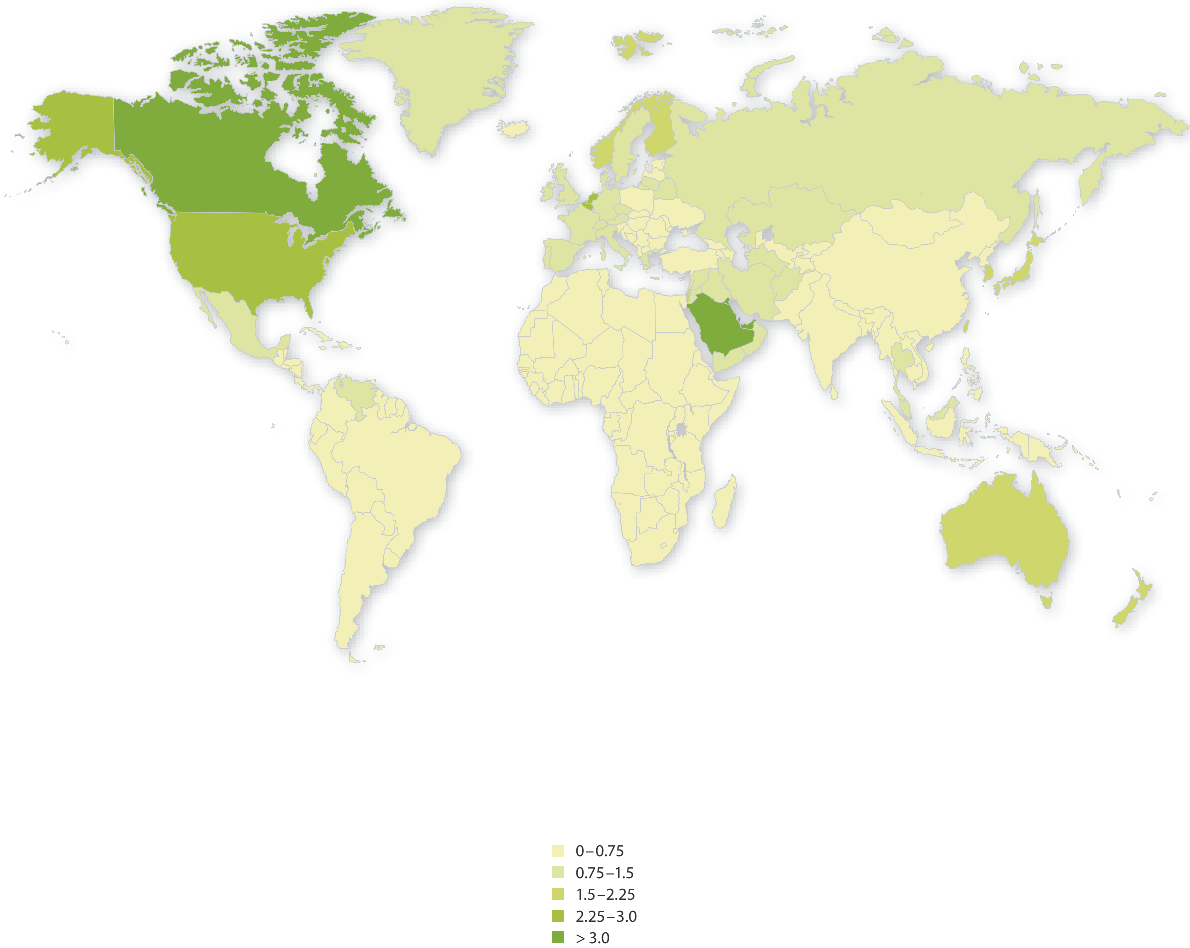


Product prices on the US Gulf Coast [USD per barrel]



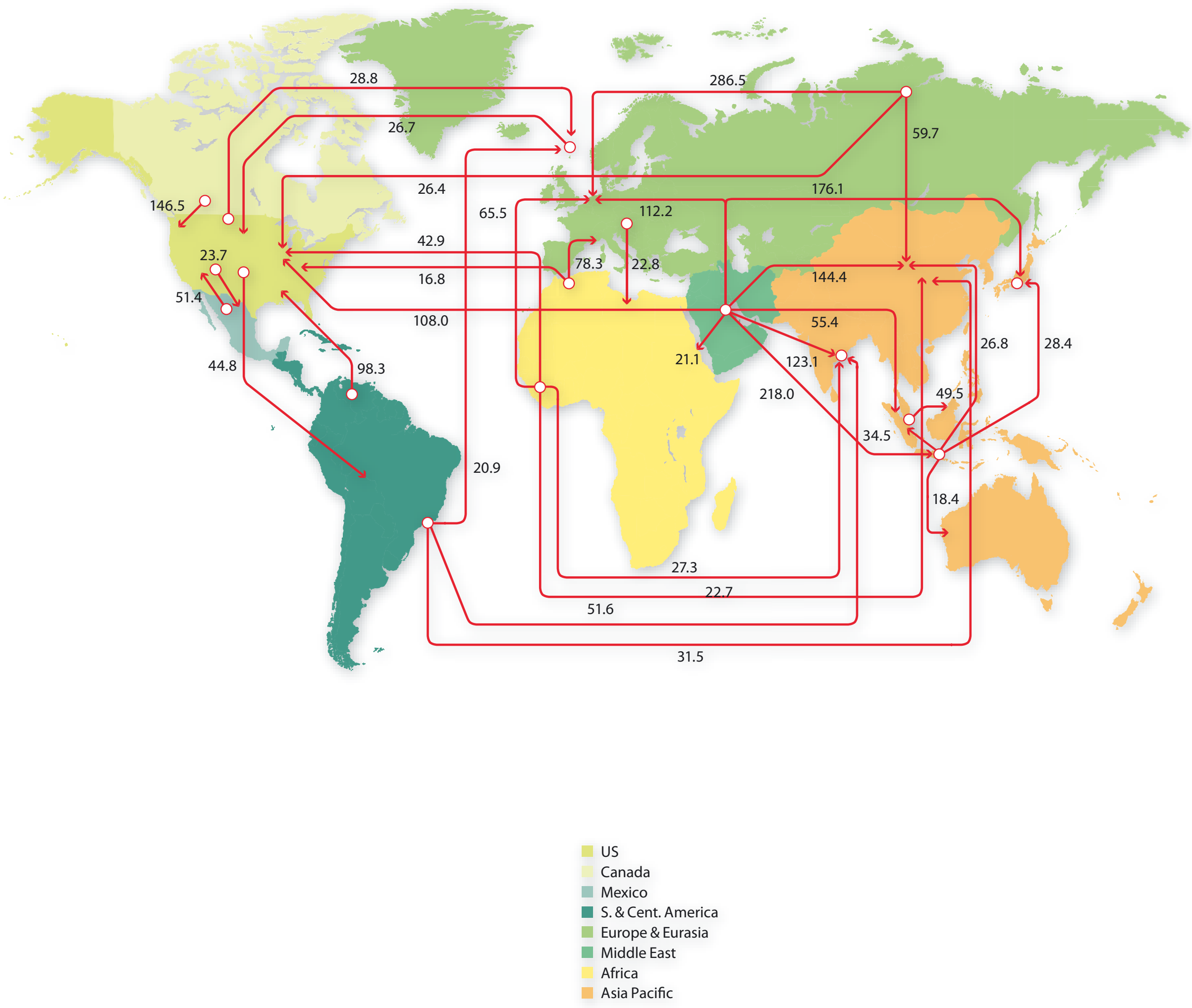
Source: BP Statistical Review of World Energy 2013

Oil consumption *per capita* in 2012 [tonnes]



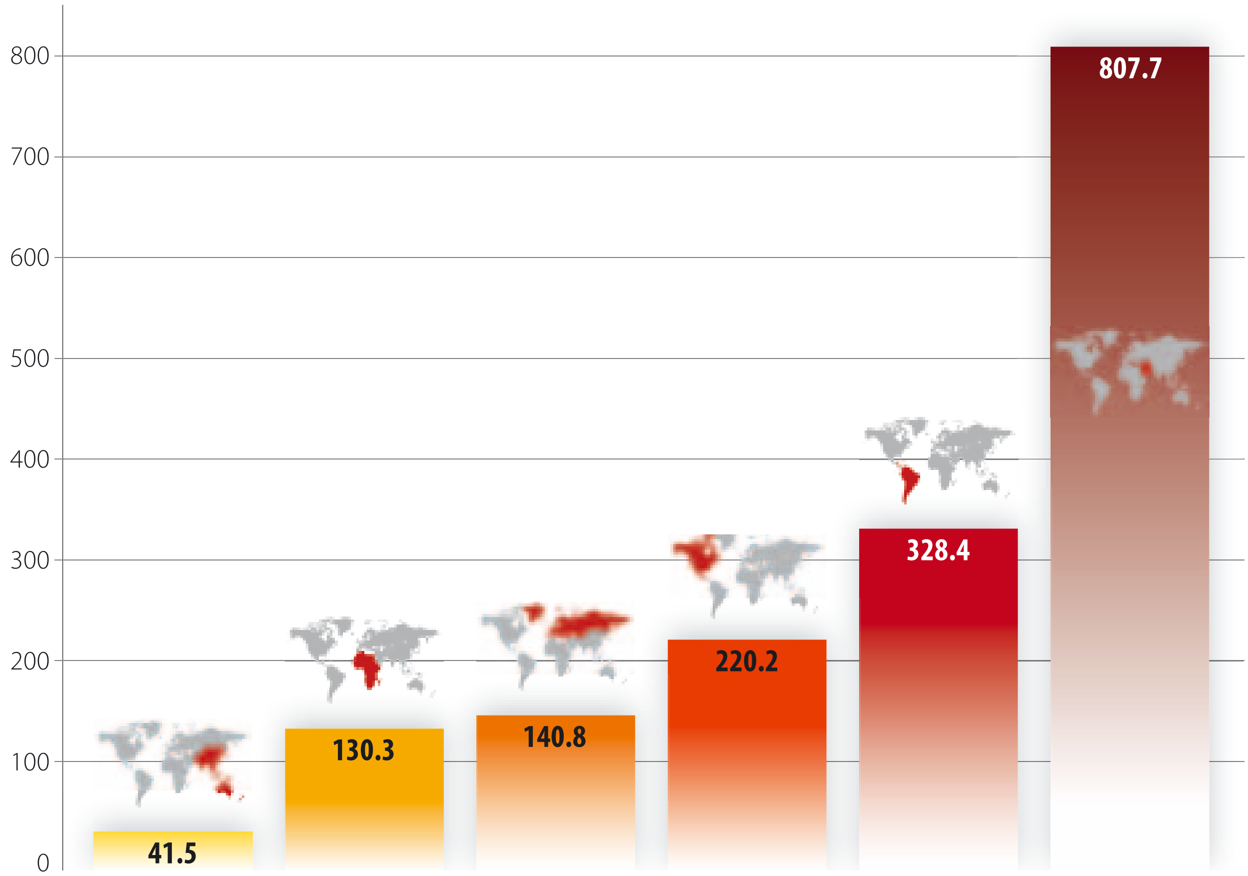
Source: BP Statistical Review of World Energy 2013

The main directions in oil trade in 2012 [in m tons]



Source: BP Statistical Review of World Energy 2013

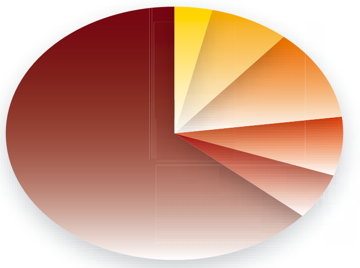
Oil: Proved reserves [in bln barrels] by the end of 2012



Asia and Pacific	41.5
Africa	130.3
Europe and Eurasia	140.8
North America	220.2
South and Central America	328.4
Middle East	807.7

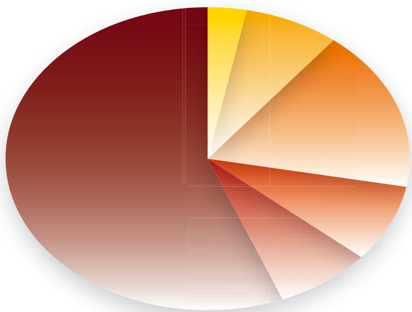
Source: BP Statistical Review of World Energy 2013

Distribution of confirmed oil resources in 1992 – 1039.3 bln barrels total



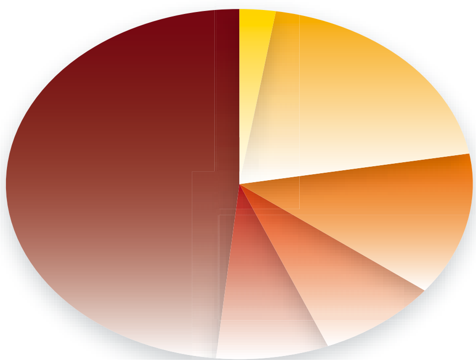
- Asia and Pacific....3.6%
- South and Central America....7.6%
- North America....11.7%
- Europe and Eurasia....7.5%
- Africa....5.9%
- Middle East....63.7%

Distribution of confirmed oil resources in 2002 – 1321.5 bln barrels total



- Asia and Pacific....3.1%
- South and Central America....7.6%
- North America....17.3%
- Europe and Eurasia....8.3%
- Africa....7.7%
- Middle East....56.1%

Distribution of confirmed oil resources in 2012 – 1668.9 bln barrels total



- Asia and Pacific....2.5%
- South and Central America....19.7%
- North America....13.2%
- Europe and Eurasia....8.4%
- Africa....7.8%
- Middle East....48.4%

Source: BP Statistical Review of World Energy 2013

GAS:

exploration,
distribution, sales

Modern approach to technical safety of transmission gas pipelines

Minimizing the risk on pipelines

ANDRZEJ DIETRICH, JAKUB BADOWSKI

Gas transmission through high pressure gas pipelines is generally thought to be one of the safest means of transport. Correctly designed, built and maintained pipeline system should not fail and should not cause considerable hazards to environment. Owing to the fact that the gas transmission system is equipped with modern safety and signaling devices and due to properly trained staff who manage and supervise the installation, the danger of explosion and fire can be avoided and this is confirmed with many years of world experience in such system operation.

The latest foreign publications show that the number of transmission pipeline failures in selected European countries equals 0.37 per 1000 km of pipeline (EGIG 8th Report, 2010) [7]. This points to high level of reliability of the pipeline transmission systems. However, failures sometimes do occur, for instance as a result of third party interference – often with dramatic consequences.

When introducing the widely used term "integrity" of a gas pipeline, it can be assumed that a gas pipeline is integral if its technical condition ensures safe and effective gas transmission under required working pressure during many years of operation. In short, an "integral" gas pipeline is a safe gas pipeline.

Despite such impressive statistics, general consciousness concerning possible failures, more and more demanding market and competition caused the industry to deal – on global scale – with the problems of gas pipeline safety in a more determined way. In the USA, two major pipeline failures drew the attention to the problem of petroleum and gas transmission safety. One of the failures took place in 1993 near Washington and concerned the oil pipeline. Its burst caused hundreds of thousands of liters of oil to leak into the nearby Potomac river. The other one concerned a gas pipeline and it occurred in March 1994 in Edison, New Jersey. The gas that leaked from the burst pipeline started to burn; the column of fire could even be seen in New York. Fortunately, as a result of this incident nobody was hurt, however, hundreds of people had to leave their houses and 8 residential houses were burnt to foundations.

It can`t have escaped the attention of the omnipresent media in the United States. The society wanted the legislator to regulate the law which concerns the safety of oil and gas transmission. In turn, the legislator wanted the industry to create formal programmes of pipeline management with emphasis on increased safety of transmission of the raw materials. The representatives of gas and oil industry and the Department of Energy made a decision on strict cooperation in developing a method to reduce the risk related to pipeline operation. Similar activities and works were undertaken in Canada, Australia, Mexico and Japan.

By the year 2004, in the European Union countries, there were no major gas pipeline failures, however the last of them – near Ghislenghien, about 30 km from Brussels in Belgium – provoked renewed discussion about gas transmission systems safety. As a result of ruptured gas pipeline (DN 1000), which worked under pressure 7 MPa, 24 people died and 150 people had to be hospitalized; most of them had serious burns. In the same year, similar oil pipeline failure occurred in Walnut Creek, California, in which 4 people lost their lives. Both failures were caused by a third party interference in the pipeline.

Gas pipeline "ageing" and resulting unexpected failures are a serious problem which leads to pipeline ruptures and sudden gas leakage. As a result of gas explosions, the main hazards for inhabitants and the environment are fires and related heat radiation; material loss is also considerable.

Recently, the view has been taken many times that transmission pipelines should be included in the European Union legal regulations concerning the risk of major failures. It is closely related to the so-called "precaution principle" or "prevention principle", on which the whole EU laws concerning the environment preservation are based. According to general approach of the Union regulations, it is better to take precautions considering the potential damage than to react only when such damage occurs.

In 1998, the European Commission worked out a legal document called briefly PSI – *Pipeline Safety Instrument – Regulatory Benchmark for the control of major hazards involving Pipelines*, which transfers the requirements of the Seveso II Directive concerning gas pipelines [11]. It must be emphasized that the regulations included in this document are not binding to this day.

However, regardless of that, in Europe, especially in Great Britain, Holland and Norway works on risk management systems have been continued for a few years with respect to – among other things – pipeline transmission of fuels. Methods and techniques connected with risk analysis are applied whenever potential hazards exist for man, environ-

ment and material goods; they have been used for a long time in fields like: transport, nuclear power, agriculture, medicine, insurance, banking and construction and production (e.g. of airplanes). In gas industry, this method began to be used relatively recently, however it is already widely accepted. The benefit from implementing the method of risk analysis is not only the possibility of reducing potential risk related to gas pipeline operation but it also has a notable economic effect.

The issues of gas pipeline technical safety

In recent years, on global scale, changes can be noticed in the approach to gas pipeline safety. These changes are mainly the attempts to abandon the command legislation which defined in detail in what way gas pipeline operators should carry out their responsibilities. In the new approach the responsibility

Fig. 1. Gas pipeline safety

Since the risk of failure exists and it is very real, the fundamental issue is – both for gas pipeline operation and improving the project norms and safety regulations – the necessity for understanding the risk and representing it in numbers, wherever possible.

Formalized and precisely executed system of risk management enables directing funds (unfortunately limited) for goals which have the greatest influence on integrity and gas pipeline safety. Such systems appear under various names; in case of gas transmission they are most commonly called *Pipeline Integrity Management Systems* – PIMS.

of the operator/owner of a gas pipeline will be to estimate potential risk involved and to take necessary precautions to reduce the risk.

Command regulation treated all gas pipelines in the same way; in the new approach each of them is treated individually. This approach and implemented legal regulations increase the demand for knowledge concerning risk analysis and management.

The issue of technical safety of gas pipeline transmission is difficult and complicated – even its definition is problematic. When introducing the widely used term "integrity" of gas pipelines, it can be assumed that a gas pipeline is integral if its technical condition ensures safe and effective gas transmission under required working pressure during many years of operation. In short, an "integral" gas pipeline is a safe gas pipeline.

Gas pipeline integrity should be ensured at all stages of its "life": from design, through construction, commissioning, technical approval and operation, until its withdrawal/liquidation, while at every stage the life and health of local inhabitants should be taken into account, as well as respect for natural environment which might be at risk during the gas pipeline operation. The safety of gas transport system ought to be considered both from the point of view of reliability analysis and risk analysis.

Figure 1 presents a graphic illustration of a comprehensive view on gas pipelines` safety; the common part (marked in green and defined by intersection of three circles) denotes the area of issues relating to their safety.

Gas pipeline integrity management system

In the United States, Canada, Australia and Europe, Pipeline Integrity Management Systems (PIMS) are being worked out and implemented. They usually concern only the linear part of gas pipelines but they do not consider other components of transmission systems, such as e.g. compressor stations, gas stations or measuring systems.

In 2002, the new American standard ASME B31.8S: *Managing System Integrity of Gas Pipeline* has been issued [9]. It is an acknowledged standard in the field of gas pipeline integrity management and very often used not only in the USA but also in Europe. It applies only to this field and constitutes an annex to the technical regulations issued earlier which concern transmission and distribution gas pipelines – ASME B31.8: *Code for Pressure Piping, Gas Transmission and Distribution Piping Systems*. This standard is the result of many years` work of many people from research and development units, gas pipeline operators and regulation offices. It has been approved by the American National Institute of Standards and Technology and has been acknowledged as international standard. It is intended for pipeline operators and it is supposed to help them work out and implement an effective integrity management system of gas transmission systems. It discusses the programme, formulates the process of gas pipeline safety management and also emphasizes the importance of gathering and analyzing data. It presents the ways of estimating the risk and evaluation of pipeline integrity and possible reactions of operator to received results and what is more, it standardizes the terminology.

Gas pipeline integrity management, according to ASME B31.8S, is executed through the Integrity Management Program (IMP), which is a set of procedures and methods realized through appropriate processes (defined and described). Whereas the Pipeline Integrity Management System (PIMS) is the computer realization of Integrity Management Program (IMP). It is an intergrated, modular computer system which automates processes described in IMP. PIMS is an elastic system which uses the available knowledge and experience (including the so-called good practice) and modern information technology.

Properly constructed and implemented Pipeline Integrity Management System should significantly reduce the risk of serious failures of gas distribution network. The effect of its implementation ought to be the reduction of maintenance costs and more effective use of funds spent on gas pipeline safety. PIMS should become an element of general Pipeline Network Management System. Risk estimation and evaluation of gas pipeline integrity are the essential tasks realized in the PIMS system.

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Pipeline operators need to become more responsible for their company's safety. Risk estimation and evaluation of integrity are supposed to serve for them as the evaluation of the current

technical and safety condition of operated transmission network and it is vital that the risk estimation and integrity evaluation cannot be carried out separately but they constitute a fundamental part of the program. Risk estimation is essential for the system, it influences considerably the pipeline integrity evaluation. In turn, information obtained during integrity evaluation is used in the process of risk estimation.

Every programme of integrity management may be subject to constant changes and it should be elastic, however the changes introduced should be well justified and documented. Integrating the data about gas pipelines from various sources is an important task of the program.

Arising new technologies for diagnostic testing and pipeline rehabilitation should be evaluated and if they work properly, they should be included in the program. Methods of estimating the programme`s operation ought to constitute its integral part. The importance and necessity of commitment on the part of the company's (operator's) supervisors is emphasized in developing and implementing the program.

Automation of processes described in IMP and the use of modern information technology enable the construction of Pipeline Integrity Management Systems. If working properly, they should reduce the probability and effects of potential failures.

Currently, in the United States, the pilot programme is run which implements the integrity management system in selected operators [12].

The American standard ASME B31.8S is currently the only standard in the world which has been entirely devoted to PIMS. Others, such as the European norm PL EN 15494 of the year 2006, recommend only development and implementation of the PIMS system by the operator [13]. According to that norm, "*the pipeline integrity after its commissioning should be ensured by precisely established program of use, maintenance and technical supervision (Pipeline Integrity Management System)*". This norm, however, lacks instructions what elements such a system should comprise and how to build a suitable program.

In the year 2007, a Polish Standardization Document was published, *Gas Supply Systems – Frame of reference regarding Pipeline Integrity Management System (PIMS)* – PKN-CEN/TS 151732007 [8], which is trying to fill in the gap concerning PIMS system construction in Europe. In the meantime, the most technologically advanced operators of transmission networks in Europe built their own systems which systematized the so-called good practices by using modern information technologies. The PiMSlider® from Gasunie company, Holland, can be considered a model system. This system was invented on the basis of ASME B31.8S standard, considering the so-called good practices used in this company.

