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The Polish Petroleum and Natural Gas Market

2014

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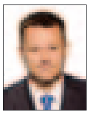

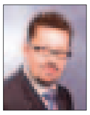

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PBT 4%
CAGR (04 – 08)
Revenue 20%
PBT 15%
£ million
Income
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BGI/BlackRock deal costs
893
336
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1,665
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06
1,926
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1,844
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08
987
265
H1 08
963
382
276
106
H1 09
1,142
04
1,431
05
2216
06
2335
07
Total income

WICEPREZES RADY MINISTRÓW
MINISTER GOSPODARKI
Janusz Piechociński

Introduction by Deputy Prime Minister Janusz Piechociński, Minister for Economy, for the yearbook "The Polish Petroleum and Natural Gas Market" issued by the Oil and Gas Institute

Warsaw, 04 August, 2014

Janusz Piechociński – Deputy Prime Minister, Minister for Economy

Dear Sir/Madam,

I am really pleased that I can recommend you another edition of the yearbook "The Polish Petroleum and Natural Gas Market". The Oil and Gas Institute – National Research Institute takes up the most interesting issues for the petroleum and gas sector in a comprehensive way, which makes it a perfect supplement and systemization of our knowledge in these areas.

At present, the energy sector is fundamental for the economy and it makes the basis for operation of all the branches of industry. One of the greatest challenges that contemporary world is facing is to ensure energy security, understood as providing stable supplies of energy sources, independent from political pressure.

Great significance for the operation of petroleum sector in Poland and, by the same, for stability in respect of supplying the national market with petroleum and fuels has an amendment to the act on the reserves of oil and petroleum products of 30 May, 2014. As a result of the act, the obligation of creating and maintaining the oil and fuel reserves will now be shared by the entrepreneurs and a public entity (Material Reserves Agency). The amendment to the act will also allow to combat the grey zone on the liquid fuel market. The general goal of the introduced changes is to control the illegal trade in liquid fuel in Poland.

In order to increase the energy security of Poland, all the time, investment works are conducted in the gas sector. The construction of gas pipelines and expansion of natural gas storage reservoirs will contribute to increased energy independence of Poland which is becoming the regional leader in this respect.

"The Polish Oil and Natural Gas Market" is an interesting suggestion not only for experts in the power industry but also for all the people who wish to broaden their knowledge on widely understood sector of oil and gas. I warmly invite you all to read this year`s edition.

Janusz Piechociński
Deputy Prime Minister, Minister for Economy


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The Economy of Oil and Gas

Geopolitics of hydrocarbons

The impact of global trends on domestic manufacturers

Tomasz Baranczyk, Wojciech Słowinski, Jacek Ciborski, Grzegorz Kus, Maciej Chyz, Maciej Szumieluk

What is the impact of transformation of the global oil and gas market on the Polish oil and gas and chemical sectors? The impetus for change on domestic market are, among other things, external political events, such as the tense political situation in Ukraine caused by the armed conflict which makes the European Union much more focused on the need for independence of the Community states from energy supplies from the eastern direction.

In this context, over the past few months, many ideas and declarations have arisen concerning the possibility of diversification of gas supplies to Europe, which is crucial for energy security of the EU states and operation of their economies. Poland has proposed joint purchases of natural gas by the member states of the European Union. Spaniards propose wider use of regasification terminals by other member states.

Across the Atlantic, the United States declared the opening of their market for liquefied natural gas exports, and other terminals obtain permission for export of liquefied natural gas to the so-called non-FTA countries, which includes the countries of the European Union – as of 11 June 2014, there were seven such permits for export of up to 96 billion m^3 of gas per year. In this context, it is worth analyzing the real possibilities of diversification of the sources of gas and oil supplies to Europe, taking into account the potential and expansion plans for the European and Polish infrastructure.

The data reported in this article take into account the legal and factual status as of 31 July, 2014.

According to the EIA data of 2013, Gazprom, the Russian monopolist in the export of gas, supplied about 154 billion m^3 of gas to the EU countries. Currently, the regasification capacity of LNG terminals in Europe amounts to around 185 billion m^3 of gas and there is another 29 billion m^3 in construction. At the same time, according to Eurogas, in 2013, the actual use of the regasification capacity amounted to about 47 billion m^3 of gas.

Unexploited potential

Currently, the regasification capacity of LNG terminals in Europe amounts to around 185 billion m^3 of gas (excluding small-scale LNG terminals and terminals in Turkey) and another 29 billion m^3 in construction (without terminals in the Canary Islands, located outside the European transmission network). At the same time, according to Eurogas, in 2013, the actual use of the regasification capacity amounted to about 47 billion m^3 of gas. Therefore, unexploited regasification potential amounts to approximately 138 billion m^3 of gas per year.

According to the EIA data of 2013, Gazprom, the Russian monopolist in the export of gas, supplied about 154 billion m^3 of gas to the EU countries, whereas the total consumption in the EU amounted to 462 billion m^3. Theoretically, there is a real possibility of replacing the eastern sources of supplies with gas from the LNG terminals.

Required large investments in infrastructure

The existing LNG capacity in Europe is just one side of the coin. In practice, the reorientation of the direction of gas supplies for entire Europe would require billions of euros for investments in the expansion of the existing infrastructure. For example, the current regasification capacity of terminals in the Iberian Peninsula is about 68 billion m^3. With the annual demand of Spain and Portugal for gas (about 38 billion m^3 in 2013, of which domestic production provided only 1.1 billion m^3), this means about 30 billion m^3 which could be sent across France to other European countries by means of interconnections. Meanwhile, the current capacity of interconnectors is only 5.2 billion m^3. Another problem is the price competitiveness of gas supplied in this way. The impact of the American LNG terminals exporting gas from shale deposits on global LNG prices is currently difficult to estimate and, if it occurs, it will certainly be shifted in time. The first terminal condensing gas in the United States is to be launched only as late as in 2016.

In addition, it should be noted that export of relatively cheap gas from North America to European markets would not be in line with the interests of the U.S. economy. In particular, it affects the area of chemical and petrochemical industry as well as refineries in the American continent. These sectors, thanks to cheap raw material base, are experiencing a kind of renaissance. According to the American Chemistry Council, the American chemical industry's investment outlays in the years 2011, 2012 and 2013 grew respectively by 14.9%, 16.9% and 10%, reaching 42.4 billion dollars. By the year 2018, investments are to reach the level of 61.2 billion dollars (twice as much as in 2010). At the same time, in 2011, a trend existing for many years was permanently broken and the U.S. became a net exporter of petrochemical products. Therefore, first of all, we should expect LNG sales by Americans to regions characterized by high costs of natural gas (Asia and South America), and only then to Europe.

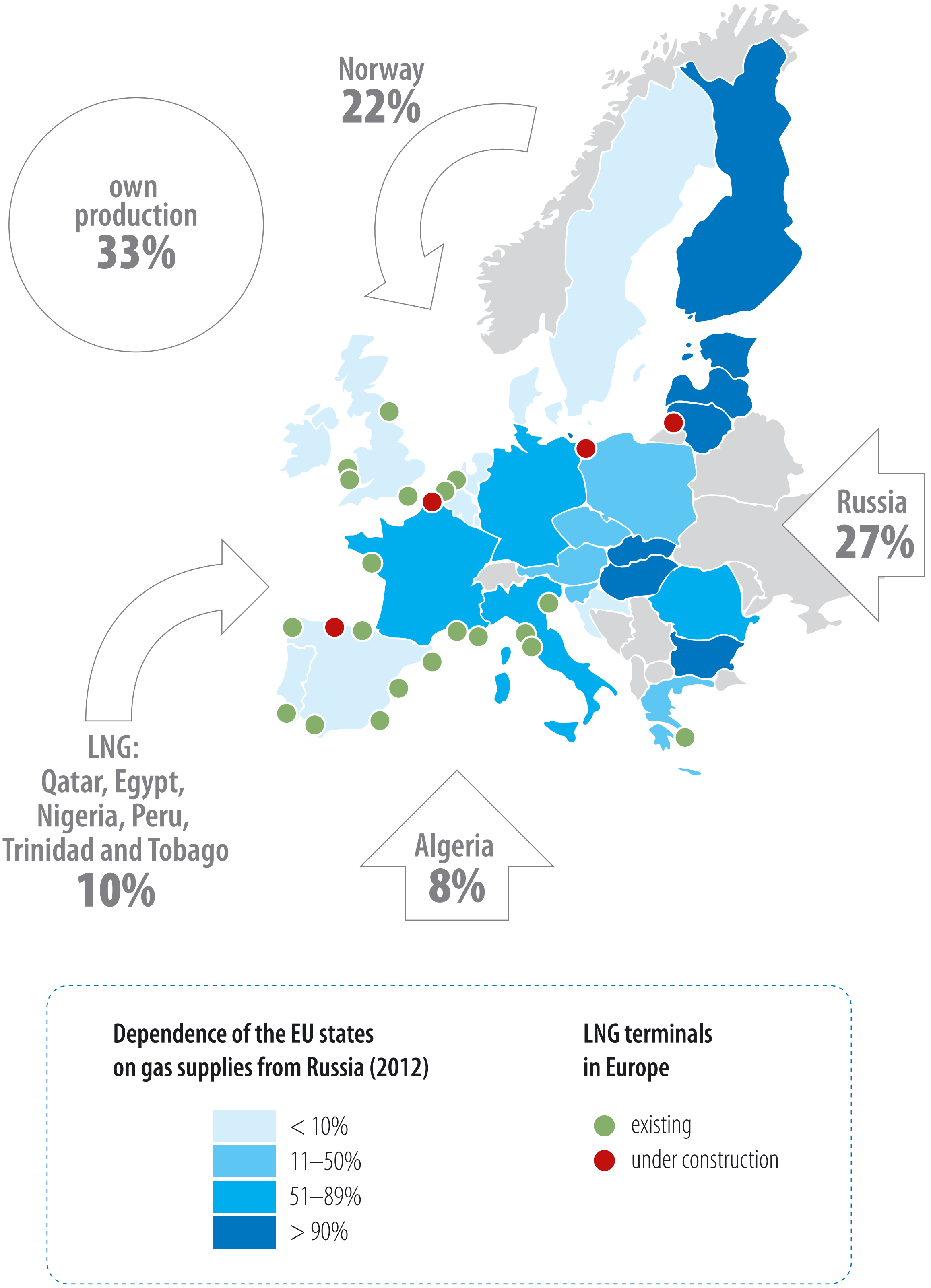


Fig. 1. Sources of gas supplies to the European Union. *Source: Compiled by PwC on the basis of Eurogas 2013, Gas Infrastructure Europe, ENI World Oil, Gas Review 2013*

Table 1. Operating LNG terminals in Europe

Location	Country	Regasification capacities [billion m^3]
Milford Haven (South Hook LNG)	Great Britain	21
Isle of Grain	Great Britain	19.5
Barcelona	Spain	17.1
Rotterdam	The Netherlands	12
Huelva	Spain	11.8
Cartagena	Spain	11.8
Montoir de Bretagne	France	10
Zeebrugge	Belgium	9
Sagunto	Spain	8.8
Fos Cavaou	France	8.25
Sines	Portugal	7.9
Porto Levante	Italy	7.56
Bilbao	Spain	7
Milford Haven (Dragon LNG)	Great Britain	7.6
Fos Tonkin	France	5.5
Revithoussa	Greece	5.3
Teesside	Great Britain	4.2
Toscana Offshore	Italy	3.75
Mugardos	Spain	3.6
Panigaglia	Italy	3.4
	TOTAL	**185.06**

Source: PwC analysis based on Gas Infrastructure Europe

Table 2. European LNG terminals under construction

Location	Country	Regasification capacities [billion m^3]
Dunkirk	France	13
Gijon (Musel)	Spain	7
Swinoujscie	Poland	5
Klaipeda	Lithuania	4
	TOTAL	**29**

Source: PwC analysis based on Gas Infrastructure Europe

Unconventional opportunity?

With this in mind, and given the relatively low level of development of the gas system in East Central Europe, it seems that Russia will for long remain a major supplier of natural gas in the region. Regardless of the direction of the supply, both the gas flowing to Poland from Germany and from the south of the continent, it is and will be mostly of Russian origin. For this reason, more and more attention in the European Union is being devoted to the search for alternative sources of energy as the only viable option to reduce dependence on supplies of hydrocarbons from Russia. The proposals under consideration include promoting the search for unconventional natural gas and crude oil.

Increased interest on the part of investors in hydrocarbons from unconventional sources appeared in Poland after publishing the Advanced Research International for the Energy Information Administration, estimating recoverable gas reserves from shale formations in Poland at 5.3 trillion m^3 (as of April 2011, the first wells were made a little earlier – in 2010). From that time, until the end of June 2014, 64 exploration wells were made in Poland and a total of 26 fracking treatments of varying scope were conducted. The Polish Exploration and Production Industry Organization estimates that the current total sum of capital expenditure of companies related to exploration of shale gas is greater than PLN 2 billion.

> The reasons for the slow pace of exploration work can be seen, e.g. in the absence of clear vision and resulting from it concrete proposal of regulatory environment in support of the business – both nationally and in the European Union.

In terms of the number of wells made on the Old Continent and aimed at the study of gas resources from unconventional reserves, Poland remains the undisputed leader. However, comparing the number of wells performed in Poland in order to confirm the potential of unconventional deposits to the number of wells drilled in the same period of the initial stage of identification of the resources in the Marcellus field in the U.S., undoubtedly – the number of fracking treatments performed is insufficient to confirm the reserves, not to mention the evaluation of their potential for commercial development. Moreover, the pace of current and planned drilling work is falling. This reduces the chances of accurate documentation of the reserves in the prospect of the next few years. According to current plans submitted by concession holding operators, 342 exploratory wells are planned by the year 2021, but only 85 of them are mandatory, while the remaining 257 may be performed as an option.

Will the new regulatory environment increase hydrocarbon extraction?

The reasons for the slow pace of exploration work can be seen, e.g. in the absence of a clear vision and resulting from it a concrete proposal of the regulatory environment in supporting the business – both nationally and in the European Union. As a result, some investors decided against continuation of the work and the number of granted exploration licenses in Poland fell from the record 115 in 2012 to 76 in early July 2014.

The withdrawal of several large investors from the market, as well as exacerbation of the political situation in eastern Europe associated with the Crimean conflict, resulted in the acceleration of the pace of work on the regulation of the legal environment, the lack of which introduced great uncertainty concerning the investment plans of the license operators. The result of this acceleration in the recent months has been submission of a package of laws to the Parliament by the government, relating to regulation of hydrocarbon production which, according to the intentions of the government, is to speed up the exploration of shale gas and bring new investors to Poland.

On July 11, 2014 the Parliament adopted amendments submitted by the Senate to amend the Geological and Mining Law Act. The amended law, after being signed by the President, shall come into force in January 2015. On 27 July, the Sejm passed the law on special hydrocarbon tax which may determine the attractiveness of investment in the shale gas business. The proposed fiscal arrangements lived to see fundamental change involving postponing the effectiveness of the Act on the special hydrocarbon tax to 1 January 2016.

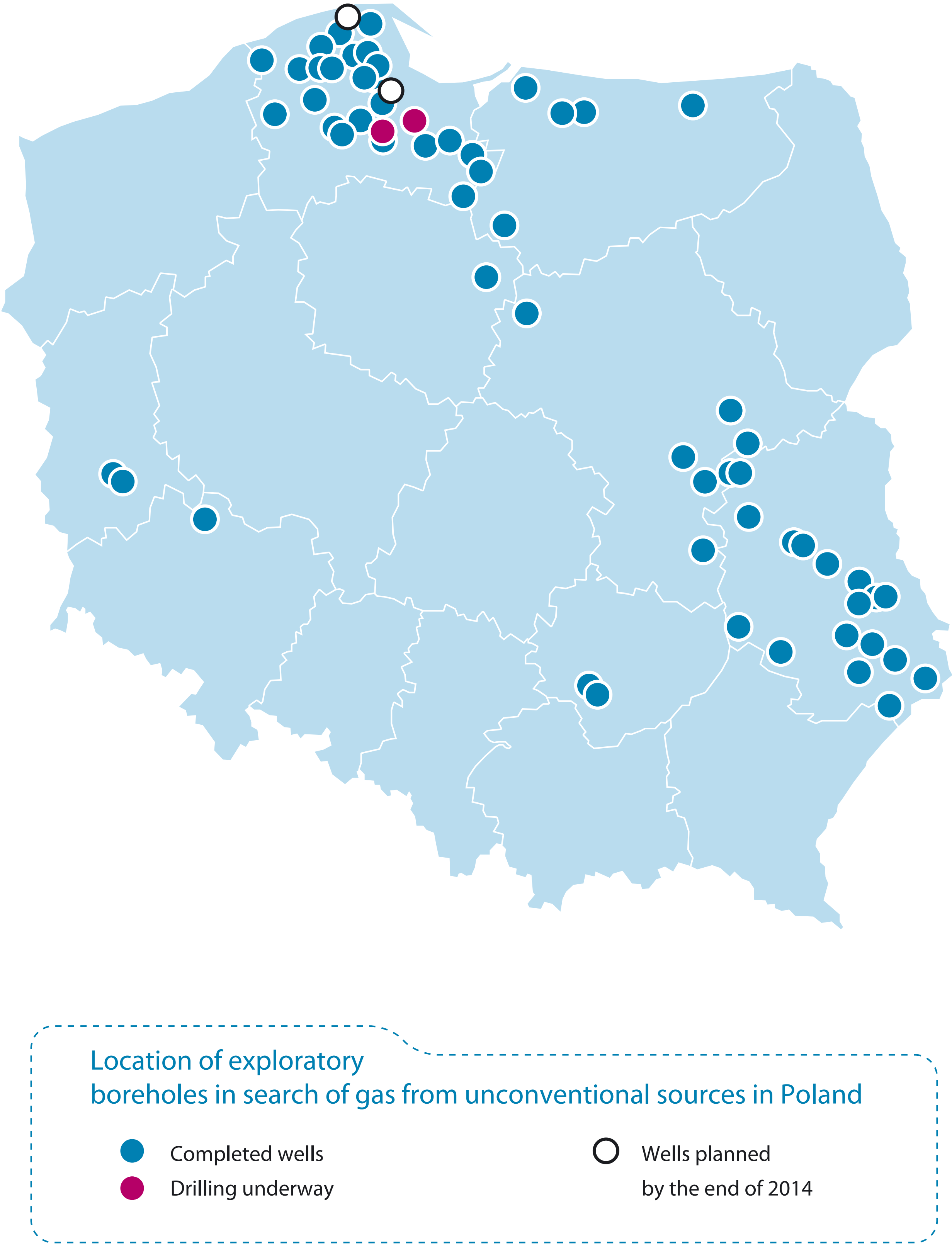


Fig. 2. Location of exploratory boreholes in search of gas from unconventional sources in Poland. *Source: PwC, based on data from the Ministry of Environment of 30 June, 2014*

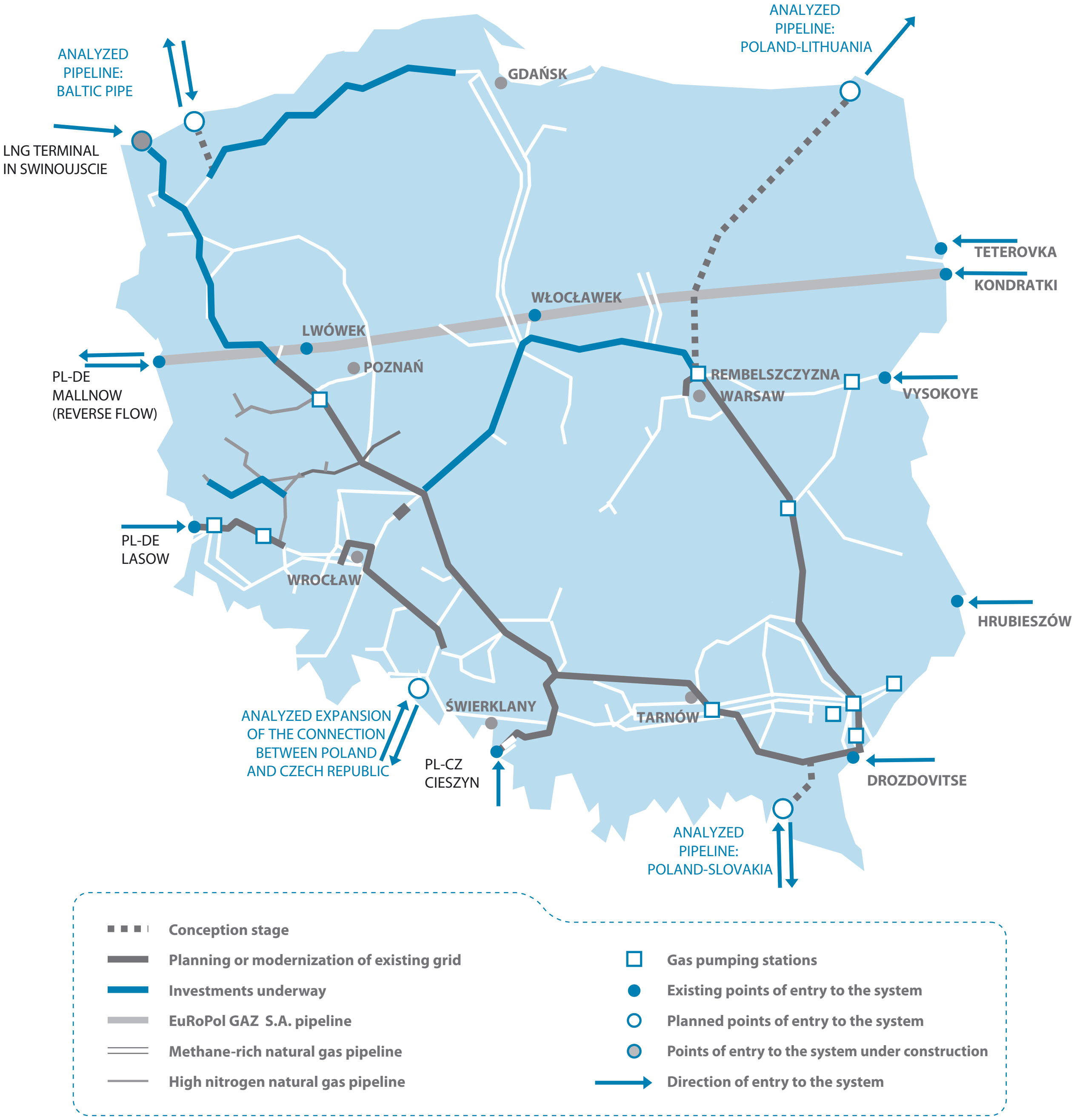


Fig. 3. The map of gas inter-system connections in Poland. *Compiled by PwC, based on Gaz-System data*

Geological and mining law: a new quality or insignificant refreshment?

The oil and gas industry has received changes in the geological and mining law with a very moderate enthusiasm. Thorough reconstruction of the license system provided for in the amendment, involving the introduction of a single exploration-identification-extraction license and developing the licensing procedure for prequalification of applicant entities are not critical to the pace of exploration work under the existing licenses.

For the current exploration and identification license holders transitional provisions concerning priority of licensing are most important, because they guarantee the award of extraction license without having to organize tenders. According to the Act, they retain precedence for three years of receipt of the decision approving the geological documentation of the deposit – if it took place after the date of enforcing the amended Act, or five years – if such a decision was received before that date.

One of the concerns of the industry were legal impediments to the conduct of joint ventures, which resulted from a failure to grant joint licenses to several entrepreneurs and the inability to divide the mining usufruct between them. The joint operations agreement introduced by the amendment solves the aforementioned problems by providing a possibility to obtain a joint license by a number of entrepreneurs at the same time, if they enter into such an agreement. Nevertheless, quite rigid parameters of the agreement set at the statutory level (e.g. at least 50% share in the cost for the operator, the obligation to keep separate accounts, or additional preparation of financial statements) may hinder the practical application of this instrument.

(Not) encouraging taxes?

According to the Ministry of Finance, the current level of resource rent in Poland on extracting hydrocarbons is approximately 21% of gross profit. A law on special hydrocarbon tax will introduce two additional burdens: a special hydrocarbon tax and a tax on mineral extraction regarding crude oil and natural gas. The Ministry predicts an increase in the resource rent to approximately 40% of gross profit when it comes into effect in 2020.

The Ministry of Finance expresses the opinion that new taxes will encourage entrepreneurs to invest in Poland because despite the increase in the total number of burdens, the Polish system is to be one of the most competitive in Europe. Meanwhile, assuming the calculation of the Ministry of Finance to be correct, increase in the total burden on companies extracting oil and natural gas will reach almost 100%. Moreover, all the time, there are many uncertainties about the actual amount of the resource rent. In the assessment of operators, it may be at the level of 60% to as much as 130% of gross profit. It seems that such large discrepancies are mainly due to a different method of calculation adopted by the Ministry of Finance, not taking into account discounting of costs over time.

In the issue of investment incentives or tax relief incentives aimed at increasing the scale of search and ultimately – exploitation, the law on special hydrocarbon tax should be amended. For example, a mechanism can be introduced for discounting or indexation of costs taking into account the impact of inflation, waiver of taxes on certain fossils, introduction of a broader catalog of preferential rates and exemptions for unconventional and marginal deposits or mechanisms that reduce the level of taxation in the case of certain funds being invested in Poland.

Strategic or missed opportunity?

The current situation in the exploration sector – as it seems – is derived from the long-term regulatory uncertainty and lack of clear and motivating incentives for investment.

The new legal environment for the production of hydrocarbons solves several problems hindering the pace of exploration work, and in the taxation part, it gives a few years of "tax holiday", which, however, will cover mainly the entities currently conducting production from domestic fields. So far, none of those searching for shale gas has declared the start of industrial-scale production by 2020.

At the same time, intensification of the search may be discouraged by the proposed mechanism of calculating taxes based on the stock market reference prices of hydrocarbons, and not the actual sales price of raw materials, since the amount of taxes in certain situations will be unrealistic with reference to the real profits from extraction.

The issue of extraction of hydrocarbons from unconventional sources, since the publication of the report of the Energy Information Agency, for the recent three years at least has been one of the main themes of debate on the Polish energy security. Unfortunately, this debate was not followed by concrete solutions which would stimulate the development of the sector, and the proposed design of the regulatory system does not seem to create in our country conditions for a significant increase in the level of production in the next few years. In comparison to those European countries that are either skeptical about gas exploration and extraction from shale formations (France, Germany, the Netherlands), or where investors face great opposition to investment (Romania, Bulgaria, Lithuania) – Poland is the leader. However, looking from a global perspective, Poland is still at a preliminary stage of development, exploration and production in this sector. It may easily lose attractiveness in the eyes of investors in favor of such countries as Argentina (over 160 wells in search of hydrocarbons from unconventional deposits so far) and China (more than 30 wells so far; plans of the Chinese government include achieving the level of production of 6.5 billion m^3 from unconventional deposits already in 2015).

Better infrastructure – greater independence

The distant and uncertain perspective of gas production from new sources, a stable level of domestic production and the possible increase in demand of the Polish economy for natural gas will result in growing dependence of Poland on imports of the so-called blue fuel. In 2013, over 72% of the supply of gas to the domestic market was imported, of which over 77% from Russia. Our country's dependence on natural gas supplies from the east is derived from historical circumstances and adaptation of the national network to transportation of gas from the south-east into the country. Quite recently, Poland had only one interconnection – in Lasow, enabling the supply of gas (about 1 billion m^3 per year) from alternative directions.

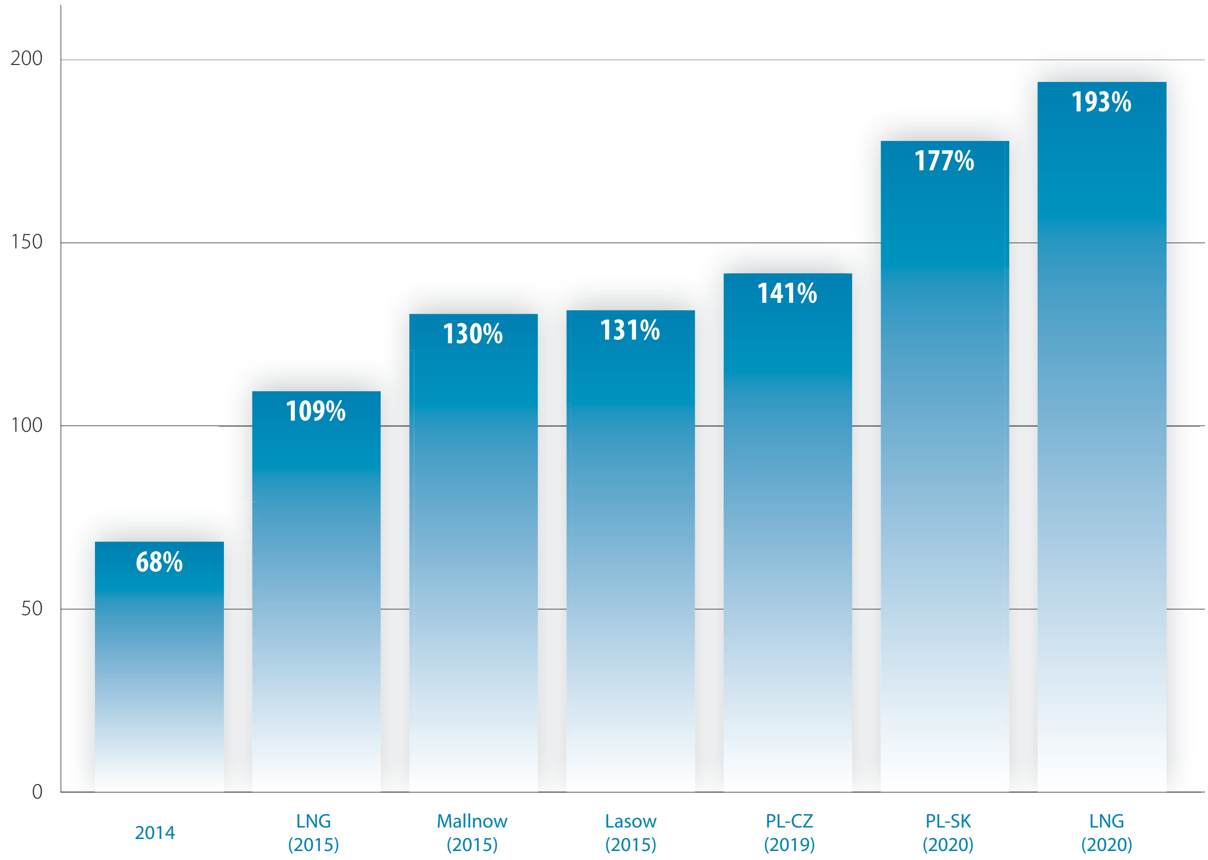
The lack of possibilities of supplies from other directions than eastern was considered to be one of the main risks for efficient operation of the economy. The solution adopted by Poland was expansion of the interconnections with the EU countries. However, in the recent years, investments in gas infrastructure in Poland gained significant acceleration. The

Table 3. Alternative sources of natural gas supplies to Poland

Location	Collection from	Current capacity [bcm]	Target capacity [bcm]	Year of completion
Swinoujscie LNG	Global	0	5.0 (7.5)	2015 (2020)
Mallnow (physical reverse)	Germany	5.5	7	2015
Lasow	Germany	1.5	1.6	2015
PL-CZ	Czech Republic	0.5	7	2019
PL-SK	Slovakia	0	5.8	2020

Source: PwC on the basis of public information

Index of covering import demands for natural gas, based on alternative sources



Source: PwC, based on public information

result is the launch of a new connection with the Czech Republic (September 2011) and the expansion of the node in Lasow (January 2012) – each of them provides the possibility of importing additional 0.5 billion m^3 of gas per year.

The real change in the market, however, was the launch of the initially virtual (November 2011), and now also physical reverse on the Yamal Pipeline (April 2014). In the event the exports from the east are withheld, the changes allow the security of supply at around 5.5 billion m^3, and after the extension of entry points – even 7 billion m^3 of gas per year. Completion of the LNG regasification terminal in Swinoujscie will allow to import an additional 5 billion m^3 of gas from other directions, with an option of increasing the capacity to 7.5 billion m^3 in 2020. Implementation of these investments will limit the Polish dependence on natural gas supplies from Russia and give alternative supplies in crisis. The scale of this alternative is well seen in a simple comparison: in the period 2007–2013, imports from the east amounted to an average of 8.9 billion m^3 of gas per year. So, the terminal at opening will initially offer delivery from a non-dominant direction at the level of over 60%, and ultimately more than 80% of gas from the leading supplier. In addition, the situation in terms of opportunities for diversification of supplies will be improved thanks to investment associated with the construction of the North-South corridor (interconnections with the Czech Republic and Slovakia). By the year 2020, if the planned investments are realized, the replacement of imported gas from dominating direction will be almost 200%, which is shown on the diagram below (the data do not comprise the planned pipeline Bernau-Szczecin).