When introducing such a system with the operator, it is essential to focus on two issues:
- prevention of pipeline failures,
- limitation of adverse effects, if such a failure occurs.

The system provides:
- technical pipeline integrity,
- acceptable level of risk,
- pipeline's fitness for the purpose.

Its fundamental function is to support the operator while taking decisions about all aspects of pipeline integrity management. Figure 2 shows the idea of PIMS system which is used in Gasunie company.

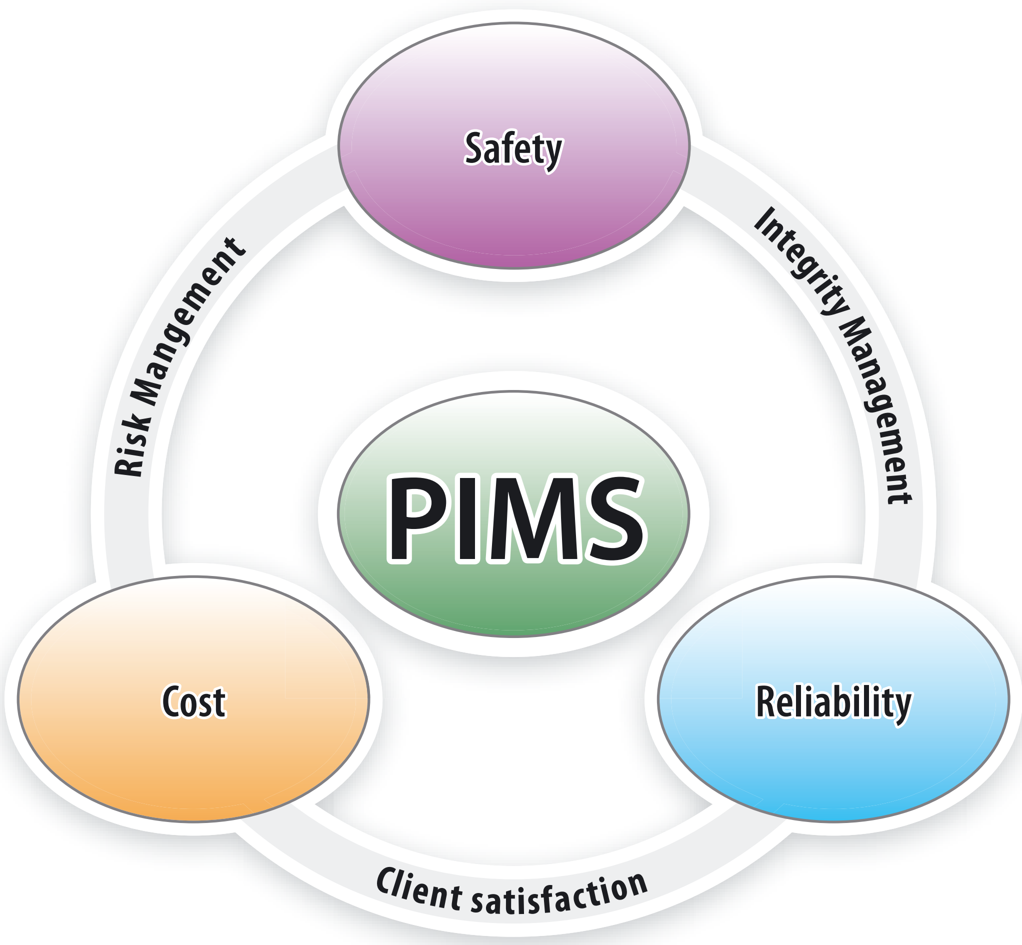

Fig. 2. The idea of PIMS system used in Gasunie

Summary

There is no established and acknowledged methodology in Europe for construction of pipeline integrity management systems. In Holland, transmission pipeline operator Gasunie invented and implemented pipeline integrity management system (PIMS) which involves most of the elements required by the ASME-B31.8S standard. Its key role, as in the quoted standard, is risk estimation and pipeline integrity evaluation.

The national operators of transmission pipelines should study the compliance of their maintenance and renovation practice with:

- Integrity Management Program (IMP) – described in the ASME B31.8S and
- Pipeline Integrity Management System (PIMS) – eg. PiMSlider®.

At the same time, they should start building their own pipeline integrity management system.

In the Oil and Gas Institute in Krakow, a computerized system was developed for estimating the risk of pipeline operation (SOREG) [4]. This system covers both transmission and distribution pipelines and it might be an essential element of PIMS domestic system. It has been implemented successfully in EuRoPol GAZ S.A. company. The other gas pipeline operators, despite positive assessment resulting from pilot implementations, have not decided yet on its full implementation.

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

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Meeting the requirements of the market

PGNiG TECHNOLOGIES – comprehensive approach to the oil and gas sector

PGNiG Technologies is the company which arose as a merger of four companies – previously component parts of the PGNiG Capital Group – which have a few dozen years` experience in the oil and gas industry.

Owing to combined offers of several entities, the company may offer customers its services in design, construction and commissioning of natural gas and petroleum wells, compressor stations, underground gas storage facilities and transmission pipelines and also production of drilling equipment elements, surface drilling equipment and elements for wells and drilling platforms.

Reliability and quality

PGNiG Technologies is valued by investors as a reliable partner executing the entrusted tasks on time, while retaining the highest technical and qualitative standards.

Successfully executed projects of strategic character for the Polish gas industry prove its consolidated position on the market, documented with a number of references. The licenses held, including API Spec. 6A, enable it to maintain the position of a national leader in production of equipment for surface drilling equipment.

Consolidation of four companies within PGNiG Technologies made it possible also to participate in tenders which require broad competences and great manufacturing potential. In addition, the company has the Division of Research and Development in its structures which helps to introduce innovative technologies and increase competitiveness on the market.

Goals and priorities

One of the main objectives of the company for the next year is continuation of commenced process of getting the company ready for a debut in the Stock Exchange.

– *We wish to raise funds earned in the Stock Exchange for further development of the company. We also expect that PGNiG will still remain our largest shareholder* – says Janusz Radomski, Chairman of the Board at PGNiG Technologies. – *Another vital issue this year is the introduction of the SAP system. Implementation of integrated management system will ensure modern management of the company and will help control both the expenses and all the business segments of the enterprise and currently run projects* – he adds.

The company is planning continuous consolidation of its position in the current market and also development of new competences, e.g. in the sector of power industry. Plans of the company cover the development of performance potential so as to meet the requirements of the market.

There are grounds for hope in the development of production with respect to providing equipment for shale gas wells. Recently, a compact wellhead was designed and introduced in production for exploring both conventional and unconventional gas deposits.

Great hopes for development are connected with strengthening and extension of cooperation with Norwegian concern Aker Solutions, for which – for a dozen years of so – the company has produced equipment elements for the offshore drilling rigs. In May this year, PGNiG Technologies also signed a contract for high speed piston compressor packaging with GE Oil&Gas, which extends the scope of the company business.

Challenges

Owing to possessed base and high qualifications of the staff, the company undertakes the execution of difficult and challenging tasks. In the last days of January this year, a consortium of companies made up of PGNiG Technologies and BSiPG Gazoprojekt with the cooperation of subcontractor – the Nawitel company – completed the works connected with crossing the Vistula river with the HDD method on the route of constructed gas pipeline Rembelszczyzna-Gustorzyn for the investor, GAZ-SYSTEM S.A. The length of the passage under the Vistula is 1339 m and it is the longest drilled passage of this kind in Poland, and also one of the longest in Europe.

Current projects of the company

- construction of high pressure gas pipeline 8.4 MPa DN 700 between Rembelszczyzna and Gustorzyn 175.2 km long, including 19 HDD drillings. Investor: Gaz-System S.A. Its completion is planned for June 2014.
- Execution of construction and installation works for the construction of gas pipeline DN 700 between Gustorzyn and Odolanów. Construction of four interchanges and 10 shut off and relief valve systems. Investor: Gaz-System S.A. Customer: ZRUG Poznań.
- Installation of additional compressor for the underground gas storage facility in Husów. Scope of works: delivery of two compressor generators, pump capacity: 171 000 m^3/h, collection capacity: 172.8 000 m^3/h, drawing up of the project documentation, author`s supervision, supervision over installation of the generator, start-up of the compressor generator following the completion of construction and installation works. Investor: PGNiG S.A. Branch in Sanok.
- Construction of gas pumping station in Hurko Natural Gas Mine. Two compressor generators of capacity approximately 8650 nm^3/h; suction pressure 1.7 MPa and pumping pressure 2.2 MPa. Scope of works: preparing documentation, delivery and installation of compressor generators, construction of related units, construction of technological installations, author`s supervision, construction and installation works. Investor: PGNiG S.A. Branch in Sanok.
- Modernization of the distribution and measurement interchange in Hermanowice with construction of the clearing point. Scope of works: construction and installation works for execution of the project of integrated modernization of the interchange with construction of the measuring point which comprises all the elements (sectors). Investor: GAZ-SYSTEM S.A. Branch in Tarnów.
- Modernization of natural gas pumping station in Żuchlów. Scope of works: modernization of compressors, replacement of the piping, performing electrical works, control and measurement instruments and automation, design and execution of oil and coolant heating installation. Investor: PGNiG SA Branch in Zielona Góra.
- Development of natural gas deposit in Komorze. Scope of works: development of the borehole Komorze-1 in all sectors. Commencement: 12.06.2013. Investor: FX Energy Poland Sp. z o.o.
- Construction of gas pipeline DN800 M2/1 along the route Trojane-Vodice. Scope of works: transportation of pipes and curves, bending the curves, welding and installation of gas pipeline, sealing the welds, hydraulic tests and drainage in section of 20.1 km. Investor: Geoplin Plinovodi d.o.o.

Reasons for application and principles of physical influence of propellants on the near-borehole structure and their implications for stimulation

Propellants in the "tool kit" of deposit engineers

Antoni Frodyma

The aim of drilling a borehole is creating its hydraulic connection with the deposit and maintaining the borehole in good condition throughout its technical life-span.

In the process of drilling and development of the oil and gas extraction boreholes, contamination occurs, however, in the near-borehole area with drilling and cement solution components, salt precipitates, asphalt-tar substances and other solid particles. This leads to deterioration of primary filtration properties of the deposit rock and decrease in the potential current borehole output. More damage with respect to rock permeability is done in the course of perforation treatment around the walls of the perforation casing as a result of exceeded strength of the rock, its background and structure grains due to pressure created by the impact of the penetration stream.

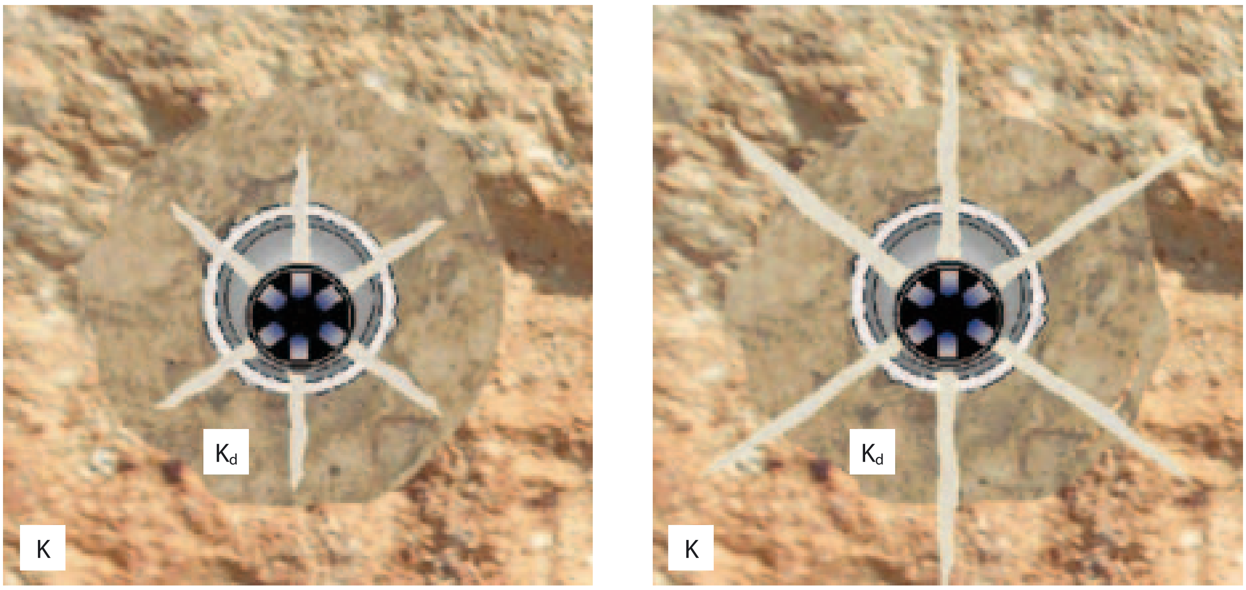


Fig. 1. Making incorrect (on the left) and correct access to the rock undamaged by perforation. *K – undamaged permeability, K_d – damaged permeability* [2]

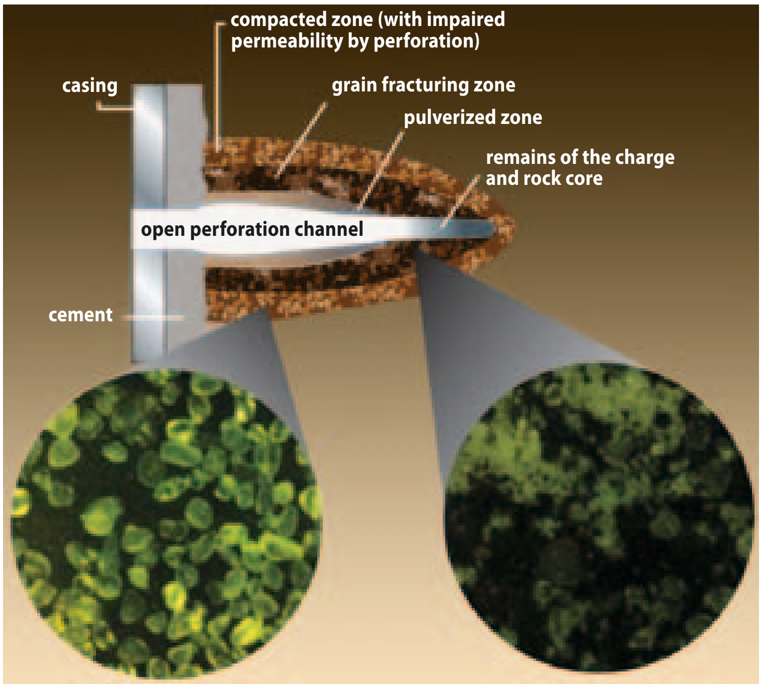


Fig. 2. Zones with various extent of permeability damage around perforation casing due to penetration stream effect [6]

Introduction

Damaged permeability due to perforation

Damaged permeability, which may be ascribed to rapid action of the penetration stream, can be divided into several zones, illustrated in Fig. 2.

As demonstrated in Fig. 2, starting from the perforation casing axis, there is a powdered zone, where, in the result of substantially exceeded grain strength in all directions (pressure in the head of the shaped charge may reach 100 GPa!) total destruction of the grain structure occurred. Subsequently, there is the zone of grain fracturing, in which the strengths were exceeded in the main stress directions, which led to grain fracturing.

This zone is surrounded by another one – a compact area in which damage was done to the primary mechanical structure of the rock, with undamaged grain.

According to some test findings, the degree of permeability damage in the crushed area around the perforation casing may reach from 40% to even 100% of primary permeability.

Moving on along the perforation casing axis, at its head we will come across mostly the remains of the shaped charge inserts which effectively hinder the flow from the deposit to the perforation casing in this part of it. The image showing such remains of the shaped charge insert in the sandstone rock and the calcareous rock was presented in Fig. 3, in CT images of the perforation casing obtained in the laboratory in simulated borehole conditions.

So many perforation defects have been cumulated in the above description that it might seem it is one of the worst things that can be done to the borehole; this is not, though – presented defects have been shown in the small space of the picture on purpose, so as to present all of them. Actually, along the entire perforation casing length there are sections where the intensity of defects is slight and the influx from the deposit may occur.

However, when the deposit parameters are poor and their additional deterioration by making perforations is not advisable or permeability has to be improved, as it deteriorated after long-term borehole exploitation, then the stimulation method and influx intensification are the right solutions. One of the methods is fracturing, which occupies the most important place.

When the deposit parameters are poor and their additional deterioration by making perforations is not advisable or permeability has to be improved, as it deteriorated after long-term borehole exploitation, then the stimulation method and influx intensification are the right solutions. One of the methods is fracturing, which occupies the most important place.

Various stimulation methods and intensification of extraction

The first stimulation method (introduced in the 19th century) with the use of explosives was torpedo: a dynamite explosion was initiated in the borehole, obtaining enlarged borehole diameter and creating

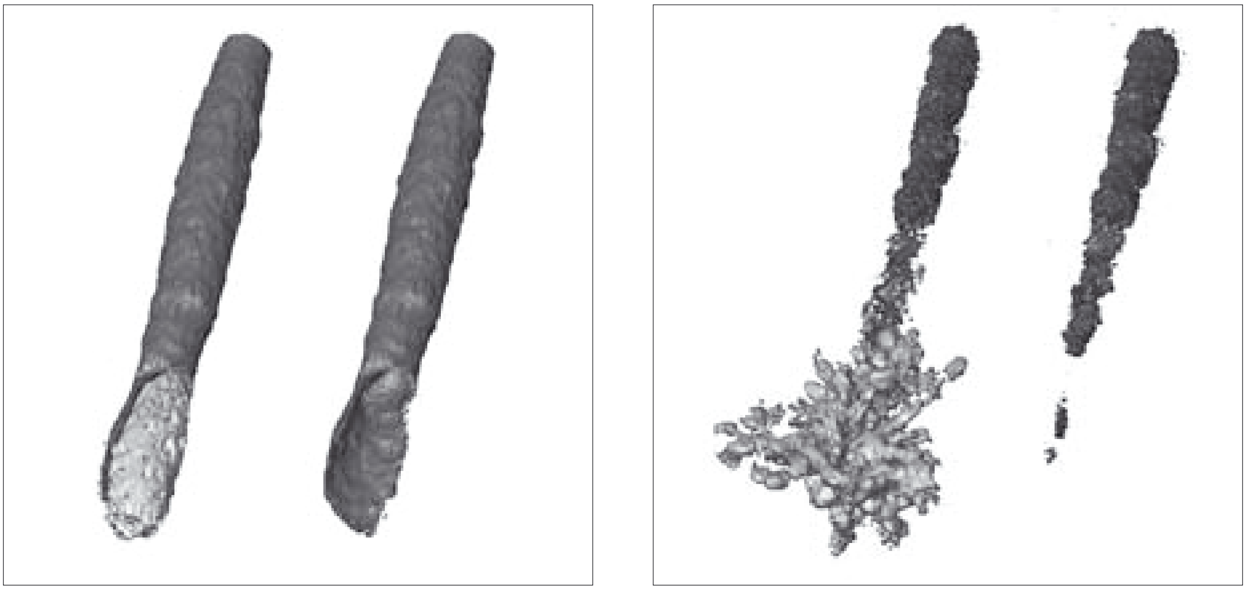


Fig. 3. CT images of perforation casing obtained in laboratory-simulated borehole conditions, demonstrating the remains of shaped charge in sandstone (left side) and calciferous rock (on the right) [1]

an extensive network of cracks in the near-borehole area. Still, this led to damage in the rock structure and relatively fast loss of the effects of the treatment, threatening with the risk of major damage to its construction.

Hydraulic fracturing was introduced in 1940s and it is still used successfully today.

The third of the stimulation methods which actually also consists in creating cracks in the near-borehole rock structure is the use of propellants – solid fuels, which in the course of very fast but not detonative burning generate large volumes of gas; because all the process takes place under fluid tamping (i.e. fluid column in the borehole), the energy and pressure of gas originating from the burnt fuel cause fracturing of the rock around the bore. Those three kinds of approach to stimulation (i.e. influx intensification in the borehole) are demonstrated in Fig. 4.

On account of different dynamics of action, each of the methods causes different kinds of rock cracking. The patterns of cracks arising in the vicinity of the borehole in the result of application of different stimulation methods are shown in Fig. 5.

The dynamics of action, which conditions the system of cracks arising near the borehole, consists in rapid increase in pressure in the treatment area. In case of detonated explosives, the whole phenomenon of detonative burning lasts a few to a dozen or so microseconds, and the pressure reaches maximal values of about 7000 MPa. When solid fuel is burnt – propellants, whose burning lasts several dozen miliseconds, i.e. three orders of magnitude longer than detonative burnings, the pressure is obtained of about 140 MPa. However, in hydraulic fracturing, where the pressure increase is obtained by pumping the fracturing fluid to the borehole, the pressure increases very slowly (for several dozen minutes), reaching the value of several dozen MPa.

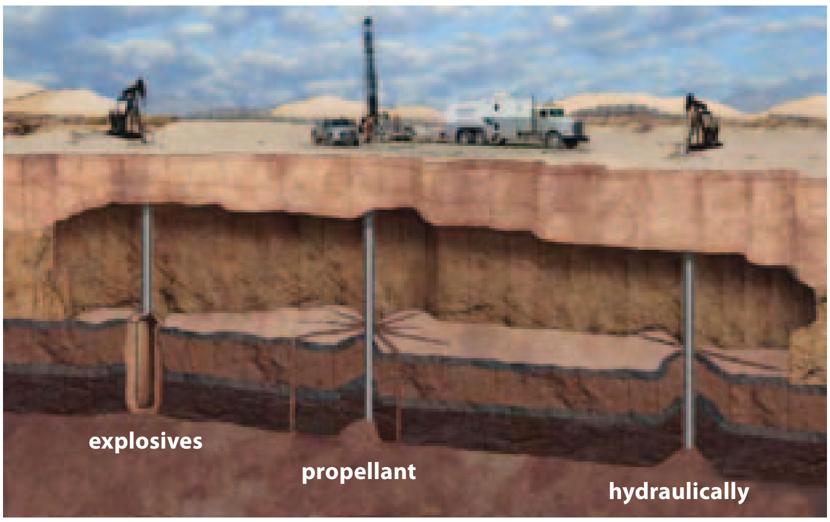


Fig. 4. Three methods of stimulation and intensification of extraction with the use of high-energy materials and hydraulic fracturing [5]

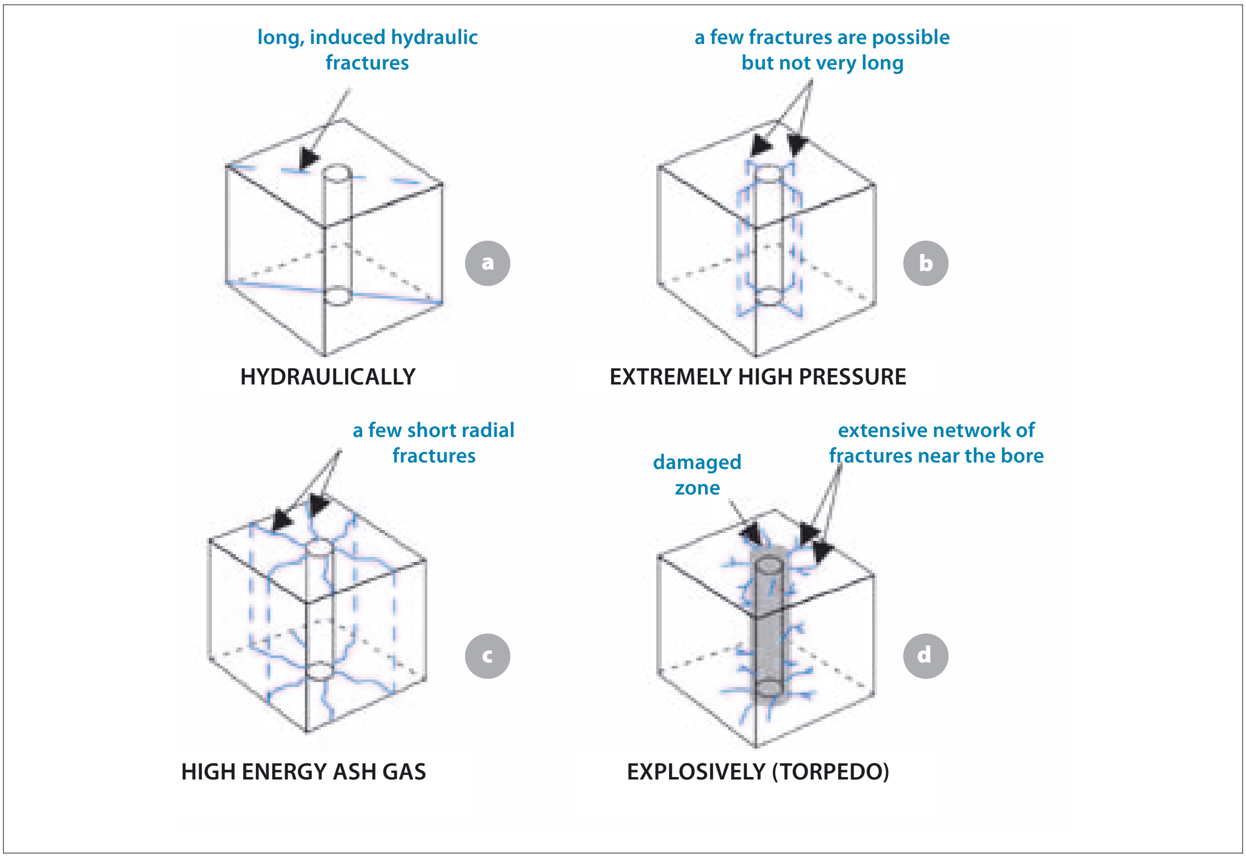


Fig. 5. Patterns of cracks arising near the borehole when using different influx stimulation/intensification methods

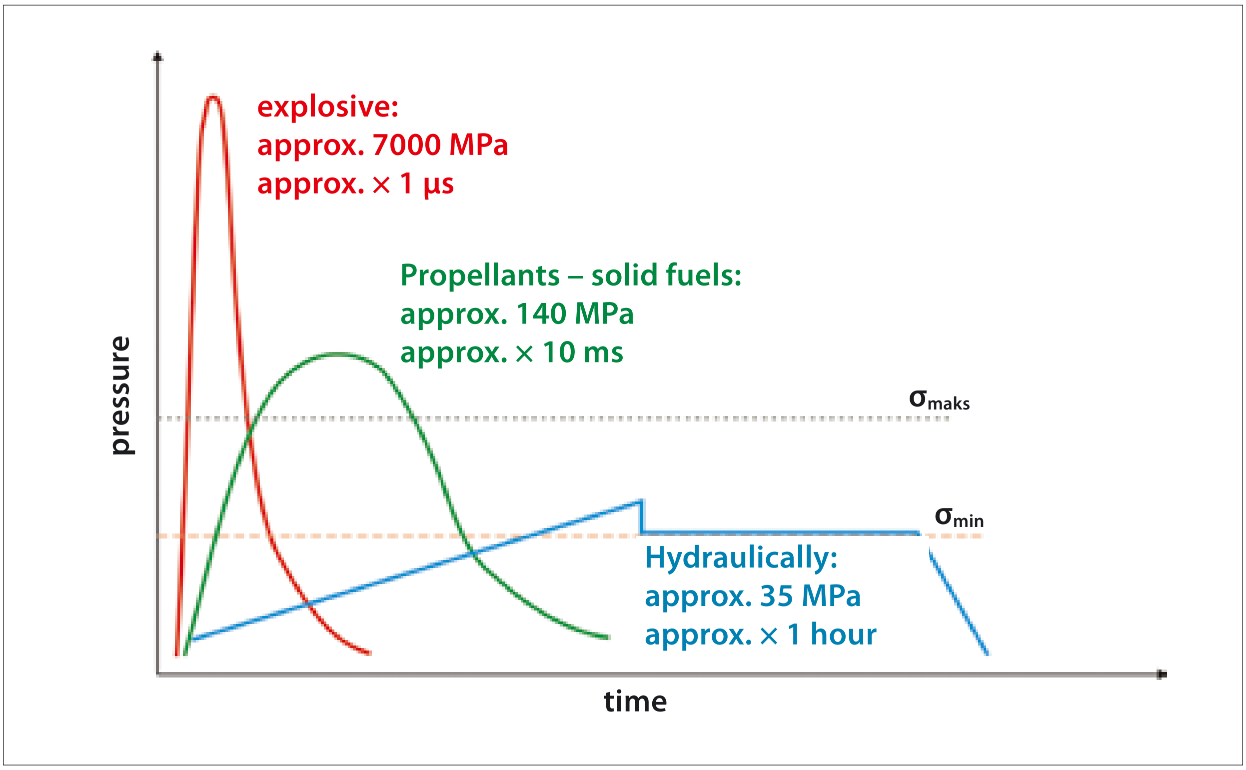


Fig. 6. Visual comparison of dynamics in pressure change in detonation, deflagration (propellant) and hydraulic fracturing

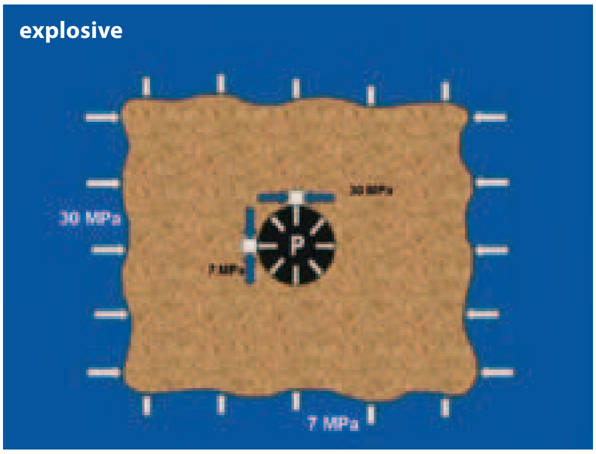


Fig. 7. Stress distribution in the rock and pressure in the borehole, caused by detonative combustion of explosive material [5]

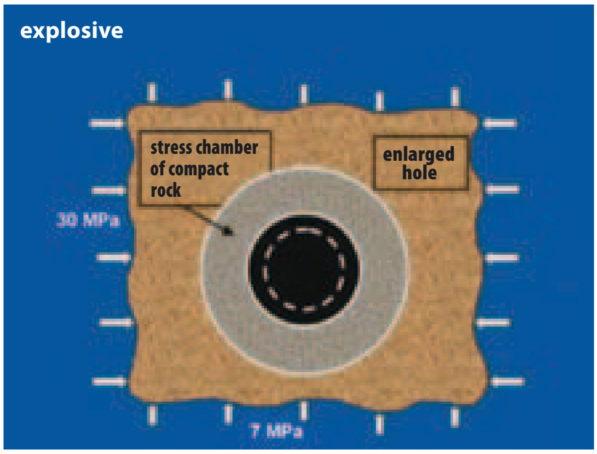


Fig. 8. The impact of explosive in the borehole [5]

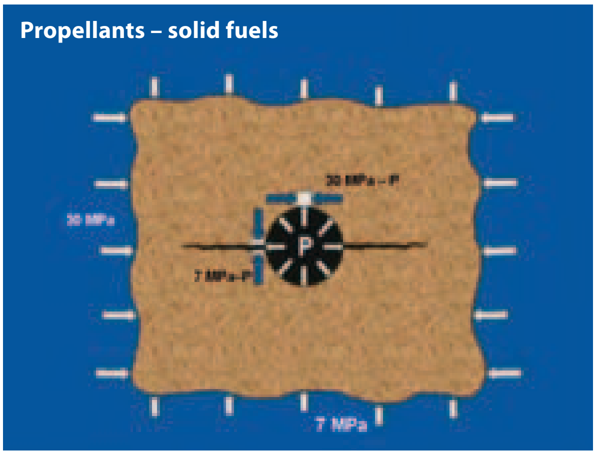


Fig. 9. Initiation of the first fracture at exceeded minimal horizontal stress in the rock, pressure created due to burnt propellant [5]

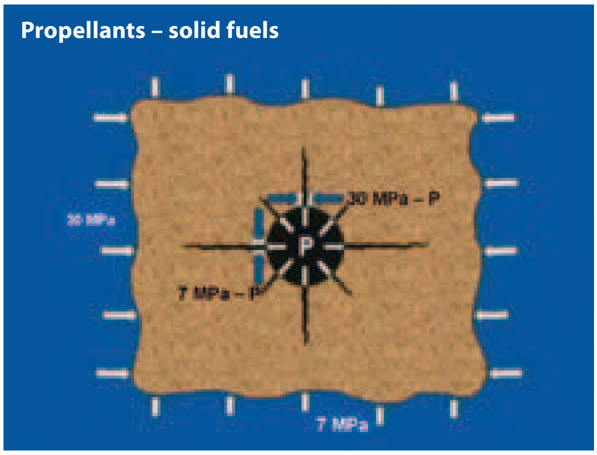


Fig. 10. Initiation of subsequent fractures – perpendicular to the first one – (on exceeding the maximal horizontal stress in the borehole) and diagonal fractures (with the pressure still increasing) [5]

The diverse dynamics of the phenomena occurring when using explosives, propellants and hydraulic fracturing are presented in Fig. 6.

Physical effects of different stimulation methods on the rock

In the rock lying at a certain depth, stresses occur in which two main kinds can be distinguished: maximal and minimal. They are always set at the right angle to each other. The situation of such hypothetic stress condition (maximal stress = 30 MPa and minimal stress = 7 MPa) in the rock and pressure propagating in all directions in the borehole which pierces this rock, was shown in the scheme in Fig. 7, in a situation when explosive was used in the borehole.

As indicated earlier, (Fig. 7), the pressure caused by burning explosive may reach about 7000 MPa – the value which substantially exceeds all the main stresses in the rock. Hence the multidirectional cracking of the rock and damage of its structure – with enlarged diameter of the bore and creating a tight zone around it, with stress cage and extended fracture networks. Damaged rock structure loses its mechanical strength, endangering the borehole structure, as demonstrated in Fig. 8.

When solid fuel – propellant – is burnt, the increase in pressure is slower, and its maximal value (Fig. 7) reaches approximately 140 MPa. At the first stage of pressure increase the minimal stress is exceeded and that is how the fracture arises (horizontal line in Fig. 9).

However, fuel combustion is still continued and the pressure is still growing because the arising fracture does not extend so dynamically as to completely compensate for very fast increase in gas volume and pressure resulting from propellant combustion.

Therefore, at the moment of exceeding the maximal stress, a fracture is initiated in perpendicular direction to the first one. If, at that moment, there is still unused fuel and total effect of increased volumes of gas originating from the burnt fuel and fracture propagation (which occurs at the cost of the volume of arising gas) results in further increase in the borehole pressure, additional fractures arise in diagonal directions – at the angle of 45° and 30° to the main stress.

The impact of explosives, solid fuel and hydraulic fracturing on rock samples: laboratory test results, as demonstrated in Fig. 11.

Potential areas of application of solid fuels in stimulation

Stimulation with solid fuels (propellants) may be seen as the method for creating short fractures (several meters long) with no need to develop extensive equipment on the surface. This method may be applied in the following situations:

- Initiation of fractures exceeding the extensive damage zones; both in case of the newly made boreholes and those already productive;
- Fracturing which exceeds the perforation damage when the negative pressure possible to achieve (necessary for making perforation at negative pressure) is insufficient;
- Initial treatment, prior to hydraulic fracturing, to "break through" the rock formation;
- Improved connection with the natural fractures.

In view of growing interest in acquisition of natural gas from shale formations where the core issues in accessing the deposit are extensive and multiple hydraulic fracturing operations, it may be interesting

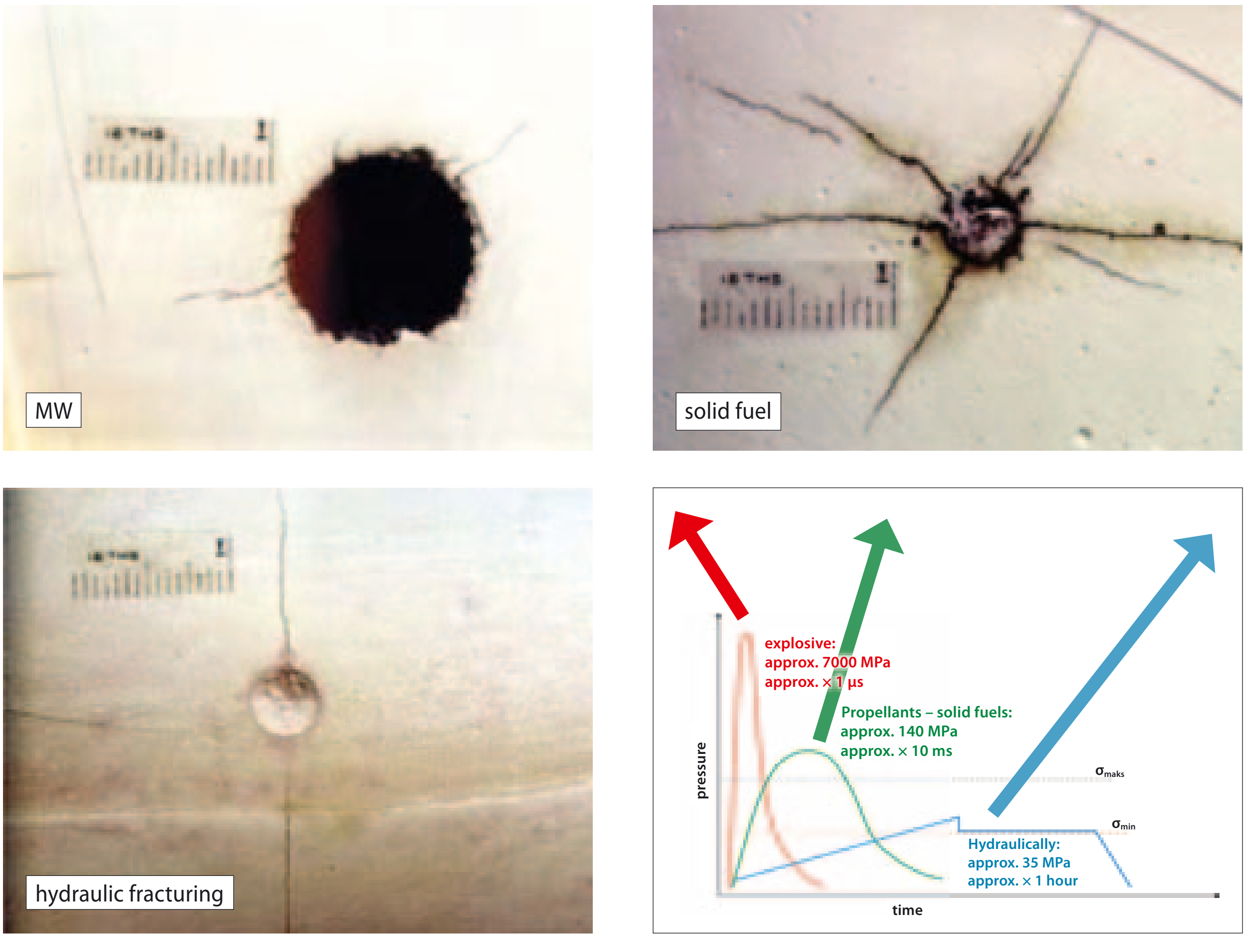


Fig. 11. The impact of explosives, propellant and hydraulic fracturing on initiation of fractures in the borehole

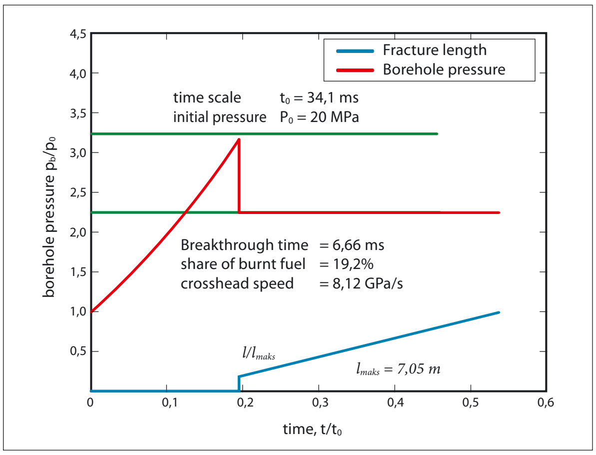


Fig. 12. Fracturing pressure graph and the length of created fracture based on model calculations. Green lines represent minimal (lower) and maximal horizontal stress in the rock. P_b *– borehole pressure,* P_0 *– initial borehole pressure, t – time,* t_0 *– initial time*

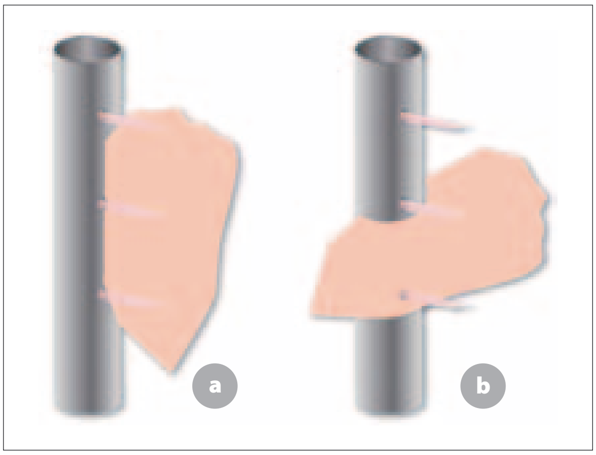


Fig. 13. Fracture initiation through perforation casings using the method of: a) solid fuel (propellant) combustion; b) hydraulic fracturing (in shallow boreholes and those with considerable inclination angle the fracture may not lie in the borehole axis) [6]

to use the solid fuel as the initial approach which allows in the first place to "break through" the rock, i.e. to initiate operations to make the fracture deeper, which requires the pressure about 20÷30% higher than the pressure needed in further operations to propagate the fracture deep down the deposit.

The use of solid fuel for initial treatment prior to hydraulic fracturing

Fig. 12 presents a graph showing pressure values in hydraulic fracturing made on the basis of model calculations, which makes it clear how much higher the pressure for initiating the fracture must be in comparison with the one needed for its further expansion. Performing the initial fracturing treatment using solid fuel and initiating the fracture considerably contributes to lowering the pressure which must be created by pumps and power generators installed on the surface in a fracturing operation. By the same, the emission to the atmosphere is reduced. Also, the borehole load carrying capacity is lower as well as the risk of its damage.

> Next to hydraulic fracturing and the torpedo – stimulation methods with the use of explosives, the third stimulation method, which also consists in creating cracks in the near-borehole structure is the use of propellants – solid fuels, which in the course of very fast but not detonative burning generate large volumes of gas.

Another essential feature in the effects of solid fuel burnt in lined and perforated borehole is that it initiates fractures in all perforations and always in the borehole axis, as the initial impact pressures are significantly higher than the main stresses occurring in the rocks. Only when the gas energy is substantially used, the arising fracture begins to fit in the plane of maximal stress.

However, in hydraulic fracturing, fracture initiation may occur even in a single perforation casing – at the weakest spot and the remaining perforation casings will then be used to a lesser extent, which is demonstrated in Fig. 13.

When the pressure for fracturing fluid is set, it seeks the route with the lowest resistance for the flow – often through the micro space between the cement casing and rock formation, until it finds the weakest point and returns to preferred direction. In the result, bendiness occurs which increases the treatment pressure, hinders the flow and causes untimely backfill subsidence.

Initiation of the fracture with the use of propellants, inducing the fractures through all perforation casings by breaking through the crushed zone, reduce the fracturing pressure: it reduces the bendiness, flow resistance and generally contributes to hydraulic fracturing success.

The use of solid fuel in horizontal boreholes

Solid fuels facilitate making stimulations in many planned treatments performed on a one-off basis. While hydraulic fracturing is always run in stages, by separating particular treatment intervals from each other by means of packers, in the case of solid fuels, the whole multipartite set of fuels can be put in the borehole and fired, with the fuels spaced on the cable, in line with the scheme for stimulation operations in intervals planned for fracturing.

The whole process of solid fuel burning takes place under fluid tamping, and the impact of arising gases is basically restricted only to the interval marked by the length of the fuel rods: according to model calculations, the movement of the fluid column above and below the burning fuel rods is only several dozen centimeters (on account of fluid inertia and non-compressibility) during the whole process of combustion. Therefore the process has only local effects.

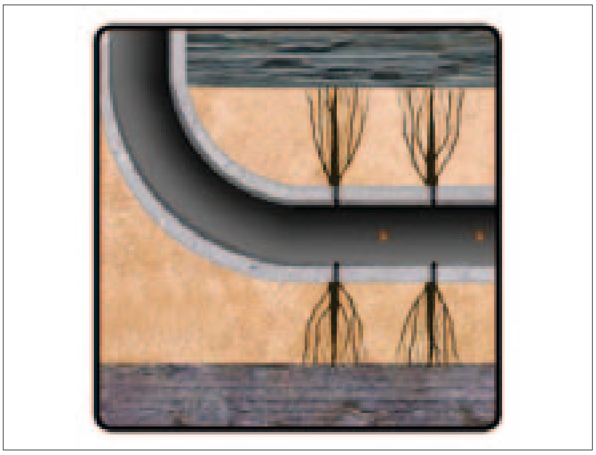


Fig. 14. Diagram of fracturing with the use of solid fuels in horizontal borehole [6]

The advantages of such treatment are the following:

- Possibility of cheap stimulation of long intervals – even several hundred meters of propellants can be introduced to the borehole simultaneously.
- The fractures are created along the whole length of productive horizon, no need to arrange operations in stages, as in hydraulic fracturing.
- Minimal number of equipment necessary in the borehole area.

The treatment is environment-friendly – the amount of fluids and chemical substances used for this operation is minimal.

Treatments with the use of propellants in deposits with natural fractures

When stimulation is to be performed in a reservoir with natural fracturing, hydraulic fracturing is unfavourable inasmuch as it will lead to increasing one or two fractures already existing. However, the use of propellants which results in creating several (4–6) radial fractures ranging up to several meters, will connect the system of natural fractures with radial ones and will cause substantially improved influx, as shown in Fig. 15.

Stimulation with solid fuels and environment protection issues

In stimulation treatments performed with the use of solid fuels, practically no substances used in the operation or formed in its course get to the environment. Fluid tamping, which is indispensable for the treatment, usually involves the brine or specially prepared fluid (including the oil), compatible with the fluids which occur in deposit rock, used in smaller volume than the capacity of the borehole.