Security of oil supplies

Security of oil supplies and prices of raw materials are the key factors in the development of industry. In the case of the chemical industry natural gas is one of the main raw materials. For this reason, any actions aimed at increasing the degree of independence from suppliers, as well as those affecting the price of raw materials are crucial for the development of the sector and its competitiveness.

In this context, the situation of Polish refineries and petrochemical industry is slightly different, for them the basic raw materials are, respectively, crude oil and refined products (LPG and naphtha). Despite the dominant share of crude oil imported from Russia (more than 93% of Polish imports in 2013), thanks to its maritime infrastructure, Poland is a participant in the global market for this material. Naftoport transshipment terminal allows to secure gas supplies to the country from other directions than the east, and the level of mandatory reserves is sufficient to ensure the continuity of production.

In 2013, the Polish Oil and Gas Company [PGNiG] with the opening of their modern Lubiatow-Miedzychod-Grotow fields produced a record 1.1 million tons of oil (compared to about 0.5 million tons in 2012). Domestic crude oil processed in 2013 amounted to 24.3 million tons. Domestic production meets the needs of Polish refineries in little over a week, but it is worth to appreciate the development potential of domestic reserves, as a form of supplementing the oil imports.

On the other hand, the construction of an oil terminal in Gdansk launched in March 2014 by the PERN "Przyjazn" company, with bases eventually able to accommodate 700 thousand m^3 of oil, fuel and chemicals, can create additional opportunities for the development of national and regional market – while increasing the ability to protect stocks of raw materials for the Polish market and becoming a logistics liaison with the European and global market. It is evidenced by the fact of signing in April by the PERN "Przyjazn" company a long-term oil supply agreement with the Italian oil company Eni Trading & Shipping SpA, previously absent in the Polish market.

The construction of the Gdansk terminal is part of a wider policy of expansion and modernization of the national oil and gas infrastructure. It is, on the one hand, a response to the challenges of energy security and, on the other hand, it increases the flexibility of national entities in the rapidly changing global petrochemical market, significantly affected by the so-called "shale revolution" in the United States.

The American market has the largest share in the consumption of oil in the world (20% in 2013, according to the BP data). The United States is also the third largest oil producer following Saudi Arabia and Russia. In 2013, own production in the U.S., for the first time since 1995, exceeded imports. At the same time, the increase in production in 2013 by 15.3% to 7.5 million barrels per day was the highest since 1940. And all that thanks to crude oil accumulated in layers of shale, extraction from the Bakken and Eagle Ford fields underlies the increase in production. According to forecasts by the Energy Information Administration, production in the U.S. in 2014 will rise even to the level of about 8.3 million barrels per day, and over the next few years will continue to be growing rapidly, which may have an impact on larger supplies of petroleum products to the European market. At the same time, thanks to access to cheap raw materials, the U.S. petrochemical industry and chemical industry today is experiencing a period of rapid development, which is for European companies in this sector an enormous challenge in maintaining markets for its products in competition with supplies from the United States.

Petrochemistry as an opportunity for the development of chemical sector in Poland

For the chemical industry, absorbent, fast growing domestic demand for petrochemicals and their derivatives is the reason for the development of the national resource base. It would enable the improvement of competitiveness of the current production and further extended value chains of Polish companies in the oil, gas and chemical industries. Extending the portfolio by attractive specialty products requires increased outlays in research and development.

Products of the petrochemical sector are mainly used in all economic sectors, being simultaneously present in all households in Poland. The increase in consumption of chemicals and plastics, manufactured on the basis of olefins and aromatics produced in petrochemical complexes, is highly correlated with the rate of economic growth. It is expected that Polish economy will gradually catch up in this regard with Western European countries, which in turn will mean that, in future years, the demand for the products of the petrochemical sector in our country will grow dynamically.

The current consumption of petrochemical products per capita in Poland is significantly lower, as compared to Western European countries. The level of consumption in such countries as Germany, France and the Netherlands is on average 2.5 to 3-fold higher. This factor reflects the potential for further development of the market and shows its future absorption capacity.

In Poland, there is now one petrochemical complex, in Plock, controlled by PKN ORLEN. The raw material base manufactured there for the petrochemical sector is then partially processed by the ORLEN Group. However, a number of other entities, consuming significant volumes of imported propylene, benzene and butadiene, operate in the market, they include: the Azoty Group, Synthos and PCC Rokita.

The growth in demand for chemicals and plastics that has taken place in the recent years, however, has not been accompanied by adequate development of the national resource base. This resulted in a significant deficit in foreign trade. According to the CSO data, in 2013 alone, the deficit increased by PLN 0.5 billion, reaching the level of PLN 17.2 billion. The high level of dependency on imported feed refers both to semi-finished products (e.g., propylene or butadiene) and products (e.g., polyethylene and polypropylene). Lack of investment leading to the expansion of domestic production facilities – in the face of growing demand for chemicals and plastics in Poland – will further deepen the deficit in foreign trade.

Internal market, characterized by high and rapidly rising demand – largely covered with imported articles – is a great opportunity for the Polish companies. Its use, however, requires investment in new production capacity and construction of installa-

tions producing semi-finished products for further processing.

Raw material as the basis for the development of petrochemical sector

The basic raw materials in the petrochemical sector are derivatives of crude oil and those related to natural gas extraction. Geographical disparities between prices of raw materials are the main factor which determines the concentration of petrochemical production in the area. Historically, the Middle East was the region characterized by high availability of hydrocarbons, cheap in exploitation. Therefore, it is this region of the world that was called the future of the petrochemical industry.

Despite the significant increase in oil production in Poland in 2013, the internal production still covers a minor part of the demand of domestic refineries. The lack of own significant oil reserves, however, is compensated by high efficiency of Polish refineries being beneficiaries of the Urals-Brent price difference. This leads to a situation in which, despite the absence of their own oil, domestic refineries are able to offer for the market competitive derivative products, such as naphtha or LPG. These, in turn, are the primary feed raw material in the petrochemical industry.

Analysis of the Polish trade balance clearly indicates that despite the surplus of naphtha, our country is a net importer of produced olefins which are the basic feed raw material for further processing, for example to produce plastics. What is more, insufficient domestic production of ethylene, propylene and butadiene, inhibits the development of the entire chemical sector.

While oil is sold on an open, highly competitive market, the access to olefins is limited. Polish chemical companies are therefore forced to import them, thereby making themselves dependent on external entities and price fluctuations on international markets. Basing the investment on imported feed raw materials, in turn, makes it difficult to extend value chains and expand the portfolio of innovative specialist products.

Revolution of obtaining gas from shale formations taking place in the United States has changed the global balance of power. The spread of the use of hydraulic fracking resulted in a significant increase in the U.S. natural gas production. Along with it, production of heavier fractions increased: ethane, propane and butane. Large availability of raw materials, with simultaneous export restrictions, resulted in decline in their prices. Unexpectedly for all, the United States has become one of the most attractive regions in the world for petrochemical production location, due to the availability of cheap raw material.

The increase in supply and decrease in prices of hydrocarbons from unconventional sources have increased the profitability of the operation of the U.S. refineries which was converted to an increase in production capacity of gasoline – so far imported, e.g. from Poland. In the long term, it could mean loss in the market for naphtha manufactured at LOTOS Group, currently sold as an intermediate product for further processing. As a result, it is necessary to take steps to use the own surplus of material. The most obvious is its use as input raw material in petrochemical installations.

Cheap raw material is one thing. Development requires innovation

As the example of BASF activities in the German market shows, even the lack of access to cheap, domestic raw materials can be compensated by simultaneous closeness of a receptive market and being present in segments of specialized and innovative products, characterized by above-average margins. Introducing a new product on the market, however, involves big expenses for research and development, which is a long-term investment and not giving a guaranteed payback. The example of BASF may be inspiring, their global expenditure on research and development in 2012 amounted to about € 1.7 billion. In the same period, the total expenditure in this area in Poland amounted to about € 3.5 billion.

Investment in research and development which allow to create new, specialized products and go down into the depths of the value chain, e.g. through the creation of specialized research centers, are becoming increasingly important for the Polish companies. This direction allows to move away from the production of bulk products – low margin by nature. The forerunner in this field is Synthos company which intensively expands their own R&D center.

Expansion of production capacity, for example caprolactam in China, today makes the Azoty Group process this raw material into a more advanced form – polyamide 6. It can be expected that the current trend for existing customers to become independent from imports will continue, and hence – Polish chemical companies exporting their products will have to be even more competitive.

Adopting bold development activities would not only allow Polish companies to expand into new markets, but also allow them to retain the current international competitiveness in the domestic market and defend the national one. In the face of intensively growing production capacity in developing countries that slowly become producers of advanced products, once being suppliers of raw materials, the pressure on efficiency continues to grow.

> According to the EIA data of 2013, Gazprom, the Russian monopolist in the export of gas, supplied about 154 billion m^3 of gas to the EU countries, whereas the total consumption in the EU amounted to 462 billion m^3.

The experience of Western European countries, however, shows that even in spite of the difficult regulatory environment, lack of own energy resources and high cost of energy, it is possible to remain competitive. By accessing and knowing the local markets, own raw material base and successfully conducted research, Western companies retain their leading positions in their respective industries, while intensifying their presence in new areas of business. It seems that this business model can be an inspiration for the Polish companies to build a strong market position.

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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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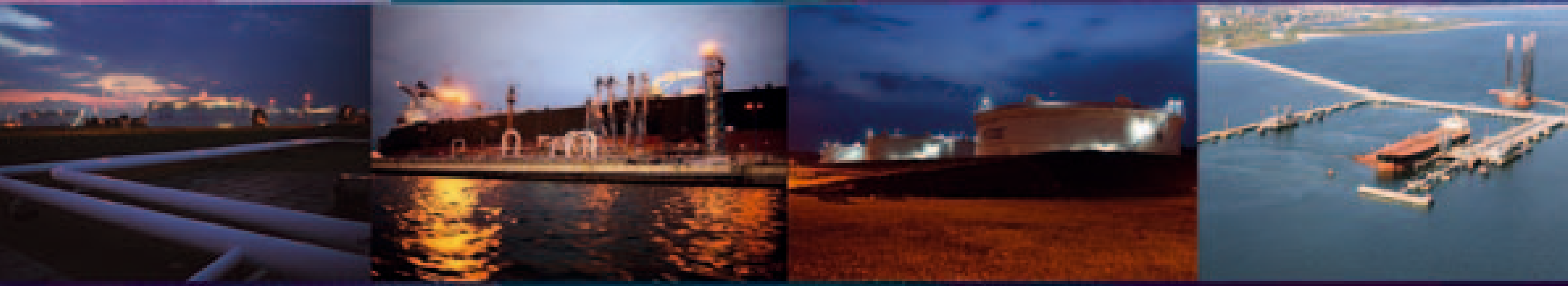


Leader in oil and fuel logistics

Hazard identification and risk assessment in the oil and gas sector

Hazard Identification and Risk Assessment

Methods of hazard identification and risk assessment are in different various branches of industry and petrochemical, maritime or extraction processes.

DNV·GL

The goal of the analysis is collection of information essential to make decisions concerning the estimate of the level of risk related to the operation of the object/process. For some installations and devices, the EU directives require risk analysis. If it is at least at tolerable level, it means that the requirements in respect of staff safety, appropriate operation of the installation and safety of the natural environment are satisfied. In some cases, performing the risk analysis is not imposed by the law and it is not obligatory, however it is a good engineering practice.

> The qualitative methods used in risk assessment consist in estimating the probability and the level of effects for identified hazards, based on expert evaluation.

Hazard identification and risk assessment consists of several logically related steps. At each stage, in an orderly manner, risk analysis is made.

At next stages of risk assessment various methods may be used – qualitative or quantitative depending on the type of object/process and client`s needs. The selection of methods at each step of analysis depends e.g. on: the goal of analysis, phase of the life cycle of the object (e.g. design, approval, operation, utilization), type of analyzed system, potential risk level, possibilities of combining the methods used with available data, staff capabilities and availability, and also definition of solutions which meet both the legislative and standardization requirements. The division of the methods of risk assessment into qualitative and quantitative are presented in Fig. 2.

The qualitative methods used in risk evaluation consist in estimating the probability and level of effects for identified hazards, based on expert evaluation, e.g. during the workshop with qualified engineering staff participating in the process of installation design project or working on the installation which is at operational stage.

The most frequent methods used include e.g. HAZID (Hazards Identification), HAZOP (Hazards and Operability Study), Risk Ranking and also FMEA (Failure Mode and Effect Analysis).

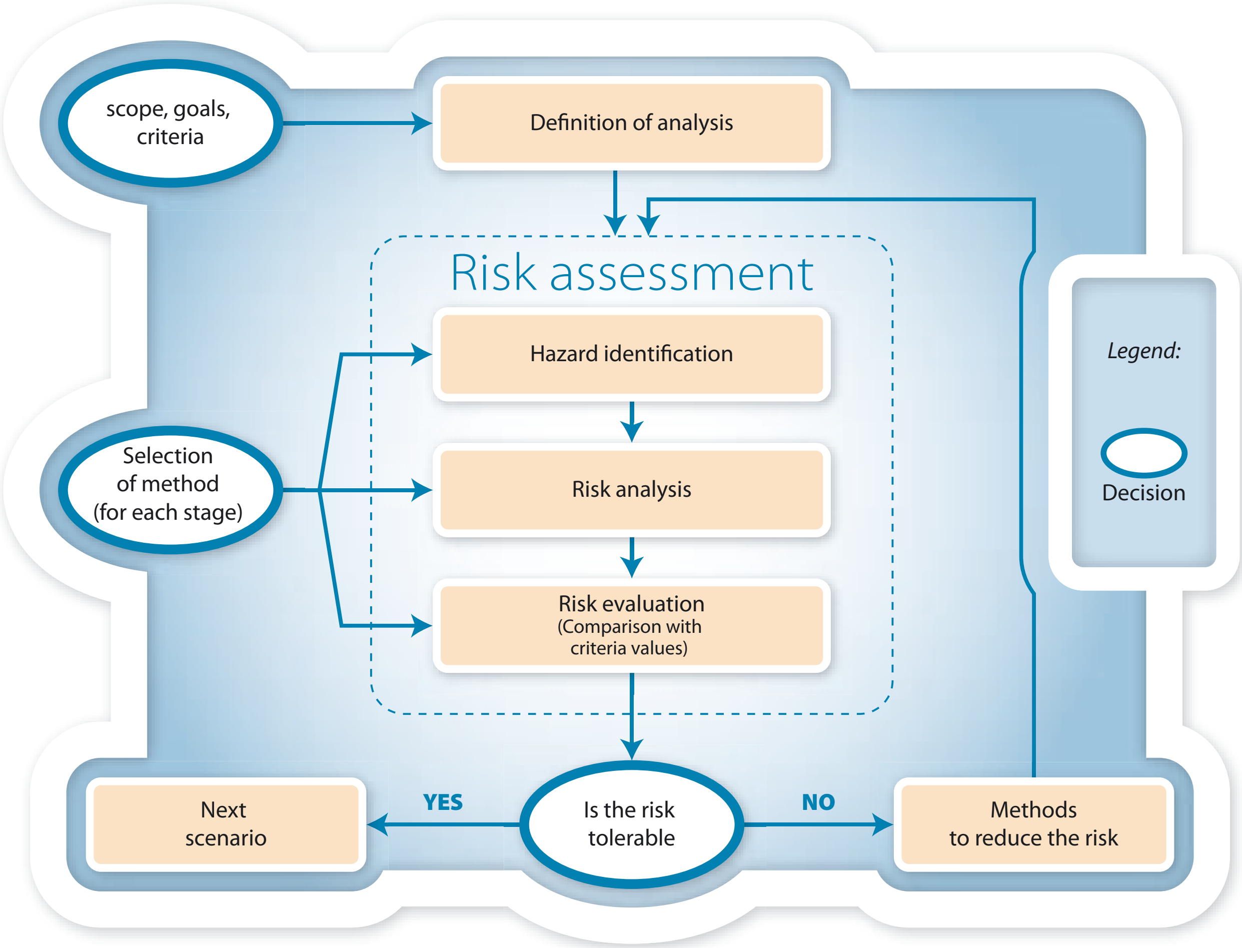


Fig. 1. Methodology for hazard identification and risk evaluation in industrial practice

In subsequent parts of the publication, qualitative methods were described as used in industrial practice by DNV GL most often.

Hazard and Operability Study (HAZOP)

Essential documentation: technical diagrams and P&ID (Pipe and Instrumentation Diagrams), detailed technological description and operational procedures.

Steps of analysis: the HAZOP method divides the installation into logical fragments making a coherent whole. The fragments of the installation are sections and junctions whose selection and division is made by an engineering team – specialists in a specific field. The analysis is made for defined key words and special criteria (safety of people, installation, environment) and it consists in identification of hazards which may occur while the installation is operating. An additional scope may be ranking of the risk whose aim is to analyze the risk during the workshop and compare the risk values (evaluation) for particular hazards with previously defined criteria values.

Hazards with critical or high risk require project changes (Fig. 3).

The result: a report in the form of spreadsheets and a list of recommendations which aim at reduction of the risk involved in identified hazards to at least a tolerable level.

Failure Mode and Effect Analysis (FMEA)

Essential documentation: Diagrams of the installations analyzed, e.g. electrical, monitoring, au-

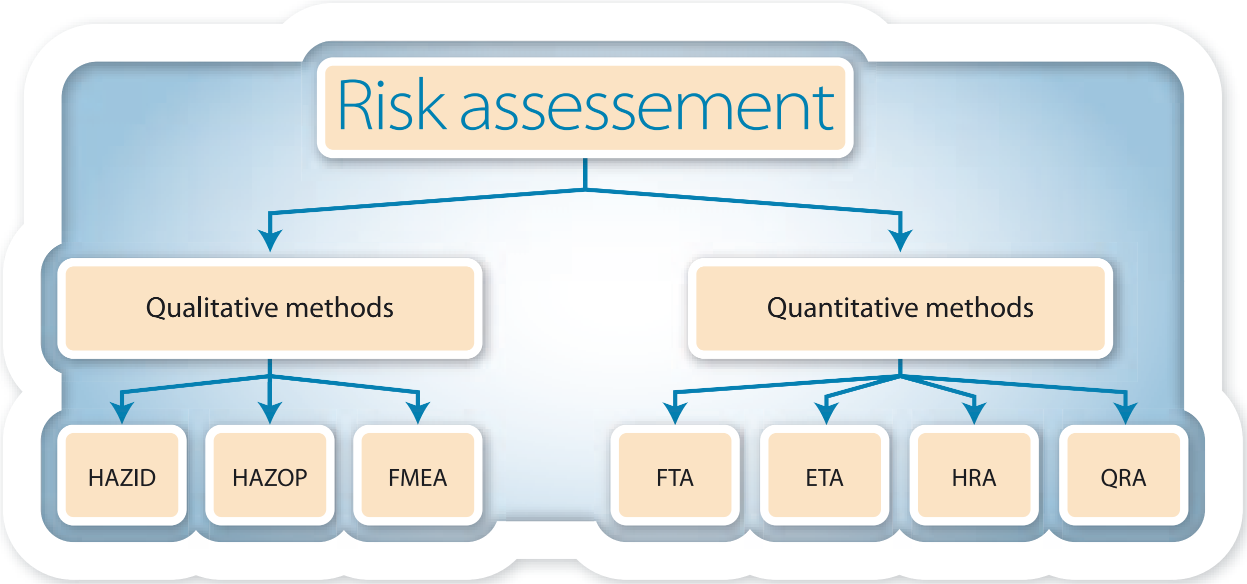
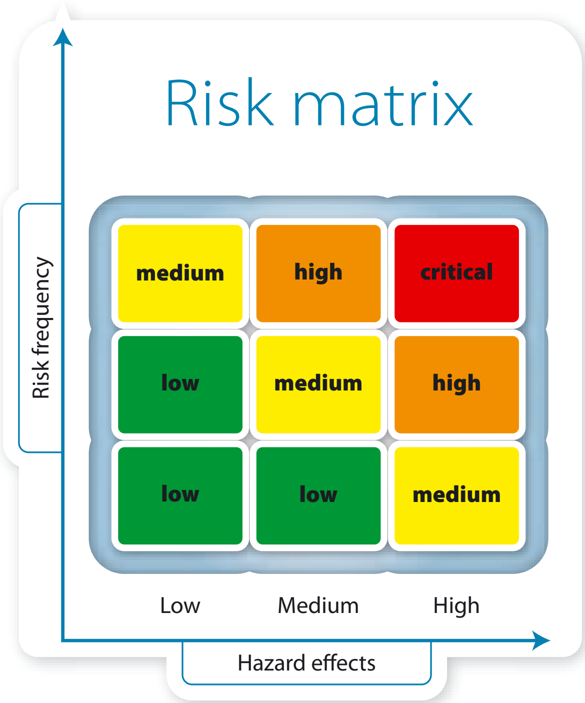


Fig. 2. Division of risk assessment methods into qualitative and quantitative

tomation and I/O systems, calculations and description of operation relating to particular systems and components.

Steps of analysis: the FMEA method consists in division of the installation into systems and components.For the identified systems and components analysis is made of the effect of a single failure on the correct operation of the whole system in relation to the identified maximal acceptable damage (defined by the investor).



	medium	high	critical
	low	medium	high
	low	low	medium
	Low	Medium	High

Fig. 3. Risk evaluation shown in a diagram

The result: the report contains detailed analysis of each system and recommendations on changes aiming to streamline the project with relation to identified maximal acceptable damage (defined by the investor).

Quantitative methods specify the probability values and the scope of effects for specific single actions, entire identified scenarios, as well as for the whole enterprise.

The methods used most often comprise e.g.: the Event Tree Analysis (ETA), the FTA method (Fault Tree Analysis), HRA (Human Reliability Analysis) and also quantitative methods QRA (Quantitative Risk Analysis) based on identification of the Safety Integrity Level (SIL).

Anticipated result of risk evaluation for particular elements of the process or installation is increased process reliability, lower risk of critical failures, increased safety of the staff and reduced negative effect on the environment.

DNV GL has extensive experience in respect of conducting risk evaluation by the following methods:

- FMEA for the maritime sector objects equipped with Dynamic Positioning, RPS, RP, Fire&Gas, Topside and Subsea systems.
- HAZID and HAZOP for objects in petrochemical, food and extraction sectors.

Analyses are conducted based on specialist software developed by the DNV GL company, e.g. MAROS, and they depend on the availability of necessary data. ■

OIL:

exploration,
extraction, sales

Dysfunctions of fuel injection system

Low residue – a serious problem

Zbigniew Stępień

Everyday life practice confirms the fact that precisely working high-pressure fuel injection systems of the Common Rail type (HPCR – High Pressure Common Rail) used in modern diesel (self-ignition) engines play an essential role in reducing the emission of harmful exhaust fumes and fuel consumption. They also enable optimization of the engine`s operational parameters, depending on the needs.

In the result, the need to meet more and more restrictive regulations in the future in respect of successive reduction of permissible limits of emission of harmful fumes and CO_2 from diesel engines will be directly connected and conditioned by further development of more and more precisely operating high-pressure fuel injection systems.

Problems with residue in fuel injection systems

Widespread use of diesel engines with indirect fuel injection in passenger cars (in the 1980s) revealed a problem with coke formation on the fuel injector nozzle, which has a negative effect on the engine's operational parameters and properties, including more difficult start-up, reduced power, higher smoke volume and increased fuel consumption and emission of harmful exhaust fumes.

Coke formation is the process of depositing a carbon residue on the surface of the nozzle. In pintle type nozzles, the deposit forms between the pin of the nozzle, its body and the seat and they are potential source of adverse changes in the engine`s performance [1] – Fig. 1.

Progress at the expense of more problems

In the mid-nineties of the 20th century, widespread use of engines with direct fuel injection brought rapid development of high-pressure fuel injection systems. Among them, in the subsequent years, the HPCR systems gained the most popularity. However, also in this case a problem appeared in connection with formation of external coke deposit accumulating in the ducts and around the outlet orifices in multiple-hole nozzles. In engines with direct fuel injection the nozzle cups go directly into the engine combustion chambers so they are exposed to temperatures of several hundred degrees Celsius. Therefore, the nozzles have to guarantee the appropriate timing and duration of the opening and injection of the fuel to the combustion chambers. When closed, the system must be completely sealed as leaks might have an adverse effect on the emission of harmful engine fumes and increase the fuel consumption and

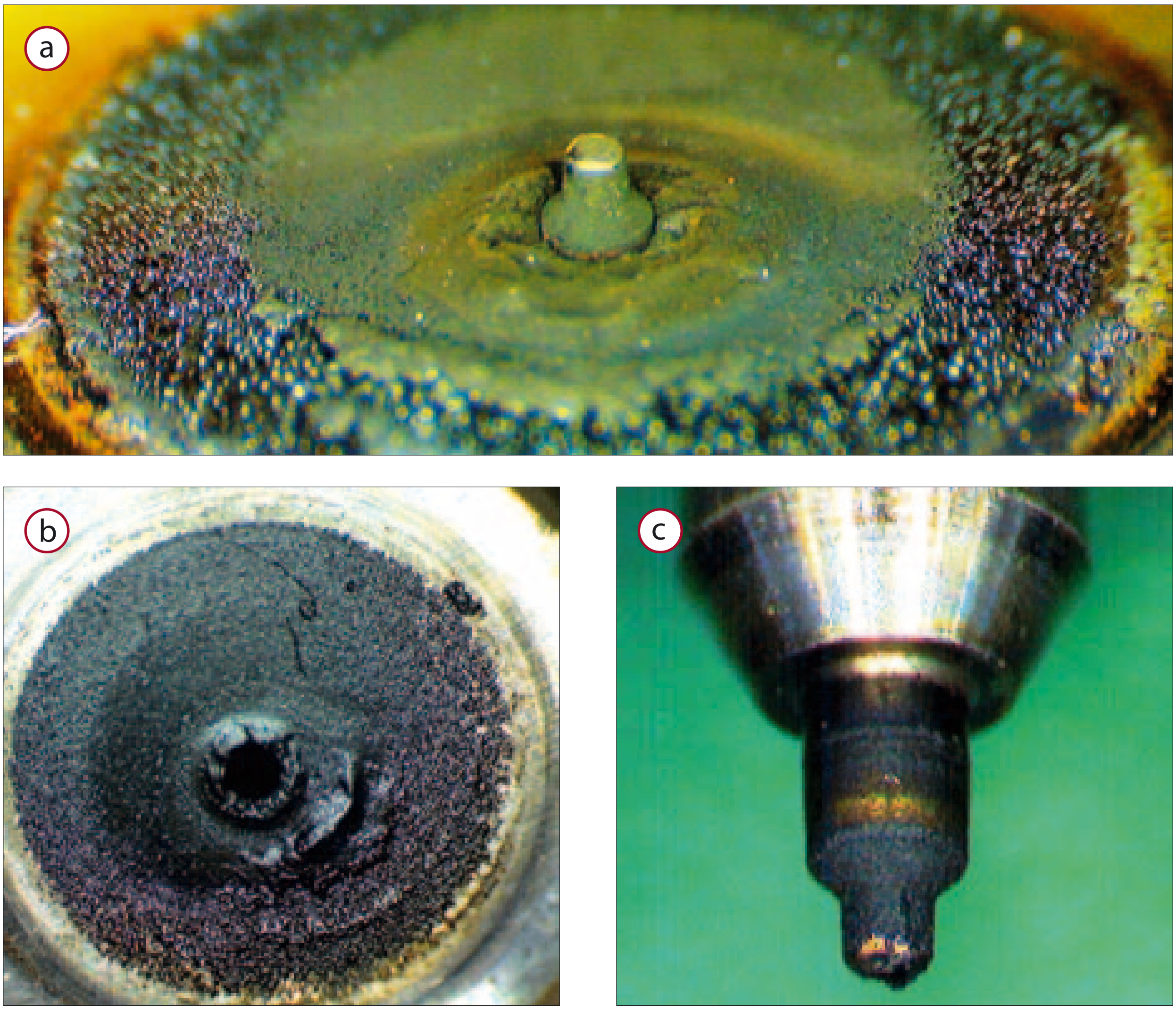


Fig. 1. Coke residue on the front surface of the pintle nozzle: a) front surface of the nozzle with protruding pintle tip, b) deposit around the fuel outlet orifice, c) deposit on the nozzle pintle tip

they might lead to coke formation and distorted fuel spray injection from the orifices.

The phenomenon of coke formation or blocking the injector nozzle may be additionally accelerated by some properties of the fuel and high nozzle cup temperatures which may reach about 300°C. Observed carbon and coke deposits around the nozzle holes in HPCR systems are more granular in nature than those appearing on injector nozzles of older generation engines (with indirect fuel injection).

Testing the mechanism of coke formation demonstrated that the coke accumulates in time, creating thicker and thicker deposit around the orifice. Its location also indicates that in certain time intervals, depending on the fuel composition and conditions of the engine performance (mostly – the temperature of the nozzle section which is inside the engine combustion chamber), the part of the coke deposit directly adjacent to the orifice edge crumbles and is replaced by fresh residue. It should be remembered that in engines with indirect fuel injection, the type of applied nozzle has a great impact on the volume and pace of coking on the injector nozzle. Whereas in engines with direct fuel injection it is the fuel that plays the key role in formation of the coke deposit [1, 2, 3] – Fig. 2.

In subsequent generations of HPCR fuel injection systems the maximum injection pressure gradually increased (from 135 MPa up to over 200 MPa) and great emphasis was put on the shape of the fuel injector outlet ducts. Reduced was also the diameter of the fuel outlet orifices, which served the purpose of better dispersion and preparation of the combustible mixture in the engine cylinders. In the result, very precise conical injection ducts are made (the outlet orifice is 0.05 mm to 0.12 mm in diameter) by means of electrical discharge machining. For a better, more stable fuel

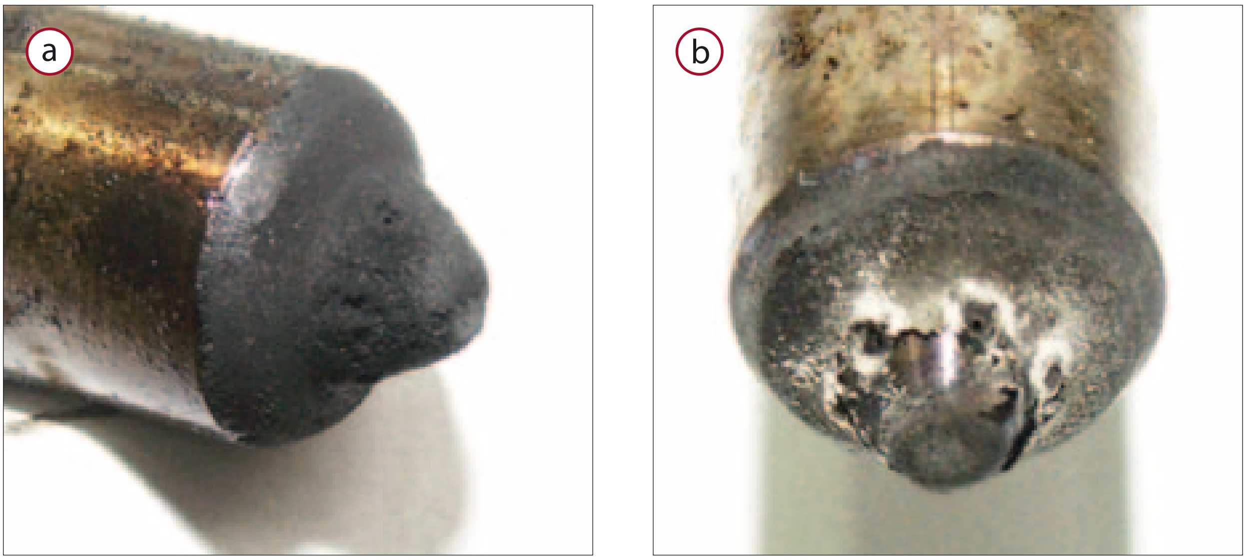


Fig. 2. Coke residue on injector cup in the HPCR system: a) coke residue disintegrating around the fuel outlet orifice, b) crumbling of the coke around the fuel outlet orifice

injection, the duct inlet edges are rounded by means of flow grinding with the use of special fluid, that is by electrical discharge machining.