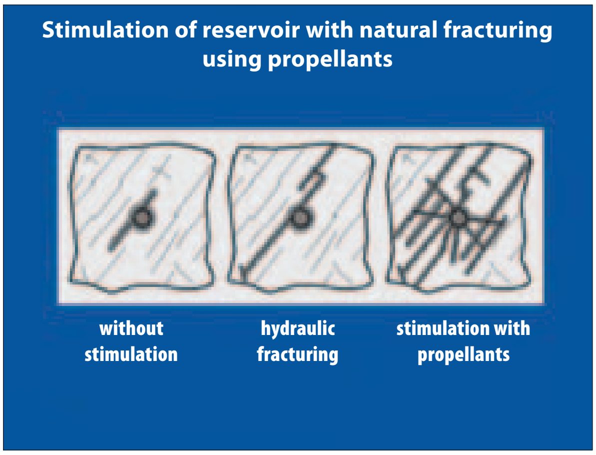
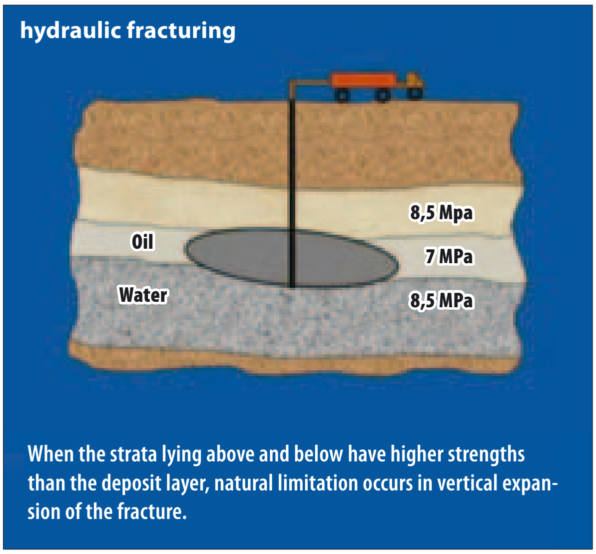


Fig. 15. Comparison of the effect of hydraulic fracturing and the treatment with the use of solid fuels in deposits with natural fractures [5]

Fractures created during the treatment with the use of propellants are spreading only in radial direction and do not tend to expand vertically on account of limited volumes of gas arising in fuel combustion and due to dynamics of the impact. As opposed to that, in hydraulic fracturing the vertical expansion of the fracture is practically uncontrollable, which



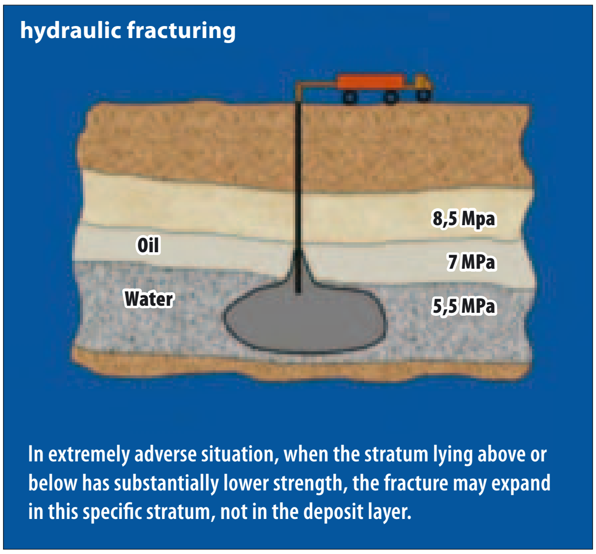


Fig. 16. The risk of uncontrollable spreading of the fracture in case of hydraulic fracturing and considerable difference in stress in the strata located above and below the deposit layer [5]

∧ Large-scale hydraulic fracturing

> Treatment with the use of propellants

Fig. 17. Comparison of the scale of operations of hydraulic fracturing and fracturing with solid fuel

poses the risk of early saturation of the deposit and borehole or contamination of the water-bearing strata with treatment fluids (Fig. 16).

As indicated earlier, the hydraulic fracturing operation is associated with using a large number of pump generators, mixers, tanks, piping, etc., on the surface, whereas in order to perform the treatment with solid fuels, a vehicle with a small cable traction is sufficient enough. Such visual comparison of the scale of both operations is shown in Fig. 17.

Obviously, the objective here is not to discredit the hydraulic fracturing and glorify the use of propellants but rather to emphasize that each of these methods has its own area of applications and each of them should be found in the "tool kit" of deposit engineers.

Summary

- The application of propellants in stimulation/intensification operations used so far prove them to be an effective tool which should be part of the "tool kit" of each engineer in this type of operations.
- Propellants very effectively reduce the pressure needed for initiation of fracture propagation in hydraulic fracturing – less energy is required on the part of pump generators, less fume emission to the atmosphere, smaller load for the borehole structure and the environment.
- Using propellants in view of the risk of saturation of the borehole due to uncontrollable fracture propagation in vertical direction or when operating in difficult terrain is often the only option available when performing the stimulation treatment.
- The treatment is simple to perform, it does not involve consumption of large quantities of valuable water or damage to the surface.
- In vertical and horizontal boreholes stimulation of several hundred meters of productive horizon can be performed in a single operation, at very little load for the environment and expenses many times smaller than in hydraulic fracturing.

In view of growing interest in acquisition of natural gas from shale, where the core issues in accessing the deposit are extensive and multiple hydraulic fracturing operations, it may be interesting to use the solid fuel as the initial approach which allows in the first place to "break through" the rock, i.e. to initiate operations to make the fracture deeper.

- The use of propellants in combinations with perforators appears to be an effective and profitable influx stimulation treatment in old deposits, where the return of expenses incurred in hydraulic treatment is rather unlikely.

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Commissioning of spirally welded pipes and technical equipment used in transmission pipelines for flammable media – Project of Gaz-System S.A.

Effectiveness and quality of final technical inspections

Mariusz Stachurski

Oil and gas extraction onto the surface of the ground is an extremely complicated undertaking. Underground transmission lines made of steel pipes are the best solution known so far for this kind of transport.

Polish gas system has approximately 17 thousand km of high-pressure gas pipelines, 79 thousand km of distribution network, 23 gas compressor stations and approx. 4000 gas pressure regulating and metering stations of 1st and 2nd degree.

Quality requirements

Increased energy consumption and growing demand for energy carriers, especially in case of natural gas, is the determinant factor in development of transmission pipeline networks. Considerable distances between the source of natural gas and oil and their consumption place require construction of transit pipelines of very high performance parameters e.g.: gas pipelines together with equipment having diameter over 1000 mm and pressure 10 MPa. Pipelines of this kind require using pipes of strength 690 MPa (485 MB, 555 MB) and very good weldability. Such requirements generate development of low-alloy steels (C 0.16%, Si 0.55%, Mn 1.9%) often with Nb, Mo, Ti microalloys, received by controlled rolling, that is thermo-plastic (OCP) or thermo-mechanical processing (TM).

In production of pipes for this type of pipelines, the requirements contained in DIN standards or their American (API 5L) and European equivalents (EN ISO 3183) are applied [source: Long-distance pipelines – Odysseum Publishing House].

Inspections

Since November 2011, Bureau Veritas Polska Sp. z o.o. [Ltd.] has been partnering GAZ-SYSTEM S.A. project, an investment closely connected with the liquefied gas terminal (LNG) in Świnoujście, under construction. Combining this project with construction of gas pipelines is supposed to enable the Central and Eastern European countries to access the global market of liquefied gas, using the Polish transmission infrastructure. Bureau Veritas deals with technical inspections connected with commissioning of pipes and equipment used in transmission pipelines for flammable media. Thermo-mechanically rolled steel of L485 MB type and – for the first time in Poland – steel L555 MB were applied as basic materials. Pipes and equipment were ordered with recognized and globally

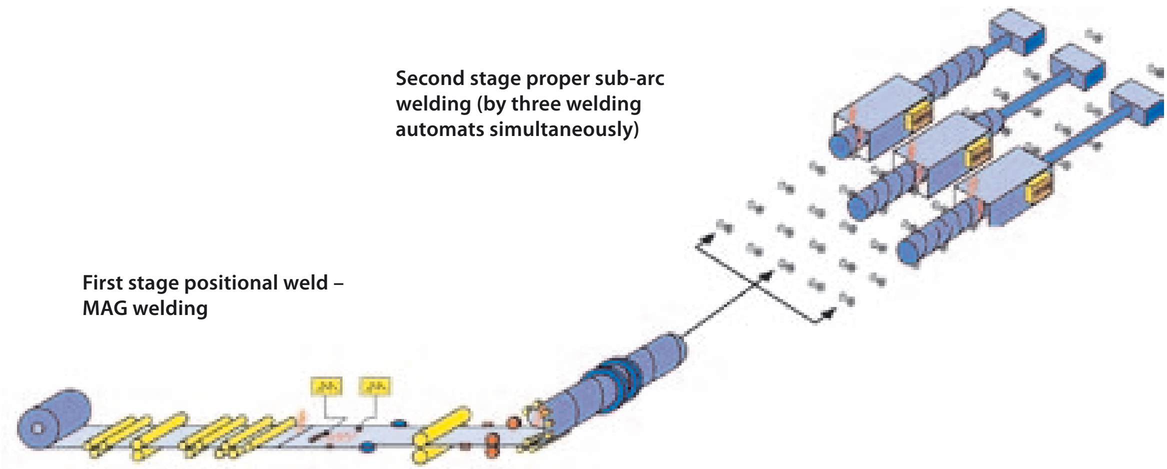

Fig. 1. Spiral two-stage pipe welding used at Salzgitter Mannesmann Grossrohr GmbH, German company [source: Salzgitter company presentation]

esteemed companies which applied the state-of-the-art production technologies for this type of elements. (Fig. 1).

Gaz-System S.A. strategic pipelines (Fig. 2) supervised by Bureau Veritas are built in sections:

- Szczecin – Gdańsk,
- Szczecin – Lwówek,
- Gustorzyn – Odolanów,
- Świnoujście – Szczecin,
- Rembelszczyzna – Gustorzyn

Range of services rendered within the GAZ-SYSTEM project comprises:

- Gaz-System S.A. staff training in inspection activities while commissioning the pipes and equipment,
- audits of production plants and pre-inspection meetings,
- commissioning of pipes and equipment at manufacturer's plant (continuous supervision – permanent presence of an inspector during production),
- commissioning of pipes and equipment at the storage area (qualitative and quantitative inspection of pipes and equipment delivered by the manufacturer to the storage area),
- full range of technical advice.

Many factors decide about effectiveness and quality of final technical inspections:

- suitable staff training and experience,
- inspection procedures and equipment,
- environment in which the inspection is carried out,
- psychological pressure on the inspection staff,
- time of work during the day,
- applied standards, requirements and guidelines,
- applied systems of staff, procedures and equipment certification.

Since October 2011, Bureau Veritas Polska Sp. z o.o. have commissioned for the Gaz-System S.A. project approx. 800 km of spirally welded pipes, insulated with (polythene or polypropylene) and painted inside with epoxy paint, of diameter 700 mm and 800 mm, and also approx. 250 pieces of technical equipment of diameter DN 100 to DN 800.

The author is Manager of the GAZ-SYSTEM Project in Bureau Veritas Polska Sp. z .o.o.

Bureau Veritas is the world leader in the TIC branch (Testing, Inspection and Certification) delivering high quality services providing assistance to customers to fulfill constantly growing requirements connected with quality management, health and safety at work, environment protection and social responsibility.

Fig. 2. Diagram of strategic gas pipelines built in Poland [source: Gaz-System S.A.]

Biomethane from biogas

New substitute for natural gas

ALINA REJMAN-BURZYŃSKA, JOANNA KRZEMIEŃ

Biogas is a renewable source from which biomethane can be obtained – valuable gas fuel which powers motor vehicles and gas grids. Growing interest in biogas as fuel is connected with the European Union climate policy and the resulting strategy of promotion of renewable energy sources, the use of which reduces carbon dioxide emission to the atmosphere and mitigates negative impact of fossil fuel burning on the environment.

Innovative technologies for using biogas were discussed at the International Conference "Biogas for Europe's Future" which took place on 4th June, 2013 in the Central Mining Institute in Katowice. This conference closed the SEBE project – "*Sustainable and Innovative European Biogas Environment*" which was realized as a part of CENTRAL EUROPE Program. The project was realized in the years 2010–2013 by consortium which included 14 partners from eight Central European countries: Austria, Czech Republic, Germany, Poland, Slovakia, Slovenia, Hungary and Italy. ICS Internationalisierungscenter Steiermark GmbH (Styrian International Cooperation Center) from Austria was the leading partner of the project.

From biogas to biomethane

Biogas is the product of fermentation of anaerobic biomass, i.e. sewage, animal excrement (liquid manure, compost), green waste coming from agriculture and food or energy plants (corn, grass, sugar beet and other). Methane (50÷70%) and carbon dioxide (30÷50%) are its main ingredients; in smaller amounts, it contains hydrogen sulfide, ammonia, mercaptans, water (as steam) and small amounts of nitrogen, oxygen and hydrogen. For instance, it is possible to obtain 20 m^3 of biogas from 1 m^3 of liquid manure and 30 m^3 of biogas from 1 m^3 of compost of energy value about 23 MJ/m^3.

The potential of raw materials for biogas production in Poland – taking into account agriculture, food industry, sewage treatment plant and municipal landfill site – is huge. It is estimated at 187 PJ, which corresponds to 36% of country's annual demand for natural gas, while the potential of agricultural biogas is 93% [1]. Currently biogas production in Poland is at 5.7 PJ, which makes up 1% of annual demand for natural gas [2, 3].

Biogas plant development is one of the aims of Poland's energy policy until the year 2030 which assumes that the participation of renewable energy sources in the final energy consumption will increase up to 15%, and in the transport fuel market up to 10% [4]. It is estimated that between the years 2010–2020 in Poland approximately one agriculture biogas plant will be built in every commune, which comes to about 2.5 thousand objects of that kind in the whole country [5].

Refined biogas can be used for electric and thermal energy production in cogeneration (CHP – *Combined Heat and Power*). Generated energy can be used for producer's own purposes or sold outside (electric energy is transmitted to energy grid, and heat may be used for heating purposes). On account of low transmission efficiency the heat should be used in the close vicinity.

Table 1. Comparison of selected biogas, biomethane and natural gas parameters [6]

Parameter	Biogas	Biomethane	Natural gas
CH_4	45÷75%	94÷99%	93÷98%
CO_2	28÷45%	0,1÷4%	1%
N_2	< 3%	< 3%	1%
O_2	< 2%	< 1%	-
H_2	Trace amount	Trace amount	-
H_2S	< 10 ppm	< 10 ppm	-
NH_3	Trace amount	Trace amount	-
Calorific value	5.5÷7.7 kWh/m^3	10.2÷10.9 kWh/m^3	9÷11 kWh/m^3

In order to obtain gas fuel which could power motor engines or gas grid, biogas has to be put through cleaning and upgrading processes. As a result of cleaning process biogas is stripped of hydrogen sulfide and other pollutants which are present in raw gas. Upgrading process results in enriching biogas with methane by removing carbon dioxide. As a result of upgrading and then compression, biomethane is obtained (CBM – *Compressed BioMethane*) which corresponds in its quality and chemical composition to fuel, i.e. natural gas (CNG – *Compressed Natural Gas*). Both fuels: natural gas and biomethane can be used interchangeably for powering the gas grid or motor vehicles. CBM fuel can also be mixed with CNG. Comparison of selected biogas, biomethane and natural gas parameters is shown in table 1.

Options for biomethane applications

Biogas cleaned and upgraded to biomethane can be pumped into gas grid and used as CBM, LBM (*Liquefied BioMethane*) transport fuel or after being processed it can power fuel cells. Possible options of biogas use are shown in figure 1. The quality of gas fuel from biogas pumped into the network has to be maintained at the level which meets the gas grid parameters and legislative requirements in a particular country. The EU lacks unified international regulations which would concern pumping biogas into the gas grid. The best conditions for pumping biogas into transmission and distribution network exist in Germany, Austria and Switzerland.

Required purity for biogas which powers cars is: minimum 96% of methane, fumes – less than 15 mg/Nm^3, H_2S no more than 100 mg/Nm^3, and number of particulates cannot exceed 40 microns.

More than 200 installations for biogas into biomethane treatment exist in the whole world. Germany is the world leader regarding the number of installations – because they have 107 objects of that kind. The second leader is Sweden which puts biogas through treatment in 56 installations. There are also installations for producing biomethane from biogas in: Holland, Switzerland, USA and Austria [6]. The list of installations for biogas to biomethane treatment operating all over the world is shown in figure 2.

Poland does not fully use biomethane's potential – so far, no installations for transforming raw biogas to biomethane have been built in our country. The already produced biogas is used only for generating electric energy and heat. According

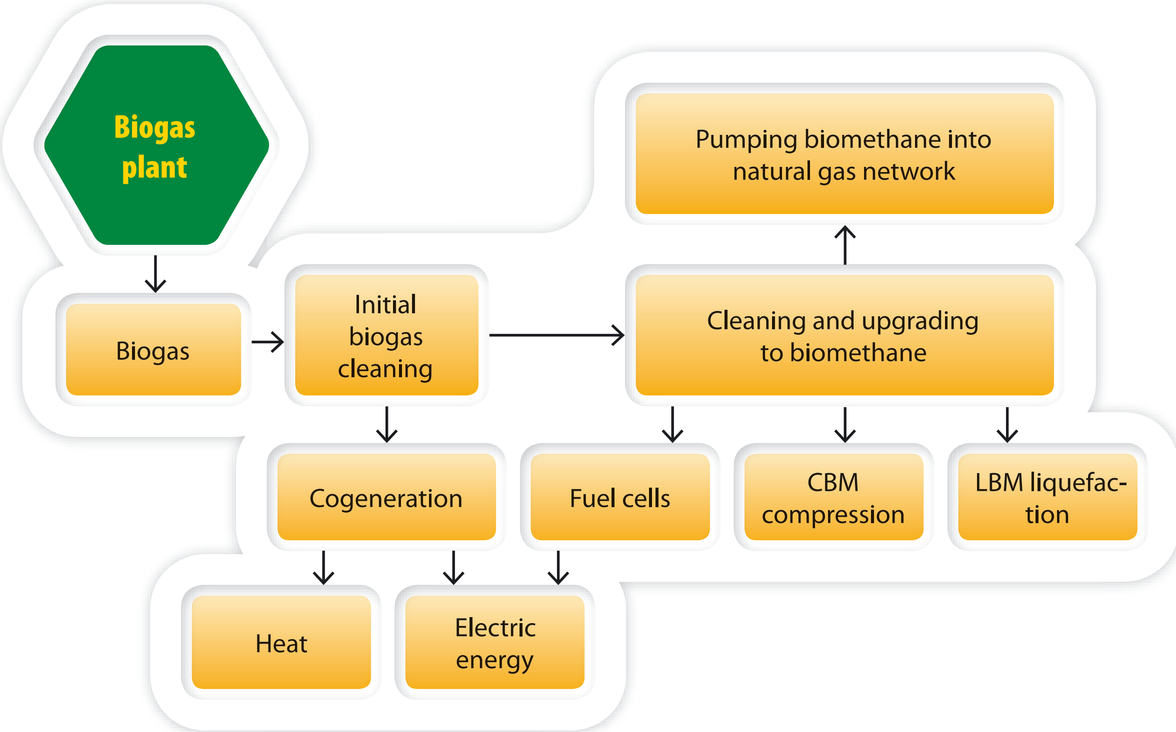

Fig. 1. Options for biomethane applications

to the Energy Regulatory Office information as of 31.03.2013, Poland had 207 biogas plants of total power 136 MW. Most of them were objects which used landfill biogas (97 installations) and sewage treatment biogas (79 installations) [8]. Agricultural Market Agency, which keeps register of gas utility companies processing agricultural biogas, entered 34 installations which generate energy from agricultural biogas. In all these objects biogas is burnt in cogeneration systems where combined electric energy and heat are produced [9].

In Poland, the requirements for connection to the gas grid are regulated by Energy Law of 10th April, 1997 (Journal of Laws of 2012, No. 0, item 1059) and the Ordinance of the Minister of Economy of 2nd July, 2010 (Journal of Laws 2010 no. 133 item 891, revised) on detailed terms of gas system operations. Directives concerning the quality of compressed natural gas are contained mainly in the Ordinance of the Minister of Economy of 28th December, 2006 (Journal of Laws of 2006, No. 251, item 1850) on compressed natural gas quality requirements and in norms: PN-EN ISO 15403-1:2010 – *Natural gas. Gas used as compressed fuel for vehicles. Part 1: Definition of quality*, and also PN-EN ISO 15403-2:2010 – *Natural gas. Gas used as compressed fuel for vehicles. Part 2: Quality specification*.

Biomethane as natural gas substitute

Compressed biomethane can be used in the same vehicles as CNG, that is in passenger cars, delivery vans, trucks, buses and in the special type vehicles (e.g. forklift trucks). Vehicles powered with this fuel may have spark ignition engines or self-ignition engines. Powering a vehicle with CBM fuel, just like CNG, guarantees greater security while it is used and also in case of an accident. On account of high durability of the fuel tank (pressure tank), there is only small risk of its damage. In case of gas leak, pressure is reduced from 20 to 0.1 MPa, which is accompanied by a sudden drop of gas temperature and the small holes are covered with ice, which considerably hinders the outflow of gas.

Cars powered with natural gas (CNG) are produced in the whole world by many car concerns, such as: Mercedes, Volvo, Ford, Fiat, Volkswagen and Opel. Many years of experience made compressed gas power systems as reliable as those powered by traditional liquid fuels. Vehicles using one fuel (called *monovalent*) are powered exclusively by compressed gas fuel, which enables reaching greater power. Vehicles using two fuel types (*bivalent* type) can be powered by natu-

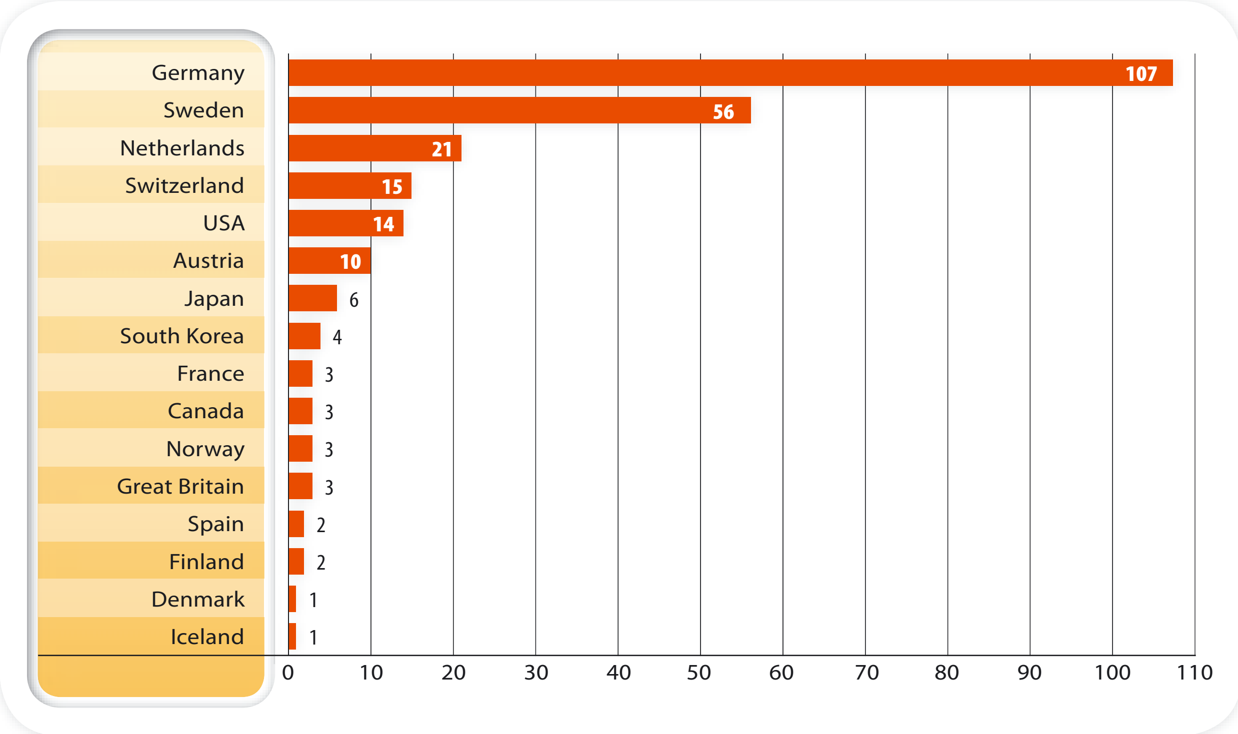

Fig. 2. Installations for upgrading biogas to biomethane from all over the world [7]

ral gas and petrol. When driving a *bivalent* vehicle, the source of power can be changed, which helps to cover longer distances.

Unfortunately, CBM/CNG powered cars have flaws, e.g. the necessity for using high pressure tanks, which would be resistant to mechanical damage. Available steel tanks are heavy and limit the vehicle's capacity, and composite tanks are expensive.

The availability of CBM fuels in the fuel market does not only result from the amount of produced biogas – it is also connected with availability of CNG infrastructure. Currently, all over the world, there are over 17 million cars powered by natural gas and there are 21 thousand filling stations offering this fuel. The greatest number of cars powered by CNG fuel are in: Iran, Pakistan, Argentina and Brazil.

The European leader concerning the number of cars powered by CNG fuel is Italy with more than 746 thousand vehicles of this type and 909 filling stations offering compressed natural gas (Fig. 3).

In Germany, considering the dynamic development of biogas production (about 7874 biogas plants) and well developed network of CNG filling stations (over 900 filling stations), the fuel is used in ever increasing volumes as fuel for vehicles. In Berlin, there are 11 filling stations with BioCNG fuel (CNG with 20% biomethane).

In our country, CNG filling stations are still poorly developed but it might also be used for biomethane. Poland has 23 CNG filling stations and there are about 2.5 thousand vehicles powered by this fuel; the capital has only one such petrol station. Buses powered with CNG fuel are used by 21 transport companies and general number of CNG powered buses in use is 311 [10, 11].

Conception of installation for biomethane production

Currently used technologies of cleaning and upgrading biogas to biomethane are mainly based on processes of physical and chemical absorption, pressure swing adsorption, membrane separation and cryogenic separation.

Presently there is no installation in Poland for changing raw biogas to natural gas quality, so this valuable gas fuel potential is not used.

In Department of Energy Saving in the Central Mining Institute in Katowice, as part of the SEBE project, a conception of installation for cleaning and upgrading biogas to biomethane was elaborated. Biomethane

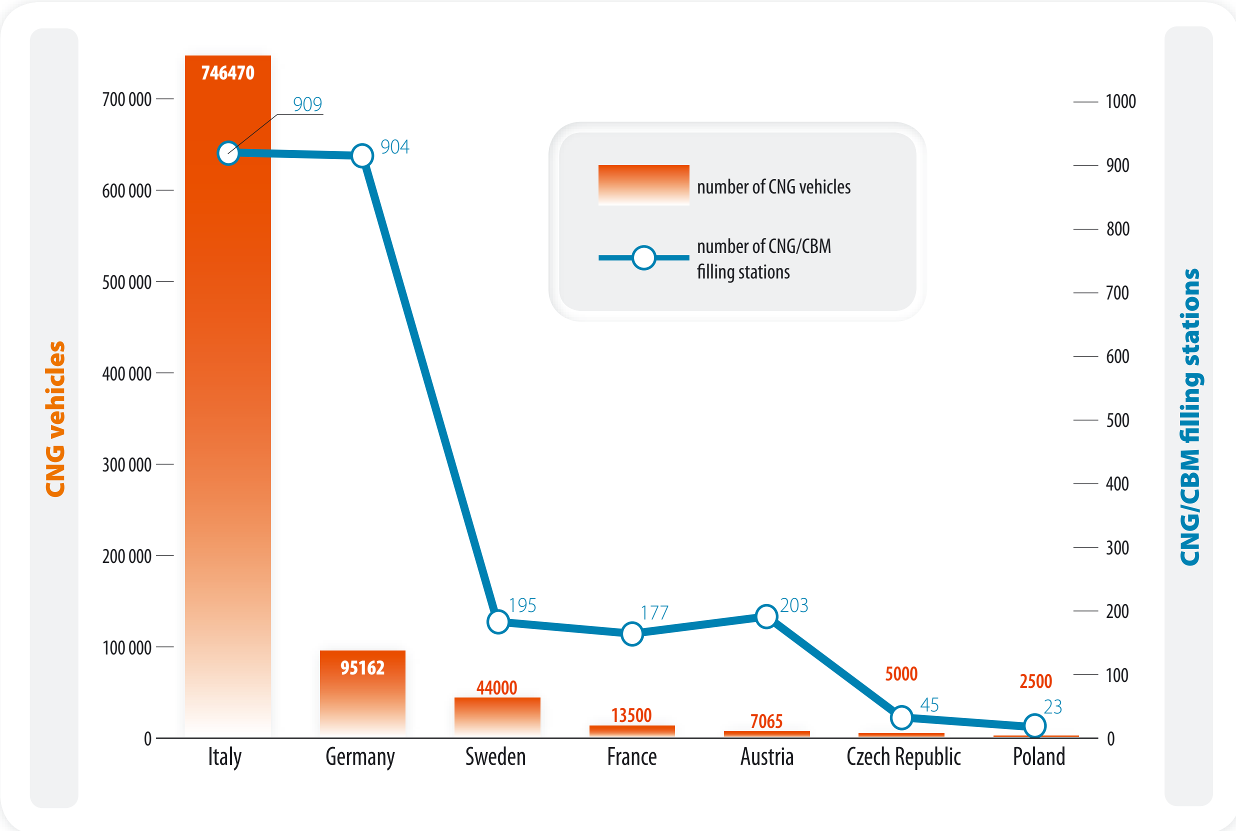

Fig. 3. CNG/CBM market in selected European countries [10, 11]

could be pumped in the natural gas distribution network as compressed CBM and/or used as fuel for cars. The installation for biogas to biomethane upgrading is shown in Figure 4.

Suggested technological system of cleaning and upgrading biogas includes desulfurization and high pressure water cleaning. The installation has 3 units: cleaning biogas from hydrogen sulfide and siloxanes, enriching biogas in methane by removing carbon dioxide and a station which injects biomethane to gas-pipeline (0.5 MPa or 1.6 MPa) or a station which compresses biomethane to 2.3÷2.5 MPa.

At the first stage, the raw biogas is put through desulfurization which uses Biosulfex – the Polish technology from PROMIS Sp. z o.o. company. Then the gas goes to pressure water cleaning installation with regeneration. The sulfur pulp which is non-reactive and non-toxic is the product of desulfurization process which transforms hydrogen sulfide to elementary sulfide. In the absorption column under 1 MPa pressure and temperature of about 20°C carbon dioxide is washed out of biogas as a result of physical absorption in a stream of water. In desorption column, after biogas expansion, it is removed and water is recycled to the system.

The installation project was elaborated on the basis of national engineering knowledge, using original technical solutions. Base project was prepared in co-operation with Mokrosz Sp. z o.o. company. The project enables also making “turnkey” installations. The unit cost of biogas upgrading is estimated to be:

- 0.26÷0.28 PLN/m^3 for biomethane to gas grid;
- 0.36 PLN/m^3 for compressed biomethane for cars.

According to the current legal regulations and unstable fossil fuel market, the obtained technical and economical indicators make the installations for biogas to biomethane upgrading an interesting alternative for widely used cogeneration CHP systems.

Summary

Making use of the huge biogas potential in our country, especially as gas fuel, should be considered a rational direction for fuel market development. Implementing technologies for upgrading this valuable resource in Poland would extend the possible options

Fig. 4. Installation for biogas to biomethane upgrading

of its application, which would make it possible to use the potential more effectively.

The project of biogas upgrading installation presented in this article, created on the basis of the national potential of engineers who took advantage of the Polish suppliers of equipment helps to take a closer look at the options of making biomethane from biogas from the technical and economical point of view. The easiness of scaling up the project creates a chance for adapting the installation of pressure water cleaning for every type of biogas plant. Estimated costs of biomethane production in order to use it as gas fuel in network or in transport in relation to natural gas price, and considering the support system (colourful certificates), enable to implement this technology in Poland in the near future.

The authors are researchers at the Central Mining Institute in Katowice

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Methods of pipeline reliability assessment

Comprehensive method of risk assessment

Paweł Domżalicki, Ph.D.

Pipelines are still the most effective way of transporting hydrocarbons – especially in case of natural gas. However, using onshore pipelines was always connected with Risk and Integrity Management.

Stories are known of failures or catastrophes caused by leakage or even gas pipeline explosions. Consequences of such incidents are particularly serious in highly urbanized areas. For the reasons already mentioned, the methods of onshore pipeline assessment are particularly significant as – apart from risk assessment – they indicate the measures of failure prevention. This issue is usually quite complex, e.g. on account of various geographic and weather conditions and third party damage risk in the pipeline exploitation.

Mechanisms of pipeline degradation and risk connected with failures

In discussions on pipeline degradation, mechanical damage is taken into consideration such as deformation, cracks and its corrosive degradation – both inside and outside. Stress corrosion cracking is a particular phenomenon which is determined by tensile stress combined with corrosion environment. The most serious is the fact that crack colonies often appear without visible loss in material thickness. Corrosion develops after some time of incubation, which poses a threat, mainly to the older pipelines.

It is worth remembering that the knowledge about potential mechanisms and degradation phenomena – especially those related to corrosion – is still incomplete. An example can be the cases of stress corrosion cracking found in the 1980s in carbon steel in non-alcaline environments and that of ethanol which is more and more widely used as fuel. Stress corrosion cracking phenomenon in the latter case was discovered in the 1990s [1].

Problem of infrastructure ageing – service prolongation or construction of new pipelines?

As the pipelines grow old, the effects of degradation cumulate. Resulting weakening of the pipeline wall must be connected with reduction of allowable operational pressure and deterioration of transmission profitability. The decision on reducing the operational pressure is taken voluntarily by the pipeline operator or forced by the executive authorities. In both cases, there must be strong reasons for such a decision. Significance of the methods of assessment of the pipeline condition consists in the fact that they enable selection of the weakest spots for repair and restoring the exploitation parameters. The options of using particular assessment methods, their costs, results quality and necessary stoppage periods for inspection are the elements which affect the decision on the pipeline **service prolongation** or building a new one.

Methods of pipeline reliability assessment

There is a number of methods which help assess the pipeline's condition. The most obvious one is the hydrostatic test which consists in filling a pipeline with water under pressure. Problems connected with this method are: the necessity for excluding the tested segment from service, providing huge amount of water and its disposal and draining the pipeline after the test. All that considerably limits the frequency of making such tests.

In this method, a phenomenon known as pressure reversal can occur. It means that during a hydrostatic test, as a result of increasing the existing cracks to subcritical sizes, the pressure causing pipeline failure after the test may be lower than the maximum test pressure [2]. It is hard to predict the pipeline's life-span on the basis of results of this test.

Inspections with intelligent pigs provide information about the current condition of the whole surface of the pipeline wall. Intelligent pig is a measuring device which moves inside the pipeline along with the transported medium. Its transition does not disrupt significantly the pipeline's operation. Various kinds of pigs enable the assessment of: any change of the pipeline route, a deformation e.g. oval shape, a wall material loss and appearing cracks. Using pigs is determined by particular pipeline construction. The most important is the interior geometry and equipping the pipeline with launcher and receiver of pigs. Unfortunately, considerable part of the old pipelines is not adapted to this method.

According to the current legal condition, gas pipeline of increased medium pressure and high pressure of diameters equal and longer than DN 200 should be adapted to cleaning by pigs or to interior inspection [3].

Coupons and corrosion sensors enable the estimation of wall deterioration in time; periodic in case of coupons or continuous for the sensors. The drawback of these tests is their spot character and the question to what extent the results in the spot of sensor assembly reflect the condition of the whole pipeline.

Direct tests have similar restriction as for representativeness. They are used much more seldom as they involve digging out of the place of inspection. However, they provide more information about the local en-

vironment of the pipeline and the deterioration phenomena in the spot of excavation.

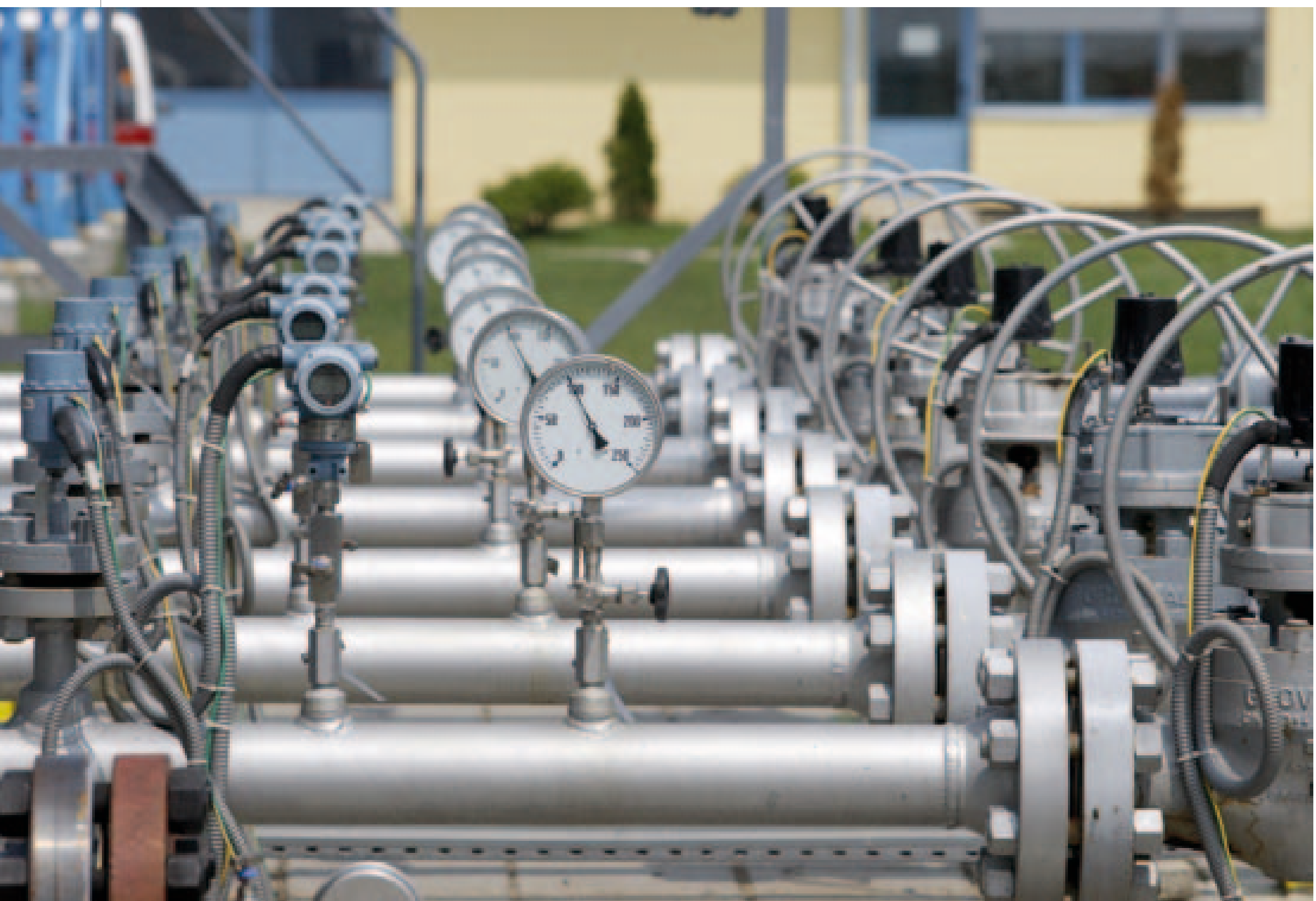
A specific kind of techniques are indirect inspections in the surface of the ground, above the buried pipeline, which give information about the condition of the pipeline's external surface. They are linked with the main anticorrosive protection techniques: protective coatings and cathodic protection. The basic measured parameter is the potential – voltage between the pipeline and reference electrode which is placed on the surface. Electric and magnetic field measurements in the ground are also used, as they are connected with operation of anticorrosive protection systems and factors which influence them (e.g. electric traction). A vast array of methods is used, e.g.: intensive measurements, CIS, DCVG, PCM. Each and every of them has restricted area of application and interpretation of the results becomes sometimes problematic. There are devices which enable combined use of a few techniques of indirect inspection, e.g. developed in DNV KEMA CSS for simultaneous CIS, DCVG and dGPS measurements in a single transition over a pipeline [4].

ECDA, ICDA, SCCDA methodologies as overall approach to the problem of assessment and planning of future inspections

Taking into account all possible options and restrictions of particular inspection techniques, NACE – National Association of Corrosion Engineers developed ways for estimating corrosion which would use various techniques combined together. Methodologies were invented for:

- assessment of internal corrosion: DG-ICDA (Dry Gas Internal Corrosion Direct Assessment),
- stress corrosion: SCCDA (Stress Corrosion Cracking Direct Assessment) and
- external surface corrosion: ECDA (External Corrosion Direct Assessment).

These methodologies are used mainly when there is no possibility of using intelligent pigs.



The assessment of the pipeline condition is carried out in four steps. In case of ECDA it is:

a) pre-assessment, with the use of current information about the pipeline's condition and its division to zones of similar character,
b) indirect inspections over the pipeline; at least two complementary methods should be selected for each zone,
c) direct inspections (excavations) in areas selected in the previous stage. Apart from assessment of the pipeline's condition, their aim is to check the effectiveness of indirect inspections and repair of detected damage,
d) post assessment, overall analysis of the data, remaining life calculations, definition of reassessment intervals, assessment of ECDA effectiveness and feedback [5].

Cyclically repeated ECDA process leads to adaptation of the methodology to the needs and possibilities and for better planning of further inspections and for minimization of number of necessary excavations.

The ECDA methodology is commonly used in the USA and Europe. Most often, the pipeline operators already have developed variants of this methodology as an effect of their experience and cooperation with external specialists.

Progress in development of methods of pipeline risk assessment and management – MARV™ system

Another step in the development of methods of pipeline risk management is the MARV™ system (Multi-Analytic Risk Visualization) developed and implemented by DNV.

MARV™ can take into account many factors which influence the risk of pipeline failure and they involve:

- production defects,
- construction defects,
- dangers connected with the weather and earth movement (e.g. earthquake),
- corrosion (external and internal),
- mechanical damage (e.g. as a result of incidental effect),
- sabotage,
- improper service.

Sometimes these hazards can be interconnected. For the assessment of incident probability, the model based on Bayesian network is used.

Bayes' theorem connects the probability of occurrence of an effect, such as corrosion, with probability of its cause, e.g. water presence. Particularly valuable property of Bayes' theorem is that this relation is reversible. Therefore, in the above example, knowing about actual occurrence of the effect – corrosion, we are able – using a model – to estimate the probability of occurrence of water as the cause for corrosion. Bayes' theorem gives mathematical basis for correction of the risk model through observations. In more complex systems, such as pipelines, many factors can be connected to each other to form complex networks [6].

In order to develop truly comprehensive method of risk assessment, it is important to use all available information about the pipeline. There are many types and sources of information and not all of them are easily available. Information concerning a pipeline can be divided to three main categories: event database, time-dependent data and place-dependent data. MARV™ system can use many data sources. Determination of confidence intervals of analyzed data allows to take appropriate action (e.g. collecting more data for a better risk assessment or taking precautions).

The essential thing in risk management program is a good tool for visualization and that is why MARV™ system uses, e.g. GIS technology. The result visualization can be done on a geographic maps.

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PGNiG SA – greater energy security due to intensification of extraction and expansion of underground gas storage facilities

Key to success

Strategic goal for the Polish Oil and Gas Company (PGNiG SA) is intensification of extraction from own deposits, which will favorably affect the financial results of the company but will also help increase the energy security of the country. The latter goal is aided by the expansion of underground gas storage facilities, currently in progress.

PGNiG SA is making attempts to accelerate the process of development of already identified deposits. Since the company bets on upstream, it can be expected that their activity in this field will increase.

In the year 2013, PGNiG intends to allot for investments in the prospecting and extraction sector about 2.4 billion PLN. The directions of development will soon be presented, but already at the moment it can be said with absolute certainty that one of the elements of this strategy will be continuation of shale gas prospecting in Poland. The plans comprise making 33 boreholes this year, including 13 in search of gas from unconventional deposits.

Gas from shale

Currently, out of 111 concessions for shale gas prospecting awarded by the Ministry of Environment, 15 belongs to PGNiG SA. These concessions cover the stretch of land from Pomerania through Mazovia and Lubelszczyzna to the Subcarpathian region. However, the most prospective region – with regard to deposits of gas from shale – is for PGNiG the Pomeranian concession in Wejherowo. The first boreholes have already been made in this area and subsequent ones will be commenced soon.

As part of the works performed so far, fracturing of the borehole Lubocino-2H was made, the results of which confirm the occurrence of natural gas and oil in Ordovician and Silurian deposits and the possibility of their inflow to the borehole. However, further tests are indispensable, including drilling new horizontal bores so as to finally assess the possibilities and volumes of potential production. Experience acquired in fracturing of the Lubocino-2H borehole will have a great impact on more effective running of the process in new horizontal bores. PGNiG SA began preparatory works for making another horizontal borehole in Lubocino-3H (the drilling is planned for September this year).

The progress of prospecting for gas in shale will depend largely on the pace of obtaining administrative permits allowing to enter the area and begin preparatory and then drilling works. Currently, performance of 10 obligatory and 84 optional boreholes are declared in the Ministry for Environment (with regard to gas prospecting from shale). The boreholes will be complete by the year 2021.

It is worth noting that the number of boreholes will certainly be changed as PGNiG SA are running procedures to introduce changes in several concessions concerning the time they are applicable and the scope of prospecting works, including also the number of boreholes.

In order to increase the effectiveness of gas prospecting from shale, PGNiG SA also intends to exchange the data related to prospecting and extraction from unconventional deposits with other fuel companies as the key to success is the policy of new opening. The patterns proven in the prospecting and extraction sector in the USA and Canada are well worth following.

Therefore PGNiG SA will offer other companies – on the principle of reciprocity – the results of their own tests made so far, while prospecting for gas from shale. Owing to that, the works may speed up, be more effective and contribute to the development of the whole sector.