While introducing new injector constructions it was considered that the shape of the injector cup, fuel injection pressure as well as conditions of the environment to which the fuel is injected and its properties are decisive factors which affect the technical injection parameters, whereas the geometry of the fuel outlet orifice determines the processes of turbulence, cavitation and spatial distribution of the fuel stream rate inside the injector. The application of conical outlet ducts in injectors allows to increase the velocity of the fuel stream and its momentum, which significantly enhances the spraying quality and contributes to better blending of the fuel and air in the combustion chamber. However, all the structural and technological solutions mentioned above may not produce expected results due to residue arising on the walls of the injector ducts owing to bad fuel quality. Ever increasing accuracy of manufactured fuel injectors and the need for their more and more precise action involve serious problems which affect appropriate injector operation [2, 3, 4].

> Roughly since 2008, the incidents of failures in HPCR systems – and also in the engines – have alarmingly increased in the world.

Low residue – a serious problem

Roughly since 2008, the incidents of failures in HPCR systems – and also in the engines – have alarmingly increased in the world. It turned out to be connected with the formation of residue on the internal elements of the HPCR systems. Performed chemical analyses proved the residue composition to be different from that of the coke deposits in ducts and on edges of injector outlet orifice examined so far. It has also been found that the factors responsible for arising of this new type of deposit, called *Internal Diesel Injector Deposit* (IDID) and conditions responsible for its growth are completely different from those typical of coke deposit [4] – Fig. 3.

In the currently used HPCR systems the pressure of fuel injection reaches 220 MPa and the quantity of dispensed and then injected fuel – considering a passenger car engine of cylinder capacity about 2 dm^3 – can range from 1 mm^3 (initial pilot dose) to 40 mm^3 (the dose at full engine load). Simultaneously, the time of injecting the fuel dose is 1–2 milliseconds, which in the case of multiple injection strategy (with many phases) means performing up to 10 000 injections per minute [5]. Still, these are not the peak possibilities of fuel injection systems as the fastest electromagnetic injectors applied reach the opening time equal to 0.303 ms and more and more often piezoelectric injectors are used with opening time of 0.1 ms. Considering the operational parameters of the injector described and very high performance accuracy required (the space between the injector housing and cylindrical, guiding part of the pin which moves in it is approx. 1 µm) in connection with very high fuel injection pressures, all kinds of internal deposits on the surfaces of collaborating elements have harmful effect on the operation of the whole team. Injectors must guarantee proper timing and duration of the opening and fuel injection to the combustion chambers. When closed, they must be completely sealed as leaks might have an adverse effect on the emission of harmful engine fumes and increase the fuel consumption. They might also lead to coke formation and distorted fuel spray injection from the sprayholes.

For the surface which seals the head of the injector`s housing to be reliable and capable of preventing fuel injector leaks, the deviation of its shape cannot exceed 1 µm.

IDID slow down the injectors` operational rate (the so-called overdrive time) and they cause sticking together (immobilize) of the cooperating working elements, which leads to losing control not only in quantitative and qualitative fuel dosing, but also the dose distribution and duration of the spray. IDID also lead to uncontrollable disruption in the parameters of oscillating pressure of multi-phase fuel injection by depositing on the electromagnetic armature and anchors which control the fuel flow in injectors. In practice, this results in more difficult engine start-up, its unsteady work – both in neutral gear and while the vehicle is moving, uncontrolled power shifts and changing engine`s torque, even its unexpected stoppage. In the result, it has a bad impact on the fuel consumption values and it increases the emission of harmful fumes to the atmosphere.

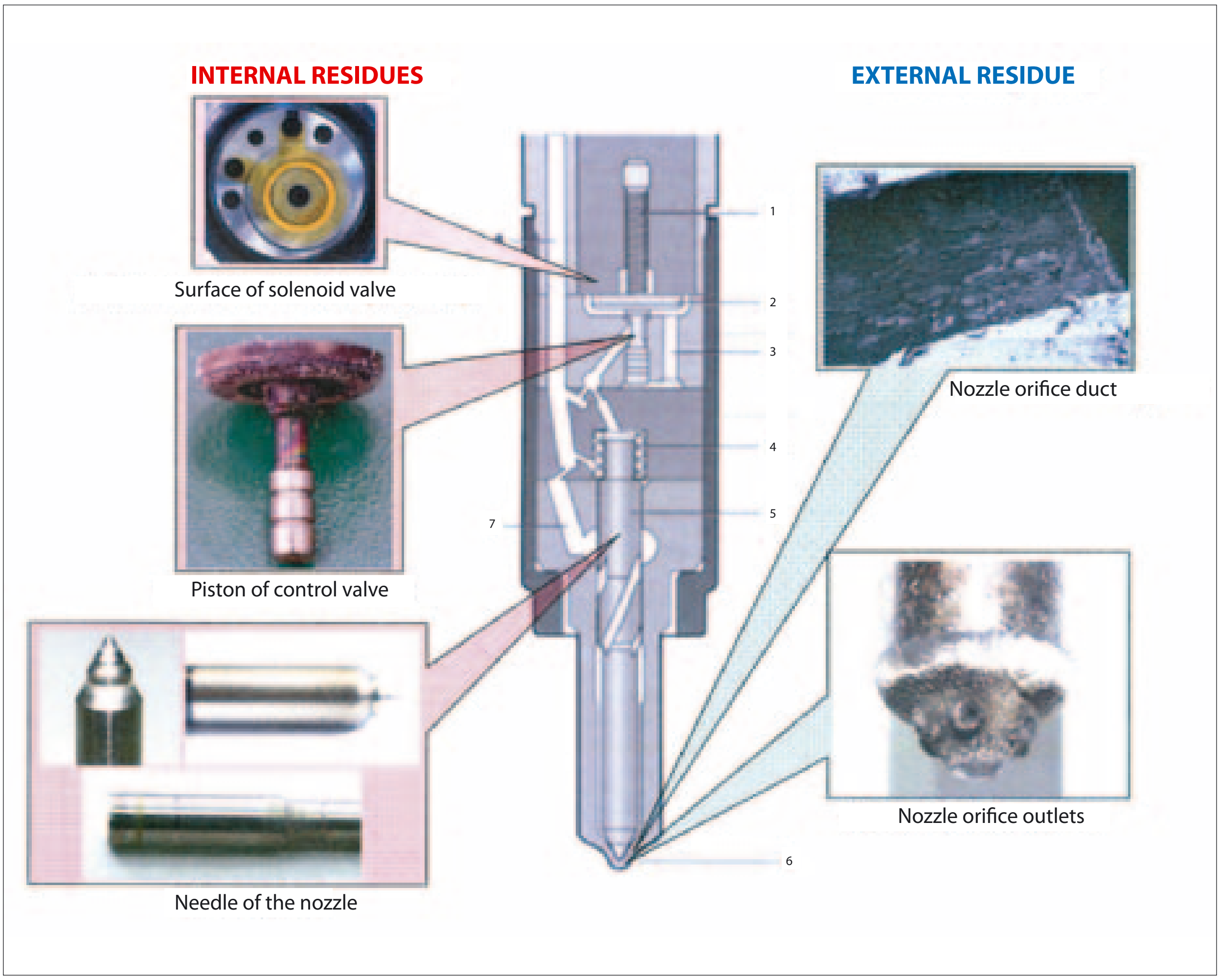


Fig. 3. Injector cross section in HPCR fuel injection system with marked areas of internal and external deposits: 1. solenoid valve spring, 2. control valve, 3. fuel discharge channel, 4. fuel distributor control plunger, 5. injector pin, 6. injector orifice, 7. injector`s initial chamber

The IDID-related hazards to the correct operation of the HPCR system result from reduced performance dynamics of the internal working elements in injectors or their complete sticking together, leading to hydraulic dysfunction of the injectors` operation. In the case of external coke deposits, the risk results from partial or entire obstruction of the fuel outlet at the injector`s orifice, which affects the quantity and quality of the fuel sprayed in the engine combustion chambers. As tests carried out in several research centers [6, 7] demonstrate, the IDID formed also in former generations of injection systems, i.e. with distributor pumps and even in-line injection pumps, but they had no effect on their correct functioning on account of low thickness of created layers and greater performance tolerance between the movable working elements, particularly injectors.

With reference to changes in composition and technology of produced fuels, the increasingly common use of low sulfur diesel and systematically increasing admixture of biocomponents led to a more intense formation of deposits on the internal surfaces of pump elements and injectors in the HPCR systems.

What factors facilitate the formation of internal deposits?

Performed IDID tests permitted hypothetical assumption of several mechanisms for creating the deposits, however each of the mechanisms requires further testing in order to be verified and ultimately confirmed. This results from substantial complexity of the factors and conditions which may have an impact on the initiation and then formation of the deposits. It has been established that this has an effect not only on the specific fuel composition and additives used but also various impurities (even in quantities below 1 ppm) which get into it accidentally both during fuel production and transport, and the quantity and quality of FAME contained in the fuel, engine performance conditions, etc. Moreover, the physical character of the deposits may vary as they may be metal salts or ash free composites [2, 4, 7, 8]. The critical conditions in which IDID may be arising are not known.

As a result, the discovered (based on performed tests and simulations) factors and conditions which determine the IDID formation comprise:

- **fuel-related factors:**
  - » sulfur content in the fuel (the lower the content, the greater probability of IDID formation),
  - » content of base originating from hydrocracking,
  - » content of compounds of low molecular mass (slightly soluble in low sulfur diesel),
  - » content of aromatic hydrocarbons,
  - » content of acid,
  - » content of polar substances (additives) containing N and S,
  - » content of inorganic ions Na, Ca, etc.,
  - » quantity, type and quality of biocomponents contained in the fuel;

- **connected with fuel additives:**
  - » content and type of corrosion inhibitors,
  - » content and type of lubricating additives,
  - » content and type of detergent additives,
  - » content and type of additives which increase the cetane number,
  - » content and type of defoamers;

- **mechanical:**
  - » high pressures and temperatures in HPCR-type systems,
  - » small and successively decreasing tolerances in performance of cooperating elements,
  - » extremely small spaces between the key elements of pressure-related working components of injectors,
  - » multiple (multiphase) single-dose fuel injection which makes the injection system very sensitive to disturbances in work dynamics of the key working elements.

With reference to changes in composition and technology of produced fuels, the increasingly common use of low sulfur diesel and systematically increasing admixture of biocomponents led to a more intense formation of deposits on the internal surfaces of pump elements and injectors in the HPCR systems. Also, successive implementation of new technologies – particularly in the HPCR systems – revealed their great susceptibility to dysfunctions and damage caused, e.g.

by insufficient effectiveness of detergent additives for this type of construction, sufficiently effective to keep them clean and clean up the coke deposits in the ducts and injector`s spraying cups, but ineffective in the case of IDID.

In modern fuel injection systems, the fuel flowing through them is used as lubricant. Currently produced types of diesel contain various acid components. Unsaturated fatty acids of various degree are commonly used as lubricating additives. As demonstrated, such acids easily react with ions of metals which act as fuel impurities, forming soap and deposits. For example, the soaps of fatty acids containing zinc lead to formation of coke deposits which block the outlet orifices in injector spraying nozzles. It has long been known that carboxylic salts and polar compounds of low molecular mass dissolve with greater difficulty in the low sulfur diesel oils than in the high sulfur types used formerly. That, in combination with conditions prevailing in injectors in the HPCR systems accelerates the formation of internal deposits. For instance, sodium soaps of fatty acids are slightly soluble in diesel oil so they may increase the tendency to create internal deposits in injectors.

The increasing share of FAME in diesel oils has an effect on the increased sodium content in the fuel because this metal is a component of typical catalysts used in reactions of transesterification. FAME included

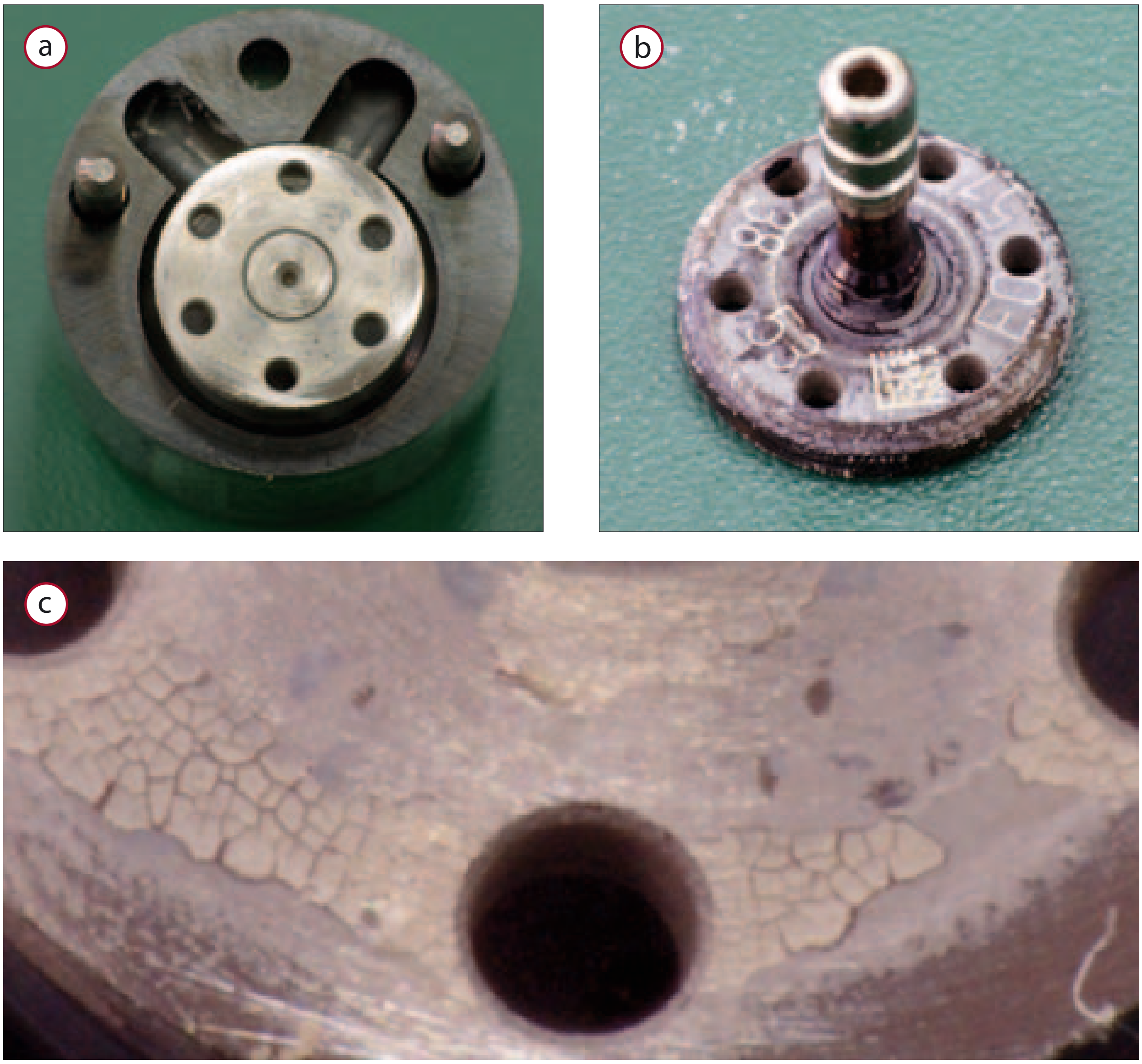


Fig. 4. Deposits of soap which contains metallic ion (mostly sodium or chloride soaps of fatty acids): a) lower surface of solenoid valve piston which controls the fuel flow, b) the view of solenoid valve piston with enlarged surface of the mushroom valve (c)

Fig. 5. Viscous, wax seal polymeric organic or amide deposits: a) upper surface of the body of solenoid valve piston controlling the fuel flow, b) injector spray pin

in diesel oil may additionally speed up the formation of IDID due to acid contaminants contained in them and those arising in FAME production and also those formed in autocatalytic division of fatty esters with metal ions taking part. Deposits created in this way may make the surfaces of movable elements stick together [2, 4, 7, 8] and accelerate corrosion.

In the USA, Denmark and France it has been observed that sodium salts, usually in the form of nitrites ($NaNO_2$), used as corrosion inhibitors in fuel transmission pipelines, already at the fuel content > 0.1 mg/kg may react with fatty acids used as lubricating additives, creating sodium soaps of fatty acids [6]. Similarly, sodium chlorides used as drying factor in the production of diesel oil may get to the fuel at the stage of its production and create soaps in combination with fatty acids, precipitated as IDID. In general, sodium soaps of fatty acids are slightly soluble in diesel oil, therefore they easily separate from it and stick to the internal surfaces of working elements of the fuel injection system components in the shape of white-grey deposit – Fig. 4.

In the European countries, more frequent is the IDID created from organic polymers, the shape of viscous, brown wax seal covering the internal surfaces of the HPCR system elements and its chemical composition is completely different from that of the soaps containing metallic ion. The composition of the deposit is free from the metallic ions. They arise in reaction of detergent additives commonly used in diesel oils in the form of PIBSI (*polyisobutylene succinimide*) with formic acid, corrosion inhibitors or lubricating additives which constitute monomers or dimers of fatty acids. Particularly prone to formation of the deposits is PIBSI with high content of primary amine in interaction with dimers of carboxylic fatty acids. The deposits created are insoluble in generally used organic solvents, which makes their analysis and determination of their chemical structure extremely difficult.

Tests carried out recently also point to the possibility of IDID formation from the products of fuel oxidation. Such products may occur specifically in the case of unstable diesel containing FAME or they may originate from the ageing of ester fatty acids in the lubricating additives [2, 4, 7, 8] – Fig. 5.

Summary

The problem of damage in HPCR-type fuel injection systems due to IDID formation acquires more and more significance globally, while the knowledge related to the mechanism of their formation and composition is still unsatisfactory. Engine failures connected with described dysfunctions of fuel injection systems are encountered all over the world and their number has been rising fast recently.

Engine manufacturers and car users, as well as fuel manufacturers, more and more often turn to various research institutes requesting their advice on solving this kind of problems. The hypotheses made so far require further, comprehensive testing in order to be confirmed or verified. There are many reasons indicating that the solution of the problem should be sought in the technology of fuel production, reduction of impurities which may get to diesel oil during its transportation and distribution and in particular, verification of fuel additives` composition – considering both increased effectiveness of detergent additives and also lack of their interaction with other package components and application of effective additives of other types, e.g. metal deactivators, preventing the process of FAME ageing, etc.

The significance of the problem is attested by the fact of appointing the so-called *Ad-Hoc Injector Sticking Task Force* (September 2011) as part of the Polish Committee for Standardization CEN/TC 19/WG 24 and creating a new working group by CEC (*Coordinating European Council for the Development of Performance Tests for Fuels, Lubricants and Other Fluids*) to deal with the development of methodology for testing such phenomena – *Test Development for Internal Diesel Injector Deposits (IDID)*.

It should be noted that no comprehensive, recognized or standardized methodology has been developed (in Poland, Europe or worldwide) which would allow to examine the mechanism of development and multidisciplinary evaluation of the phenomenon of formation of adverse internal deposits (IDID) in HPCR fuel injector systems in modern self-ignition engines.

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Stimulation treatment design in injection wells

Effective management of waste water – how to maintain absorbency of injection wells

Elżbieta Biały

An important issue in many oil and gas mines is management of waste water, that is mine waste and deposit water extracted along with oil and natural gas in the production process. One of the management methods is injection of the waste water into unproductive absorptive horizon through specially selected injection wells.

Although this method has its unquestionable merits as it is simple, successful and cost-effective, some complications may occur in its application. In the result of pumping large volumes of waste, in time, difficulties may appear with maintaining absorbency, which is caused by clogging of the near-well zone. Intensification of this phenomenon may completely exclude the wells from operation.

> Solid particles introduced to the porous medium cause physical changes in the medium, reducing its porosity and permeability, which finally reduces the well absorbency. The process which leads to such changes is called colmatage.

The appropriate solution to the problems may be suitably designed, prepared and performed stimulation treatments whose task is to clear the near-well zone. Preparation of technology to restore or increase the absorbency of the injection well requires numerous preparatory tasks, like e.g.:

- analysis of the reasons for absorbency loss in the wells selected for injection,
- indication of an appropriate type of stimulation treatment,
- selection of technological fluids and chemical additives to improve the declogging of the near-borehole area,
- laboratory tests which allow to select appropriate components for the treatment fluid,
- tests for effectiveness of damage removal with the use of *core flow* tests,
- analysis of obtained results and development of special guidelines for industrial application.

Analysis of the reasons for absorbency loss in wells selected for injecting the waste water

An essential factor for the effectiveness of the process of injecting the waste water is the permeability of the near-well zone and the physicochemical state of injected brine, and particularly the presence of clogging components [3, 5, 7].

The phenomena of negative impact on the operation of the absorptive well comprise:

- insufficient cleaning of injected deposit waters of substances clogging the near-well area and reducing the deposit absorbency,
- liberation of products of reaction between injected water and the absorptive layer,
- formation of emulsion in the near-well zone,
- liberation of gas from the injected water,
- proliferation of microorganisms.

Solid particles introduced to the porous medium cause physical changes in the medium, reducing its porosity and permeability, which finally reduces the well absorbency. The process which leads to such changes is called colmatage or clogging.

The factors responsible for colmatage are:

- suspensions and residues made up of rock material (loam, rock grains, sand, dust, colloidal silica), mechanical contaminants, iron and manganese oxides and hydroxides originated and precipitated from the solution during chemical and physical changes occurring in production and storage of deposit water;
- ions of metals, particularly iron and manganese. As a result of changed physicochemical parameters induced by processes connected with production, storage and repeat injection to the deposit such as: changes in pressure and temperature, degassing, changes in pH and changes in electrochemical potential and also admixture of various chemical substances – it is possible that these metals will create suspensions and colloidal solutions or – in the ionic form – will take part in complicated processes that occur in the deposit;
- carbonate and bicarbonate ions, and – to a lesser extent – also sulfate ions. These anions, in combination with considerably high content of calcium may, in conditions of increased alkalinity or temperature, cause precipitation of calcium carbonate. When soluble barium compounds are present in confined groundwater, the presence of sulfate ions will lead to precipitation of barium sulfate which is insoluble and impossible to remove;
- oil-derivatives which may form emulsion with water, blocking the porous structure of the interceptor;

- methanol – may cause precipitation of salt residue from the deposit water. This phenomenon can be observed particularly in water with significant volume of calcium and sulfate ions or hydrogen sulfide.

In order to analyze the reasons for loss of absorbency of injection wells it is vital to know the mineral composition of both the water pumped to the injection wells and also deposit water. Essential parameters are also the pH rate and oxidation-reduction potential Eh. The known value of these parameters, together with the knowledge of general water mineralization, allows to predict the conduct of the components of hydrogeochemical components of the environment. The tool which allows to determine the influence of changes in the main parameters describing water on the processes of precipitation of residue and solving minerals and changes in corrosion properties is the AquaChem software. On the basis of information on chemical composition of the native deposit water and injected water, simulation may be performed of the processes which occur when they are mixed [2].

Apart from the factors described above, the damage of the near-borehole zone is accelerated by such phenomena as:

- loam migration,

- migration of particles,
- salt bridge,
- water block,
- changed wettability.

Methods of increasing the well absorbency

The basic methods of increasing the well absorbency are:

- mechanical removal (drilling) of loam particles and residue, which are mainly products of corrosion (mainly iron (II) sulfides) and secondary mineralization (aragonite, calcite, silica, gypsum, anhydrite, etc.). The effects of this method are short-lived, they last only several months;
- acidation;
- hydraulic fracturing;
- application of chemical inhibitors – modification of pH value of the drilling waste in order to reduce or prevent precipitation of secondary minerals and corrosion in the borehole and its vicinity, and also in installations on the ground [9];
- cleaning of the borehole.

The method which ensures long-lasting and suitable effects is acidization by performing the following stimulation treatments:

- "acid bath",
- matrix acidization,
- deep acidization.

"Acid bath" is an operation of treating the borehole with acid in order to remove contamination from the walls of uncovered horizon. The goal of the treatment is to dissolve some compounds and change the consistency of the residue accrued in the borehole. It should be preceded by cleaning the borehole bottom and pipes. If not cleaned before the acidizing, the process may lead to the loss of permeability of the near-well zone, greater than before the treatment, as loosened due to acid operation insoluble residue particles are pumped into the deposit where they settle, blocking the pores and small fractures. Acid baths are also performed before the main acid treatment, in boreholes operated for extended periods, with corrosion products accumulated, such as oxides, hydroxides and iron (II) sulfides which, along with the pressure fluid injected into the deposit may significantly reduce the permeability of the near-well zone.

The residue contained in the boreholes is usually slightly soluble in acid and therefore, for performing acid bath treatment acid concentration of 10÷15% is used, and with substantial contamination the concentration increases to 20%.

For cleaning boreholes contaminated with corrosion products 2÷3% acetic acid is added to the solution of hydrochloric acid. At present, the chemical companies offer also special fluids for cleaning the bottom of the borehole and the pipes before treatment. They are usually a mixture of surfactants, solvents and acids.

The method commonly used for removing damage or increasing the permeability of the rock in the near-well zone is matrix acidization. This is a treatment which removes the damage in the vicinity of the borehole in the range of several dozen centimeters. It aims to inject the acid to the well at injection pressure lower than the fracturing pressure. The basic mechanism of acidization is known but in combination with deposit conditions, such as e.g. heterogeneity of the deposit and occurring minerals it is extremely complicated. The most essential element in designing the treatment is selection of appropriate treatment fluid.

Basic acids used for matrix acidization are:

- hydrochloric acid (HCl),
- mixture of hydrochloric and hydrofluoric acid (HF),
- acetic acid (CH_3COOH),
- formic acid ($HCOOH$),
- fluoroboric acid (HBF_4) – less commonly used,

and for specific applications – various mixtures of the acids mentioned.

The goal of acidizing is to trigger reaction beyond the deposit rock and/or the material that occludes the pores, in the result of which soluble salts will be created. These compounds may be brought out to the surface or shifted through the pores to a certain distance away from the well. That is why the acids which create insoluble residues in the reaction cannot be used in the simulation. This group of acids comprises:

- HF (which may create insoluble CaF_2),
- sulfuric H_2SO_4 ($CaSO_4\downarrow$),
- phosphoric H_3PO_4($Ca(PO_4)_2\downarrow$).

In general, using oxidizing acids like HNO_3 and H_2SO_4 is not recommended as they might react with hydrocarbons. However, acids such as HCl, CH_3COOH, $HCOOH$ create salts in reaction with carbonates, respectively: $CaCl_2$, $Ca(CH_3COOH)_2$, $Ca(COO)_2$, which are soluble in their exhausted solutions and in most deposit brines.

The acid which is most often used in stimulation treatments is the solution of 15% HCl concentration by weight, although the concentration may change from 5% to 35%. Hydrochloric acid, in reaction with deposit rock, dissolves limestone, chalk, dolomites and other carbonates.

Acidization with HCl is based on chemical reaction of the acid with carbonate rock or carbonate intrusions in sandstone deposits or carbonate compounds as components of the cement. Created in the reaction of hydrochloric acid with carbonate rock calcium and manganese chloride and magnesium, they are soluble in water and easy to remove from the deposit.

In sandstone rock with carbonate intrusion or carbonate binder, the hydrochloric acid may be used only to increase the permeability of the near-well zone because in acidization of sandstone in which the volume of carbonate binder is 10÷20%, the acid penetrating deep into the deposit carries the loose granules of sand resulting from damaging the rock structure. The sand may be carried out from the deposit along with the fluid remaining after the reaction. The universal use of hydrochloric acid is caused by its very good solubility and cost-effectiveness.

Another stimulation method is injection of acidizing fluid in the form of foaming solution into the well. General recommendation for using the method is the application in wells yielding low output but those which at the initial stage were very effective and in the wells in which classic acidizing did not produce expected results. Foaming may be obtained by means of CO_2 or nitrogen.

The foam is produced by adding gas to the acid in the presence of foaming agents. As a result of carbonation a colloid is made in which the dispersed phase is gas and the dispersion medium is the liquid. Stability and quality of the liquid depends on the properties of the foaming agents.

The positive effects achieved when using liquids containing CO_2 are:

- protection of the loam particles from swelling,
- hindering the precipitation of aluminium and iron salts from the process fluid used in the reaction,

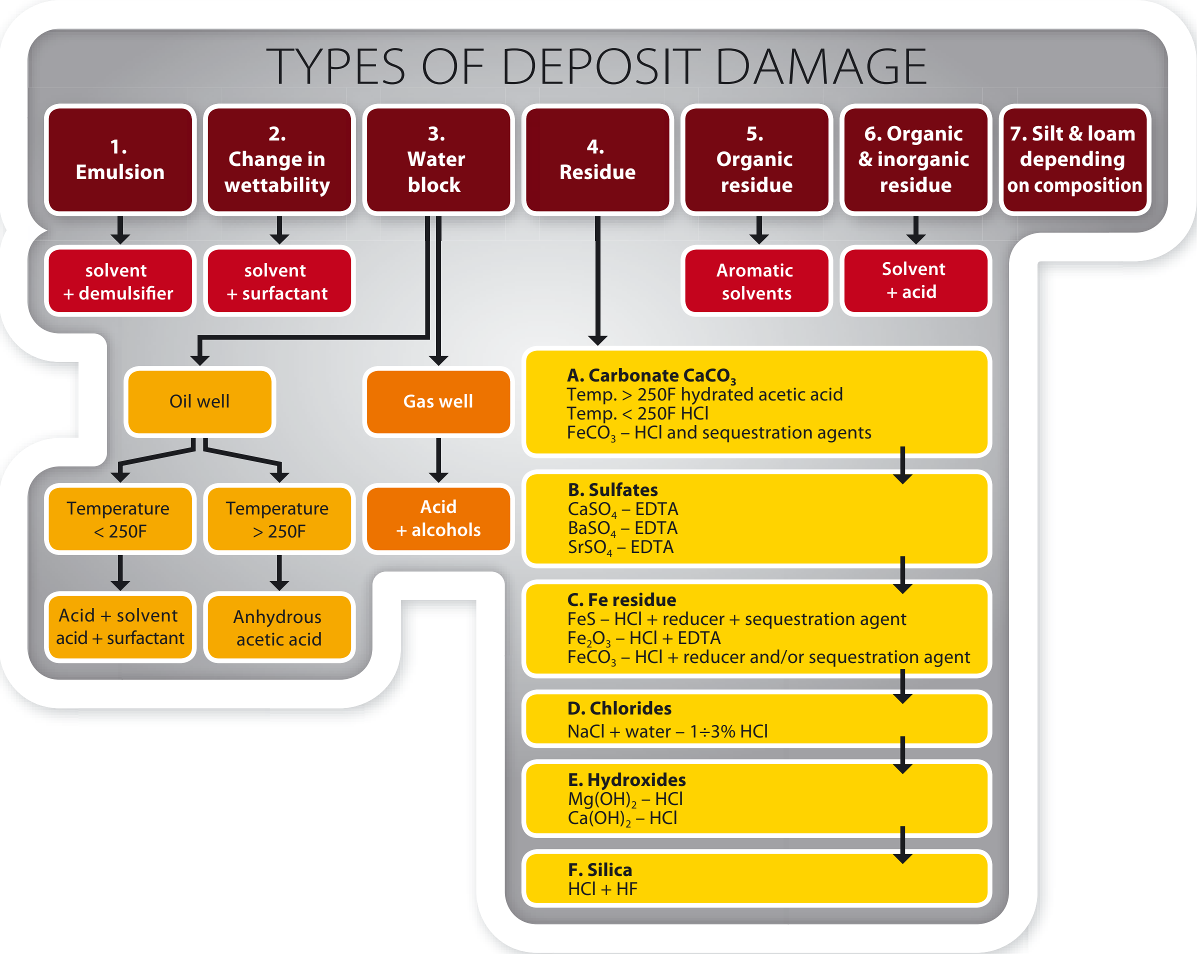

Fig. 1. Method of treatment fluid selection depending on the type of deposit damage [1]

Table 1. Methods of removing the damage caused by inorganic residue in the near-well zone [4]

Type of residue	Most common form	Treatment fluid type
carbonate	$CaCO_3$	HCl
sulfate	$CaSO_4 \cdot 2H_2O$	EDTA*
	$BaSO_4/SrSO_4$	EDTA
chloride	NaCl	H_2O/HCl
iron	FeS	HCl + EDTA
	FeO_3	HCl + sequestration agent
silicate	SiO_2	HF
hydroxide	$Mg/Ca(OH_2)$	HCl

*EDTA – the abbreviation comes from the English name: ***e***_thylene_***d***_iamine_***t***_etraacetic_ ***a***_cid_. It is a widely used complexation factor for many metal cations, such as Ca^{2+}, Mg^{2+} or Fe^{3+}.