Lubiatów Mine

Gas from shale is definitely a great chance for Poland for enhancing the energy independence. However, there are still many years to come, before its resources are documented and proven by tests and extraction begins on a scale which will enable Poland to obtain profits. Therefore PGNiG SA intensify their prospecting and extraction works on concessions already identified, with proven existence of conventional deposits of natural gas or oil. The best example is the recently commissioned Oil and Gas Mine in Lubiatów. This is the largest investment in the extraction sector in Poland in the last few years. Owing to the operation of the Lubiatów mine, PGNiG SA will increase their national extraction of oil and condensate from about 500 thousand tons at present to approx. 800 thousand tons a year. Natural gas, extracted as a by-product of oil exploitation (annually approx. 100 m m^3) will be used e.g. to power the heat and power plant in Gorzów Wielkopolski and also the heat and power station that is feeding the mine. The development of deposits in Lubiatów, Międzychód, Grotów (LMG) is an important step towards increasing the oil and gas extraction by PGNiG SA and strengthening the energy security of the country. The LMG deposits are ranked as the largest in Poland. Documented extractable oil resources from these deposits amount to approx. 7.25 m tons, and those rich in natural gas – approx. 7.3 m m^3.

The value of the investment comes to 1.7 billion PLN gross. It covered the management of natural gas and oil from 14 boreholes. As part of the investment, boreholes on oil and gas deposits were developed, and also the near-well zone installations were built, pipelines for the mine to connect particular boreholes with the Central Control Station in Lubiatów and pipelines to the shipping terminal in Wierzbno.

The oil and gas mine in Lubiatów is one of the most modern mines in Europe. The latest state-of-the-art technological solutions and monitoring systems have been applied in its design which significantly exceed the environment requirements. The mine was built on schedule, with no delays. In the history of PGNiG SA, this is – with regard to its scale – the second investment of this type. The first one, on the BMB deposit – Barnówko Mostno Buszewo, was the Dębno mine commissioned in the year 2000. Documented extractable resources of oil from these deposits amount to approx. 11 million tons.

Development of deposits in Poland

In the first half of the year 2013, in the operational area of PGNiG SA branch in Sanok, three boreholes were put in operation: borehole Terliczka-6k on deposit in Terliczka, borehole Pruchnik-24 on deposit in Pruchnik Pantałowice and another one in Batycze-4 as test exploitation. Total increase of natural gas extraction capacities from the connected boreholes comes to approx. 2.8 thousand m^3/h in conversion to methane-rich gas. In the operational area of the branch in Zielona Góra, apart from boreholes connected with LMG deposit (Lubiatów mine), the deposit in Winna Góra (borehole Winna Góra-1) was put in operation (in cooperation with FX Energy Poland Sp. z o.o.) with extraction capacity 1.2 thousand m^3/h in conversion to methane-rich gas.

Currently, preparatory stage is in progress for developing the deposit in Różańsko and modernization of the Zielin mine in the north-western Poland, located near the Dębno mine.

Expansion of the underground gas storage facilities

Still another strategic goal of PGNiG SA is connected with enhancing the energy security of Poland – the construction of new gas storage capacities. In the prospect of the coming years, the company intends to increase the storage capacities to 3 bcm, i.e. by more than ⅓ in relation to the present 1.8 bcm. All capacities, besides those obligatorily used by GAZ-SYSTEM for stabilization of the system, will be available on the TPA principles. PGNiG SA puts strong emphasis on development of cavernous capacities of the underground gas storage facilities (UGS), which will have vital importance for improving the offer for customers.

Construction of storage capacities covered e.g. currently advancing expansion of cavernous underground gas storage facility in Mogilno – its capacity will rise from 400 m m^3 to over 800 m m^3 – and the already started modernization of UGS Husów, thanks to which it will increase capacity by 100 m m^3. Also near Gdynia, cavernous UGS Kosakowo of capacity 250 m m^3 is under construction. It should be reminded that cavernous storage facilities are the most important for the security of transmission system as the gas reserves can be accessed really fast, which is particularly essential in winter, when the demand for gas is higher.

In the year 2012, modernization of UGS Strachocina was completed in the vicinity of Sanok, which increased capacity of the storage facility from 150 m m^3 to 330 m m^3. Moreover, construction works were completed in UGS Wierzchowice, which is the largest storage capacity facility in Poland. What still remains to be done as part of this investment is commissioning of particular installations and functionalities of the storage facilities. Advancement of the project realization comes to 97%. On completion of the investment, active capacity of this storage facility will rise to 1.2 bcm.

In the course of construction, expansion and modernization of UGS, PGNiG SA uses the EU funds. For execution of the works in UGS Wierzchowice, Kosakowo, Strachocina and Husów the company obtained more than 670 m PLN from the European Union. ■

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Establishment of Structural Framework for Risk Management in Shale Gas

Recommended Practices for Gas from Shale

Michał Gronert

MANAGING RISK DNV

Shale Gas is a game changer in the global energy market. The North American shale gas revolution has made gas an increasingly important source of energy and awoken potential shale gas nations across the globe, including the UK, Poland, Germany, Australia, Turkey, Romania, Argentina, Russia and China.

The shale gas industry is facing a variety of potential challenges: safety management, assessment of the effect on human health and environment, although it must be remarked that public opinion is polarised in respect of their impact on man.

Risk Management

The industry can gain acceptance of the interested party only by implementing operational best practices and demonstrating that the shale gas prospecting and extraction can be executed in a safe and responsible manner. These are the key reasons why DNV has developed Recommended Practices consisting of risk management principles and best industry practices applied in shale gas operations.

The basic aim of the Recommended Practices is to establish guidelines and recommendations for the processes required to ensure the safety of people and the environment during all phases of shale gas field development and exploitation. The intention is to raise the general awareness of the risk and describe how to manage the risk in the most efficient way.

Recommended Practices developed by DNV present risk management principles to prevent potential hazards related to shale gas exploitation in a manner easy to describe, accurate, balanced and transparent. The RP recommend the application of accepted international standards, guidelines and best practices in industry to mitigate identified shale gas risks. For example, the recently published report of the Royal Society in the UK mentions the ISRS (International Safety Rating System) as the best practice for risk management.

Extensive approach to management

DNV's Recommended Practices focus on the following aspects: management systems; safety, health and the environment; well integrity; management of waste, water and energy; infrastructure and logistics; public engagement; communication of the interested parties and obtaining permits.

DNV recommends that the management processes and procedures related to shale gas projects are built on the risk management framework and take into account the specific aspects concerning shale gas operations.

DNV recommends that shale gas operations are effectively monitored and the results are transparently communicated to all relevant parties. To establish proper points of reference and consistent monitoring prior to, during and after operations, DNV advises to carry out extensive baseline surveys prior to commencement of shale gas exploitation. The information gathered should be openly passed to the interested parties and society.

Most of the health and safety aspects in shale gas exploitation are well known; they are common for the majority of oil and gas extraction. DNV's Recommended Practices address the health and safety risks in a broad context, including those specific for the shale gas industry. DNV recommends the best tools and processes to safeguard employees on the worksite as well as the people in areas directly and indirectly affected by shale gas exploitation.

Sections of Recommended Practices

1. Introduction

Indicates the goals, framework and structure of Recommended Practices.

2. Application

Describes how the Recommended Practices may be used, identifies the anticipated users, the principle of equivalence and reference of the Recommended Practices to legislative instruments and other codes and standards.

3. Definitions

Defines key terms and concepts and lists acronyms and abbreviations used in the Recommended Practices.

4. Risk management principles

Outlines the risk management recommendations that are consistent with ISO 31000. Further, it stipulates requirements and recommendations as to the framework operations in respect of gas from unconventional deposits based on the management system and principles applicable to shale gas management processes.

5. Health and safety risk

Provides recommendations for the management of health and safety issues related to shale gas fields. The predominant health and safety risks associated with shale gas operations comprise:

- potentially large numbers of wells and well pads with high-density distribution and also the associated
  - » infrastructure and logistical operations
  - » equipment for hydraulic fracturing which involves fracturing fluids operating at high pressure
  - » vehicle traffic.

6. Environmental risk

Identifies and describes recommendations for the management of environmental risk. The predominant environmental risk is related to:

- the contamination of surface and groundwater,
- greenhouse gas emissions (combustion gases from engines, fugitive methane, flaring, ventilation) and other emissions to the atmosphere,
- the release of chemicals,
- the impacts/effects of dust, odours, noise and light,
- issues of management of the waste which remains after exploitation and related storage, transportation, treatment, recycling, reuse and/or disposal.

7. Risk related to wells

Provides recommendations for the management of risk associated with the wells. The main risk is related to:

- the flow of gas or liquids between the production zone and groundwater aquifers
- the contamination of aquifers during drilling operations.

8. Water and energy risk

Addresses the management of risks related to the acquisition, transportation, storage and use of water and energy.

9. Risk related to infrastructure and logistics

Discusses recommendations for the management of risk associated with the development and use of new and existing infrastructure. Further, it addresses the challenge for logistics.

10. Public engagement and risk related to communication of interested parties

Provides a set of recommendations for communication of the interested parties and winning the social engagement. The lack of public awareness of the hazards and opportunities related to shale gas, including the lack of factual and objective information may constitute an important business risk for the project.

11. Risk related to permits

Provides a set of recommendations for obtaining permits. The main challenges related to issuing permits for shale gas projects involve:

- public engagement/acceptance that influences issuing permits
- communications with regulators during the process of permit issue and understanding their requirements
- several levels of authorities (national, regional and local) which may have different views on shale gas
- the absence of legislation for shale-gas-specific aspects
- the risk of litigation with landowners, organisations and members of the public.

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Expansion of the terminal in Świnoujście – supplementary functionalities

Multifunctional LNG terminal

RAFAŁ WARDZIŃSKI

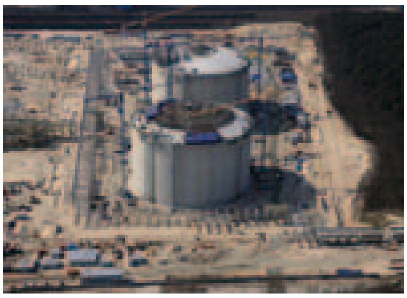
Most of the LNG import terminals in Europe render supplementary services besides their basic activity, i.e. regasification. Extended range of offered services is the outcome of changes occurring in the European gas market – the small-scale LNG market is enjoying ever greater interest. That chance has also been recognized by Polskie LNG company which is constructing a Liquefied Natural Gas terminal in Świnoujście.

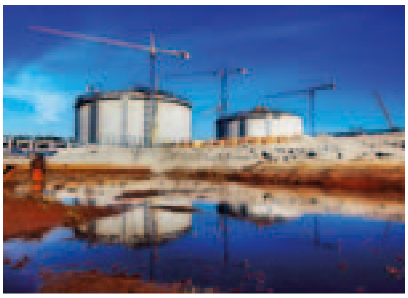
Next to the development of large LNG import terminals in Europe designed mainly for supplying gas to the European transmission network, significant growth of interest in the small-scale LNG market can be observed recently. Growing number of studies and projects oriented towards this area results, to a large extent, from the tightening of the environmental standards and increasing interest in using LNG as fuel. Moreover, the small-scale LNG allows to supply natural gas to places where the grid connections are unavailable.

Expansion of the terminal in Świnoujście

The development of the small-scale LNG market will have a direct influence on the demand for supplementary services in large terminals. By the end of the year 2012 and at the beginning of the year 2013, Polskie LNG S.A. company carried out market screening aiming at establishing the demand for expansion of the Baltic LNG terminal in Świnoujście. The entities interested in the LNG market, including the Polish and foreign companies dealing with trading of gas and energy, participated in the survey.

The results of the survey pointed at substantial demand for the increased regasification capacities and supplementary services. The revealed market potential already today substantiates the terminal expansion by another LNG tank that will increase the import capacities from 5 to 7.5 billion m^3 of gas. Market demand concerns also the regasification services and additional functionalities of the terminal – mainly the LNG reloading to road tankers, to smaller sailing vessels and bunkering of ships with LNG. The involvement in those three most prospective areas will translate to growing demand and the role that the LNG terminal in Świnoujście will be playing in the region.





Loading to tankers

In the first years, the optimal model of engagement seems to be the use of infrastructure for loading the road tankers – the possibility that the road transport provides is, first of all, the speed and flexibility of supplies and lack of restrictions imposed by location.

The main recipient may be i.a. the city transport in the biggest cities. Providing the service of loading to road tankers in the terminal may take place by means of infrastructure intended for loading and it is not connected with any additional, high financial outlays.

Loading to ships

In subsequent years, with increasing demand, the infrastructure for loading the LNG to ships might be used. Recently, in response to the oncoming date of enforcing the regulation concerning the emission of contamination by ships, the plans were presented by the major harbours in the North and Baltic Seas for availability of the service of bunkering the ships with LNG. In compliance with the European Union plans, it should be expected that by the year 2020, the infrastructure will arise which will allow steady development of the LNG market as navigational fuel in the Baltic Sea. This, in turn, should translate to increased demand for services rendered by the terminal in Świnoujście which would offer LNG supplies to smaller satellite terminals. The opening of these functionalities would be connected with construction of additional infrastructure for loading ships.

Subsequent services which in the prospect of the coming years might be rendered by the terminal in Świnoujście is loading the raw materials to rail tankers and commercial LNG storage in the terminal tanks.

According to the European Commission, liquefied natural gas is the most prospective, alternative fuel for transportation by water. Since 2015, in the territory of the European Union, new standards will be obligatory in relation to fuels used in navigation (ten times lower limit of sulphur content in fuel for all vessels sailing in the Baltic, North Sea, and the English Channel – reduced from 1% to 0.1%), which in practice will eliminate the use of the most popular fuel so far, that is heavy diesel oil, i.e. mazut in favour of LNG. An immense role can be played by the LNG terminal in Świnoujście in which ship owners will be able to buy the fuel.

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

Gas consumption [billion m³]

Country	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Change 2012 over 2011	2012 total share
US	536.0	540.8	526.4	511.1	524.0	545.6	570.8	584.0	603.6	648.5	681.4	4.7%	20.4%
Canada	187.9	184.7	183.7	187.1	188.4	182.7	176.6	164.0	159.9	159.7	156.5	-2.3%	4.6%
Mexico	39.7	41.7	43.4	52.3	57.3	53.7	53.4	59.4	57.6	58.3	58.5	0.1%	1.7%
Total North America	**763.6**	**767.2**	**753.6**	**750.6**	**769.7**	**781.9**	**800.8**	**807.4**	**821.1**	**866.5**	**896.4**	**3.1%**	**26.8%**
Argentina	36.1	41.0	44.9	45.6	46.1	44.8	44.1	41.4	40.1	38.8	37.7	-3.0%	1.1%
Bolivia	4.9	6.4	9.8	11.9	12.9	13.8	14.3	12.3	14.2	16.5	18.7	13.4%	0.6%
Brazil	9.2	10.0	11.0	10.9	11.2	11.2	14.0	11.7	14.4	16.7	17.4	3.7%	0.5%
Colombia	6.2	6.1	6.4	6.7	7.0	7.5	9.1	10.5	11.3	11.0	12.0	9.0%	0.4%
Peru	0.4	0.5	0.9	1.5	1.8	2.7	3.4	3.5	7.2	11.3	12.9	13.7%	0.4%
Trinidad & Tobago	19.3	27.0	30.2	33.0	40.1	42.2	42.0	43.6	44.8	42.9	42.2	-1.8%	1.3%
Venezuela	28.4	25.2	28.4	27.4	31.5	29.5	30.0	28.7	31.0	31.3	32.8	4.7%	1.0%
Other S. & Cent. America	3.3	3.1	3.1	3.4	3.8	3.9	3.7	4.2	3.6	3.1	3.6	14.4%	0.1%
Total S. & Cent. America	**107.9**	**119.4**	**134.7**	**140.5**	**154.3**	**155.7**	**160.4**	**155.9**	**166.6**	**171.5**	**177.3**	**3.1%**	**5.3%**
Azerbaijan	4.7	4.6	4.5	5.2	6.1	9.8	14.8	14.8	15.1	14.8	15.6	5.1%	0.5%
Denmark	8.4	8.0	9.4	10.4	10.4	9.2	10.1	8.4	8.2	7.1	6.4	-9.4%	0.2%
Germany	17.0	17.7	16.4	15.8	15.6	14.3	13.0	12.2	10.6	10.0	9.0	-9.8%	0.3%
Italy	13.4	12.7	11.9	11.1	10.1	8.9	8.5	7.3	7.6	7.7	7.8	1.7%	0.2%
Kazakhstan	9.1	11.9	13.1	13.5	13.9	16.7	18.7	17.8	17.6	19.3	19.7	2.0%	0.6%
Netherlands	60.3	58.1	68.5	62.5	61.6	60.5	66.6	62.7	70.5	64.2	63.9	-0.8%	1.9%
Norway	65.5	73.1	78.6	85.1	87.9	89.7	99.3	104.8	107.7	101.7	114.9	12.6%	3.4%
Poland	4.0	4.0	4.4	4.3	4.3	4.3	4.1	4.1	4.1	4.3	4.2	-1.1%	0.1%

Gas consumption [billion m³]

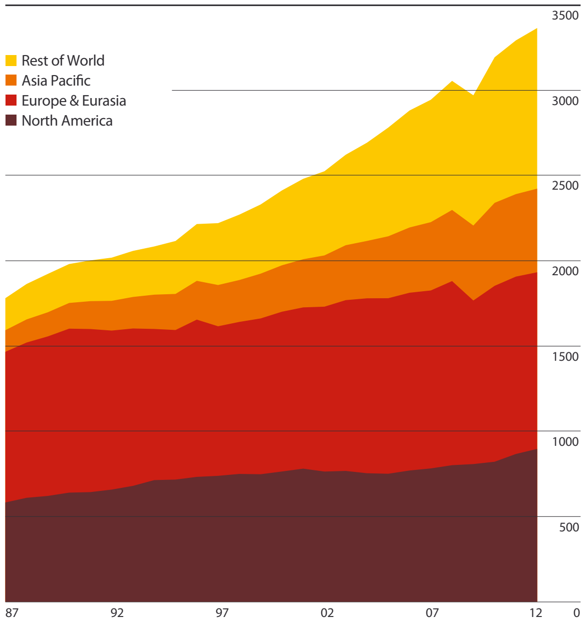
Country	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Change 2012 over 2011	2012 total share
Romania	13.2	13.0	12.8	12.4	11.9	11.5	11.4	11.3	10.9	10.9	10.9	*	0.3%
Russian Federation	538.8	561.5	573.3	580.1	595.2	592.0	601.7	527.7	588.9	607.0	592.3	-2.7%	17.6%
Turkmenistan	48.4	53.5	52.8	57.0	60.4	65.4	66.1	36.4	42.4	59.5	64.4	7.8%	1.9%
Ukraine	17.0	17.6	18.4	18.6	18.7	18.7	19.0	19.2	18.1	18.6	18.6	-0.8%	0.6%
United Kingdom	103.6	102.9	96.4	88.2	80.0	72.1	73.5	62.4	59.7	47.6	41.0	-14.1%	1.2%
Uzbekistan	51.9	52.0	54.2	54.0	54.5	59.1	62.2	60.0	59.6	57.0	56.9	-0.4%	1.7%
Other Europe & Eurasia	11.2	10.6	11.0	10.9	11.5	10.8	10.3	9.7	10.2	10.2	9.8	-4.3%	0.3%
Total Europe & Eurasia	**966.5**	**1001.2**	**1025.5**	**1029.1**	**1042.1**	**1043.2**	**1079.3**	**958.8**	**1031.2**	**1039.9**	**1035.4**	**-0.7%**	**30.7%**
Bahrain	9.5	9.6	9.8	10.7	11.3	11.8	12.7	12.8	13.1	13.3	14.2	6.9%	0.4%
Iran	75.0	81.5	84.9	103.5	108.6	111.9	116.3	131.2	146.2	151.8	160.5	5.4%	4.8%
Iraq	2.4	1.6	1.0	1.5	1.5	1.5	1.9	1.2	1.3	0.9	0.8	-9.3%	*
Kuwait	9.5	11.0	11.9	12.2	12.5	12.1	12.8	11.5	11.7	13.5	14.5	7.2%	0.4%
Oman	15.0	16.5	18.5	19.8	23.7	24.0	24.1	24.8	27.1	26.5	29.0	8.9%	0.9%
Qatar	29.5	31.4	39.2	45.8	50.7	63.2	77.0	89.3	116.7	145.3	157.0	7.8%	4.7%
Saudi Arabia	56.7	60.1	65.7	71.2	73.5	74.4	80.4	78.5	87.7	92.3	102.8	11.1%	3.0%
Syria	6.1	6.2	6.4	5.5	5.6	5.6	5.3	5.6	8.0	8.7	7.6	-13.4%	0.2%
United Arab Emirates	43.4	44.8	46.3	47.8	49.0	50.3	50.2	48.8	51.3	52.3	51.7	-1.5%	1.5%
Yemen	.	.	.	.	.	.	.	0.8	6.2	9.6	7.6	-21.3%	0.2%
Other Middle East	0.3	0.3	1.5	1.9	2.6	3.0	3.6	3.0	3.4	4.4	2.7	-40.1%	0.1%
Total Middle East	**247.2**	**262.9**	**285.1**	**319.9**	**339.0**	**357.8**	**384.2**	**407.3**	**472.7**	**518.7**	**548.4**	**5.4%**	**16.3%**
Algeria	80.4	82.8	82.0	88.2	84.5	84.8	85.8	79.6	80.4	82.7	81.5	-1.7%	2.4%

Gas consumption [billion m³]

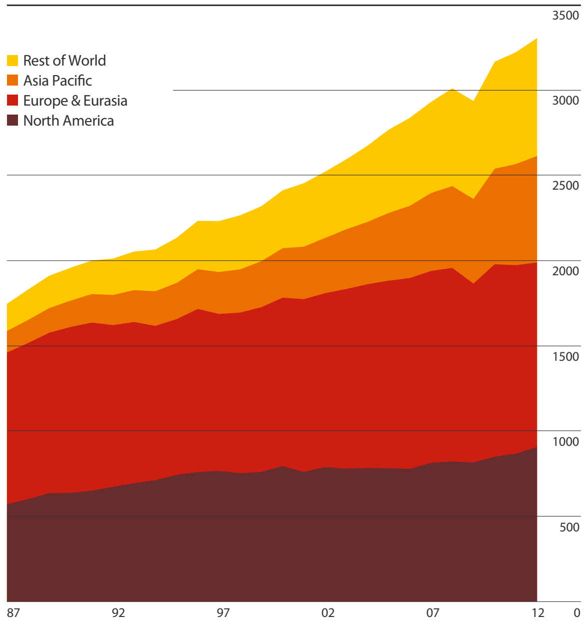
Country	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Change 2012 over 2011	2012 total share
Egypt	27.3	30.1	33.0	42.5	54.7	55.7	59.0	62.7	61.3	61.4	60.9	-1.2%	1.8%
Libya	5.9	5.5	8.1	11.3	13.2	15.3	15.9	15.9	16.8	7.9	12.2	54.8%	0.4%
Nigeria	18.0	22.5	24.5	25.0	29.7	36.0	35.7	26.0	37.3	40.6	43.2	6.2%	1.3%
Other Africa	6.6	7.2	8.9	9.9	10.4	12.3	15.8	16.3	18.4	18.6	18.4	-1.0%	0.5%
Total Africa	**138.2**	**148.2**	**156.4**	**177.0**	**192.5**	**204.1**	**212.2**	**200.4**	**214.3**	**211.2**	**216.2**	**2.1%**	**6.4%**
Australia	32.6	33.2	35.3	37.1	38.9	40.0	38.3	42.3	45.6	45.0	49.0	8.8%	1.5%
Bangladesh	11.4	12.3	12.8	13.8	15.1	15.9	17.0	18.5	19.9	20.1	21.8	8.2%	0.6%
Brunei	11.5	12.4	12.2	12.0	12.6	12.3	12.2	11.4	12.3	12.8	12.6	-2.1%	0.4%
China	32.7	35.0	41.5	49.3	58.6	69.2	80.3	85.3	94.8	102.7	107.2	4.1%	3.2%
India	27.6	29.5	29.2	29.6	29.3	30.1	30.5	39.2	50.8	46.1	40.2	-13.1%	1.2%
Indonesia	69.7	73.2	70.3	71.2	70.3	67.6	69.7	71.9	82.0	75.9	71.1	-6.6%	2.1%
Malaysia	48.3	51.8	53.9	61.1	63.3	64.6	64.7	63.4	65.2	65.3	65.2	-0.3%	1.9%
Myanmar	8.4	9.6	10.2	12.2	12.6	13.5	12.4	11.6	12.4	12.8	12.7	-0.6%	0.4%
Pakistan	24.6	30.4	34.5	35.5	36.1	36.8	37.5	38.4	39.6	39.2	41.5	5.6%	1.2%
Thailand	20.5	21.5	22.4	23.7	24.3	26.0	28.8	30.9	36.3	37.0	41.4	11.5%	1.2%
Vietnam	2.4	2.4	4.2	6.4	7.0	7.1	7.5	8.0	9.4	8.5	9.4	10.6%	0.3%
Other Asia Pacific	10.8	10.6	10.0	11.0	14.6	17.4	18.3	18.6	18.1	18.4	18.1	-1.9%	0.5%
Total Asia Pacific	**300.5**	**322.0**	**336.4**	**363.0**	**382.6**	**400.5**	**417.1**	**439.6**	**486.5**	**483.6**	**490.2**	**1.1%**	**14.5%**
Total World	**2523.9**	**2620.7**	**2691.6**	**2780.0**	**2880.1**	**2943.2**	**3054.0**	**2969.3**	**3192.3**	**3291.3**	**3363.9**	**1.9%**	**100.0%**

* less than 0.05%

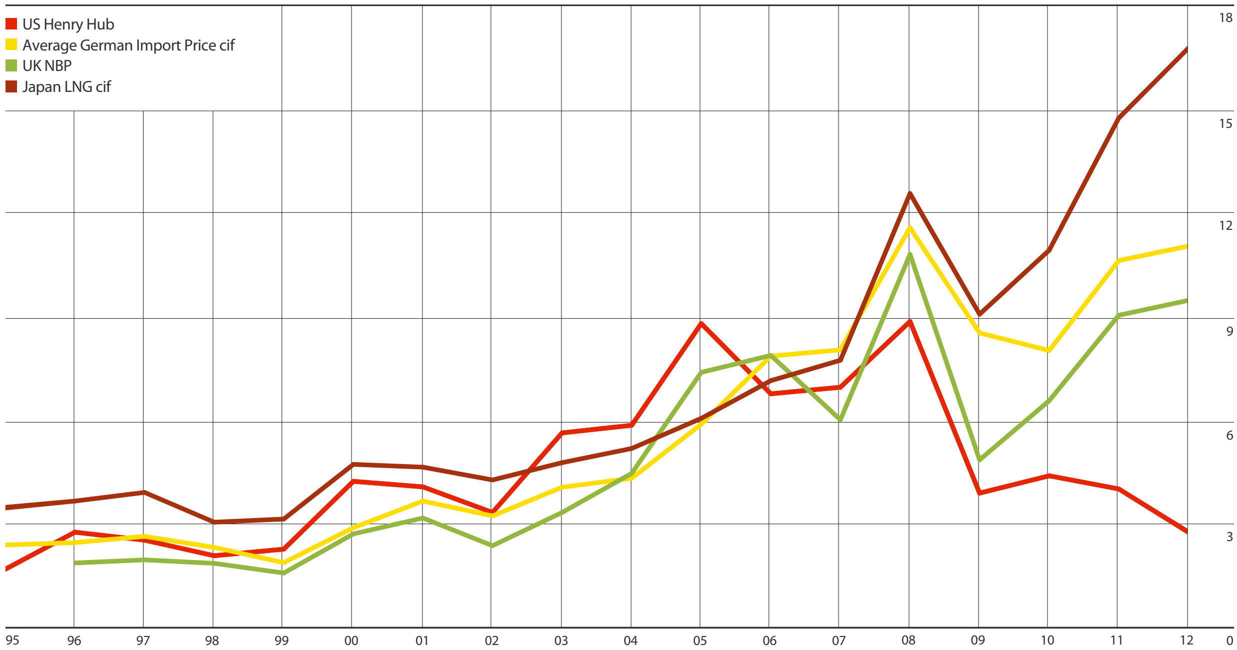
Gas production [billions m^3]



Gas consumption [billions m^3]

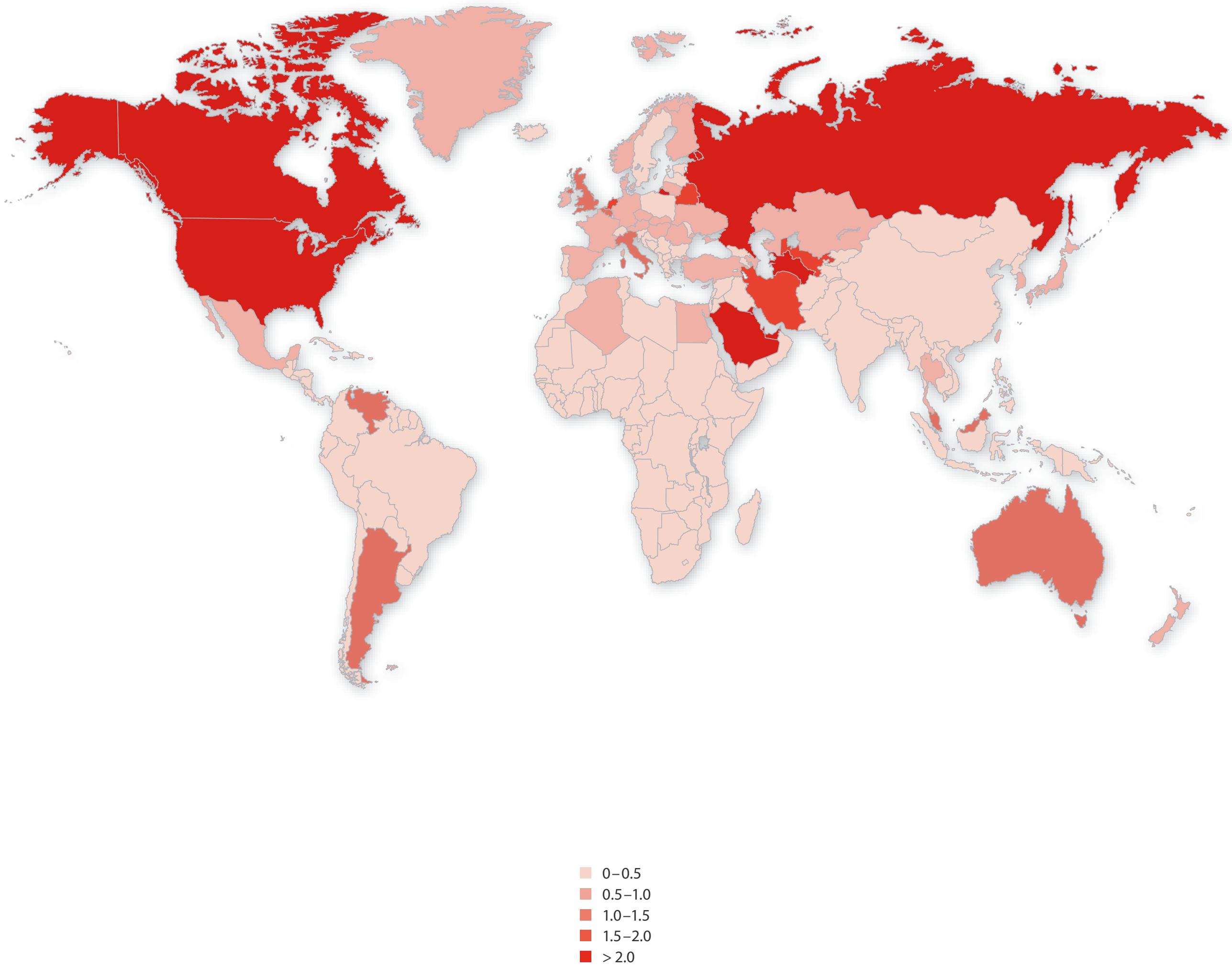


Gas prices [USD for MMBtu]



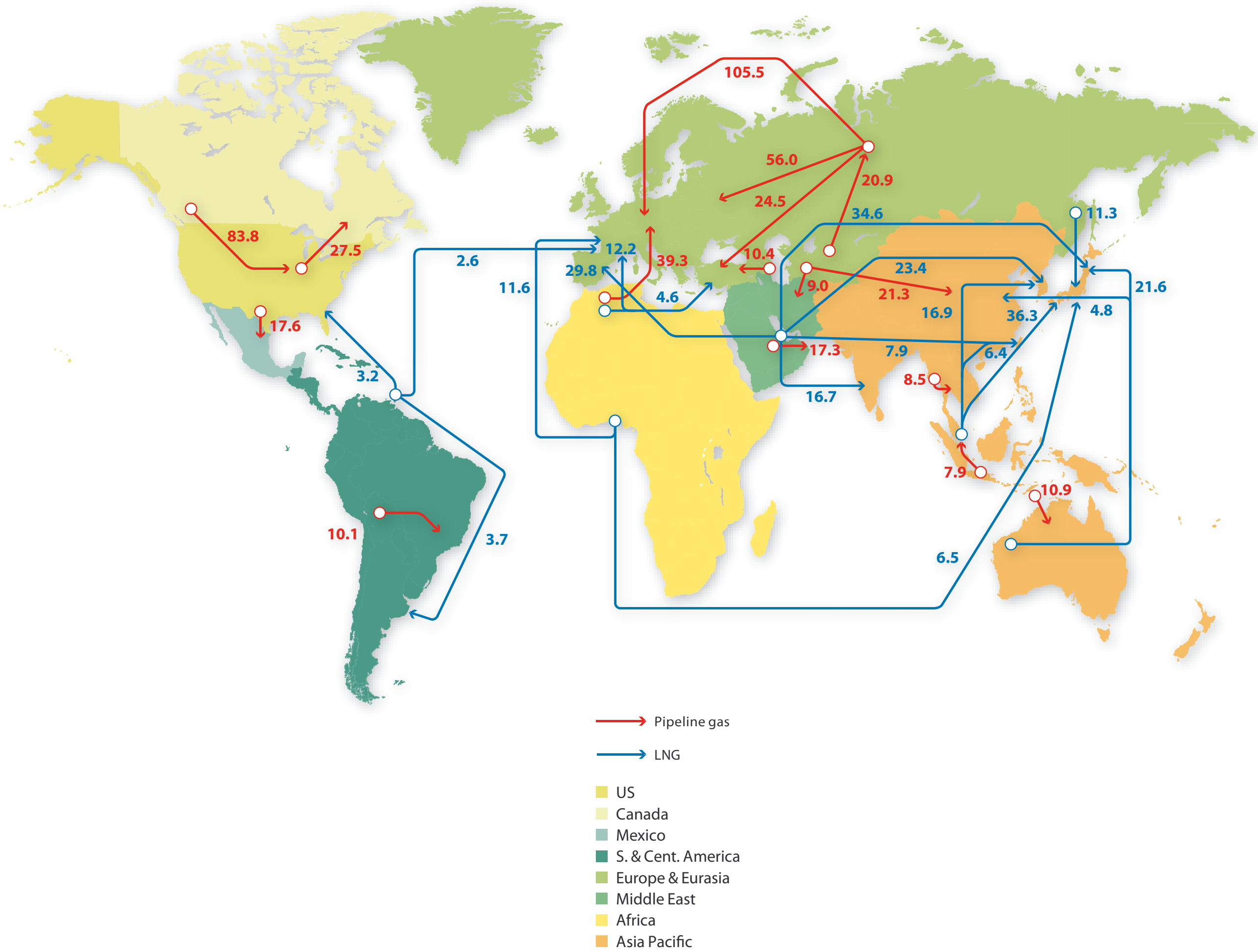
Source: BP Statistical Review of World Energy 2013

Gas consumption *per capita* in 2012 [tonnes oil equivalent]



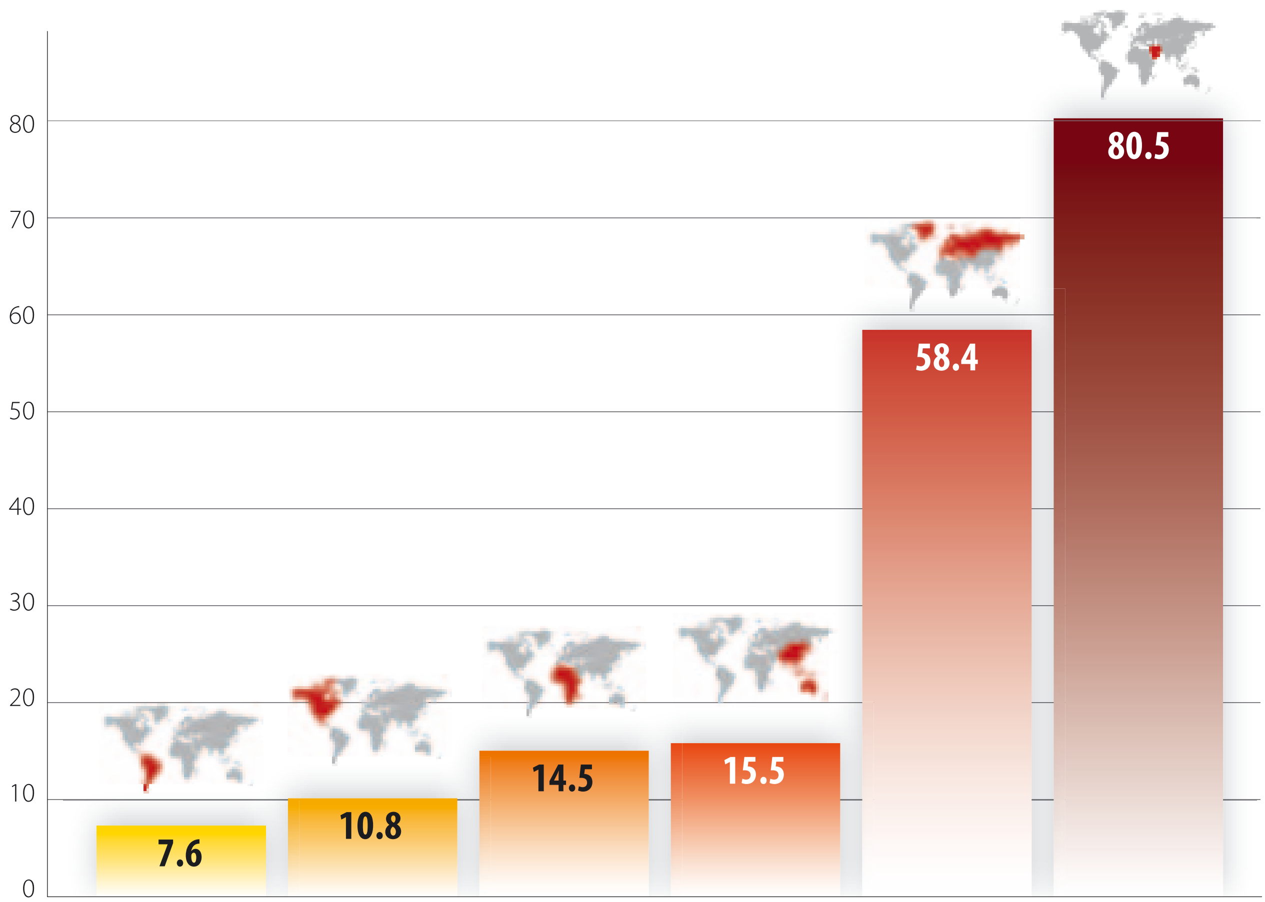
Source: BP Statistical Review of World Energy 2013

The main directions in natural gas trade in 2012 [in billion cubic metres]



Source: BP Statistical Review of World Energy 2013

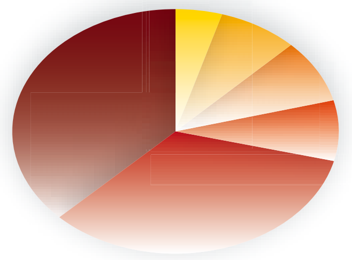
Natural gas: Proved reserves by the end of 2012 [in trillion m^3]



South and Central America	7.6
North America	10.8
Africa	14.5
Asia and Pacific	15.5
Europe and Eurasia	58.4
Middle East	80.5

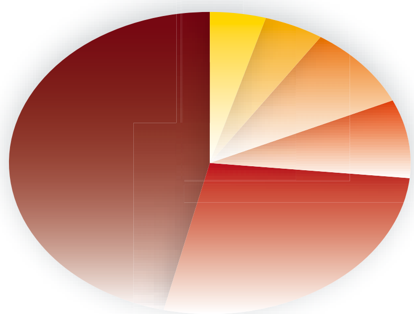
Source: BP Statistical Review of World Energy 2013

Distribution of confirmed natural gas resources in 1992 – 117.6 trillion m³ in total



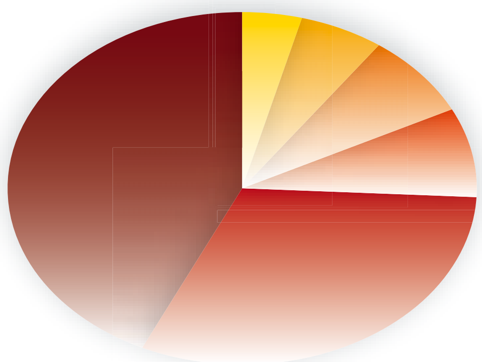
- South and Central America 4.6%
- North America 7.9%
- Africa 8.4%
- Asia and Pacific 8.0%
- Europe and Eurasia 33.7%
- Middle East 37.4%

Distribution of confirmed natural gas resources in 2002 – 154.9 trillion m³ in total



- South and Central America 4.5%
- North America 4.8%
- Africa 8.9%
- Asia and Pacific 8.4%
- Europe and Eurasia 27.1%
- Middle East 46.3%

Distribution of confirmed natural gas resources in 2012 – 187.3 trillion m³ in total



- South and Central America 4.1%
- North America 5.8%
- Africa 7.7%
- Asia and Pacific 8.2%
- Europe and Eurasia 31.2%
- Middle East 43.0%

Source: BP Statistical Review of World Energy 2013

Ecology

in the oil and gas industry

Reports on the impact on environment of granted concessions for prospecting and identification of hydrocarbon deposits in shale structures

Is the environment endangered?

Joanna Zaleska-Bartosz

Prospecting and identification works in shale structures while searching for natural gas deposits have been conducted in Poland for three years by companies which hold appropriate concessions granted by the Minister for Environment. In compliance with the binding law[1] (as of May 2013), obtaining a concession for prospecting and identification of deposits is preceded by administrative procedure consisting in issuing an environmental impact statement.

If the prospecting and identification works in natural gas deposits involve performing geological tasks which require the use of explosives or drilling deeper than 1000 m, regardless of the geological formation in which the works are run, they are qualified as works which may have a significant impact on the environment. This means that the body which issues the environmental impact statement may find it necessary to assess the impact, which practically means an obligation to make a report on the environmental effects of the works (facultative assessment).

Report on environmental impact

In practice, the assessment of impact and the report requirement when the planned undertaking is linked – among other things – with the application of new technologies, raise protests of local communities or they are likely to influence adversely the protected elements of environment.

As the concessions granting authorization to run geological works cover vast areas (often featured by considerable natural value and great sensitivity to potential changes, including the areas under statutory wildlife protection) the bodies which issue environmental statements usually find it necessary to make an assessment of the effects on environment and to make a report. It concerns mostly the cases when the prospecting and identification works involve shale formations, which have recently become a new objective for geological works. The bodies authorized to issue environmental impact statements define also the scope of the report in statements which impose such obligation. In the report, the entrepreneur must specify the location of planned works so as to make it possible to describe the actual effect of the undertaking on specific components of the environment, based on valorization and inventorying of the nature.

In case of reports on typical investments for which the exact location is known beforehand, each time a detailed, sometimes even meticulous inventorying of the environment is performed in the area planned for execution of the undertaking. Such records allow to assess correctly the sensitiv-

1 *Act of 9th June, 2011, Geological and Mining Law (Official Bulletin of 2011 no. 163 item 981). Act of 3 October, 2008 on publishing the information on environment and its protection, social contribution to environment protection and assessment of environmental impact (Official Bulletin of 2008 no. 199 item 1227, revised).*

ity and condition of the environment before the investment execution, they identify the flora and fauna species likely to be destroyed and also the habitats and landscape which may be adversely transformed due to conducted works.

In case of reports made before the geological concessions are granted, such an approach is usually not possible, since the sites for future seismic works and boreholes are not indicated, and the entity applying for concession seeks authorization to run the works in an extensive area of approximately several hundred square kilometers (maximum 1200 km^2).

The area to be granted for concessions is usually extremely diversified with respect to its flora and fauna, as well as the type and extent of the territory development. Thorough wildlife and environment inventory in the concession area would be time-consuming and extremely expensive, and its results would not be fully used, as, eventually, the seismic and drilling works will not be conducted in such vast concession areas all the time the concession is valid. In view of the fact, the task of the report on the impact of prospecting and identification works on environment is to make general valorization of the environment within the borders of concession area, based on available source materials so as to be able to define the conditions of environment protection necessary to meet in geophysical examination and drilling works.

With the knowledge on the effect of geological works on specific elements of the environment, it is possible to assess the adverse effects on environment that the works may have in different sections featured by different sensitivity of the concession area. This, in turn, allows to identify in the discussed zone:

According to the draft law *Geological and Mining Law* and other laws, relief is planned from the obligation to submit the environmental impact statement before granting the concession for hydrocarbon deposits identification and extraction.

- the area in which, on account of environmental issues, the works covered by concession application are excluded,
- the areas in which – in justified cases – the works may be conducted with great care, under specific conditions described in the environmental statement,
- the areas in which conducting the works is not restricted, as long as certain commonly binding rules and regulations on environment protection are observed.

Report on shale structures

The practice developed over the years, consisting in making reports on the effect of undertakings such as prospecting and identification of hydrocarbon deposits on environment, at the time of commencing this type of compilation for prospecting and identification of natural gas and oil deposits in shale structures must have undergone some modifications. The changes have been forced by the necessity to meet the requirements imposed by the authorities which issued the environmental statements, and also the attempt to respond to social anxiety in relation to prospecting in shale formations and in particular to performed fracturing treatments. The objections are raised during social consultations which are an element of regular procedure while assessing the effects. During the consultations one of the most essential issues for the local inhabitants is the location of works to be conducted in the future.

However, meeting the requirements is an extremely difficult task, both for the entrepreneurs and those preparing the reports. Investors who apply for a concession or its modification (e.g. extending the concession by operations conducted in shale and indispensable large scale hydraulic fracturing) are unable to identify – at such an early stage of investment process – detailed locations

of future (seismic and drilling) works and their full range. Prospecting and identification of hydrocarbon deposits, irrespective of the geological structure covered is a process executed in a specific area in stages for many years. Geological works can only be planned, when operations conducted at an earlier stage in a given location prove to be positive. It is also possible that due to the lack of expected results attesting to the occurrence of prospective geological structures the extraction of which will be profitable, a decision is made to stop any subsequent activities. These works are then considerably risky and such undertaking does not guarantee reliable prospecting success. Such specificity makes it impossible to pinpoint a detailed location of all planned geological works during the concession period, while there is still the stage of applying for a concession and even earlier, the necessity to obtain a statement on environmental issues.