Table 2. General indications for the selection of treatment type and fluid composition for sandstone and carbonate rock

Treatment fluid	Sandstone rock					Carbonate rock		
	Cleaning of the near-well zone			Deep penetration		Cleaning of the near-well zone		Deep penetration
	Acid bath	Acidizing		Acidizing		Acid bath	Acidizing	Acidizing
		Carbonate cementation 10÷20%	Clay cementation	Carbonate cementation 10÷20%	Clay cementation			
HCl 5÷15% + corrosion inhibitor + surfactants	X	X				X	X	
HCl 28% + corrosion inhibitor + surfactants								X
HCl 5÷15% + CH3COOH 2÷5% + corrosion inhibitor + surfactants		X					X	X
HCl 5÷10% + HF 2÷5% + corrosion inhibitor + surfactants		—	X	—	X	—	—	—
HCl 8÷15% + NH4F·HF (4÷6% HF) + corrosion inhibitor + surfactants			X		X	—	—	—
Hydrophobic acid emulsion								X
HCl 5÷10% foaming CO_2 + surfactants + corrosion inhibitor		X		X			X	X
HCl 5÷10% air-foamed + corrosion inhibitor		X		X			X	X
HCl 15% foaming N_2 + surfactants + corrosion inhibitor		X		X			X	X

Note:
— denotes prohibition to use the process fluid in specific geological deposit
X denotes indication for using the process fluid in specific geological deposit

- maintaining gypsum and anhydrite dissolved in the water-based process fluid,
- additional increase in the deposit permeability as a result of dissolving the dolomite, limestone and silicates,
- time of reaction of the rock with acid saturated with carbon dioxide is extended and active acid may be injected into deep strata of the deposit,
- the wells treated with carbon dioxide are commissioned for production shortly after the treatment.

Carbon dioxide may be used as foaming agent in the liquid or solid shape, the so-called dry ice.

Foaming the acidizing liquid with nitrogen slows down the reaction of the acid with the rock surface, by the same achieving improved penetration of the acid. Deep matrix acidization increases the acidizing span to several meters` distance from the well.

Development of technological liquid formulas for decolmatage of the near-well zone

The selection of appropriate type of treatment liquid is determined both by the type and sort of damage but also the type of deposit rock.

Recommended type of treatment fluids for removing various kinds of damage in the near-well zone:

- inorganic residue – suggested chemical agents for the treatments are presented in table 1;
- organic residue – suggested treatment: organic solvents;
- mixed residues – suggested treatment: aromatic solvents or dispersion in acids;
- changed wettability – suggested treatment: solvent injection following the hydrophilic surfactant;
- water blocks – suggested treatment: lowering the surface tension with acid + surfactant + alcohol;
- mud and loam – suggested treatment: mixtures of HF/HCl.

Table 2 compares general indications for the selection of treatment type and fluid composition depending on the type of deposit rock.

Laboratory tests for preparation of technological fluids to remove the damage

The selection of appropriate chemical additives for technological fluids requires checking their action or conduct in combination with the basic liquid and in reaction with the deposit rock. Therefore, preparation of the formula for technological fluids for removing the damage must be preceded by the following tests:

- test for the effectiveness of clay minerals inhibition – selection of the most effective agents,

Photo 1. Tanks for the process fluids and core samples chamber

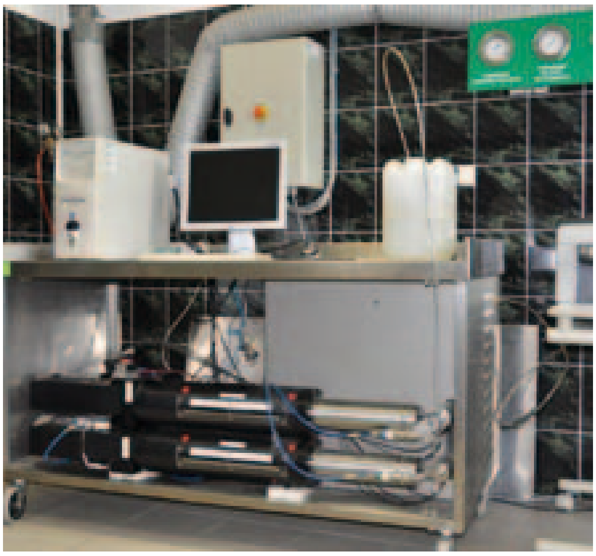

Photo 2. Acid injection system (Quizix Pump)

Photo 3. AFS equipment (Acidization Core Flooding System) for testing technological fluids on core samples

Photo 4. Core samples for flow tests

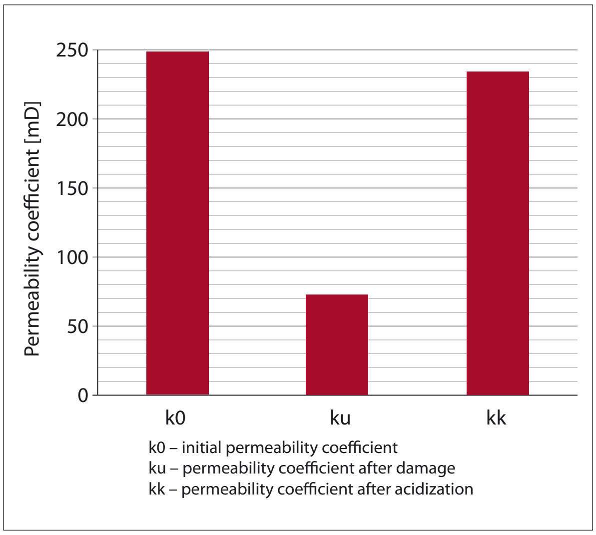

Fig. 2. Model measurement results of the core sample permeability coefficients

- test for the stability of the deposit rock in solutions of clay inhibitors,
- test for compatibility of inhibitors of clay minerals with acids,
- tests for compatibility of acids with the remaining additives for the treatment fluid, such as: stabilizer of iron compounds, corrosion inhibitors or agents reducing the flow resistance.

Other tests that should be carried out are flow tests on core samples (Photo 4) to evaluate the effectiveness of developed treatment fluids. The tests can be performed at research stands: ADS (*Acid Delivery System*) or AFS (*Acidization Core Flooding System*) (Photos 1, 2, 3).

The tests are done according to the following scheme:

1) Measurements of permeability coefficient and porosity of the cores before the flow tests.
2) Damaging the cores by putting the injection water through them.
3) Measurements of permeability and porosity coefficients following the damage.
4) Acidizing the cores with developed technological fluids and another measurement of permeability and porosity coefficients after the damage has been removed.

Based on the test results, the extent of damaged core permeability is calculated and the percentage of permeability retrieved after acidization, and then the achieved results are analyzed and instructions for industrial application are developed. Model results of such tests are shown in Fig. 2.

The devices shown in photos 1 and 2 make up a research stand for *Acid Delivery System* where *core flow* tests can be performed.

Model procedure of development of treatment fluid composition for injection well stimulation

Below, a model procedure is presented for developing the composition of treatment fluid for stimulation in injection well whose deposit rock consisted of limestone and dolomites. The deposit waters contained mainly calcium chloride with a low content of iodine, maximal value to 27 mg/l. The brine demonstrated high mineralization which was oscillating within 92÷128 g/l, and its specific gravity at 20°C was 1.087 g/cm^3. After sampling of the mine

water injected to the absorptive well, chemical analyses were performed, labeling the compounds: chlorides (Cl^-), sulfates (SO_4^{2-}), carbonates (CO_3^{2-}), bicarbonates (HCO_3^-), iron (Fe), calcium (Ca), magnesium (Mg), potassium (K), manganese (Mn), silicon (Si), sodium (Na) and stating the pH value, density, $ChZT_{(Cr)}$, dry remains, undissolved substances, and also the remains after calcination. The chemical composition of injected waste water and simulation of processes occurring when mixing the deposit water with the water injected to the absorption well, performed by means of AquaChem program, demonstrated that colmatage of the near-well zone may be caused mainly due to formation of deposits of calcium carbonate and ferrous compounds. That is why the chemical agents proposed as components of technological fluids aimed to remove the compounds. At first, several acidizing fluid formulas were prepared whose effectiveness was to be verified in flow tests on the core samples. Hydrochloric acid and organic acids: acetic and formic acids were selected as the basis for treatment fluids.

In comparison with HCl, organic acids in carbonate rocks are depleted much more slowly. They also have significantly lower corrosive properties than those of HCl. Both acetic and formic acid may be used in high temperature owing to their low corrosion properties. However, organic acids have certain limitations. First, they cannot be used in high concentrations on account of low solubility of their calcium salts. Therefore, to avoid precipitation of calcium acetate and calcium formate they are used in the following concentrations:

- acetic acid – maximal volume to 13% weight,
- formic acid – maximal volume to 9% weight.

Secondly, organic acids are characterized by low dissociation constant. They do not usually react to total acid capability because they liberate CO_2 from the dissolved carbonate. Thirdly, the volume of created hydrons falls with increased temperature, and lastly – the cost of organic acids is much higher than that of HCl for the same mass of dissolved rock.

A very important thing in acidization is to maintain the iron ions in the solution. Iron ions (Fe^{3+}) begin to precipitate from the exhausted acid at pH equal to 4. However, the ferrous ions (Fe^{2+}) do not yield to precipitation. To prevent the precipitation of hydrated iron

Table 3. Simulation results of removing the damage by waste water injection to the absorption well

Treatment fluid type	Volume of injected acid		Simulation effect
	5 PV	2 PV	[%]
10% HCl + 0.5 g/l stabilizer of iron compounds + 0.5% corrosion inhibitor + 0.2% agent reducing the flow resistivity	X		168.84
		X	94.29
9% HCOOH + 0,5 g/l stabilizer of iron compounds + 0.5% corrosion inhibitor + 0.2% agent reducing the flow resistivity	X		143.79
10% CH3COOH + 0.5 g/l stabilizer of iron compounds + 0.5% corrosion inhibitor + 0.2% agent reducing the flow resistivity	X		99.32
10% CH3COOH + 9% HCOOH + 0.5 g/l stabilizer of iron compounds + 0.5% corrosion inhibitor + 0.2% agent reducing the flow resistivity	X		111.13

oxide ($Fe(OH)_3$) suitable chemical additives are used. In many cases the piping in boreholes is covered with rust or iron (II) sulfide. After acidization with HCl the permeability of the formation may be limited due to repeat depositing of hydrated iron oxide. In order to prevent precipitation, sequestration agents are added to the acidizing fluid. An example of such agent is the iron compounds` stabilizer which prevents the formation of iron hydroxide deposit by reducing the iron ions (Fe^{3+}) to iron (II) ions (Fe^{2+}).

Another chemical agent planned as acidizing fluid component was corrosion inhibitor and micellar surfactant which reduces the flow resistivity and facilitates the process of treatment fluid retrieval.

The acidizing fluids selected for stimulation had the following formulas:

- 10% HCl + 0.5 g/l stabilizer of iron compounds + 0.5% corrosion inhibitor + 0.2% agent reducing the flow resistivity,
- 9% HCOOH + 0.5 g/l stabilizer of iron compounds + 0.5% corrosion inhibitor + 0.2% agent reducing the flow resistivity,
- 10% CH_3COOH + 0.5 g/l stabilizer of iron compounds + 0.5% corrosion inhibitor + 0.2% agent reducing the flow resistivity,
- 10% CH_3COOH + 9% HCOOH + 0.5 g/l stabilizer of iron compounds + 0.5% corrosion inhibitor + 0.2% agent reducing the flow resistivity.

Next, acidization simulation was performed on core samples in deposit temperature 61°C, according to the formula presented above.

The test results are shown in table 3.

On the basis of obtained test results, a stimulation treatment was proposed (matrix acidization) using 9% formic acid, in spite of the fact that in laboratory tests the acidizing fluid made on the basis of 10% hydrochloric acid provided better results of permeability retrieval. The reason for such a decision was the fact that the rock originating from the deposit was not compact enough, easily falling apart, and the grains were poorly cemented.

Formic acid is weaker than hydrochloric acid so its application in acidization was expected not to disintegrate the rock to the extent as to trigger sanding-up of the borehole. After the acidization simulation the cores retained their original appearance. In laboratory tests, formic acid produced equally good stimulation effects as the hydrochloric acid but it also proved to be less corrosive.

The volume of the acidizing fluid for the treatment is calculated on the basis of information on perforation interval, porosity of the deposit rock and diameter of the near-well zone which must be covered by acidization.

Guidelines for performing acidization

The preparation of acidizing formula is complete with the development of guidelines for performing the acidization. The guidelines specify the requirements connected with transportation, storage and use of chemical agents in accordance with the Material Safety Data Sheet (MSDS), and also the method of preparation of the acidizing fluid in the field and the order of mixing the chemical agents.

Since the preparation of acidizing fluid is related to collecting and preparing the basic fluid in the tanks and admixture of particular chemical compounds to it one by one, an essential question is the time of storage of the acidizing fluid in the tanks. Prolonged storage causes corrosion and absorption of corrosion inhibitors on the surface of the equipment so protection of deeply located equipment may be less effective.

Another indication concerns the preservation of absolute cleanliness of the tanks in which the acidizing fluid is prepared. Preparation of the fluid in tanks containing solid residue or remains of previously prepared treatment fluids is prohibited. The presence of contaminants may be the cause of incompatibility of the prepared fluid or its component. The requirement of preserving cleanliness refers to the whole installation for supplying and injecting the treatment fluid.

Summary

The most crucial area of the absorptive horizon of the injection well is the near-well zone. In it occur phenomena which have decisive effect on the character of the well operation. In time, the introduction of colmatage components to the zone along with the waste water leads to reduced porosity and permeability of the deposit rock. The appropriate solution then is the stimulation treatment consisting in clearing the near-well zone.

Planning the treatment of unblocking the near-well zone in order to increase the absorbency of the injection well is a process which requires both the knowledge of technical well details, geological information, chemical composition of absorbed water and waste and also performing a series of tests: both computer simulations and flow tests on core samples.

Simulations of deposit water movements, made with the use of AquaChem software allow to determine the possible directions of processes occurring while the waters get mixed and contact the deposit rock and to describe the type of chemical compounds which might adversely affect the work of injection wells.

The effectiveness of selected fluids for the treatment of clearing the near-well zone is inspected in laboratory tests performed on the core samples from the deposit rock in which stimulation treatment is planned, preserving the conditions similar to those in the borehole (pressure and temperature).

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FEM – Fugitive Emission Monitoring

Health, Safety and Clean Environment

Robert Paradysz

Fugitive Emissions of Volatile Organic Compounds (VOC) is a serious problem in many industries, particularly those dealing with oil and natural gas. Therefore, monitoring of fugitive emissions is becoming a strategic goal.

The issue of fugitive emissions comprises all kinds of leaks of substances and products which occur in installations, pipelines and their connections, flanges and regulation equipment armature, such as: pumps, valves or monitoring equipment and measuring and control apparatus.

On account of specific work conditions (high pressures and temperatures, aggressive work environment which induces corrosion and vibrations) and ageing of sealing materials, the effect of loss of containment in installations may occur very fast. These are the sources of fugitive emissions.

Legal regulations connected with fugitive emissions

The European Directive related to industrial emissions – *Directive 2010/75/EU, Integrated Pollution Prevention and Control* refers e.g. to reduction of emission of volatile organic compounds. The document which defines the methods for emission reduction is the BAT document (*Best Available Techniques*). The section of the document which discusses VOC monitoring contains computational directives and measurement methods which may be applied in monitoring of fugitive emissions of volatile organic compounds

The European Directive and its implementation in Poland will impose on industries the duty to monitor the fugitive emissions.

What is Fugitive Emission Monitoring?

Fugitive emissions are monitored in conformity with methodologies developed by the European Committee for Standardization (CEN) according to the European Norm EN 15446 and American EPA norms.

Program LDAR (*Leak Detection and Repair Program*) consists in quantitative measurement of VOC from defective sealing with the use of FID (Flame Ionization Detector). Obtained leak values in ppm, converted to volumetric flow rate, allow to determine fugitive emission in a specific period of time. Implementation of periodic monitoring of fugitive emission from installations, identification of defective equipment and leak sources, using the results to create repair programs and emission data management are the main stages of the complete LDAR program.

What are the main advantages of LDAR program?

Fugitive emission monitoring considerably affects the human health and safety issues; it reduces negative impact on the environment and it is an excellent tool which can be used in the maintenance and renovation of installations. Moreover, it can serve as perfect *benchmarking method*.

It is beneficial for health, safety and environment:

- It reduces the olfactory substances emission in the plant,
- It improves the environment conditions in the plant vicinity,
- It improves health and safety of the workers,
- It reduces the occurrence of potentially explosive areas,
- It improves the air quality by reducing contamination which affects the ozone layer,
- It is consistent and in conformity with binding regulations concerning the monitoring of VOC and other toxic gases.

Maintenance and renovation of installations:

- It contains information related to technical condition of connections and changes advancing with time,
- Using the database of defective sealing for renovation campaign may reduce fugitive emission even to 90%,
- It reduces the product loss and has a positive effect on the savings.

The difference between measurements with FID detector and infrared camera

Very often, apart from using the FID detectors, integrated programs for detection and monitoring of fugitive VOC emission also use infrared cameras.

Standardized methodology based on EN 15446 and EPA 21 directives, called *sniffing*, aims to detect all leaks – regardless of their volume. This is a quantification method, so it may serve to determine the technical condition of connections, armature and equipment and the changes advancing in time.

Leak tests with the use of an infrared camera only provide information on the occurrence of leaks, but no quantitative information is given. Such tests may be used as tentative information on leaks and it may be part of a campaign promoting periodic monitoring of fugitive emission using the extensive LDAR program.

Fugitive Emission Monitoring and operation of Bureau Veritas

In the recent 20 years of operation Bureau Veritas specialized in controlling of VOC and other gas emission in industrial areas. It may be stated that it became the leader in this sector, due to:

- active membership in the European Committee for Standardization (CEN),
- contribution to the European emission standards (norm EN 15446),
- development of software for computing the VOC emission in conformity with the norm EN 15446,
- participation in meetings of the committee X43B AFNOR (the French Standardization Organization) in the years 2009–2011 – executing projects related to VOC emission and drawing up instructions for testing it with the use of infrared cameras,
- creating an advanced *online* system (GEF) to collect data and make them available to their clients, and also
- highly qualified professional staff.

Bureau Veritas is the leader in respect of measurements of VOC emission (such as: SF_6, NH_3, H_2S, H_2, N_2), measurements of emission from the surface of water table, and also detection of gas leaks in underground grids, on the ground and in storage reservoirs using e.g. laser methods.

The author is Manager of HSE Services at Bureau Veritas Polska Sp. z o.o.

Bureau Veritas is the world leader in TIC (Testing, Inspection and Certification), providing high quality services aiming to assist the clients in meeting constantly increasing requirements connected with management of quality, occupational safety and health, environment protection and social responsibility.

The application of modern chemical synthesis in research carried out at INiG – PIB

Modern chemical synthesis – manufacture of oil additives

Wojciech Krasodomski, Jarosław Markowski, Wojciech Mazela, Michał Pajda, Michał Wojtasik, Leszek Ziemiański, Grażyna Żak

Modern chemical synthesis used at the Oil and Gas Institute – NRI Department of Additives and New Chemical Technologies is a significant part of scientific research and R&D activities regarding among other things the development of technology for manufacturing additives for fuels, biofuels, lubricants and oil products.

Modern organic synthesis

Surfactants

Surfactants being tested at the Department of Additives and New Chemical Technologies of the Oil and Gas Institute – National Research Institute, are used as detergents in hydrocarbon fuels to protect ZI (spark ignition) and ZS (self-ignition, Diesel) engines against accumulation of oil sludge and carbon deposits on injectors, spray nozzle tips and fuel pumps, that may affect optimal operation of combustion engines and lead to failure. In addition, surfactants are also used as emulsifiers and demulsification agents both in hydrocarbon fuels and in chemical additives enhancing oil and gas extraction. At Oil and Gas Institute – NRI Department of Additives and New Chemical Technologies also research is carried out on developing effective demulsifiers to separate emulsions formed during oil extraction and processing.

The surfactant group distinguishable for its application are dispersants used for example in developing compatible additive packages. The work on such substances required not only the expansion of technological facilities of the Oil and Gas Institute – NRI Department of Additives and New Chemical Technologies but also analytical and testing equipment.

There are various methods, including the use of surfactants of detergent activity, preventing unfavourable phenomena connected with deposits formed during fuel use. The application of such substances (additives) does not interfere the mentioned chemical processes but prevents the accumulation of generated deposits and removes the existing ones (such actions are called *keep clean* and *clean up*). The operation of such substances consists in creating a protecting film on the metallic surface that prevents deposit precursors to be formed. The chemical substances used as active substances of detergent activity are organic compounds of defined constitution containing nitrogen atoms. Due to its structure such compounds are of strong polarity and this feature, on the one hand, provides detergent properties and on the other hand enables adhesion to the metallic surface. Moreover, detergent additives should have appropriate thermal resistance and be compatible with a fuel and other additive constituents and motor oils. At the INiG – PIB Department of Additives and New Chemical Technologies the work is continued on chemical reac-

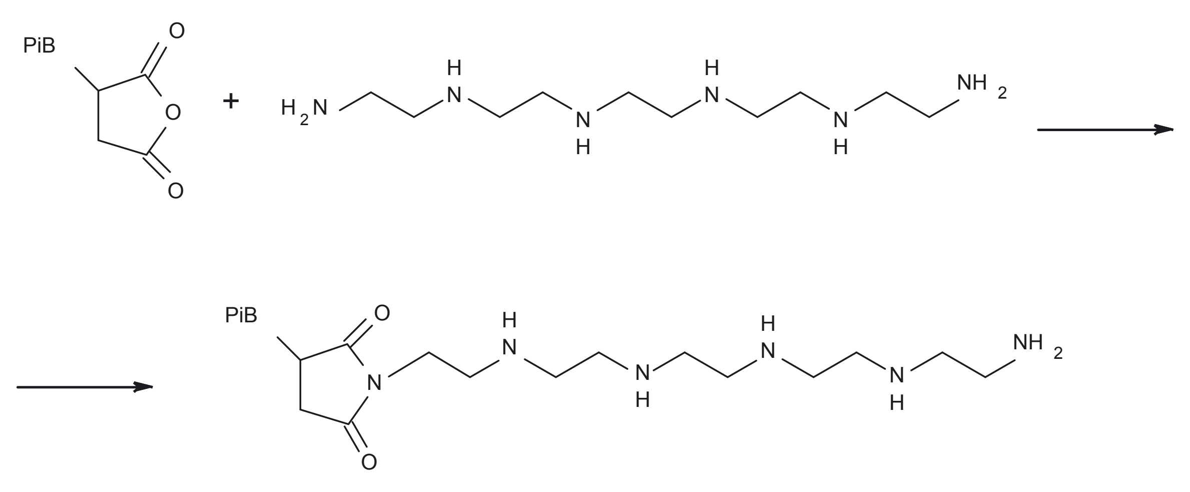


Fig. 1. Schematic of alkenylsuccinic imide formation

tions bringing such detergent substances as alkenyl succinate imidoamides, dicarbamates and Mannich bases.

The results obtained at the Department place the active detergent substances developed and synthesized at the Oil and Gas Institute – NRI according to the original technologies among the best products of such type all over the world. These substances as well as fuel additive packages containing them are the subject of patent applications submitted by the Oil and Gas Institute – National Research Institute.

Detergent additives to fuels

Modified alkenylsuccinicimidoamides are derived from anhydrides of alkenylsuccinic and polyalkylene in the process consisting in acylation of polyalkylene polyamines with alkenyl succinic anhydride.

The research carried out at the Oil and Gas Institute – NRI, both own and scientific and research projects co-financed from the funds of the National Research and Development Centre allowed the development of modern fuel additives and packages. The latest achievements regarding succinic imides /amides are the subject of the patent application P.391098 and patent PL215447 2013.

The Mannich bases used for example as components of additives for hydrocarbon fuel and lubrication oils, are detergent and dispersing agents responsible for cleaning and preventing contamination of engine parts and are also used as friction reducing oil additives.

The work carried out at the Oil and Gas Institute – NRI includes Mannich reactions consisting in condensation of phenol derivatives, amines and aliphatic polyamides and formaldehyde – these reactions are made in neutral or basic environments.

The syntheses of Mannich bases are conducted under classical one-pot analysis, continuous analysis by using a flow microreactor with the aid of microwave irradiation.

The reactions of alcoholysis and ammonolysis of isocyanates are used in the technology of carbaminate and carbamide detergent fuel additives.

> Adverse phenomena of residue formation in engines may be prevented in different ways, e.g. using substances acting as detergents

The follow up reactions pose a problem, since resulting monocarbamates may react with unreacted toluene diisocyanate or react with each other forming high-molecular products.

At the Oil and Gas Institute – NRI Department of additives and New Chemical Technologies the re-

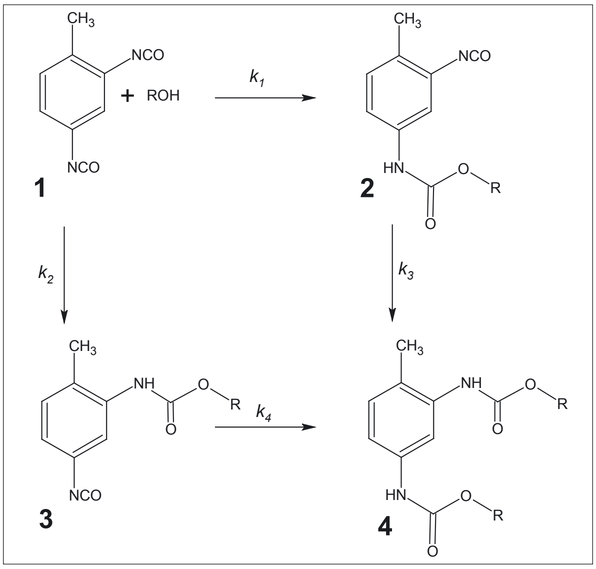


Fig. 2. Formation of mono- and dicarbamates

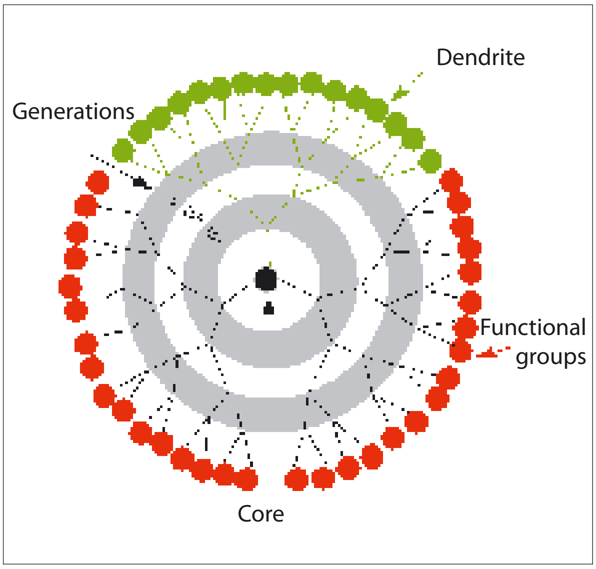


Fig. 3. Scheme of dendrimer structure

search is conducted on the run and conditions of diisocyanate alcoholysis to obtain nonequivalently substituted dicarbamates and carbamate/urea. Recently the conditions of controlled alcoholysis of toluene diisocyanate were examined thoroughly, and appropriate reactor systems were developed and a series of experiments were made to optimise the syntheses. The scientific and research project completed at the Oil and Gas Institute – NRI and co-financed by the NCBiR allowed modern additives and packages to be developed. The newest technologies developed to obtain carbamate petrol additives are the subject of patent applications P.406549 and P.406672.

Dendrimers as demulsifiers

At the Oil and Gas Institute – NRI Department of Additives and New Chemical Technologies the work is also carried out on separation of emulsions formed during oil extraction and processing. Among various active substances enabling emulsions to be separated effectively, syntheses compounds of dendrimeric structure (Fig. 3) are investigated. Such compounds differ in their specific structure from classical linear, cross-linked and branched polymer groups. The characteristic dendrimer feature is its strictly established structure and type of functional groups located on the dendrimer surface and ability to design the chemical nature of the denrimer interior.

It results from the research carried out that in some cases the use of demulsifiers containing dendrimers allowed high demulsifier efficiency to be maintained at lower share of active constituent (dendrimer). In addition, it is possible to increase the rate of emulsion separation. Compared to classical demusifiers based on phenol compounds, dendrimers pose no such significant environmental hazard.

Imidazolines as corrosion inhibitors

Imidazoline derivatives are used, among other things, as active substances in corrosion inhibitors to protect equipment in the oil and gas extraction industry. At present the Oil and Gas Institute – NRI Department of Additives and New Chemical Technologies carries out studies on synthesis of new compounds of imidazolne structure. At the above department a new method for manufacture of these substances was developed, while specifying stoichiometry precisely and process conditions. The obtained new mixture of modified imidazoline derivatives can be used as a constituent of corrosion inhibitor compounds in the oil and gas exploration industry, in oil refineries and as an additive in diesel fuels and heating oils, cutting fluids and a component of agents for temporary metal protection against corrosion.

Nanotechnology

At the Oil and Gas Institute – NRI Department of Additives and New Chemical Technologies studies are also carried out in nanotechnology. They concern the application of carbon nanomolecules such as nanotubes or graphene in fuels and lubricants and nanodispersion of metal oxides as additives of FBC type (*Fuel Born Catalyst*).

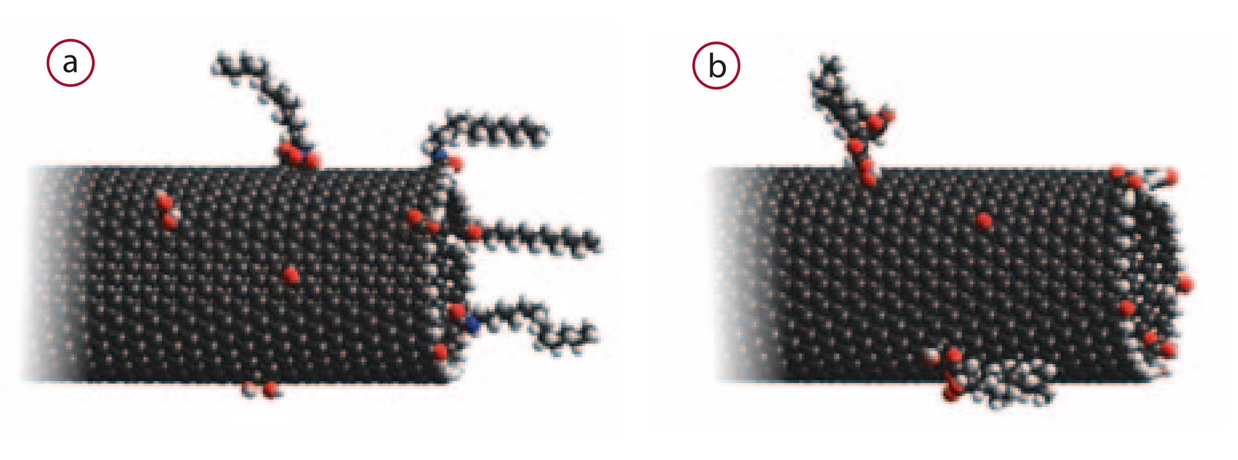


Fig. 4. Structure of model single-wall nanotube of approx. 2 nm in diameter: a) modified with amide groups, b) modified with ester groups

Graphene and nanotube chemical modifications

Nanotechnology based on carbon structures enables this compound group to be used to enhance properties of oil products.

So far, besides analysing the possibility to obtain diesel oil dispersions by using unmodified carbon nanotubes and employing various dispersers and dispersion methods, in the work carried out at the Oil and Gas Institute – National Research Institute also focuses on various nanotube modification methods to introduce amide and ester groups into nanostructures (Fig. 4).

Both the data available in the literature and the obtained results indicate that chemical modification of nanotubes may lead to industrial application of nanomolecules as oil product additives. Due to chemical modification the ability of nanotubes to make dispersions is increased. It was found that all such dispersions feature a relatively high stability, longer than 60 days.

Nanocarbon thickeners in lubricants

During research on chemical modifications of carbon nanomolecules also reactions of oxidized nanotubes are analysed to obtain structures modified with carbamates that can be used as grease thickeners.

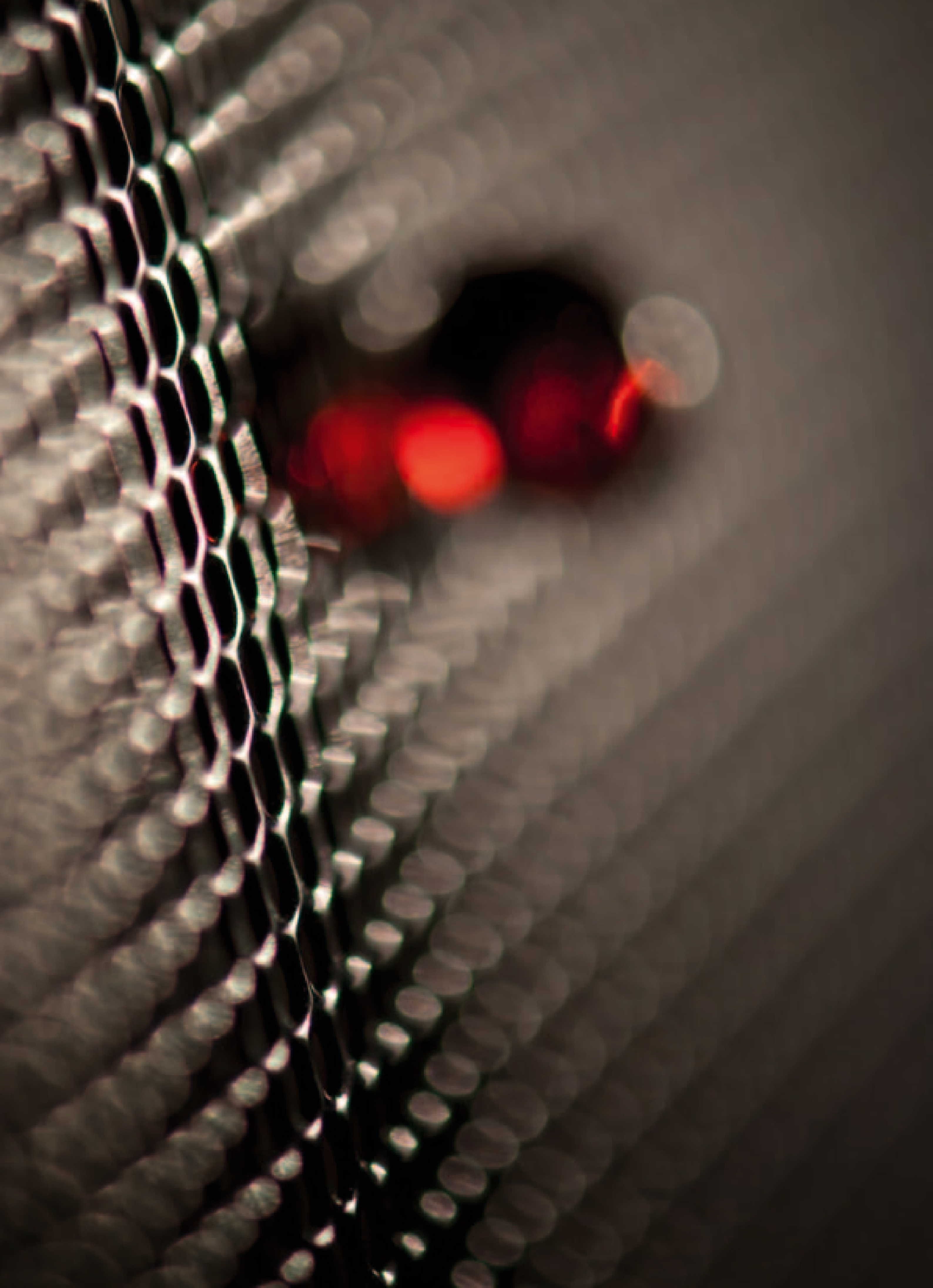
The modifications consisting in creating carbamate bonds between nanotubes and carbamides.

Nanostructures of iron oxides as combustion modifiers

On all over the world the regulations aimed at reduction of hazardous exhaust emissions are continuously introduced and reviewed to become more stringent, while considering particulate matter emission (PM). The use of additives of FBC type (*Fuel Born Catalyst*) to enhance heating oil reduces the volume of toxic constituents of exhaust gases emitted into the atmosphere. The mechanism of oxidising organic constituents of exhaust gases by using catalysts of FBC type is a highly complicated process that has not been understood thoroughly yet.

> Modern chemical synthesis used at the Oil and Gas Institute – NRI Department of Additives and New Chemical Technologies is an important part of scientific and research work targeted, among other things, at developing technology of manufacture of additives for fuels, biofuels, lubricants and oil products.

When completing the Oil and Gas Institute – NRI scientific and research projects (along with those co-



financed by the NCBiR) a technology of manufacture of combustion modifiers of FBC type used in fuels was developed (patent PL208478 and patent application P.398652) and in heating oil (patent applications P.391334 and P.404521) to reduce the emission of particulate matter. For diesel oils the FBC additives are used also as catalysts to regenerate dust particle filters (DPF). The combustion modifiers as well as packages of fuel additives containing them are the subject of patent applications submitted by the Oil and Gas Institute – NRI.

The combustion modifiers of *Fuel Born Catalyst* type of high efficiency, used as additives in diesel and heating oils and improving combustion of carbon molecules and hydrocarbons, contain FBC precursors in the form of completed nonstoichiometric iron nanooxides and/or nanohydroxides and/or nanooxyhydroxides completely and unlimitedly soluble or dispersible in fuels and an organic disperser – being aliphatic and/or aromatic acids of mono- and/or dicarboxyl or its derivatives.

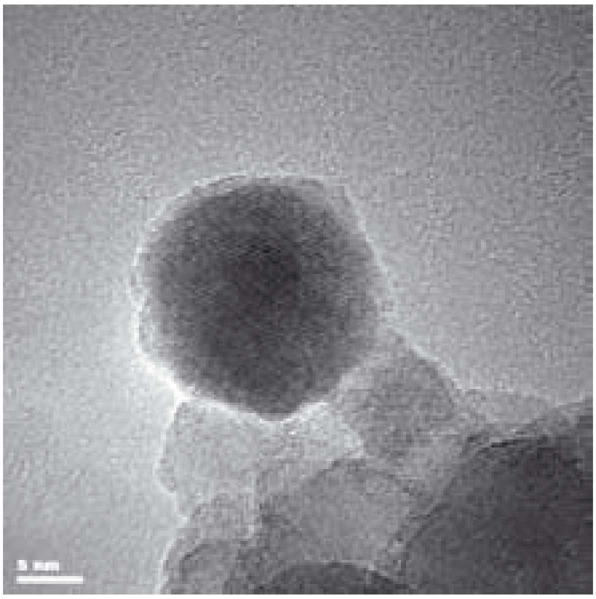


Fig. 5. High resolution (TEM) structure of FBC – scale 5 nm

The use of ionic liquids as catalysts

Another question being the aim of tests carried out at the Oil and Gas Institute – NRI Department of Additives and New Chemical Technologies is the use of ionic liquids in synthesis of additives. In refinery and petrochemical industries ionic liquids are used in the following processes:

- selective extraction and excretion of aromatic hydrocarbons from aromatic and aliphatic mixtures, namely benzene, toluene, ethyl benzene and xylenes from mixtures of hydrocarbons C_4 to C_{10},
- olefin separation from dienes,
- engine fuel desulphurisation,
- oligomerization and polymerisation (Dimersol and Difasol processes developed by the IFP),
- hydrocarbon alkylating and isomerization,
- carbonylation,
- olefin epoxidation.

During the work carried out at the Oil and Gas Institute – NRI reactions of carbamate modifications of the ionic liquids were used with anions of triflate nature to introduce the 2-propanolamine structure into carbamate. Currently, tests are being carried out on the use of ionic liquids as catalysts in esterification reactions.

Summary

Modern chemical synthesis used at the Oil and Gas Institute – NRI Department of Additives and New Chemical Technologies is an important part of scientific and research work targeted, among other things, at developing technology of manufacture of additives for fuels, biofuels, lubricants and oil products. In addition, it is also used in researches on active substances in chemical agents enhancing oil and natural gas extraction, including shale gas – these task are performed in cooperation with other research units of the Institute. Modern synthesis brings a significant rationalisation component necessary for developing innovative patented solutions that could be implemented in industrial practice. Tests that use modern chemical synthesis are possible due to competences of the research staff and modern-minded director and analytical equipment of the Oil and Gas Institute – NRI Department of Additives and New Chemical Technologies.

Authors are employed as researchers at the Department of Additives and New Chemical Technologies of the Oil and Gas Institute – National Research Institute.

Financial crimes and fuel quality monitoring

Fuel crime

Beata Altkorn

Once in a while, the media report cases of detecting one more fuel mafia. What crime does the business involve? In the harsh days of the Polish People's Republic, tanker drivers were generally suspected of illegal sales of transported fuel and refilling shortages with water – often from the nearest ditch. It was a widespread fraud and the only "fuel mafia" of that period was a gang stealing mostly state-owned fuel.

Several decades have passed since that time and both the fuel has changed and tax regulations. Poland joined the European Union. Despite the fact that fraud and violations of the law concerning fuel have evolved over the years, basically they are still tax offences related to tax settlements. They can be divided into three groups:

- fictitious invoicing,
- tax carousel,
- extortion of excise duty.

Financial crime in the fuel sector is a huge loss to the state budget. Officially, it is estimated that in 2013 the losses only due to unpaid taxes on the fuel sold amounted to PLN 4 billion [1]. Economy-related crime violates fair competition in the fuel market; it therefore also negatively influences entrepreneurs pursuing their activities in accordance with the law. An infringement occurs mainly in the case of business importing fuel from abroad in order to introduce it to the market in the country.

> Financial crime in the fuel sector is a huge loss to the state budget. Officially, it is estimated that in 2013 the losses only due to unpaid taxes on the fuel sold amounted to PLN 4 billion.

Shadow economy is the financial area of the economy of a country in which income is earned from activities not prohibited by the law but the profits from which are hidden as a whole or in part from the state authorities, tax, customs, etc. It can be said that it is illegal trade in legal goods, including motor fuel. Do not confuse shadow economy with black market which includes illicit trafficking in illicit goods [2]. According to the POPiHN [Polish Organization of Oil Industry and Trade] estimates, shadow economy in the domestic diesel market has already exceeded 10% of deliveries [3]. The size of the process is rather alarming. The largest part of shadow economy is associated with the so-called tax carousel.

Tax carousel, i.e. carousel fraud, uses the EU rules transferred to the Polish law. It's VAT fraud within the EU (transactions frequently take place in at least two EU countries), they consist of multiple export and re-import of the same goods (sometimes they are just invoices and shipping documents – without products) via a complex supply chain [4].

Table 1. Number of concessions granted for various fuel market operations [7]

Liquid fuels	Valid concessions, end of 2013 [items]
Production	69
Storage	52
Transfer	2
Trade	8747
Total	**8870**

Table 2. Fuel consumption in Poland in 2012

Fuel	Consumption in 2012 [thousand tons] [8]
diesel fuel	11 313
motor gasoline, total	3 768
LPG	2 150 [9]
Bio-fuel – ester constituting independent fuel (B100)	66

The carousel works according to the following scheme (in a simplified version which includes only a single fuel trading in the carousel and only four of its elements) [5, 6]: the fraudster is the so-called "missing trader", a dummy corporation which does not pay the VAT. The entity is generally registered by figureheads who do not have funds secured to conduct business. Virtual businesses register their activity under a fictitious address or in a place where the business is not actually conducted, and they often change the seat without notifying any competent office. Persons mentioned in registration documents as authorized to represent the company are impossible to locate. After several fuel transactions in the carousel and earning the unpaid amount of VAT – before the tax authorities begin to show interest in the business – the company disappears without a trace. At the same time, other national entities in the chain deduct the tax calculated, extorting the tax amount. There can even be a dozen of such entities in one carousel.

According to the Energy Regulatory Office (ERO), in the fuel market in Poland there are nearly nine hundred legitimate operators. This is a very large number. Among the legitimate operators there are also the mentioned virtual businesses legally registered for illegal activities. It is difficult to estimate how many entities operate without a license, that is illegally.

It can be concluded then that this type of fraud is very far from the citizens` traditional concept of adulteration of fuels by pouring.

The Poles own more and more cars and travel more and more. In 1989, only 327.000 cars travelled on the national roads. The data of the Central Register of Vehicles and Drivers indicates that currently there are as many as 19.3 million vehicles officially registered in Poland. Fuel consumption in our country in 2012 is shown in Table 2.

Each vehicle has regularly its tank fueled at one of the approximately 6.750 filling stations located in Poland. Where, then, are drivers most likely to buy adulterated fuel which may damage the engine?

Fuel quality monitoring in Poland

The overriding system of fuel quality monitoring in Poland is the government system for which the responsibility lies with the President of the Office of Competition and Consumer Protection [OCCP] who operates via Trade Inspection. In 2013, the OCCP has inspected total of 1.651 fuels and companies, 56 fuel wholesale facilities and 32 businesses producing and storing fuel. Given the total number of stations, approximately 6750 facilities, less than 25% of all entities were inspected. A total of 1851 samples

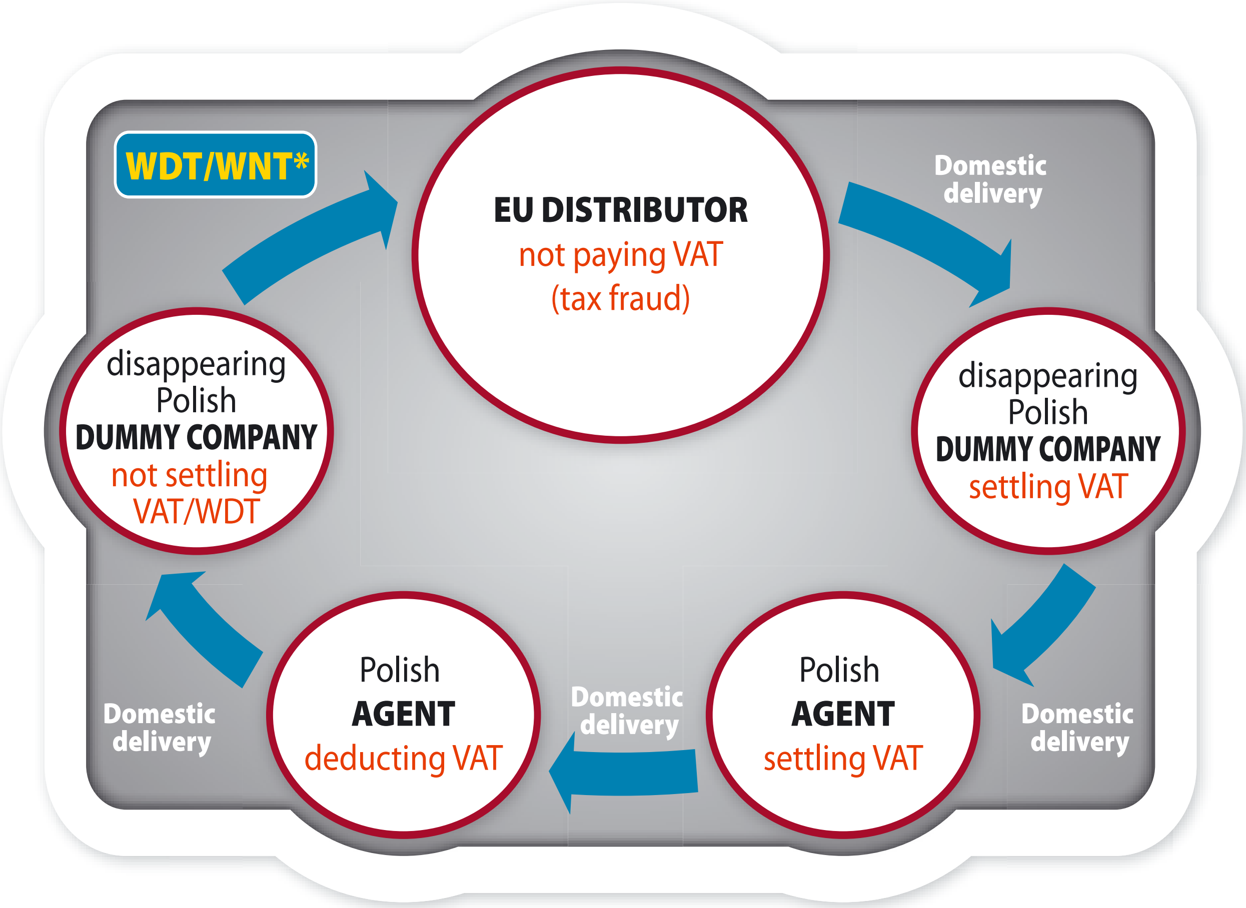


Figure 1. Diagram of the so-called tax carousel [6]
* WDT – in-Community supply of goods, WNT – in-Community acquisition of goods

were taken for laboratory analyses at that time. Currently, there are two inspection systems: European and the national system. They differ in terms of the kind of inspected fuels, as well as the scope of qualitative tests. LPG is inspected only by the national system.

In the European system, fuel characteristics are inspected within a limited range of parameters including only the qualitative framework necessary for the purposes of reporting to the EU. In the national system, fuel quality inspection is carried out in the full scope of quality parameters and results are submitted to the Council of Ministers. The way the stations/companies are selected for inspection is also different: in the European system it is done randomly, while in the national system, stations are also examined on the basis of reports from customers suspecting poor quality of the fuel sold.

Polish and foreign concerns, as well as those belonging to the network of hypermarkets, care about the quality of fuels sold in the networks of corporate and franchised stations, covering them with their own, additional quality monitoring system. It is implemented by accredited laboratories which – acting in accordance with the powers of attorney granted – perform unannounced sampling of all types of fuel at the stations, several times a year. In the case of irregularities, owners of the station networks know the adequate procedures and can quickly react to any deviations from the standard quality of fuels sold at their stations.

In the case of stations clustered in independent networks and a significant group of non-affiliated stations, the situation is much worse. Theoretically, there is a system to control fuel quality at such stations, which is called the "Golden Drop" (the system is under the supervision of the Polish Chamber of Liquid Fuels), designed for businesses whose fuel can be subject to verification, provided that station owners are members of the Chamber. In practice, however, the proportion of paid system members is negligible compared to the number of non-affiliat-

Table 3. Ownership of fuel stations in Poland

Stations' owners	Number of stations (including franchise stations)
Unaffiliated businesses or affiliated in independent networks	ca. 2940
Polish Oil Company ORLEN S.A. (including the BLISKA stations)	ca. 1780
Lotos SA Group (including the Optima stations)	ca. 440
Foreign companies, including:	ca. 1420
BP	ca. 460
Shell	ca. 460
Statoil (including the 1-2-3 stations)	ca. 350
Lukoil	ca. 115
Stations owned by chain stores (Carrefour, Auchan, TESCO, Intermarché, E. Leclerc and other)	ca. 170
TOTAL	**ca. 6750**

Source: www.popihn.pl – Filling stations in Poland, 2006-2013

ed stations that have not acceded to this voluntary program.

In 2013, the OCCP inspections "caught up" a total of 65 entities (service stations, warehouses, site stations), with proven marketing of liquid fuels of quality incompatible with current specifications. The number of revealed cases was similar to that in 2012, when 75 such cases were found. Given that about 40% of all stations are not affiliated and therefore they are not subject to any additional (outside the governmental) system to monitor and control the quality of fuels (annually, only about 24% of all stations are inspected under the governmental system), the probability of purchasing adulterated fuel at such a station is pretty high.

Inspection activities, though not related to fuel quality, are also conducted by the Customs Service through customs offence departments, supervision units and Customs agencies – in 2013, as a result of fuel inspection, including tanks of vehicles, the total of more than 57 000 fines for irregularities were issued [10].

Where are drivers most likely to encounter poor quality fuel?

The answer to this question is quite obvious: at any station located on a busy transit route. The driver filling up the car tank will only find out the problem a few dozen or a few hundred kilometers away. The chance that they come back to the station to demand compensation is rather small.

What fuels are adulterated? The least likely is LPG adulteration – it is transported, stored and sold under pressure, which prevents the admixture of any illegal components. You can, of course, come across a batch of poor quality fuel, but it will not be adulterated fuel. By far, diesel is the most adulterated fuel. This is due to the nature of modern fuels.

Even a quarter of a century ago, the answer to the question "What is diesel oil made of?" would certainly be: crude oil. Nowadays, however, diesel fuel is a composition of a few or several components of which only some are direct fractions derived from petroleum. The components of diesel fuel include:

1) petroleum fractions produced in the process of conservative distillation and destructive processing of crude oil and other refining processes,
2) fractions obtained in the processing of used oils,
3) fractions from decomposition of waste plastic material,
4) synthetic fractions,
5) bio-components.

In addition to components and bio-components, diesel oils also contain refining additives which improve lubrication and demulsifying, anti-corrosive, anti-foaming, anti-oxidation, low temperature and washing properties of fuels and enhance the cetane number; these fuels may also contain biocides. Adulterated diesel does not usually contain such additives, or they are present in trace amounts (depending on the type of adulteration made), so the physicochemical and performance properties of adulterated oil differ significantly from those typical of proper fuel.

Motor gasoline may also contain up to a dozen of different components, however, they are less diverse in terms of origin of these components, because they contain:

1) petroleum fractions arising from conservative distillation and destructive crude oil processing or other refining operations,
2) bio-components.

Currently used motor gasoline additives are aimed at, inter alia, preventing corrosion of metal components of the fuel system, fuel protection against oxidation during storage, as well as maintaining the cleanliness of the combustion chamber, injectors and valves.

According to the Law of 10 June 2014, amending the Act on monitoring and controlling the quality of fuel and other laws:

- motor gasoline contains up to 10.0% of bio-components by volume or to 22.0% of ethyl tert-butyl ether or ether tert-amyl ethyl by volume,
- diesel contains up to 7.0% bio-components by volume.

Bio-components for use in liquid fuels include bio-ethanol, bio-methanol, bio-butanol, FAME ester, bio-ether di-methyl, pure vegetable oil and liquid organic hydrocarbons. They are produced from biomass for the manufacture of liquid fuels or biofuels [11].

Legal production of motor fuel is based on a suitable choice of hydrocarbon fractions obtained in the above mentioned processes and bio-components and refining additives. The finished product must comply with the following standards: for petrol – PN-EN 228 or for diesel fuels – PN-EN 590. Adulteration of motor fuel is to generate profits, regardless of the quality of the product.

Considering the fact (especially in the case of diesel) that the number of legally added components is large, which can result in changing the parameters, such as appearance and odor, sometimes fuel users unnecessarily suspect the seller of adulteration of the products. It is still legal fuel, although it can be of poor quality.

Can we recognize adulterated fuel?

The area for criminal activity was created due to differentiation of excise rates for individual products – the rate of excise tax for fuel oil is much lower than for diesel. Extortion of excise tax is made by:

- adding non-excise components intended for other use than for motor gasoline to legal motor fuels,
- mixing different non-excise components in order to create products with properties similar to motor fuels,
- the sale of gasoline or diesel fuels purchased as non-excise products not intended for spark-ignition engines as motor gasoline,
- discoloration of colored light fuel oil and selling it as diesel fuel.

> From the point of view of the vehicle user – there is no big difference between legal fuel of poor quality (which occurs quite frequently) and the illegal product of poor quality.

Sometimes criminal groups cooperate with chemists with high expertise in the area of fuel, which makes the illegal product almost indistinguishable from the legal fuel with respect to fundamental physicochemical properties. Only comprehensive testing for compliance with current specifications or the use of non-standard testing methods with advanced instrumental analysis allow the detection of fraud. It

should also be remembered that – from the point of view of the user of the vehicle – there is no big difference between legal fuel of poor quality (which occurs quite frequently) and the illegal product of poor quality. In both cases, the result may be the same – damaged engine of the vehicle.

Analytical laboratory practice shows that the samples of adulterated gasoline can include all kinds of illegal components, like e.g. naphtha-based solvents, a mixture of aromatic hydrocarbons (e.g., toluene, xylenes, farbasol), a mixture of chemical recovery of hydrocarbons from coal, alcohols (isobutanol, methanol) and ethers (mainly MTBE).

Once, the most common fraud in respect of diesel fuel was discoloration of tinted and labeled fuel oil and selling it as diesel fuel. Currently, the most common fraud is buying non-excise form oil in Poland or abroad (this is the oil release agent used in the manufacture of ceramic products), or formwork oil (facilitating the separation of formwork from the product) which are similar in terms of component composition and fundamental physical and chemical properties to diesel fuel, but do not contain the appropriate additives. As a result of several rounds of reselling the same batch of product, sequentially to different companies, (tax carousel) the origin blurs and the change of qualifications for diesel takes place – which allows the introduction of this product on the market as a motor fuel.

Such phenomena can, of course, be prevented. An example would be an operation aimed at limiting the VAT-related offences, conducted from mid-June this year, jointly by fiscal inspection, the Border Guard, the Road Transport Inspection and Police. The Customs Service checked the tank with diesel fuel imported into Poland from Lithuania and Belarus in order to determine who is the real recipient of the fuel and whether the companies introducing oil onto the Polish market pay VAT and excise for it. In just a few days of the operation the number of tankers coming from Lithuania decreased from about 300 to several dozen per day [12]. The situation should also be improved by this year's amendments to some legislative acts in the area of fuel, which are to hinder illegal dealings.

What is left for fuel users, unconscious whether the fuel they buy is legal or not? Whenever fuel adulteration is suspected, the Inspectorate of Commerce or the relevant services can be notified. Sometimes, however, there are cases when bad fuel quality in the vehicle tank is caused neither by the manufacturer nor is it due to criminal activity. In the laboratory of the Oil and Gas Institute – National Research Institute, scientists have to deal with situations when buyers come with a sample of "adulterated" diesel fuel which caused a very serious failure of their vehicle. Results indeed show a very poor quality of the fuel and confirm its devastating impact on the power system of the vehicle. The explanation of the problem, however, turns out to be trivial and has nothing to do with adulteration: after having the car tuned at a specialist tuning workshop, the driver did not shut the fuel inlet flap. And this is where the human factor is involved: the painters working in a room next to the workshop got rid of gasoline – a solvent in which they soaked up their brushes, pouring the liquid into the fuel tank of the customer's car.

The author is a researcher at the Department of Petroleum Analysis at the Oil and Gas Institute – National Research Institute

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7) Report on the activities of the President of the Energy Regulatory Office in 2013, Warsaw, April 2014.
8) The annual summary report for the European Commission on the quality of fuel in 2012, the OCCP, Warsaw 2013.
9) Annual Report of the Polish LPG Association 2013, WARSAW 2014.
10) Statistical Bulletin of the Customs Service, first and fourth quarters of 2013, the Ministry of Finance, Warsaw, April 2014.
11) The Act of 25 August 2006 on components and liquid biofuels, consolidated text on the basis of Journal of Laws of 2013, item 1164, Journal of laws 2014, item 457
12) http://www.mf.gov.pl/kontrola-skarbowa/wiadomosci/komunikaty/-/asset_publisher/2UWl/content/id/9292015

Oil consumption [million tonnes]

Country	2005	2006	2007	2008	2009	2010	2011	2012	2013	Change 2013 over 2012 r.	2013 share of total
US	939.8	930.7	928.8	875.4	833.2	850.1	834.9	817.0	831.0	2.0%	19.9%
Canada	99.9	99.4	102.3	101.2	95.0	101.3	105.0	104.3	103.5	–0.5%	2.5%
Mexico	90.8	89.7	92.0	91.6	88.5	88.5	90.3	92.3	89.7	–2.6%	2.1%
Total North America	**1130.5**	**1119.7**	**1123.1**	**1068.2**	**1016.7**	**1039.9**	**1030.2**	**1013.6**	**1024.2**	**1.3%**	**24.5%**
Argentina	20.7	21.7	24.0	24.7	24.1	26.9	26.9	28.5	29.4	3.6%	0.7%
Brazil	94.2	95.8	101.8	108.6	109.1	118.1	121.9	125.8	132.7	5.8%	3.2%
Chile	11.8	13.2	17.0	17.8	17.4	15.4	16.8	17.3	17.6	2.0%	0.4%
Colombia	10.5	10.7	10.7	10.7	11.0	11.6	12.4	13.4	13.9	4.0%	0.3%
Ecuador	7.9	8.3	8.5	8.7	8.9	10.3	10.5	10.9	11.6	6.3%	0.3%
Peru	7.1	6.9	7.1	8.0	8.1	8.5	9.2	9.5	10.0	5.3%	0.2%
Trinidad & Tobago	1.2	1.4	1.7	1.8	1.7	1.9	1.7	1.7	1.8	6.3%	‡
Venezuela	28.3	29.5	29.7	33.8	34.2	32.1	31.9	33.0	36.2	10.2%	0.9%
Other S. & Cent. America	60.4	61.1	61.6	58.7	58.0	58.4	59.0	59.1	58.4	–1.0%	1.4%
Total S. & Cent. America	**242.1**	**248.6**	**262.1**	**272.8**	**272.5**	**283.2**	**290.5**	**299.2**	**311.6**	**4.4%**	**7.4%**
Austria	14.0	14.2	13.4	13.4	12.8	13.4	12.5	12.5	12.5	0.6%	0.3%
Azerbaijan	5.4	4.8	4.5	3.6	3.3	3.2	4.0	4.2	4.6	9.8%	0.1%
Belarus	7.5	8.8	8.0	7.9	9.3	7.5	8.6	8.6	8.7	0.7%	0.2%
Belgium	33.5	33.4	33.7	36.8	32.2	33.5	32.3	30.4	31.0	2.5%	0.7%
Bulgaria	4.8	5.0	4.8	4.8	4.3	3.9	3.8	3.9	4.1	4.2%	0.1%
Czech Republic	9.9	9.8	9.7	9.9	9.7	9.2	9.0	8.9	8.6	–3.9%	0.2%
Denmark	9.2	9.4	9.4	9.3	8.3	8.4	8.3	7.8	7.8	0.5%	0.2%
Finland	11.0	10.6	10.6	10.5	9.9	10.4	9.7	9.0	8.9	–1.7%	0.2%
France	93.1	93.0	91.4	90.8	87.5	84.5	83.7	81.0	80.3	–0.6%	1.9%
Germany	122.4	123.6	112.5	118.9	113.9	115.4	112.0	111.4	112.1	0.9%	2.7%
Greece	21.1	22.1	21.7	21.3	20.1	17.9	17.0	15.1	14.0	–7.1%	0.3%
Hungary	7.4	7.8	7.7	7.5	7.1	6.7	6.4	5.9	6.0	1.6%	0.1%
Republic of Ireland	9.3	9.3	9.4	9.0	8.0	7.6	6.7	6.5	6.7	4.7%	0.2%

Oil consumption [million tonnes]