These are the difficulties that those making the reports had to face in order to enable works whose geological goal was the identification of oil and gas-bearing shale formations. An additional obstacle was the relatively new history of prospecting and identification works run in shale formations in the territory of Poland, which results from insufficient experience relating to their real impact on environment. Although the techniques and technologies used in identification of shale structures are really modern and have been applied for years in domestic industry (the discovery of gas deposits in shale formations only made it more popular), the thing that basically makes the difference between identification of deposits in shale formations and geological works executed so far is the scale specific techniques used. While working in shale, horizontal drilling and hydraulic fracturing treatments are the basic techniques which are used obligatorily. There are many companies which either started or are going to start works connected with identification of shale gas/shale oil deposits whose prospective areas are in the northern and eastern part of Poland. There is a chance then that the works will be conducted here soon on a large scale. This raises fears of local communities and ecological organizations alarmed by increased activity of companies executing seismic tests and drilling works in this area. The inhabitants of the areas in which the works are planned and also the local governments – and consequently the authorities issuing the environmental statements – wish to be certain that the operations of prospecting companies will not cause damage to the environment, will not come into conflict with its valuable components (e.g. the flora and fauna protected species, valuable habitats, water intakes covered by zone protection), and also will not become troublesome on account of e.g. increased road traffic on local roads, noise or excessive use of local water supplies. It is the more essential that a vast majority of activities which accompany the prospecting and identification works are featured by strictly local character. In order to reliably assess the extent of impact that those works have on environment in a specific area, the information on locations of planned works is indispensable.

Location of the works

In order to make an effort and meet the requirements, the entrepreneurs who apply for concessions attempt to at least roughly describe the location of some operations – first of all the drillings, particularly those which are to be made first. In indicated locations the inventory is made of the flora and fauna and natural habitats. Its goal is to find out whether in the lots selected for will development it will be possible to run operations without causing damage to protected and valuable wildlife species.

The inhabitants of the areas in which the works are planned and also the local governments – and consequently the authorities issuing the environmental statements – wish to be certain that the operations of prospecting companies will not cause damage to the environment, will not come into conflict with its valuable components (e.g. the flora and fauna protected species, valuable habitats, water intakes covered by zone protection), and also will not become troublesome on account of e.g. increased road traffic on local roads, noise or excessive used of local water supplies.

Moreover, within the whole concession area special zones are mapped out where subsequent drillings are most likely. These areas and the remaining part of the concession territory are covered by natural valorization made on the basis of available source materials. Probably, just like in case of the previous environmental impact reports made for the needs of prospecting and identification of hydrocarbon deposits, such valorization of environment only allows to state the conditions which have to be satisfied in order to permit continuation of planned concession projects. The degree of its accuracy is not high though, e.g. on account of shortage of information concerning nature or because it is outdated. Many administrative districts have no inventory or valorization of nature or those already existing were made many years ago. Furthermore, the "Natura 2000" zones have no planned protection tasks and the knowledge of these areas contained in standard data forms is rather scanty. In consequence, compiled reports do not cover all the issues accurately enough and the assessment of environmental impact before issuing the statement on environmental issues takes a long time to make. By the same, granting the concession or its modification is postponed as the statement must be attached to the application for granting a concession.

The entrepreneurs who apply for concessions make attempts to at least partly define the location of some operations – first of all the drillings, mainly those which they intend to make in the first place. In indicated locations the inventory of the flora and fauna and natural habitats is carried out. Its aim is to find out whether in the lots selected for drilling development it will be possible to run operations without causing damage to protected valuable wildlife species.

Amendments to the law

According to the Ministry for Environment, in the years to come, intensified prospecting, identification and extraction works should be expected, particularly in relation to natural gas from shale formations. This will be aided – among other things – by an amendment to Geological and Mining Law which is being prepared at the moment, as well as other laws, which assumes simplification and clarification of environmental regulations. According to the draft law, relief is planned from the obligation to submit the environmental impact statement before granting the concession for hydrocarbon deposits identification and extraction.

This statement, which – in currently binding form – was one of the first administrative decisions and was connected with the necessity to assess the environmental impact on an area as large as 1200 km^2 will be awarded at the stage of obtaining the approval for the planned start-up of the plant dealing with geological works, that is immediately before the drilling starts – that is when its location is known. Resignation from submitting the environmental statement at such an early stage of planning the undertaking will certainly accelerate the administrative procedures. Also, when it is necessary to make a report on environmental impact, it will definitely cover more accurately the issues connected with environment protection.

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New kinds of cement slurries of increased elasticity

Licence for elasticity

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Elastic cement slurry has been used all over the world for many years; it is used mostly in borehole sealing in underground gas storage facilities.

The elastic cement slurry compositions in Poland were developed on the basis of polypropylene fiber and granulated rubber. They are featured by their competitive production costs when compared to foreign products. These compositions might be used for cementing the casing columns in various borehole conditions. The cement stone created after bonding the elastic cement slurries has very good technological parameters and high durability.

Introduction

Most boreholes made in our country are sealed with "conventional" cement slurries (on the basis of water, cement, appropriate additives and admixtures and the so-called fillers). Such compositions are used in the process of cementing the casings of various diameter in the Polish Lowlands, in the Carpathian Mountains and in the Carpathian foreland.

In recent years, oil companies in our country have become interested in new kinds of sealing slurries, i.e. the elastic cements. In the case of borehole cements, the elasticity (or plasticity) is usually defined as the ability of hardened cement slurry to come into such a shape that it tightly fills the ring-shaped space outside the pipes in the hole, without the effect of longterm shrinkage which makes the cement stone crack and crumble.

When it comes to a situation where shrinkage cracks and micro-annuli appear in a hardened cement layer, this layer comes off the casings or rock formation, which is the result of lack of inter-zonal isolation. Tight and durable inter-zonal isolation is the crucial property required from the hardened slurry in the ring-shaped space of the borehole [2].

During the selection of proper ingredients for cement slurry which is to provide zone separation through the whole of the borehole lifetime, the basic parameters which have to be taken into consideration are mechanical parameters of casings, cement and rock formation, which are closely connected with each other. While preparing the slurry composition, the essential property is the flexibility because it enables the hardened slurry to endure treatments which take place in the borehole, such as: pressure tests, perforation works, intensification of extraction, exploitation and gas pumping in and out (in underground gas storage facilities). High flexibility of the hardened slurry can prevent from cracking and shrinkage which is necessary to eliminate gas migration and deposit fluid penetration into the cement layer which might be damaged.

Here are the main plastic cement mixtures:

- elastic cement slurry with designed composition of grains including appropriate solid fillers,
- high plasticity latex slurry,

- swelling mixtures which contain an additive causing positive volume changes during bonding.

Elastic cement mixtures can contain various fibers or granulated rubber and at the same time be "strengthened" by e.g. adding latex and a swelling agent. These cements can also be used in conventional casing columns or lost pipe columns and also in boreholes intended for the underground gas storage facilities.

Elastic cement compositions in the world

There are elastic compositions of cement slurry known worldwide with carefully selected distribution of grain sizes in which the empty spaces are filled with solid fillers. It enables to increase the volumetric coefficient of packing the cement particles independently of suspension thickness (particles from different fractions were selected in such a way as to be more tightly packed together). Cement slurries combined in this way contain more solid substance and less liquid than conventional composition of borehole cement, which increases their resistance to stretching and bending, reduces porosity and permeability and makes it more shock-resistant.

An example of fillers in slurries are small parts of granulated low density rubber (about 1.2 g/cm^3), grain size 40÷60 granules per inch. This rubber can be used for different class cements (including Portland and borehole cement). Properly ground rubber will adjust to the empty spaces in the hardened cement slurry. Cement mixture can be strengthened by adding polypropylene fibers of 5÷15 mm length to cement. Their application is of great advantage because it reduces cement resistance to compressibility caused by using rubber. Elastic cement mixtures are very expensive in our market and they are sold mainly by companies like: Dowell Schlumberger, Halliburton and BJ Services [3, 5, 6].

The use of elastic cements in sealing the borehole is highly advantageous because of the vast array of factors which may cause stress, which can be the reason for cement coating damage. Generally they can be listed as presented in Table 1.

Protecting the borehole from the above mentioned factors can be done by using elastic cement while sealing the casings.

In Halliburton materials [6] information can be found concerning ElastiCem elastic cement. The ready product offered by this company can be as thick as 0.9÷2.6 g/cm^3, can have appropriately low rheology and filtration – about 15÷100 cm^3/30 minutes. Cement rock after bonding does not shrink and is resistant to compressibility in range of about 500÷5000 psi (3.5÷35 MPa). The Young module for elastic cement rock is from 2×10^6 psi to 0.2×10^6 psi (13.7÷1.37 GPa).

Tablica 1

PROCESS	FACTOR
Cement hydration	Shrinkage
Pressure tests	Pressure
Completion works in the borehole	Pressure and temperature
Hydraulic fracturing	Pressure and temperature
Obtaining hydrocarbon	Pressure and temperature
Pumping the fluid	Pressure and temperature
Ground unrest	Load
Perforation works	Shock wave

Elastic properties of materials

Elastic properties of solid bodies can be described using parameters like the Young module and Poisson's ratio.

The Young module (E) – also known as linear deformation module or elastic modulus – is the quantity which describes the springiness of material. It represents characteristic relationship of relative linear deformation (ε) of material to stress (σ) for every material which appears in it in respect of elastic deformation.

Table 2. Sample values of Young module for materials

Material	Young module [GPa]
Rubber	0.01÷0.10
Polypropylene	1.5÷2.0
Lead	16
Concrete	~ 27
Copper	100÷115
Diamond (C)	1050÷1200

Table 3. Sample values of Poisson's ratio for materials

Material	Poisson's ratio [-]
Rubber	~ 0.50
Copper	0.33
Steel	0.27÷0.30
Concrete	0.20
Glass	0.18÷0.3
Cork	~ 0.00

The unit of the Young module is Pascal, which is N/m^2.

$$E = \sigma / \varepsilon$$

Poisson's ratio (ν) is the relation of crosswise deformation to longitudinal deformation at the axial stress condition. This coefficient is a non-dimensional quantity and does not describe the springiness of material but the way in which it deforms.

If, in case of isotropic material in the examined solid point we distinguish a direction *m* and if in this point only the stress $\sigma m \neq 0$ (and the other stress components equal zero), the Poisson's ratio is:

$$\nu = \varepsilon_n / \varepsilon_m$$

where:
ε – deformation,
n – any direction perpendicular to *m*

Laboratory research

Laboratory research aiming at adjusting elastic cement slurries to high temperatures and deposit pressure was carried out in the Oil and Gas Institute, in Krosno Branch, according to norms: PN-EN 10426-2 *Petroleum and natural gas industry – Cements and materials for well cementing – part 2: Testing the borehole cements* and API SPEC 10. Slurries were prepared with the use of NaCl brine, KCl and also tap water. Liquid latex was included in the compositions.

After cement slurry had been prepared, rheological parameters were marked, thickness and fluidity were estimated. Cement slurry rheology was regulated with the use of plasticizers. Water loss and time of slurry thickening were measured (values 30 Bc and 100 Bc were marked) and also filtration was tested. Elastic parameters were examined, as well as compression resilience, adhesion to pipes and porosity.

In developing the compositions, the researchers were guided by the requirements that the elastic cement slurry should meet to ensure efficient cementing and effective sealing of the casings. Attention was focused mainly on good elastic properties of the hardened cement slurry and on the viscosity which should not be too high. The cement slurry needed to be easily pumped, it should take no more than 24 hours to set and it should have zero water loss [4].

To improve elasticity of the slurry and cement stone, the following additives were used:

- polypropylene fiber about 6 mm long – photograph 1,

Photo. 1. Polypropylene fiber

Photo. 2. Granulated rubber

Photo. 3. CEMPLAST – plasticizing additive

Table 4.
Components of elastic cement slurries (percentage quantities in relation to cement weight)

Cement slurry	Temperature [°C]	Water (ratio w/c)	Defrother	Fluidifier	Anti-filtration additive	Retarder	Swelling additive	Latex	CEMPLAST	NaCl / KCl * (bwow)	Silica powder	Microcement	Cement
z-1	40	0.52	1.0	0.2	0.2	-	0.3	10	10	-	-	20	100
z-2	70	0.52	1.0	0.2	0.2	0.1	0.3	10	10	-	-	20	100
z-3	80	0.54	1.0	0.3	0.2	0.2	0.2	10	10	3*	10	20	100
z-4	90	0.55	0.3	0.4	0.4	0.25	-	-	10	20	-	10	100

Table 5.
Selected test results for elastic cement slurries

Cement slurry	Temperature [°C]	Density [kg/m³]	Water loss [%]	Plastic viscosity [mPa · s]	Flow limit [Pa]	Filtration [cm³/30 min.]	Time of thickening [h : min] 30 Bc i 100 Bc
z-1	40	1790	0.0	106.5	5.5	8	30 Bc: 3 : 05 100 Bc: 3 : 22
z-2	70	1790	0.0	121.5	3.6	24	30 Bc: 2 : 37 100 Bc: 3 : 11
z-3	80	1830	0.0	103.5	7.0	10	30 Bc: 3 : 50 100 Bc: 4 : 15
z-4	90	1880	0.0	57.0	2.9	203	30 Bc: 4 : 24 100 Bc: 4 : 55

Table 6.
Selected test results for elastic cement stones

Cement slurry	Temperature [°C]	Resistance to pressing after 2 days [MPa]	Resistance to pressing after 28 days [MPa]	Adhesion to steel pipes after 28 days [MPa]	Young module after 90 days [GPa]	Poisson's ratio after 90 days [-]	General porosity after 28 days [%]
z-1	40	11.2	16.5	4.5	9.9	0.33	31.6
z-2	70	13.1	22.3	5.4	10.2	0.32	30.6
z-3	80	15.9	23.1	6.1	10.4	0.34	29.5
z-4	90	20.4	26.3	6.2	9.6	0.33	28.6

Photo. 4a. Cement stone with fiber and granulated rubber (annular space fragment)

Photo. 4b. Cement stone with fiber and granulated rubber (girder fragment)

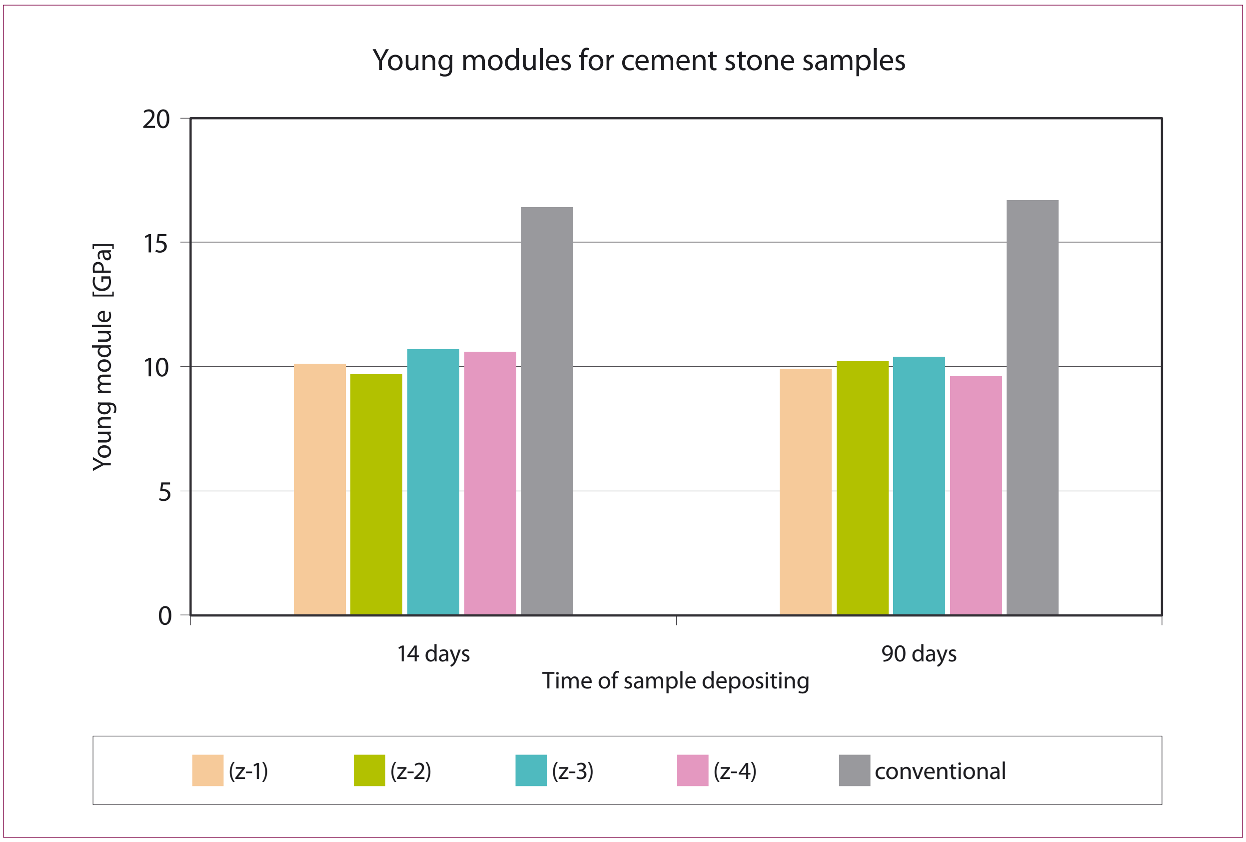

Fig. 1. Young module values for four elastic cement slurries and for "conventional" slurry

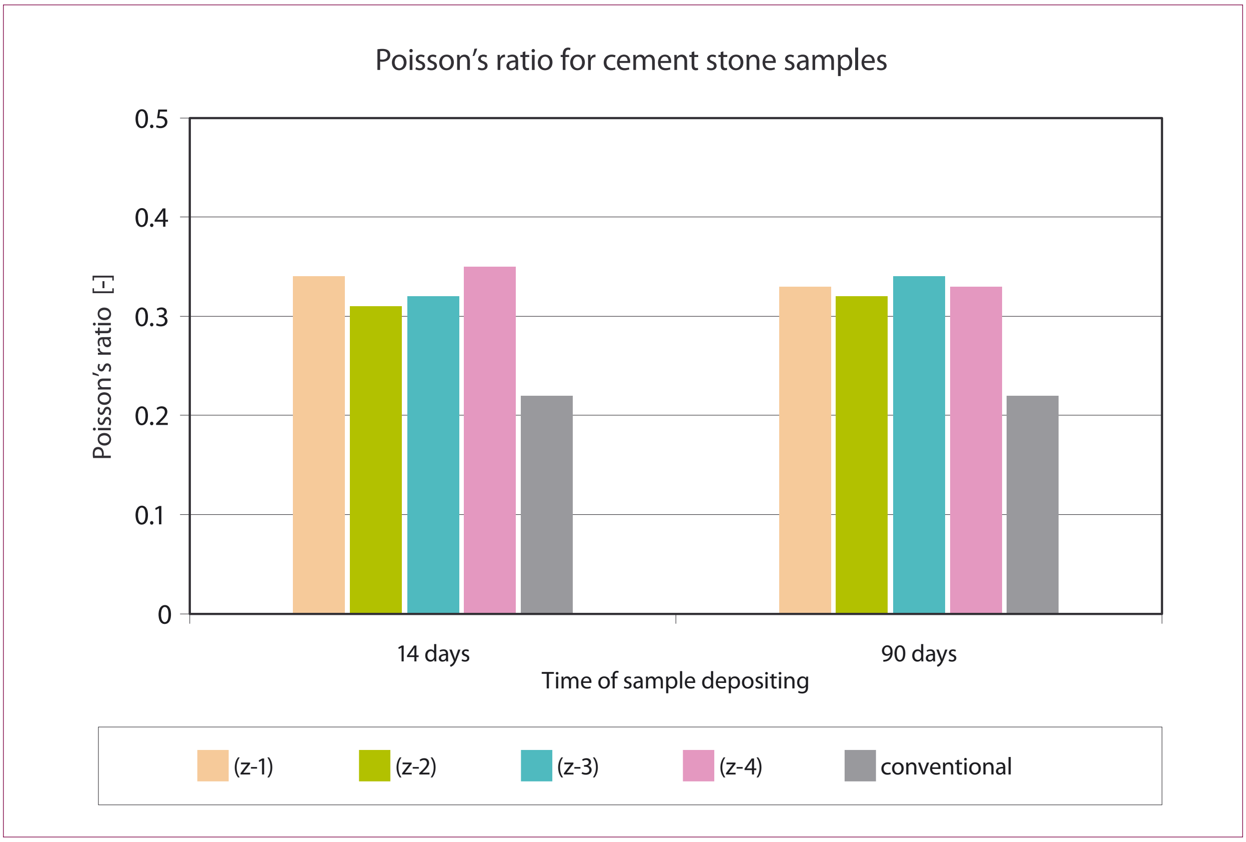

Fig. 2. Poisson's ratio values for four elastic cement slurries and for "conventional" slurry

- granulated rubber with grains the size from 0.01 to 1 mm (there were no more than 20% grains bigger than 0.5 mm) – photograph 2.

In the Oil and Gas Institute, different proportions of the above mentioned additives were tested to improve elasticity of the cement stone. A mixture of rubber and fiber additives and the filler were added to the dry cement.

As a result of laboratory tests, a plasticizing additive – CEMPLAST was invented which is now produced by the Polish Drilling Fluids Service (PSPW) on the basis of licence agreement between the Oil and Gas Institute and PSPW. It is used to improve the cement stone elasticity. It is a mixture of granulated rubber and polypropylene fiber with addition of the filler (photograph 3).

Based on the laboratory research, general compositions of elastic cement slurries were selected as suggestions for use in industry. Tables 4, 5 and 6 show basic components and test results for the slurries and cements stones.

Photographs 4a and 4b show elastic cement stones after testing the stone adhesion to steel pipe and resistance to pressing. Figure 1 and 2 present research results of the Young module and Poisson's ratio for elastic cement slurries and "conventional" slurry.

Summary

In the Oil and Gas Institute, compositions for elastic slurries and sealing stones were developed for dynamic temperatures up to 90°C and pressure to 60 MPa. These compositions were made with the use of NaCl brine with various saturation, 3% KCl and tap water. Technological parameters (i.e. rheology, time of thickening, filtration and other) of cement slurries can be regulated with additives commonly used in domestic drilling. It is possible to obtain elastic cement slurry by adding granulated rubber and polypropylene fiber to its composition.

Elastic additive created in the Oil and Gas Institute is produced by the Polish Drilling Fluids Service on the basis of licence agreement. Time of thickening of elastic cement slurries, depending on the borehole conditions, is about 2.5 to 5 hours, which enables efficient cementing. The Young module and Poisson's ratio for elastic cement slurries equal approximately to 10 GPa and Poisson's ratio – about 0.32÷0.35. In comparison with "conventional" slurry (in which the Young module exceeds 16 GPa and Poisson's ratio equals about 0.22), it can be stated that the compositions elaborated in the Oil and Gas Institute have an improved elasticity.

Slurries with elastic additive were successfully used in the national industry in cementing the casing of diameter 24" in the D-1 borehole and in cementing 7" pipes in the B-19 N borehole.

The authors are researchers in the Oil and Gas Institute

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