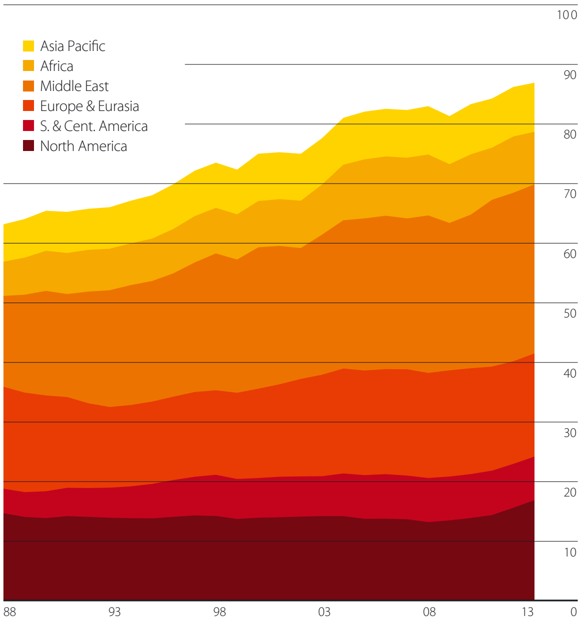
Country	2005	2006	2007	2008	2009	2010	2011	2012	2013	Change 2013 over 2012 r.	2013 share of total
Italy	86.7	86.7	84.0	80.4	75.1	73.1	70.5	64.2	61.8	–3.6%	1.5%
Kazakhstan	9.8	10.3	11.3	11.0	8.9	9.3	12.3	13.1	13.8	5.9%	0.3%
Lithuania	2.8	2.8	2.8	3.1	2.6	2.7	2.6	2.7	2.7	1.4%	0.1%
Netherlands	50.1	50.8	50.7	47.3	45.9	45.9	46.1	43.7	41.4	–4.9%	1.0%
Norway	10.2	10.5	10.7	10.4	10.6	10.8	10.6	10.5	10.6	1.0%	0.3%
Poland	22.4	23.3	24.2	25.3	25.3	26.7	26.6	25.7	24.0	–6.2%	0.6%
Portugal	16.0	14.4	14.4	13.6	12.8	12.5	11.6	10.9	10.8	–0.8%	0.3%
Romania	10.5	10.3	10.3	10.4	9.2	8.8	9.1	9.2	9.0	–1.7%	0.2%
Russian Federation	126.1	130.3	130.0	133.9	128.2	134.3	143.5	148.9	153.1	3.1%	3.7%
Slovakia	3.8	3.4	3.6	3.9	3.7	3.9	3.9	3.6	3.5	–1.3%	0.1%
Spain	79.3	79.3	80.3	77.9	73.5	69.6	68.5	64.2	59.3	–7.3%	1.4%
Sweden	17.2	17.2	16.9	16.7	15.5	16.2	14.8	14.6	14.3	–2.0%	0.3%
Switzerland	12.2	12.6	11.3	12.1	12.3	11.4	11.0	11.2	11.8	5.0%	0.3%
Turkey	31.1	32.8	33.6	32.1	32.5	31.8	31.1	31.4	33.1	5.7%	0.8%
Turkmenistan	5.1	5.0	5.2	5.4	5.2	5.7	6.0	6.1	6.3	2.8%	0.2%
Ukraine	13.7	14.2	14.7	14.3	13.5	12.6	13.1	12.5	12.2	–2.7%	0.3%
United Kingdom	83.0	82.3	79.2	77.9	74.4	73.5	71.1	71.0	69.8	–1.4%	1.7%
Uzbekistan	5.1	5.1	4.6	4.5	4.3	3.7	3.5	3.3	3.3	2.1%	0.1%
Other Europe & Eurasia	30.7	31.4	32.4	33.0	32.4	32.6	32.5	32.0	32.5	1.6%	0.8%
Total Europe & Eurasia	**964.2**	**974.3**	**957.3**	**956.8**	**912.4**	**906.4**	**902.3**	**884.2**	**878.6**	**–0.4%**	**21.0%**
Iran	80.5	87.4	89.4	93.3	95.5	86.7	88.2	89.5	92.9	4.0%	2.2%
Israel	12.2	11.9	12.4	12.2	11.4	10.9	11.5	13.6	10.6	–21.9%	0.3%
Kuwait	19.5	17.7	17.9	19.0	20.4	21.6	20.4	21.6	21.8	1.2%	0.5%
Qatar	3.9	4.5	5.3	6.1	6.0	6.5	7.8	8.0	8.5	7.1%	0.2%
Saudi Arabia	88.2	92.3	98.0	106.7	115.8	124.2	125.1	131.3	135.0	3.1%	3.2%
United Arab Emirates	24.5	26.3	28.2	29.4	27.7	30.1	33.0	34.3	35.6	4.2%	0.9%
Other Middle East	63.9	58.8	62.4	69.4	70.3	74.2	75.2	79.5	80.5	1.5%	1.9%
Total Middle East	**292.8**	**298.9**	**313.7**	**336.1**	**347.1**	**354.3**	**361.3**	**377.7**	**384.8**	**2.2%**	**9.2%**

Oil consumption [million tonnes]

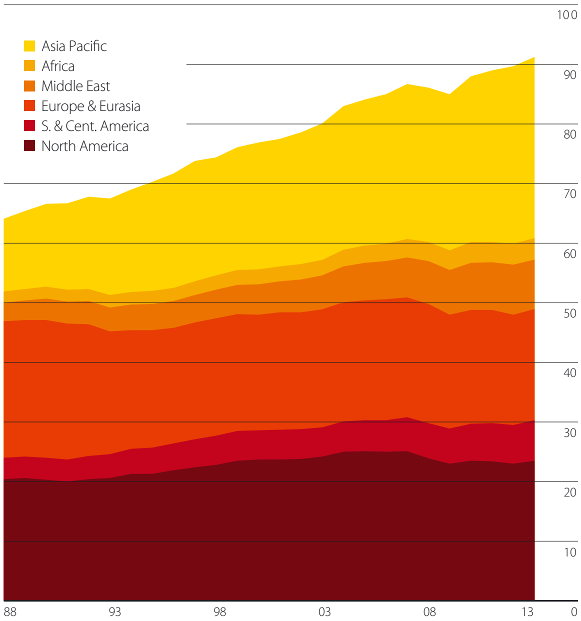
Country	2005	2006	2007	2008	2009	2010	2011	2012	2013	Change 2013 over 2012 r.	2013 share of total
Algeria	11.0	11.5	12.9	14.0	14.9	14.8	15.5	16.7	17.5	5.0%	0.4%
Egypt	29.8	28.7	30.6	32.6	34.4	36.3	33.7	35.2	35.7	1.5%	0.9%
South Africa	24.8	25.3	26.6	25.7	24.2	26.6	27.4	27.3	27.2	–0.1%	0.7%
Other Africa	73.2	73.2	75.2	80.9	82.6	86.5	81.9	86.8	90.5	4.6%	2.2%
Total Africa	**138.9**	**138.7**	**145.3**	**153.3**	**156.1**	**164.3**	**158.5**	**166.1**	**170.9**	**3.2%**	**4.1%**
Australia	40.8	42.1	42.5	43.3	42.8	43.6	45.8	47.3	47.0	–0.4%	1.1%
Bangladesh	4.3	4.3	4.2	4.2	3.7	4.3	5.5	5.8	5.7	–1.7%	0.1%
China	327.8	354.5	370.6	377.6	391.0	440.4	464.1	490.1	507.4	3.8%	12.1%
China Hong Kong SAR	13.8	15.0	16.1	14.6	16.6	17.9	18.1	17.3	17.7	2.6%	0.4%
India	121.9	128.3	138.1	144.7	152.6	155.4	163.0	173.6	175.2	1.2%	4.2%
Indonesia	60.7	58.5	60.9	60.4	61.6	66.4	72.3	73.2	73.8	1.1%	1.8%
Japan	248.8	239.6	232.6	226.3	201.8	204.1	204.9	217.8	208.9	–3.8%	5.0%
Malaysia	28.0	28.9	30.8	29.5	29.2	29.3	31.1	30.7	31.2	2.0%	0.7%
New Zealand	7.0	7.1	7.1	7.2	6.9	7.0	7.0	7.0	7.1	2.1%	0.2%
Pakistan	15.3	17.6	19.3	19.4	20.8	20.6	20.8	20.0	22.0	10.3%	0.5%
Philippines	14.8	13.3	14.1	12.4	13.2	13.2	12.9	13.0	13.7	5.5%	0.3%
Singapore	43.1	46.4	50.4	53.6	57.0	62.8	65.5	65.4	65.9	1.1%	1.6%
South Korea	104.6	104.7	107.6	103.1	103.7	105.0	105.8	108.8	108.4	‡	2.6%
Taiwan	49.4	49.2	51.2	45.8	44.0	45.3	42.5	41.9	43.4	3.9%	1.0%
Thailand	42.6	42.2	41.6	41.2	44.2	44.3	46.6	49.6	50.4	2.0%	1.2%
Vietnam	12.2	12.0	13.3	14.1	14.6	15.6	17.0	17.2	17.4	2.0%	0.4%
Other Asia Pacific	15.7	15.5	16.5	15.6	16.4	16.8	19.3	19.5	19.6	0.8%	0.5%
Total Asia Pacific	**1150.9**	**1179.2**	**1216.9**	**1213.0**	**1219.9**	**1292.0**	**1342.3**	**1398.1**	**1415.0**	**1.5%**	**33.8%**
Total World	**3919.3**	**3959.3**	**4018.4**	**4000.2**	**3924.6**	**4040.2**	**4085.1**	**4138.9**	**4185.1**	**1.4%**	**100.0%**

‡ Less than 0.05%

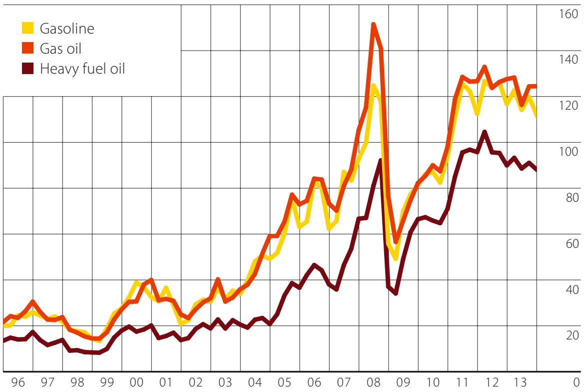
Oil production [m barrels/day]



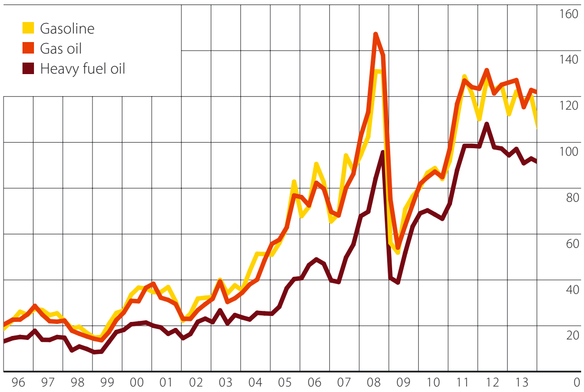
Oil consumption [m barrels/day]



Product prices in Rotterdam [USD per barrel]

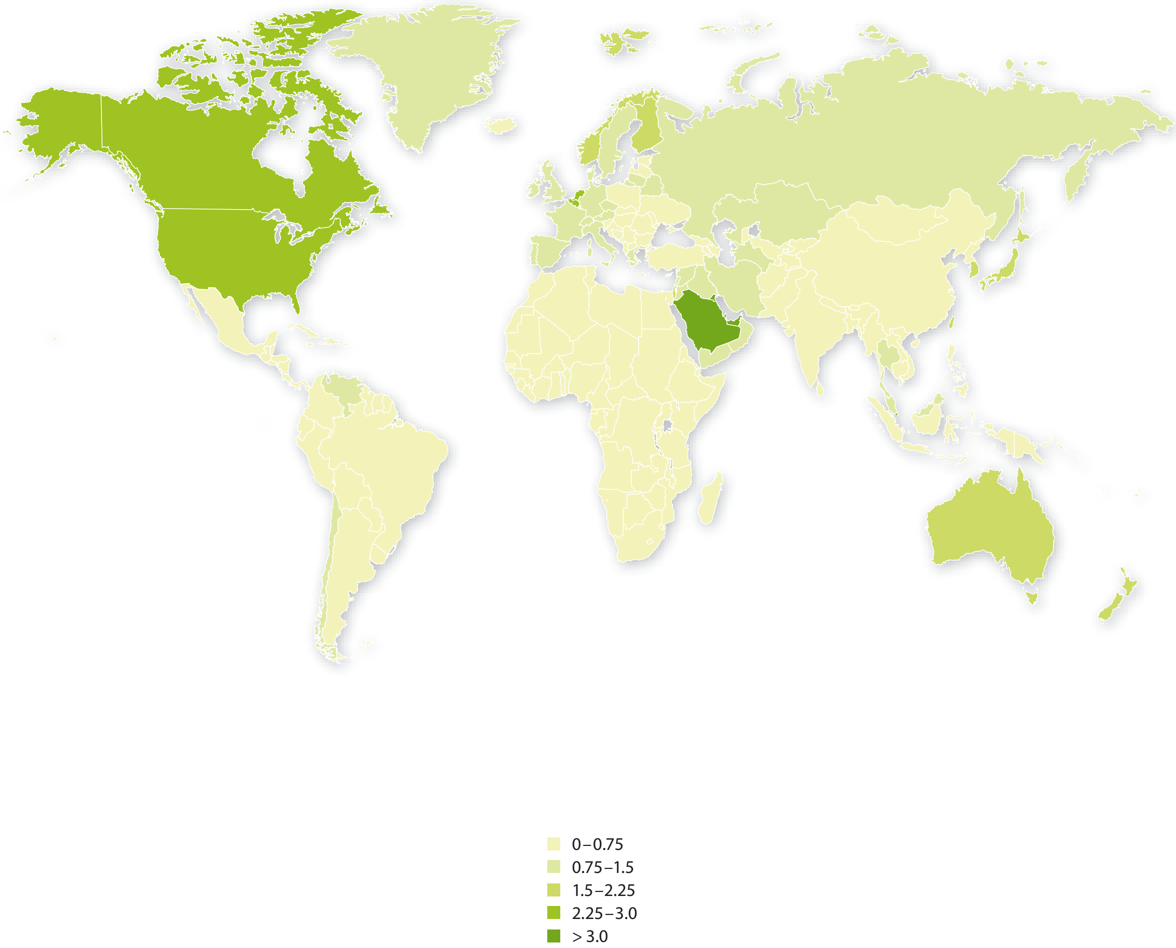


Product prices on the US Gulf Coast [USD per barrel]



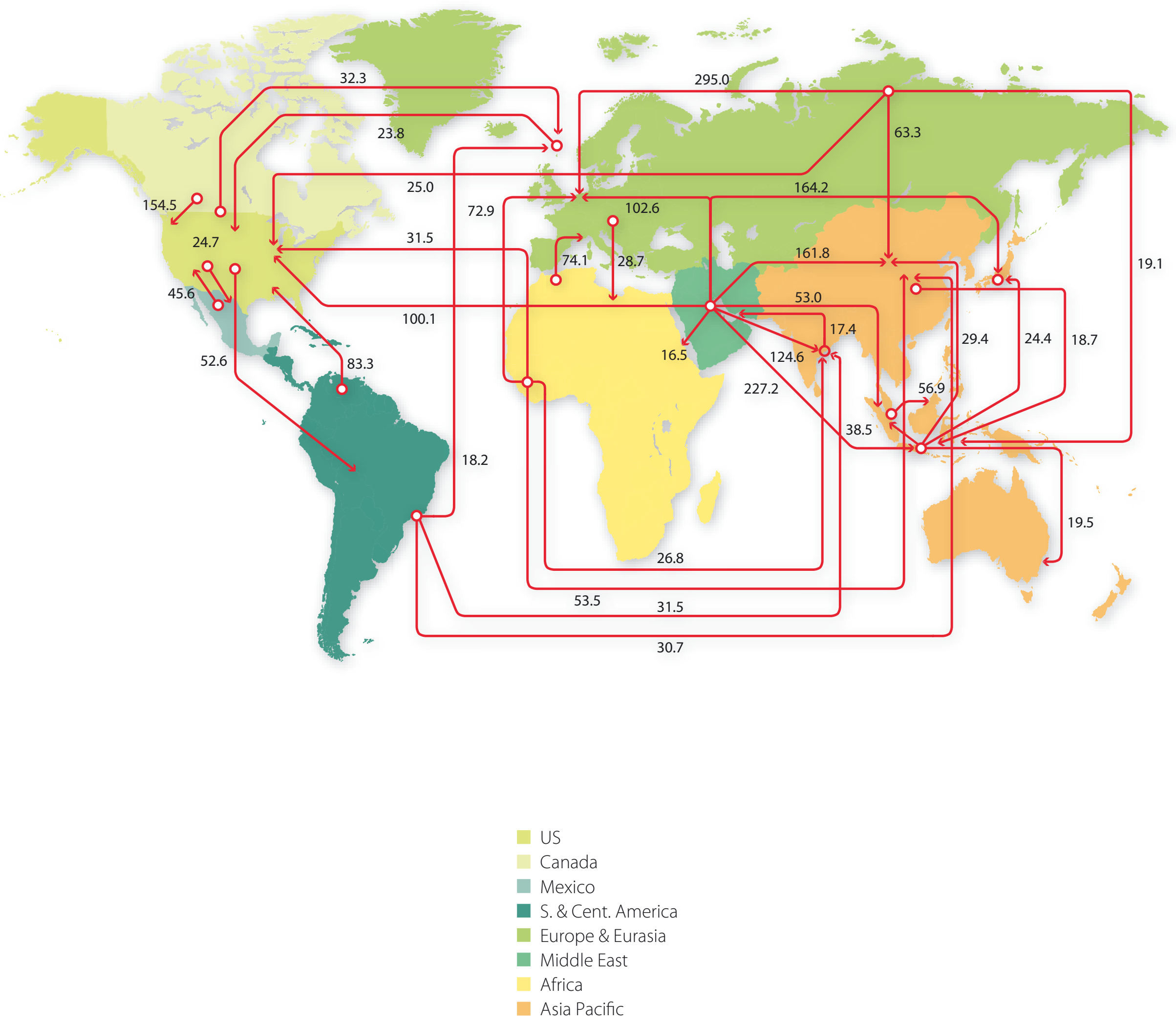
Source: BP Statistical Review of World Energy 2014

Oil consumption *per capita* in 2013 [tons]



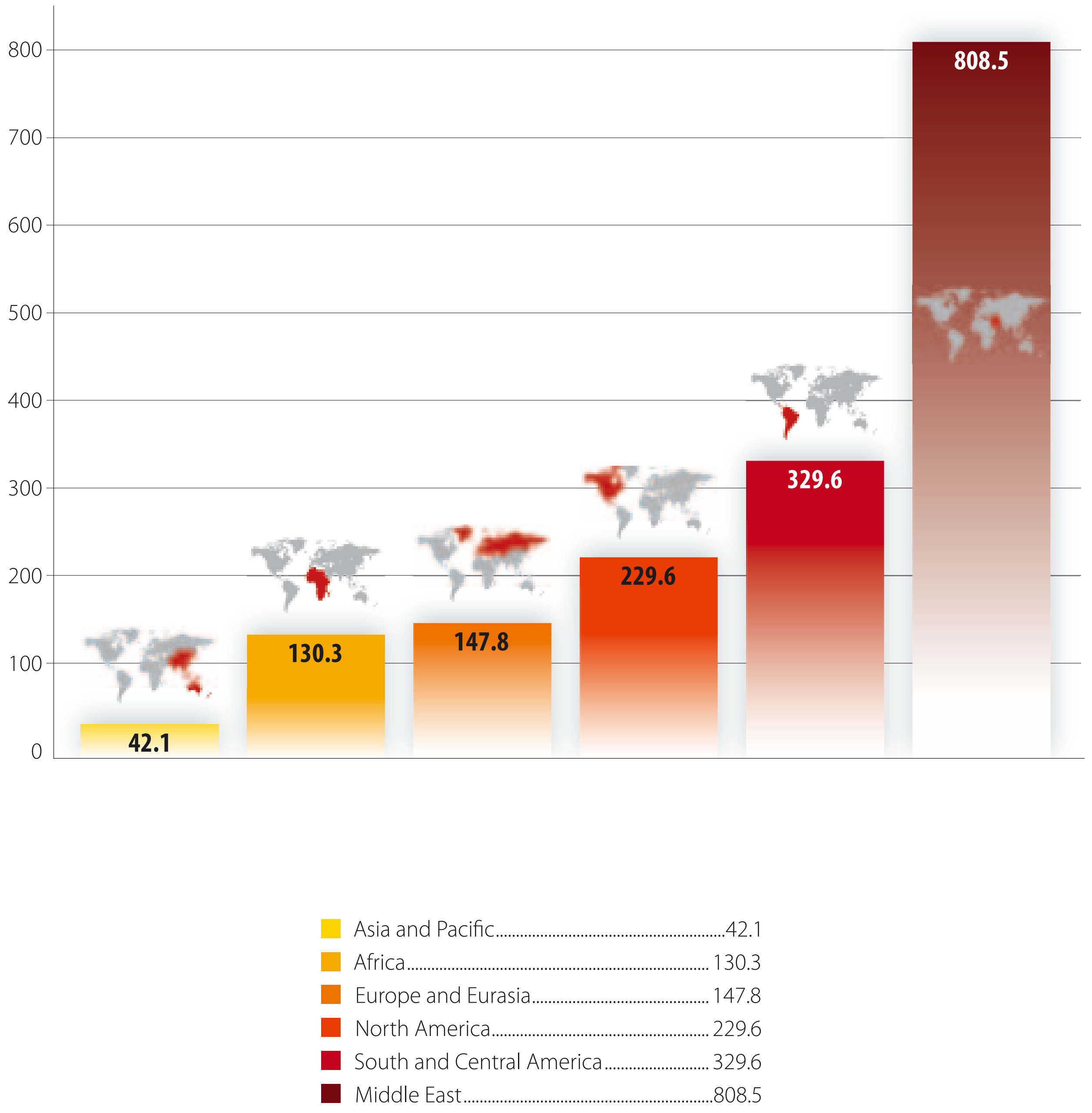
Source: BP Statistical Review of World Energy 2014

The main directions in oil trade in 2013 [in m tons]



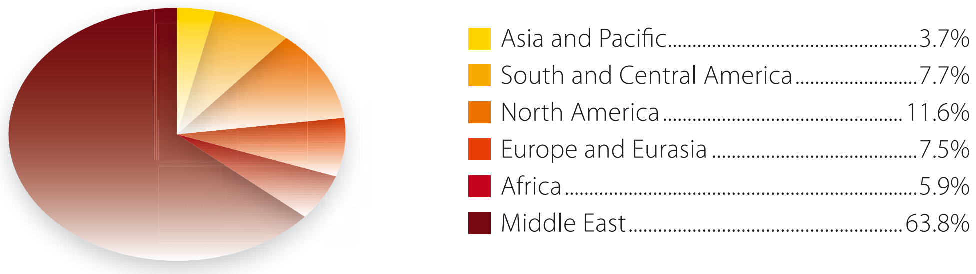
Source: BP Statistical Review of World Energy 2014

Oil: proved reserves [in bln barrels] by the end of 2013

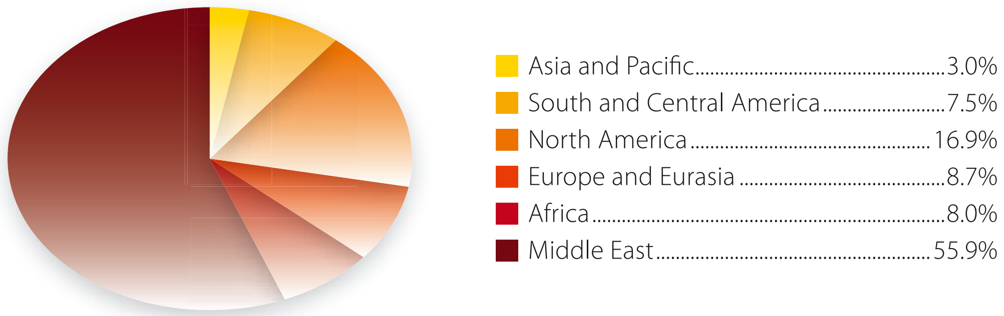


Source: BP Statistical Review of World Energy 2014

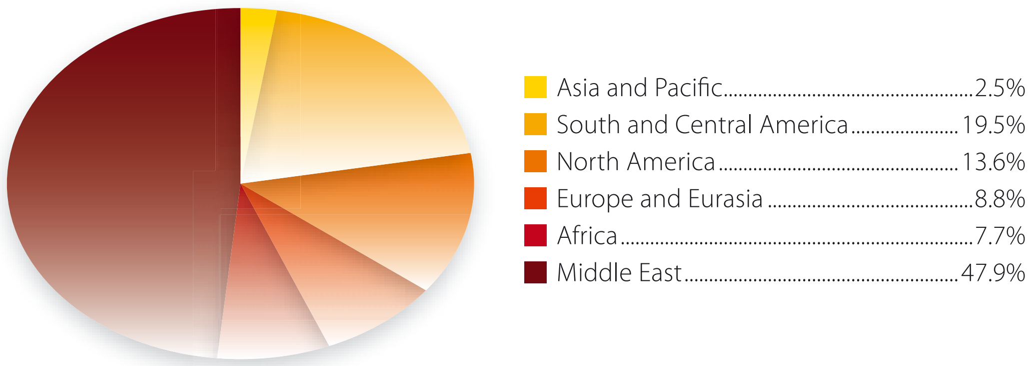
Distribution of proven oil reserves in 1993 – 1041.4 bln barrels total



Distribution of proven oil reserves in 2003 – 1334.1 bln barrels total



Distribution of proven oil reserves in 2013 – 1687.9 bln barrels total



Source: BP Statistical Review of World Energy 2014

GAS:

exploration, distribution, sales

The application of drilling core lab test results in interpretation of geophysical well logs

Abundance of information contained in the rock

Dariusz Cebulski, Marek Dohnalik, Irena Gąsior, Jolanta Klaja, Sylwia Kowalska, Krzysztof Wolański

The process of exploration, identification and extraction of hydrocarbons is closely connected with very detailed identification of the reservoir rock in which they are accumulated. One of the methods of rock identification is well logging.

The methods of geophysical well logging consist in running different kinds of well logs in the borehole, shown in the form of curves. The well logging alone is a very important stage of rock identification but much more important and responsible task is the interpretation of the logging results. Its aim is to determine precisely the basic rock parameters, mainly its mineral composition, reservoir properties (porosity and permeability) and the kind and degree of saturation of the rocks with the deposit medium.

Geophysical well logging provides a great number of geological data concerning the drilled rocks, however, all the information needs to be calibrated and then confirmed by laboratory test results. Laboratory determination of physical rock parameters can also be a starting point for construction of interpretative models of the medium in comprehensive interpretation of the well logging. Properly determined values of basic rock parameters enable reliable determination of the reservoir rock properties and they are used for estimating the natural gas and oil deposit resources.

Specialist laboratories are of great assistance here because they are able to conduct extensive tests in a professional way and meet the oil companies` requirements. One of the laboratories is the Laboratory of Rocks and Deposit Fluids at the Oil and Gas Institute – National Research Institute (INiG – PIB) in Krakow.

Laboratory tests

Laboratory tests are carried out on rock samples extracted from the borehole by drilling. For several dozen years now, the Laboratory of Rocks and Deposit Fluids at the Oil and Gas Institute – National Research Institute conducts comprehensive laboratory tests for the oil industry which include:

1) determination of the mineral composition, X-ray diffraction (XRD),
2) analysis of saturation distribution with the nuclear magnetic resonance method (NMR),
3) measurements of the rock permeability,
4) measurement of electrical parameters of rocks,
5) measurement of natural radioactive elements` content: uranium, thorium and potassium in rocks and drilling fluids,
6) measurement of specific electrical conductance of the drilling fluid with changed temperature,
7) determination of the index of ion-changeable ability of rocks (cation exchange capacity – CEC) with the colorimetric method,
8) measurement of density, volume density of rocks and general porosity,
9) measurement of elastic waves propagation velocity,
10) three-dimensional visualization and analysis of pore space structure (micro-CT).

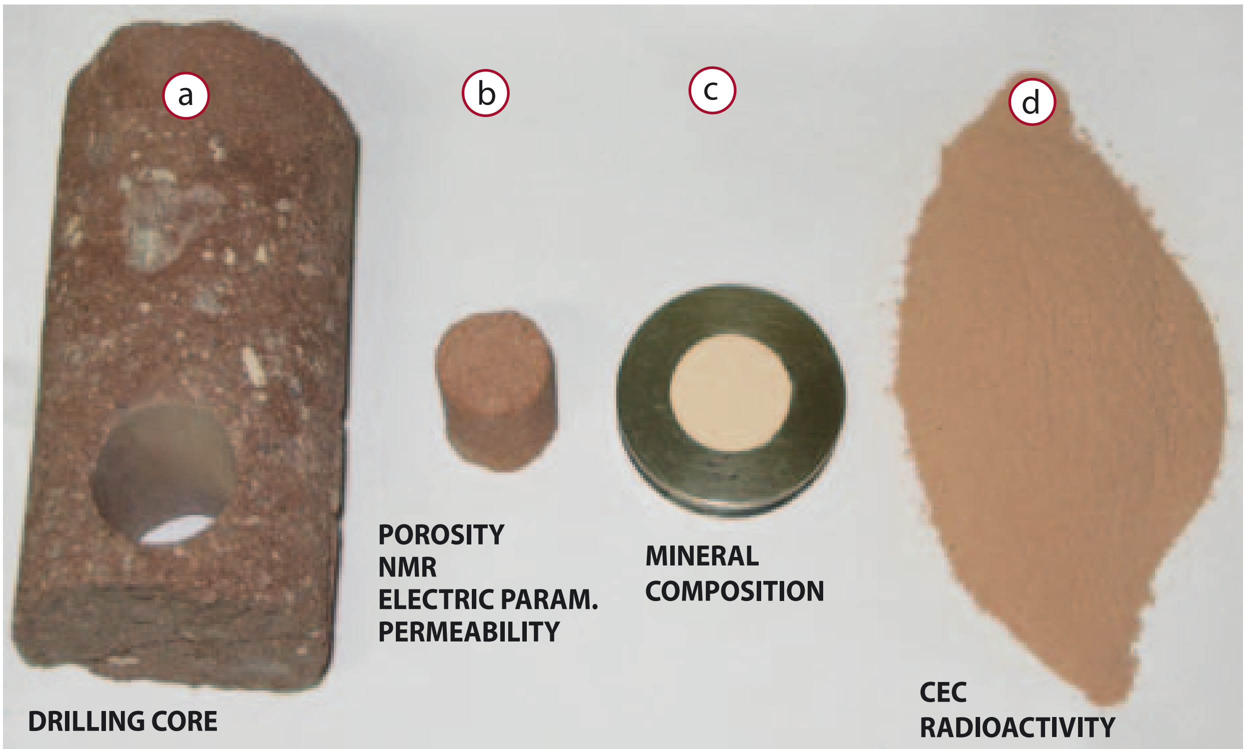


Fig. 1. Example of samples prepared for individual tests

The first six of the laboratory tests are particularly meaningful in geophysical well logging interpretation.

Laboratory tests are carried out on cylinder-shaped samples about 25 mm in diameter and 30 mm high and on powdered material. First, the cylinder-shaped samples are cut out from the core material taken. The material which is left after cutting the core is then ground and used

Measurement methods

Below, there is a short description of laboratory measurement methods used in the well logging calibration.

Quantitative assessment of mineralogical composition of the rock

The analysis of mineral composition of the rocks is usually made with X-ray diffraction method. The measurements are taken on powdered sample (Fig. 1C). Such an analysis is possible owing to the fact that the length of the X-ray waves (for a copper lamp it is 1.5418 Å) is comparable with the distance between the grid planes which occur in the crystal structure of particular minerals. Owing to this, every mineral can be described with the use of a set of characteristic inter-plane distances. Theoretical basis and measuring methodology which is established at the Oil and Gas Institute – National Research Institute [INiG – PIB], has been described in more detail in publications [13, 14].

With the above method, we obtain minimum quantitative and qualitative information on the mineral composition of the sample as well as composition of the argillaceous fraction. This information is important when making the lithological model, which helps obtain more precise well logging interpretation.

Pore space analysis using the nuclear magnetic resonance method

The nuclear magnetic resonance method (NMR) uses the phenomenon of magnetic field effect on hydrogen nucleus, that is on protons. Detailed description of NMR methodology and its application in pore structure research can be found in a number of publications [2, 5, 7–12, 15].

Testing the rocks with NMR method is most often based on the measurement of T_2 crosswise relaxation time. For the purpose of the measurement, a sample saturated with brine is used of concentration similar to deposit water mineralization.

The distribution of T_2 crosswise relaxation time reflects the distribution of pore size (Fig. 2).

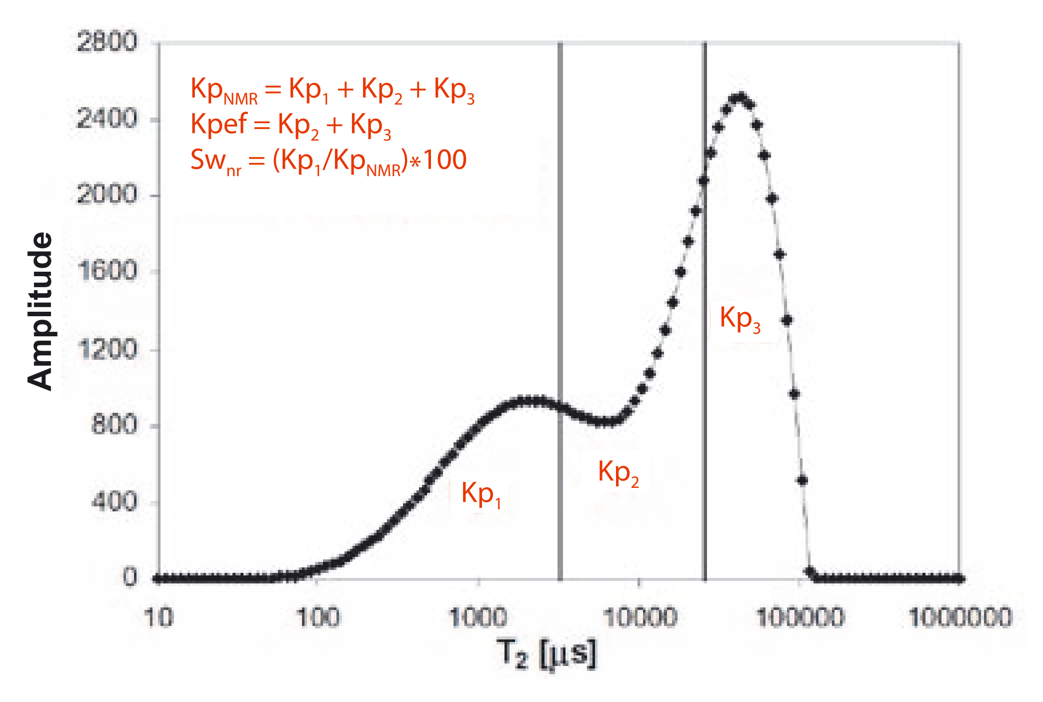


Fig. 2. Distribution of T_2 crosswise relaxation time for sandstone. Kp_{NMR} – total porosity, Kp_1, Kp_2, Kp_3 – porosity components which reflect the size of pore space filled respectively with: irreducible water, capillary water, free water; Kp_{ef} – effective porosity; Sw_{nr} – irreducible water saturation

The surface under the T_2 curve distribution is proportional to total porosity of the tested sample (Kp_{NMR}). For interpretation purposes, three areas can be identified there. The first one (Kp_1) is characteristic for the shortest time of relaxation, it concerns the smallest pores (the part of pore space occupied by immobile water – bound in loams and micropores). The second (Kp_2) which has a little longer T_2 time, reflects bigger pores filled with capillary water. The third area (Kp_3) is characteristic for the longest time of relaxation, it is connected with the biggest pores in which free flow of deposit fluids is possible. The determined parameters are used in interpretation of geophysical evaluation and in estimation of hydrocarbon deposit resources.

Measurements of absolute permeability

Permeability determines the medium's ability to conduct liquid. In order to calculate this parameter a special device is used in whose measurement chamber a rock sample is placed (Fig. 1B) and gas (nitrogen) is let in through its structure. The apparatus measures the flow of the factor with a set pressure difference before and after the tested sample. *Kpr* permeability is calculated from a formula which considers the physical properties of the gas run through and the sample geometry.

Measurements of electric parameters of rocks

Determination of electrical properties of the rocks is based on two empirical equations presented by Archie in 1942. Before the measurement, the samples are saturated with brine of concentration similar to the concentration of deposit fluids in a particular area. The saturation takes place in a vacuum chamber and it lasts minimum 12 hours. Then, in order to determine the *m* pore structure index, measurements are taken of resistivity of the sample completely saturated with brine. In order to determine the wettability index *n* of the rock, tests are made consisting in five-time measurement of electrical resistivity of the sample with various degree of saturation. Desaturation is made by spinning the sample in a special centrifuge.

Measurements of natural radioactive elements` content: uranium, thorium and potassium

Measurements of the amount of natural radioactive elements are taken with three-channel gamma ray spectrometer. The tested sample (Fig. 1D) is put into measurement vessels (80 ml capacity) and placed in a protective chamber made of lead, about 5 cm thick, which is supposed to limit penetration from the sur-

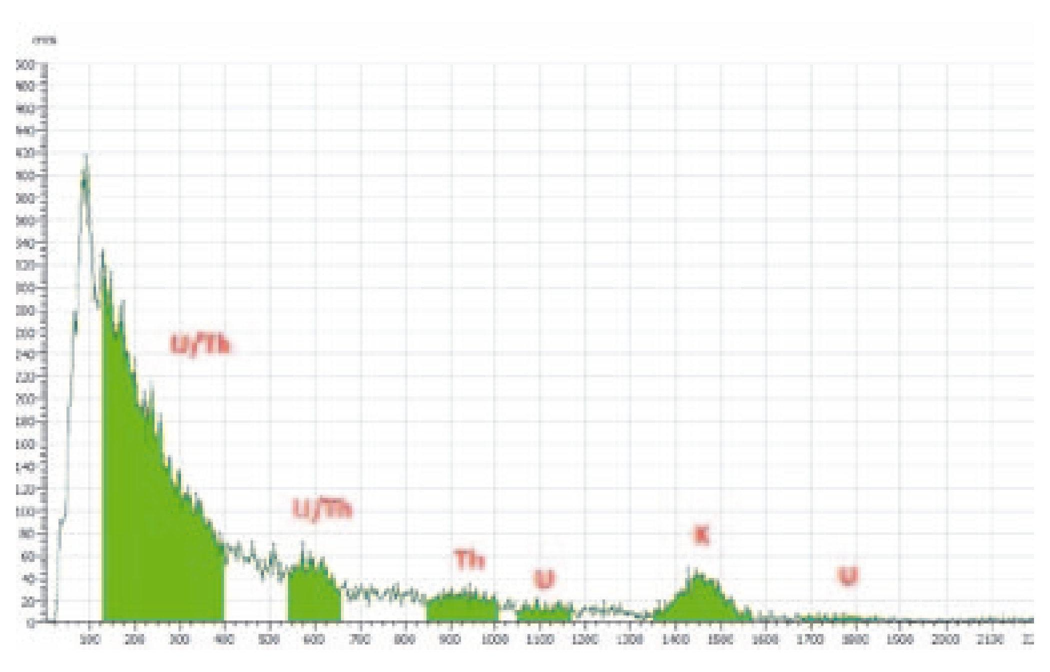


Fig. 3. Spectrum of the tested sample

rounding area (radiation from the space and from the floor and walls) to the radiation chamber.

In the chamber there is a scintillation detector with NaJ/Tl crystal and Cs-137 isotope calibration source. The detector's task is linear change of the photon energy into impulse amplitudes which are separated and counted in appropriate ranges.

After collecting the spectra (Fig. 3) a special software makes the analysis of the impulses registered in the measurement windows corresponding to appropriate energy ranges.

Individual spectrometer channels are set to register the gamma radiation ranges of photon energy: channel 1 – registers gamma radiation photons of K-40 potassium, channel 2 – gamma radiation photons of Bi-214 bismuth (which is balanced with Ra-226 radium), channel 3 – registers gamma radiation photons of Tl-208 thallium (which is balanced with Th-228 thorium). After a set number of measurement cycles the meter software calculates the concentration of potassium, radium and thorium in the sample.

The obtained results are used as points of reference for the values received from the gamma radiation logs.

Measurement of drilling fluid properties

Drilling the boreholes is effected, among other things, due to application of various types of drilling fluids or drilling muds injected to the borehole to facilitate the drilling process. The drilling fluid carries the drill cuttings (rock pieces) to the surface, helps control the pressure of the drilled rock and stabilize the borehole walls and ensures cooling and lubrication of the elements used in drilling.

The drilling fluid is a colloidal solution which contains suspended particles, e.g. of loam and different kinds of dissolved salts (including potassium salts: potassium mud, polymer-potassium), polymers and other chemical admixtures which affect the geophysical measurements performed in the boreholes.

As part of laboratory tests, measurements are taken to determine the changes in specific electrical resistivity when changes are made in the temperature of the drilling fluids, filtrates obtained from the drilling fluid and filtrate of the drilling mud. Another standard measurement taken in relation to the drilling mud is the description of concentration of radioactive elements so that the effect of applied drilling mud can be assessed on the records of radiometric prospecting.

Well Logging

The well logs are taken after the borehole is made, usually before the casing is inserted and when it is filled with the drilling fluid. The measurement consists in introducing geophysical probes to the borehole using geophysical cables (Fig. 4 and 5), and when they are taken out, different kinds of physical parameters

Fig. 4. Well logging in a borehole (truck with equipment for well logging and preparation of the probes before inserting them into the borehole)

Fig. 5. Geophysical probes: preparation for transportation and insertion into the borehole

are measured and their analysis allows to estimate the geological properties of the drilled rock.

The measurement is visually displayed by means of cross tabulation (Fig. 6 and 7; columns 1 and 2), where the negative axis Y represents depth, and the X axis – the value of measured parameters and this is shown as geophysical curves. Obtained data require a number of corrections out of which the most important are those corresponding to the effect of the drilling fluid and the diameter of the borehole which may be changed in the drilling process.

The basic aim of well logging is to determine the reservoir parameters of the rock (porosity and permeability) and the nature of saturation of the pores with natural gas, oil and deposit water (Fig. 6 and 7).

Out of many well logging methods, the most common, and indispensable for the description of the basic rock properties are:

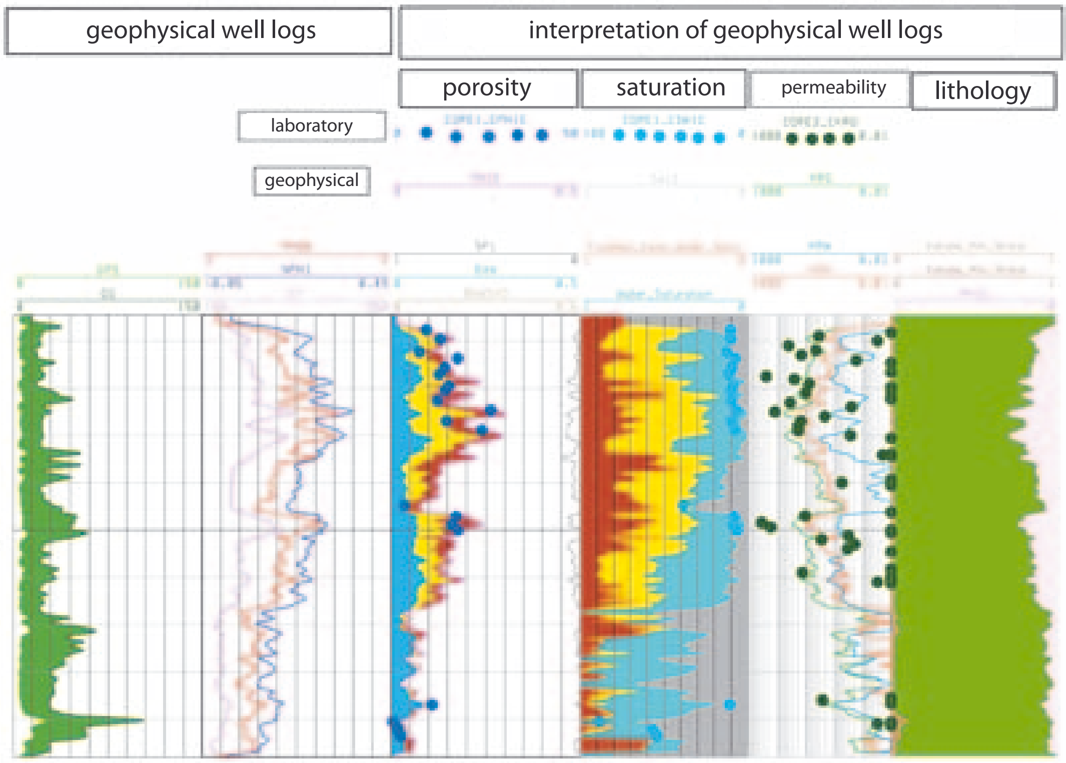


Fig. 6. Results of well logging interpretation and laboratory test results in a model borehole for the Main Dolomite deposits (dots represent laboratory test results)

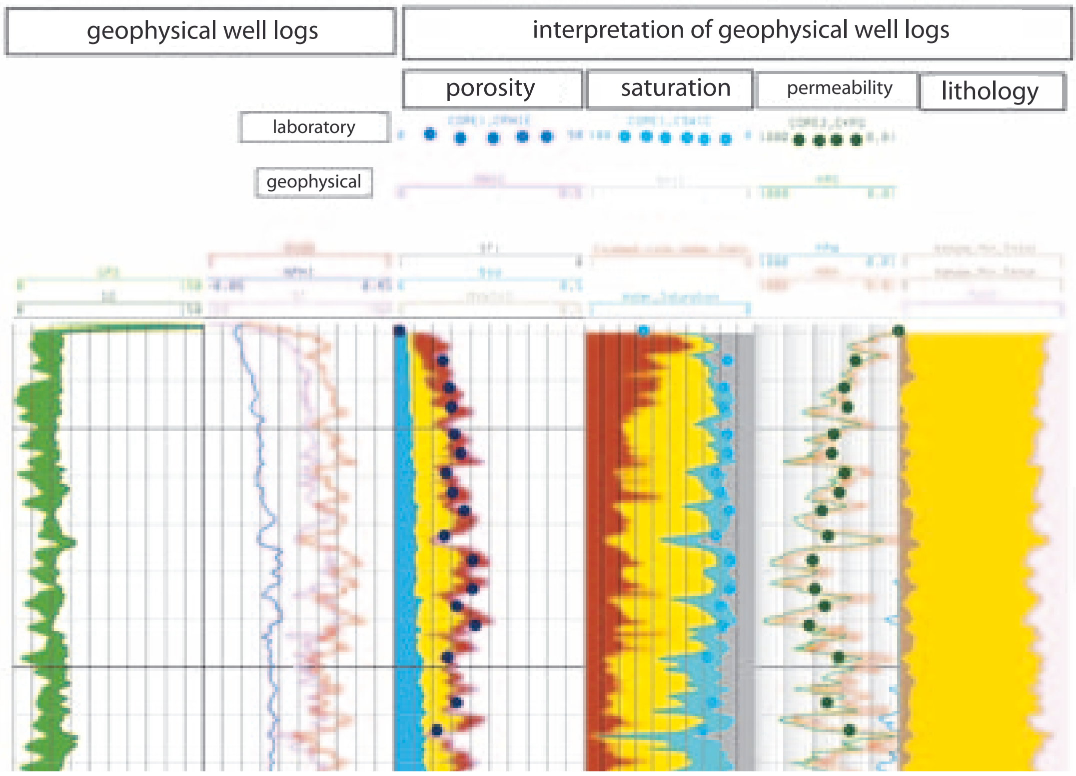


Fig. 7. Well logging interpretation and laboratory measurement results in a model borehole for Rotliegend deposits (dots represent laboratory test results)

- radiometry, i.e. the branch of the well logging which deals with examination of the phenomena connected with natural radioactivity of the rocks and phenomena observed when the rock is affected by the radiation source. The most important of them include:
    - » measurement of natural radioactivity of the rock (GG – Fig. 6 and 7; column 1), which may register a spectrum of the most vital radioactive elements which occur in the rock, such as uranium, potassium and thorium; this measurement facilitates calculation of the volume of elements called clay minerals (Fig. 6, 7; column 6), whose presence negatively affects the reservoir properties of the rock by reducing porosity and permeability,
    - » neutron logs (NPHI – Fig. 6 and 7; column 2) which use the source of radiation to determine the neutron porosity of the rock. As a result of interpretation of obtained logs, effective porosity of the rock can be calculated (PHIE – Fig. 6 and 7; columns 3 and 6), i.e. the volume of empty space in the rock from which hydrocarbons may flow to the borehole; additionally, the logging may provide qualitative assessment of saturation of the rock with hydrocarbons or deposit water,
    - » density logs (RHOB – Fig. 6 and 7; column 2), which use the radiation source to determine the rock density. With this kind of logs, when the mineralogical composition of the rock is known, its porosity can be determined (PHIE – Fig. 6 and 7; columns 3 and 6), which is directly proportional to the rock density,
- acoustic logs – which consist in transmission of acoustic waves by the probe transmitters, and then, measurement of the time the signal reaches the probe receivers. What is more, the image of the registered wave is recorded, which allows to determine many acoustic parameters, essential for the rock analysis. Owing to the acoustic logs the rock porosity may be calculated (PHIE –Fig. 6 and 7; columns 3 and 6), and also – when using more technologically advanced probes – the type of pore saturation,
- electrical logs – consisting in the measurement of rock resistivity which facilitates qualitative and quantitative description of the rock saturation (Fig. 6 and 7; columns 3 and 4: yellow and brown represent hydrocarbons, blue – deposit water). It is really important for determination of hydrocarbon reserves accumulated in the deposit.

The analysis of individual well logging methods may provide information on the rocks, but only comprehensive interpretation (Fig. 6 and 7) of several methods allows completely credible assessment of the reservoir properties and character of saturation, and also enables to determine the mineral composition of the drilled rock formations. Such interpretation contains information about all the rock components:

- on the skeleton, i.e. minerals of which the rock is built,
- porosity, i.e. the size and character of empty spaces filling the rock,
- saturating medium (natural gas, oil or deposit water), which fills the empty spaces in the rock (pores).

The results of interpretation of the well log curves should be calibrated and verified by the results of laboratory tests, therefore in most exploratory bores a drilling core is taken on which laboratory analysis is made.

Examples of laboratory test application in calibration of the well logs

The lack of accurate data concerning essential parameters used in interpretation of the well log curves may lead to incorrect analysis, which in turn may misinform the geologists who evaluate the deposit. Such situations are inadmissible, therefore, in order to verify the available information or obtain the necessary data, laboratory tests must be performed on the drill core taken in drilling, fluids obtained while sampling the borehole and the drilling fluid which is an important element both in the drilling process and well logging.

The most important laboratory tests used in well logging include the measurement of porosity by means of nuclear magnetic resonance (NMR) which enables calculation of both total and effective porosity. Obtained results permit verification of the interpretation of the well log curves, which may confirm them or lead to repeat analysis. Drawings 6 and 7 demonstrate how good the correlation between laboratory and geophysical methods may be and the drawing 8 confirms this relationship. The NMR data provide also the parameter of irreducible water saturation, i.e. that part of water saturation which is unable to flow into the borehole and which coexists with hydrocarbons filling the rock. The correlation between the laboratory data and well log interpretation is good as well (drawings 6–9).

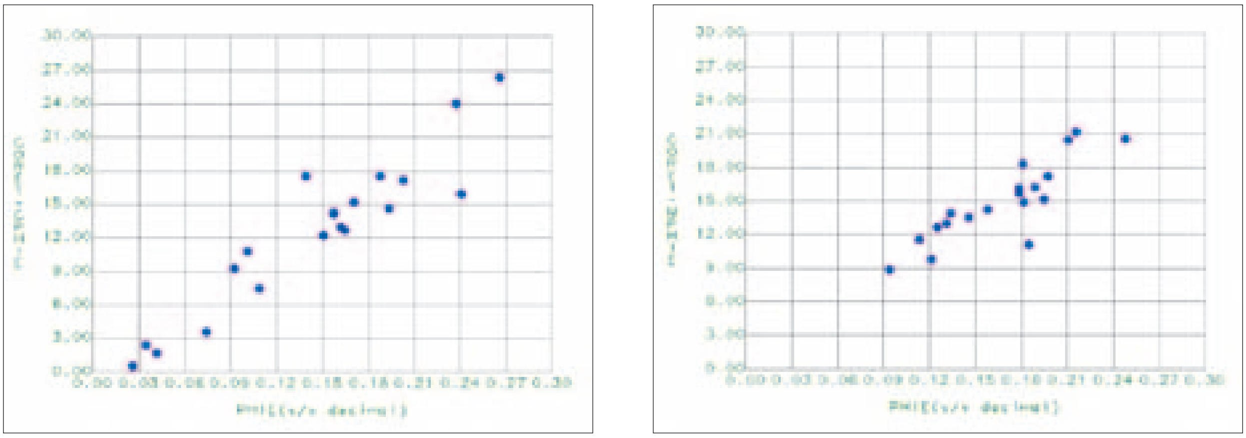


Fig. 8. Correlation of laboratory test results (Y) and well log interpretation (X) for effective porosity of the reservoir rock (a – Main Dolomite, b – Rotliegend)

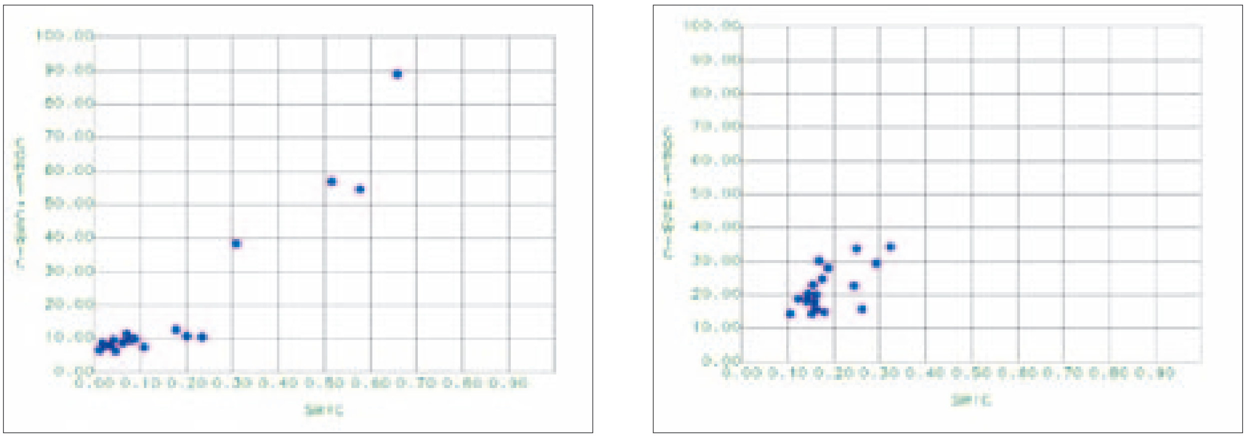


Fig. 9. Correlation of laboratory test results (Y) and well log interpretation (X) for rock saturation with irreducible water (a – Main Dolomite, b – Rotliegend)

The evaluation of rock saturation with deposit media, and particularly hydrocarbons, makes it necessary to introduce several parameters possible to determine with the use of laboratory methods. The *m* and *n* parameters which describe the nature of the rock in terms of porous structure and wettability are obtained as a result of laboratory tests of electrical rock parameters. Resistivity of the deposit water and the drilling mud filtrate can also be received in laboratory tests.

Another very important laboratory examination is quantitative evaluation of mineral composition of the rock (XRD) which allows accurate construction of mineralogical model of the rock (Fig. 6 and 7, column 6), indispensable in the process of petrophysical interpretation.

Much more complicated is the problem with determination of rock permeability (Fig. 6 and 7, column 5), i.e. its ability to let in the deposit media. Unfortunately, the well logging methods do not produce satisfactory effects, therefore very often the dependence of laboratory permeability from laboratory porosity is used (Fig. 10). The obtained algorithm is then transferred to the domain of well logs, making it possible to calculate geophysical permeability on the basis of geophysical porosity.

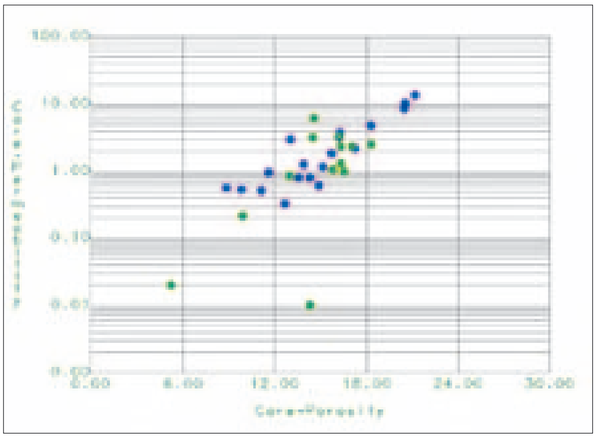


Fig. 10. Model correlation between laboratory test results in porosity and permeability

With continuous development of the research methods, there are new, often portable devices on

the market. Interesting in terms of interpretation of the well logs and applied recently by the Laboratory of Rocks and Deposit Fluids at the Oil and Gas Institute – National Research Institute [INiG – PIB], there are the gamma and X-ray fluorescence (XRF) spectrometers. Portable devices are not as accurate and precise as laboratory equipment but their fundamental asset is the possibility of taking sufficiently accurate measurement in a very short time, immediately after the core is extracted from the borehole. The application of portable devices enables to select representative samples for further examination and extension by the depth-related data. Obtained information may be used to create an appropriate mineralogical model of the rock matrix.

Summary

The article presents some examples of using the results of laboratory measurements taken for the deposits of the Main Dolomite and Rotliegend in integrated well log interpretation. The results achieved from the well logs correlate well with the laboratory data, which proves correctness of the borehole data.

The geophysical well logs provide plenty of information on the examined rock formations, but – as already noted – the obtained data must be verified on the basis of results of tests conducted in laboratory conditions.

Laboratory tests on rocks are an effective tool which supports the well log interpretation and which is used to verify the results of integrated well log interpretation.

Based on laboratory data, interpretative models are developed to determine the petrophysical parameters of the rock in the borehole. These models facilitate the description of parameters such as: porosity, saturation with irreducible water, absolute, relative and phase permeability and mineral composition. Knowing the parameters is indispensable for proper evaluation of prospective use of the analyzed rocks.

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Landfill gas and energy projects in Poland

Power generated from landfill gas

Piotr Klimek, Grzegorz Kołodziejak, Joanna Niemczewska, Joanna Zaleska-Bartosz

Energy generation from landfill gas is one of the best examples of investment which, apart from its business character, contributes to air protection by direct minimization of greenhouse gas emission from the landfill and – indirectly – by reduced demand for energy produced from conventional sources.

Another argument for taking action aiming at maximum use of the landfill gas is the fact that it arises spontaneously starting from the moment of depositing the waste in the landfill. Monitoring of the process of gas formation in the landfill is difficult and stopping the process is practically impossible. The gas which has not been used is emitted to the atmosphere or burnt unproductively in torches. When the landfill is operated in an appropriate way (the waste is concentrated and excess leachate is discharged, etc.) the quality of the gas and its volume, stable in time, may allow to start-up of the installation producing energy even in the small communal landfills. Obviously, each investment must be discussed individually and it must be preceded by reliable feasibility study which would take into account the specific scope of research work.

The analysis of situation related to the system of waste management in Poland leads to a conclusion that the quantity and quality of landfill gas will be changing in the years to come.

The analysis of situation related to the system of waste management in Poland, and in particular to reduction of the quantities of organic matter deposited in the landfill, leads to a conclusion that the quantity and quality of landfill gas will be changing in the years to come.

Landfill gas

The communal waste landfill is a "bioreactor" in which the organic matter is transformed during biochemical processes and in the effect of the transformation landfill gas is produced (basically, the mixtures of methane, carbon dioxide and nitrogen). The composition of biogas produced from organic matter deposited in the communal waste landfill undergoes a wide range of changes, both during its exploitation (waste depositing) and also after the waste disposal is complete, and after reclamation of the landfill.

Also, the intensity of gas production is changeable as well. It depends on the time which elapsed since

Photo 1. Caterpillar engine powered by landfill gas. Source: a private photo

the waste was deposited in the landfill. The composition of the biogas and intensity of its production determine the possibility of appropriate and effective management of the landfill energy potential [1].

Decomposition of organic matter may be divided into many stages, however, on account of the longest timespan and stability of the biogas composition, particularly interesting is the process of methanogenesis. The methane fermentation is a series of anaerobic biochemical processes in which macromolecular organic substances (mainly carbohydrates, proteins and fat and its derivatives) are decomposed to alcohols or lower organic acids which finally become a substrate in the process of creating methane [2]. The basic components of landfill gas produced in the process of methanogenesis include [3]:

- methane ....40÷65% mol/mol,
- carbon dioxide ....35÷60% mol/mol.

In order to obtain gas from the communal waste landfill, an installation must be built with elements collecting gas from the waste deposit (vertical wells, horizontal interceptors carrying the gas to a collection station) and collection station equipped with steam traps, blower and control and measurement instruments.

Vertical degassing wells are installed in the landfill using the method of rotary percussive drilling. Boreholes of 400÷460 mm in diameter reach the bottom of the waste. The distances between wells depend on the conditions existing in particular landfills and they can reach 30÷50 m. Perforated filters are placed in the boreholes. The space between them and the borehole wall is filled with gravel sidefill and in the upper part of the borehole – with loam sealing. Additionally, the zone around the well is covered with geomembrane. A sealing made in this way prevents the air infiltration to the waste landfill. The landfill gas collected from the well is sent to the collection station which is the integral part of the installation for gas utilization. The main task of the collection station is to collect the gas from landfill, purify it and transfer to a power producing installation [1].

Landfill gas energy technologies

The application of the landfill gas for producing electrical energy is still the most popular utilization method in Poland; over 90% of landfill gas energy pro-

Photo 2. CHP systems in the Barycz landfill near Krakow. Source: a private photo

jects aim to reach this goal. Electrical energy intended for local use or for sale to the power grid may be produced using various technologies, for example:

- piston gas-powered engines (internal combustion),
- gas turbines,
- microturbine [1].

In order to produce electrical power from landfill gas the most frequently used are the piston gas-powered engines with spark ignition, i.e. combustion (four-stroke) engines with internal combustion – commonly used in vehicles and other machines (photo 1).

Essentially, piston gas-powered engines are modified constructions, typically medium- and high speed engines powered by liquid fuel. The changes introduced in them consist in the application of different geometry of the head and top parts of the pistons and also expansion by the installations for feeding gas fuel into the engine, cooling it and collecting the heat from the car fumes [1].

Piston engines are also a great solution in the case of combined heat and power systems (CHP). Such systems with piston gas-powered engines are usually used to produce hot water (photo 2). Heat is obtained from heat exchangers: the engine`s water jacket, oil and fumes.

The basic cogeneration system consists of a module producing heat and electrical power, power overload protection system, auxiliary drive and oil system switchgear and the cooling system.

An operating engine drives the electrical generator in which electrical energy is produced. While working, the piston engine becomes hot and creates heat collected partly by the oil cooling system but its considerable quantities are released to the atmosphere together with the fumes. Both types of heat in the combined system are retrieved by heat exchangers. The heat is added up and carried by water or glycolic system to be collected outside. Auxiliary drive switchgear controls suitable water or glycol parameters on the input and output of the CHP module by switching the valves and emergency cooling system, constantly monitoring the water parameters. For the CHP modules, adopted water parameters on the input are 70°C and on the output – 90°C [1].

The analysis of energy balance in CHP generator constructed on the basis of piston engine allows to assess the effectiveness of conversion of original energy contained in supplied fuel (in landfill gas). Only 35÷40% of the original energy is converted into the most desired form – electrical energy. The remaining parts are thermal energy and energy loss. When the management of the heat produced in the system is not possible, its efficiency equals that of producing electrical energy. Unfortunately, as already mentioned, the majority of landfill gas power producing installations produce only electrical energy because the landfill areas are located at large distances from potential recipients of thermal energy.

The application of landfill gas energy in Poland

The system of energy certification introduced in Poland resulted in considerable interest of investors in the landfill gas to energy projects, which pursuant to the Act of 10 April, 1997 Energy Law (full text in Official Journal of 2012, item 1059, with subsequent modifications) is counted among the renewable energy sources. This led to a rapid increase in the number of installations producing energy from the biogas which originates from landfill deposits. While in 2002 the target installed capacity of landfill gas to energy instal-

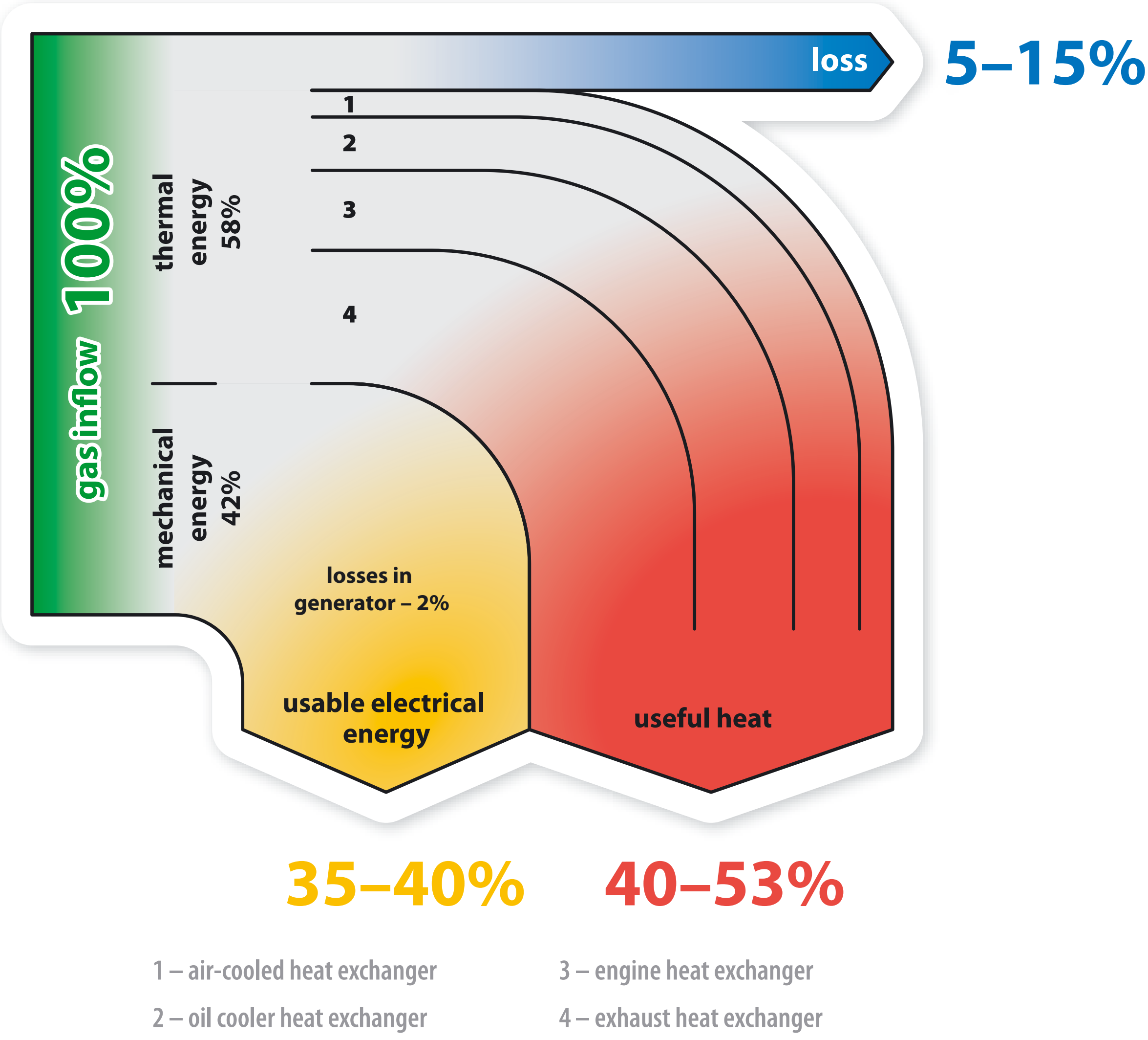

Fig. 1. presents a model energy balance in CHP generator. Source: [4]

Table 1. Number and power of landfill gas energy generating installations in Poland (as of March, 2014)

Province	Number of installations	Power [MW]
Lower Silesia	9	7.389
Kujawy-Pomerania	7	3.743
Lublin	1	0.5
Lubuskie	1	0.5
Łódź	5	4.147
Małopolskie	6	2.928
Masovia	24	12.046
Opole	2	0.453
Podkarpacie	3	1.806
Podlasie	1	0.7
Pomerania	5	4.157
Silesia	15	12.82
Świętokrzyskie	1	0.36
Warmia-Masuria	3	1.514
Wielkopolska	10	6.062
West Pomerania	10	3.769
Total	**103**	**62.894**

Source: Own compilation based on [6]

lations was only 15 MW$_e$ [5], already in March 2014 it exceeded 63 MW$_e$ [6]. Table 1 presents territorial division of power producing installations from landfill gas in Poland.

When analyzing the situation of landfill gas energy management in Poland in the recent years, it can be stated that the market is already practically saturated. The landfill deposits whose parameters allowed to begin projects consisting in producing energy from landfill gas have already been managed. On account of changed system of communal waste management, which basically meant replacement of waste disposal with processes of their mechanical-biological processing, the amount of biodegradable waste (organic matter) deposited in the landfills decreased. The type of waste finally deposited in the landfills changed as well. Currently, there is mainly biologically neutral waste deposited there and ballast generated by the installations of mechanical-biological waste processing. This leads to minimization of anaerobic process of organic substance decomposition and as a result, to reduced volume of landfill gas generated in the waste deposit. The consequence of these changes will inevitably be the reduction of the installed capacity in the landfill plants.

A proof of saturation of the landfill gas power generation market in Poland is the comparison of the number of installations and the power they produced in the year 2012 and 2014. Table 2 demonstrates the comparison of the data concerning the number of installations and their power in particular provinces.

While analyzing the information in table 2, it can be seen that in most provinces the number of newly built installations and the power generated did not change. With reference to the number of new installations only the Lower Silesia, Masovia and Wielkopolska stand out. In the Lower Silesian province 4 new installations were commissioned and the increase in the power generated was approximately 70% (from 4.3 MW$_e$ to 7.3 MW$_e$). In Wielkopolska 3 new installations were built, which led to 19% increase in power (from 5 MW$_e$ to 6 MW$_e$). An interesting case was noted in the Masovian province, where also 3 new installations were built but the total power generated by all the installations practically has not changed. This can attest to the situation already described that the installation power will grad-

Table 2. Number and power of landfill gas energy generating installations in 2012 and 2014

Province	Number of installations			Power [MW$_e$]		
	2012	2014	difference [items]	2012	2014	difference [%]
Lower Silesia	5	9	4	4.345	7.389	70
Kujawy-Pomerania	8	7	–1	3.814	3.743	–2
Lublin	1	1	0	0.5	0.5	0
Lubuskie	1	1	0	0.5	0.5	0
Łódź	4	5	1	4.206	4.147	–1
Małopolskie	6	6	0	2.928	2.928	0
Masovia	21	24	3	11.956	12.046	1
Opole	1	2	1	0.45	0.453	1
Podkarpacie	3	3	0	1.029	1.806	76
Podlasie	1	1	0	0.7	0.7	0
Pomerania	4	5	1	3.557	4.157	17
Silesia	14	15	1	11.188	12.82	15
Świętokrzyskie	1	1	0	0.36	0.36	0
Warmia-Masuria	2	3	1	1.142	1.514	33
Wielkopolska	7	10	3	5.09	6.062	19
West Pomerania	10	10	0	2.825	3.769	33
Total	**89**	**103**		**54.59**	**62.894**	

Source: Own compilation based on [6]

ually be decreasing. The fact is confirmed by the Kujawy-Pomerania and Łódź provinces where a fall was noted in the power produced.

Summary

While discussing the Polish experience related to landfill gas power generation, it must be remarked that the introduction of supporting mechanisms in the form of energy certification significantly increased the power generated from communal waste in the landfill gas power generation installations. We can claim that we took advantage of the chance of management of the fuel which otherwise would at best be unproductively burned in torches. At present, there is a difficult task for the landfill gas power producing installations in Poland to optimize the operation of the installations in the way that will allow to extend the period of their operation.

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Major projects run by Polska Spółka Gazownictwa Sp. z o.o. with the EU funds

More than 1000 km of gas distribution pipelines with the EU funds

Michał Szpila

In 2013, as a result of consolidation of distribution companies from the PGNiG Capital Group, Polska Spółka Gazownictwa Sp. z o.o. assumed the rights and obligations of the beneficiary of 38 gas pipeline construction and expansion projects.

Subsidies for realization of the investments come from the EU budget for the years 2007–2013. In the new EU budget perspective for the period 2014–2020 some more funds are planned for energy-related investments, including the gas engineering sector. Although the principles of grants are about to be altered, the company is already preparing for their acquisition.

The potential of financing and subsidies

The possibility of obtaining subsidies for gas engineering investments appeared for the first time in the EU budget perspective for the years 2007–2013. Subsidies were granted for construction of gas storage facilities, expansion of gas distribution pipelines, as well as transmission system development and construction of the first in Poland liquefied natural gas terminal.

The gas distribution companies, members of the PGNiG Capital Group, concluded total of 38 contracts for funding investment projects for construction and modernization of gas pipelines. After consolidation of the distribution area in July 2013, the beneficiary of the subsidies, responsible not only for settlement of the subsidies but, first of all, for the final accomplishment of the investment became Polska Spółka Gazownictwa which is currently the greatest beneficiary of funds in the distribution system. It results from the scale of the company`s operation but it also proves the effectiveness of planned model of operation and testifies to the company`s potential.

Of all the concluded contracts for subsidies, 18 originates from the Operational Programme Infrastructure and Environment (POIiŚ) which comprises large investments worth several dozen million PLN each. Owing to the accepted technical parameters, the projects reach beyond the regional scope so they are the feed source for more gas networks and they contribute to improved energy security of the country. The institution responsible for granting and settlement of the subsidies is the Oil and Gas Institute – National Research Institute in Krakow. The Institute, as a party to the contracts for financing, supervises the project completion and provides the necessary substantive support for beneficiaries.

Projects conducted by Polska Spółka Gazownictwa Sp. z o.o.

The largest projects conducted by PSG Sp. z o.o., aided in the framework of POIiŚ are realized by the Branch in Gdańsk, in the area of the Pomeranian province (*the project called "South-eastern gas supplies to the*

Times of major changes in Polska Spółka Gazownictwa Sp. z o. o.

Polska Spółka Gazownictwa is a company of great importance for the Polish economy and energy security of the country. This modern enterprise with rich traditions is drawing on the experience of over 160-year-old history of gas engineering in Poland. The company came into being in July 2013, as a result of consolidation of six distribution companies which belonged to the PGNiG S.A. Capital Group. Currently, Polska Spółka Gazownictwa experience a special time – the company is facing great challenges resulting from major changes in the market.

At present, Polska Spółka Gazownictwa are implementing a new, innovative model of business, targeted at improvement in the effectiveness of the structures and business operations. It will enable e.g. limitation of administration procedures, reduction in the management levels and facilitated circulation of information in the company. Uniform sales model will be implemented with respect of distribution and customer service. Moreover, we intend to raise the effectiveness of executed projects and continue investments, including those co-financed from the EU funds.

Consolidation of all the structures in Polska Spółka Gazownictwa and extensive changes in many areas of the company business testify to the decisive character of the operations which will allow to strengthen the leading position of the company in the natural gas distribution market and will contribute to developing a new quality in the Polish gas engineering sector.

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city of Gdańsk and gasification of Wiślinka and Wyspa Sobieszewska) and Kuyavian-Pomeranian and Warmian-Masurian provinces (*Construction of high pressure gas network along the line Szczytno-Młynowo-Muławki k. Kętrzyna and gas network to the communes*, and *Construction of high-pressure gas network along Brodnica-Nowe Miasto Lubawskie-Iława DN300 and gas pipeline to the communes*).

Projects of comparable size in the east and south of Poland are performed by the Branch in Tarnów in the Lublin province (*Gas pipeline to the Włodawa region*) and Świętokrzyskie province (*Gas pipeline to the communes of Chęciny and Sitkówka-Nowiny; Gas pipeline in the communes of Małogoszcz and Włoszczowa*).

Investments of smaller size, but of great importance for improved operation of the gas distribution network are realized by the Branch in Poznań in the Lubuskie province (*Providing equal access to the gas network in the area of the commune of Gorzów*) and also in Masovia, by the Branch in Warsaw in the Masovia region (*Gas pipeline to the city of Stanisławów and improvement in gas supply network in Mińsk Mazowiecki*) and by the Branch in Wrocław in the Lower Silesia (*Development of gas supply system in selected localities of the Strzelin and Wiązów communes in the Strzelin district*).

With the EU subsidies, investments are underway, targeted at supplying gas to the recipients in the areas where gas has never been supplied before, in the following provinces: Podlaskie (*Expansion of gas distribution system in the Białystok agglomeration; Providing access to natural gas in the locality of Suwałki, based on LNG technology*), Opole (*Gas pipeline in localities in Komprachcice and Dąbrowa communes*), Silesia (*Gas pipeline in localities in Herby and Blachownia communes*), Pomerania (*providing gas to the region of Kartuzy district*), Kuyavia-Pomerania (Natural gas – energy for generations, gas pipeline to the communes of Dobrcz and Koronowo; Natural gas – energy for generations, gas pipeline to the communes of Rypin and Osiek; Natural gas – energy for generations, gas pipeline to the communes of Łochowo, Łochowice and Lisi Ogon in the Białe Błota commune) and West Pomerania (*Construction of medium pressure gas network in the seaside area in communes of Darłowo, Mielno and Dziwnów*).

The portfolio of the EU-subsidized projects realized by Polska Spółka Gazownictwa Sp. z o.o. is complemented by 20 agreements for co-financing concluded with the province marshals who decided to support strategic gas engineering investments from the EU funds given to them in the framework of Regional Operational Programmes. The scale of the projects is smaller than in the case of those supported from POIiŚ and their scope and character make them suitable mainly for the provinces in which they were located. Such projects are executed by the company in provinces: Lower Silesia (13 projects), West Pomerania (1), Kuyavia and Pomerania (3) and Łódź (3).

Development and modernization owing to the EU funds

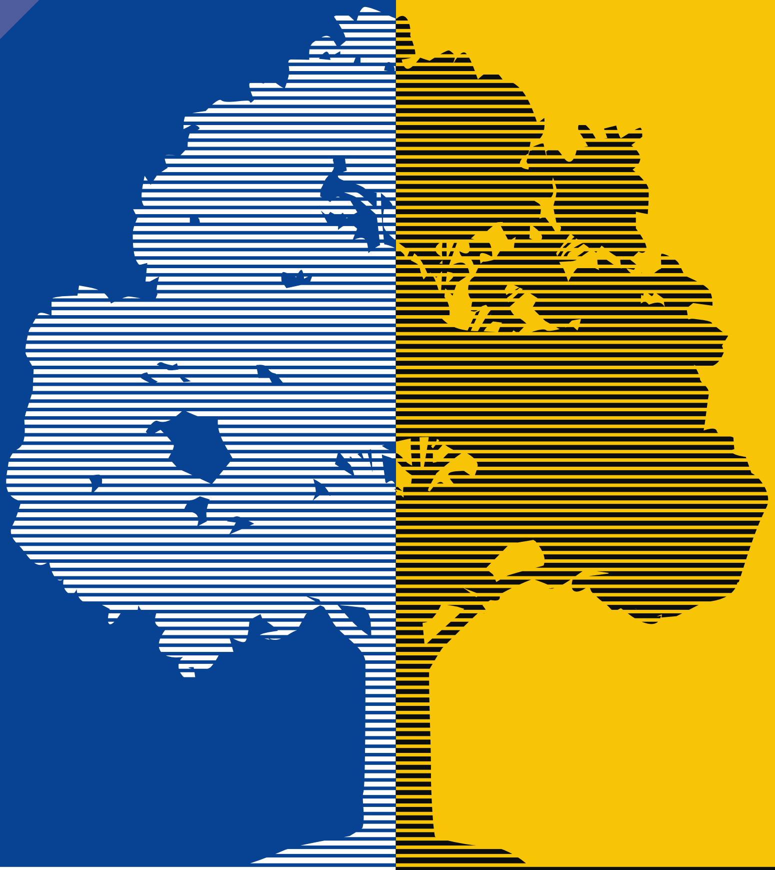
As part of the EU projects, more than 1000 km of gas distribution pipelines will be installed and modernized in all regions of Poland. Total outlays for execution of the projects and the value of obtained subsidies will only be known after completion and settlement of the investments, as modification of the projects, necessary to implement when the works are underway, and the amount of outlays after adjudication of the tenders for construction works, may diverge from the original assumptions adopted at the stage of application for subsidies. Completion of the projects is planned for the year 2015.

Less than two years that remained for completion and settlement of the EU projects funded from the budget for the years 2007–2013 is a great challenge for the company and a signal for more intense commitment. Failure to finish the project on time may result in reduction of the subsidies or the necessity of their return. Therefore, the projects are realized within appointed entities and project teams who run the projects, which guarantees continuity and effectiveness of further work. After consolidation, on account of the number and scale of the projects, European Funding Office was created in the Head Office of the Polska Spółka Gazownictwa Sp. z o.o., responsible for monitoring of advancement of the project works, acquisition of essential data and ensuring effective swapping of information and experience owing to created system of internal reporting. The European Funding Office is also supposed to provide effective cooperation related to the EU projects with other entities of the PGNiG Capital Group, beneficiaries outside the group and institutions which grant the subsidies, in particular, the Oil and Gas Institute – National Research Institute and the Ministry of Economy.

Plans for the future

The years to come will also be the period of intensive preparations and vital adjudications for the system of granting the EU subsidies in subsequent EU budget perspective. In the years 2014–2020, Poland will receive from the European budget € 82.5 billion to aid the projects in all economic sectors. Polska Spółka Gazownictwa Sp. z o.o., as the largest beneficiary in the gas distribution sector makes use of gained experience and joins in the activities of the national and European administration, making a contribution to improve the system of granting subsidies. Simultaneously, a company strategy is prepared in respect of obtaining the EU funds for investments, which will define the principles for qualification of co-financing projects, will indicate the key projects and unify the approach to arrangements for co-financing applications.

At this moment, it is impossible to decide on the success of the activities related to preparations for the 2014–2020 perspective. In the new perspective, the volume of public aid for a single project may turn out to be smaller than so far. Moreover, the European Commission expects concentration of funds on projects dealing with "intelligent" functionalities. At the same time, we can expect facilitation in terms of the national regulations. In the 2007–2013 perspective, complicated and time-consuming procedures of awarding subsidies caused considerable delays already at the start of the investment. Therefore, in the years 2014–2020 gas distribution projects will be qualified for co-financing without any tenders. This raises hope for significant shortening of the procedure of evaluation and signing the co-financing agreements. ■



Assessment of the use of gas from shale formations in standard gas appliances based on U.S. data

Quality of gas from Polish shale reserves

Zdzisław Gebhardt

One of the problems to be considered in projects related to the acquisition of natural gas from shale is the problem of the quality of the gas with respect to the possibility of its combustion in the currently used gas appliances.

This is not a new problem, because, as it is known in Poland, natural gases are present in various composition configurations of such basic elements as methane and nitrogen, with additional hydrocarbon and non-flammable gases present in low or even trace concentrations. Currently, Polish Standards distinguish three subgroups of natural gases (E, Lw, Ls), and until 2011, PN standards included Lm and Ln groups as well. Generally speaking, natural gases extracted in Poland from classic reserves are characterized by the Wobbe index range from 25 to 57 MJ/m^3. The quality of gas from Polish shale reserves is currently difficult to assess, therefore this article focuses on data published in the United States, where the exploitation of shale gas has reached a very advanced market level. For comparison, parameters of the first gas drill holes made in Poland have been presented.

Characteristics of the main shale gas reserves in the U.S.

The map of shale gas reserves shown in Figure 1 is the one most often presented in literature.

The paper [2] describes 6 major shale gas fields: Barnett, Marcellus, Fayetteville, New Albany, Antrim and Haynesville. Analysis of the parameters of the fields and composition of gases extracted from them may be helpful in assessing the expected output from the Polish reserves.

Barnett Field

The gas field is located in the state of Texas at a depth from 1980 m to 2896 m. Main operators include the following companies: Chesapeake Energy,

Table 1. Composition of gas produced from the Barnett field

Source	C_1	C_2	C_3	CO_2	N_2
1	80.3	8.1	2.3	1.4	7.9
2	81.2	11.8	5.2	0.3	1.5
3	91.8	4.4	0.4	2.3	1.1
4	93.7	2.6	0	2.7	1
Average	86.75	6.725	1.975	1.675	2.875

Source: U.S. Energy Information Administration based on data from various published studies. Canada and Mexico plays from ARI.
Updated: May 9, 2011

Figure 1: Map of shale gas reserves in North America

Devon and EOG Resources. Average gas production in 2008 ranged within 590÷4720 m^3/h. Gas composition adapted from the paper [1] is shown in Table 1.

NOTE: Abbreviations used in the tables for gas formulas are: C_1 – methane, C_2 – ethane, C_3 – propane, C_4 – butane, C_5 – pentane and higher, CO_2 – carbon dioxide, N_2 – nitrogen.

Calculated parameters of gas compositions listed in Table 1 are shown in Table 2.

Marcellus field

The Marcellus field is located in the north-eastern part of the United States, extending over the states of Pennsylvania, Ohio and West Virginia at a depth of 610 m to 2438 m. The field, with a huge potential, in initial drills, showed gas flows at the same level as the Barnett field, in the range of 590÷4720 m^3/h. Its potential is attested by the information that in 2013 the deposit operator, Southwestern Energy Company, reached the level of 487 286 m^3/h, while the total production of gas from the Marcellus field in March 2014 reached the amount of 17 108 115 m^3. According to

Table 2. Calculated parameters of gases with compositions shown in Table 1

Parameter	Heat of combustion *Hs* [MJ/m^3]*	Relative density *d*	Wobbe index (upper) W_s [MJ/m^3]
source 1	37.895	0.656	46.782
source 2	43.457	0.662	53.392
source 3	37.975	0.603	48.899
source 4	37.120	0.595	48.103
Average	39.112	0.629	49.303

* In the following publication, all gas energy parameters are given for reference conditions of 15°C and 1013.25 mbar

Table 3. Composition of gas from the Marcellus field [1]

Source	C_1	C_2	C_3	CO_2	N_2
1	79.4	16.1	4	0.1	0.4
2	82.1	14	3.5	0.1	0.3
3	83.8	12	3	0.9	0.3
4	95.5	3	1	0.3	0.2
Average	85.2	11.275	2.875	0.35	0.3

Table 4. Calculated parameters of gases with compositions shown in Table 3

Parameter	Heat of combustion H_s [MJ/m^3]	Relative density d	Wobbe index W_s [MJ/m^3]
source 1	44.473	0.661	54.701
source 2	43.626	0.647	54.223
source 3	42.467	0.642	52.994
source 4	39.021	0.581	51.214
Average	42.397	0.633	53.298

forecasts, in 2015 the field will provide 25% of natural gas used in the USA [5].

The Wobbe indexes calculated on the basis of the composition indicate that in addition to the enormous mining potential, the reserve is characterized by a very stable parameter corresponding to the stability of the thermal load of the burner, which is the Wobbe index.

Fayetteville field

The reserve is an unconventional gas reserve with thickness from 15 m to 165 m, extending along the State of Arkansas at a relatively small depth from 460 to 1980 m. Initial extraction, ranging from 1415 to 4840 m^3/h, was quickly growing in subsequent years, so as to reach 67 881 thousand m^3 in 2005. In 2009, 14.7 billion m^3 of gas was sold from this field, and, in 2013, material production was already at the level of 29 billion m^3 [6].

New Albany field

The New Albany is 30 to 120 m thick and is located in southern Illinois, stretching over the states of Kentucky and Indiana, but at a smaller depth, from 150 to 1500 m. Initial extraction from this reserve reached the value of 2360 m^3/h. So far, it has been little exploited (in 2012–2013, there were only 8 concessions obtained for horizontal drilling).

Parameters calculated for this composition are shown in Table 8 and indicate that, despite some content of carbon dioxide, these gases have a very stable value of the Wobbe index.

Antrim field

One of the most interesting fields – due to the composition of the gas – is located in the state of Michigan, Antrim reserve. The uniqueness of the composition of the gas from the field is due to the way it was created in the process of bacterial processing of organic material contained in the shale (the process is similar to that for the formation of biogas). By 2008, 9,000 drill wells provided a total of 71 billion m^3 of gas.

Haynesville field

Presented as the last, this field is most similar to Polish deposits, due to its depth – Haynesville is located on the border between North Louisiana and East Texas at the depth of 3000 m. Temperature of the reserve is 177°C and its pressure ranges from 210 to 280 bar. Initial gas production was at the level of 2950 to 23600 m^3/h [2].

Composition of gas from boreholes made in Poland

Table 13 shows four gas compositions from the boreholes in which it occurred (with oil) with parameters that enable pre-exploitation.

Parameters of test gases

To assess the possibility of use of gases shown in Table 14, Table 15 presents the characteristics of the test gases used in the study of gas appliances, designed to be supplied with the natural gas group E for which methane is the reference gas (G20).

As it is shown in Table 15, test gases represent extreme situations which may occur during handling the distributed gas. Critical gases: of incomplete

Table 5. Average composition of the Fayetteville gas [Tab. 2]

Source	C_1	C_2	C_3	CO_2	N_2
Average	97.3	1	0	1	0.7

Table 6. Calculated parameters of gases with compositions given in Table 5

Parameter	Heat of combustion H_s [MJ/m^3]	Relative density d	Wobbe index W_s [MJ/m^3]
Average	37.421	0.572	49.501

Table 7. Average composition of the New Albany gas [3]

Source	C_1	C_2	C_3	CO_2	N_2
1	87.7	1.7	2.5	8.1	0
2	88	0.8	0.8	10.4	0
3	91	1	0.6	7.4	0
4	92.8	1	0.6	6.6	0
Average	89.875	1.125	1.125	8.125	0

Table 8. Calculated parameters of gases with compositions shown in Table 7

Parameter	Heat of combustion H_s [MJ/m^3]	Relative density d	Wobbe index W_s [MJ/m^3]
source 1	36.649	0.665	44.950
source 2	34.541	0.666	42.310
source 3	35.615	0.636	44.647
source 4	36.295	0.634	45.577
Average	35.775	0.650	44.359

Table 9. Average composition of the gas from the Antrim field, based on [4]

Source	C_1	C_2	C_3	CO_2	N_2
1	27.5	3.5	1	3	65
2	57.3	4.9	1.9	0	35.9
3	77.5	4	0.9	3.3	14.3
4	85.6	4.3	0.4	9	0.7
Average	61.975	4.175	1.05	3.825	28.975

Table 10. Calculated parameters of gases with compositions shown in Table 9

Parameter	Heat of combustion H_s [MJ/m^3]	Relative density d	Wobbe index W_s [MJ/m^3]
source 1	13.661	0.877	14.584
source 2	26.707	0.742	30.999
source 3	32.786	0.671	40.027
source 4	35.567	0.666	43.591
Average	27.180	0.739	31.616

Table 11. Average composition of the Haynesville gas, based on [2]

Source	C_1	C_2	C_3	CO_2	N_2
Average	95	0.1	0	4.8	0.1

Table 12. Calculated parameters of gases with compositions shown in Table 11

Parameter	Heat of combustion H_s [MJ/m^3]	Relative density d	Wobbe index W_s [MJ/m^3]
Average	35.957	0.602	46.338

combustion and yellow tips – G21, and blow-off of the lifted flame – G231, represent the extreme parameters of the Wobbe index, which for the actual group E gases cover the range of 40.9÷54.7 MJ/m^3.

Table 13. Composition of gas in boreholes in Poland with parameters that enable to pre-exploitation

Hole	C_1	C_2	C_3	C_4	C_{5+}	CO_2	N_2
Lubocino-1	73.61	13.16	6.38	2.571	1.466	0.11	2.34
Berejów separator	66.76	11.9	8.23	5.048	3.59	0.53	3.33
Berejów, natural gasoline-recovery	62.14	12.01	8.42	4.496	7.947	0.85	3.72
Syczyn	84.25	5.97	3.33	1.46	1.066	0.15	3.57

Table 14 Energy parameters of the gases shown in Table 13

Parameter	Heat of combustion H_s [MJ/m^3]	Relative density d	Wobbe index W_s [MJ/m^3]
Lubocino-1	48.552	0.766	55.475
Berejów separator	53.301	0.866	57.277
Berejów, natural gasoline-recovery	59.927	0.991	60.199
Syczyn	42.647	0.678	51.793

The flashback gas – G222 – shows, however, possible presence of unsaturated hydrocarbons with a burning rate much higher than the rate of methane combustion in the composition of the gas fed into a device, and thus contributing to the creation of a flashback behind the burner nozzle. Test gases specified with the above standard allow to get similar results in different laboratories for the same types of devices.

Evaluation of the usefulness of shale gas

Analyzing the earlier presented compositions of gases from American and Polish shale formations, we can immediately notice a relatively large discrepancy of gas composition dependent on the location of the reserve. The Antrim field can be excluded from analysis as, considering its depth and the resulting temperature and pressure, it is unlikely for a similar process of formation of methane to take place in any Polish reserves.

Considering the Marcellus and Barnett fields, we can see similarity in the content of ethane and propane, when compared to Polish gases. These fields provide high-yield production of gas, locating in the upper limits of the Wobbe index for group E. On the basis of the composition ratio of methane and ethane in these gases, it can be assumed that they are very similar to those of the Lubocina and Barejów gas drill wells in relation to which material from the U.S. fields is better than gases from Polish reserves after natural gasoline-recovery – containing, as can be seen, quite a large amount of C_{5+} hydrocarbons (this group includes hydrocarbons up to C_{11}).

Among the U.S. reserves, excluding the said Antrim, other reserves produce gases that are very well suited into the range of Wobbe index included in the EN 437 standard for group E, and – vice versa for Polish reserves – only the Syczyn gas can be directly consumed in gas appliances category I2E. Other gases need to be adjusted, for example by removing the excess of higher hydrocarbons – starting off with butane.

It is interesting to compare the gas from the Barnett and Marcellus fields with hypothetical configurations of gas reserves from Lubocino-1 and Syczyn, as obtained after computed separation of such hydrocarbons as butane and higher.

In conclusion, it should be noted that the above analysis applies, so far, to Polish gases coming from only three boreholes. However, if the trend of gas

Table 15. Characteristics of the tested gases in accordance with EN 437, dry gas at the temperature of 15°C and pressure of 1013,25 mbar [7]

Family and gas group	Test gases	Indication	Volumetric composition [%]	W_i [MJ/m³]	H_i [MJ/m³]	W_s [MJ/m³]	H_s [MJ/m³]	d
Group E	Reference gas	G20	$CH_4 = 100$	45.67	34.02	50.72	37.78	0.555
	Critical gas of incomplete combustion and yellow tipping	G21	$CH_4 = 87$ $C_3H_8 = 13$	49.60	41.01	54.76	45.28	0.684
	Critical gas of flashback	G222	$CH_4 = 77$ $H_2 = 23$	42.87	28.53	47.87	31.86	0.443
	Critical gas of flame lift	G231	$CH_4 = 85$ $N_2 = 15$	36.82	28.91	40.90	32.11	0.617

compositions obtained in the new boreholes remained at this level, there should be no problem with using them. The U.S. example shows that this trend is highly probable.

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Table 16. Comparison of gases from the Barnett and Marcellus fields with hypothetical configurations of gases from the Lubocino-1 and Syczyn fields

Parameter	C_1	C_2	C_3	CO_2	N_2	Wobbe index
Barnett	86.75	6.725	1.975	1.675	2.875	49.303
Marcellu	85.2	11.275	2.875	0.35	0.3	53.298
Lubocino-1	76.71	14.17	6.65	0.115	2.44	53.876
Syczyn	86.43	5.99	3.43	0.155	3.68	50.352

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Connecting of the Polish gas network with systems in the neighbouring countries

Improvement of energy security in Central and Eastern Europe

Rafał Wittmann, Agnieszka Ozga

Assessment of the current state of development of natural gas market in Central and Eastern Europe, with special attention to prospective opportunities of satisfying the needs of natural gas customers in this region confirm that actions taken by operators of gas transmission systems in the field of building interconnections are fully justified. Owing to these connections, closer cooperation between the operators of transmission infrastructure in Central and Eastern Europe will be enabled. They will also ensure better conditions for implementation of the most important objectives of the European Union and concerning energy independence and development of a competitive energy market.

The recent experience clearly shows that, despite many years' cooperation, traditional gas suppliers are not always able to ensure stable supplies necessary for economic development of the European Union countries. Gas supplies are used as a political tool irrespective of the market trends. In addition, frequent disruptions in gas supplies caused by factors independent from countries which are gas buyers undermine the trust to the gas sector. What is more, the current trends aim at limiting the use of technologies based on natural gas and replacing them with other solutions, including those based on coal.

Creating the Energy Union

To limit negative aspects with regard to gas supplies and enable restoration of trust in natural gas, it is necessary to make modifications in the current strategies and search for new solutions in fuel acquisition from alternative directions and on more attractive conditions. This need is reflected in a widespread discussion on the European forum about creation of the so-called Energy Union which is to be the next important step in the direction of strengthening the foundations of European economy. This concept, winning much support recently, should be perceived in a particular way by the countries in Central and Eastern Europe.

They are located the closest to the eastern sources of gas, therefore they have the most difficult conditions to obtain gas from other directions. These difficulties are caused by considerable fragmentation of the market which is currently composed of many countries with gas consumption at the level of 5 to 15 bcm/y. Despite the fact that in total, the size of the gas market for the Central and Eastern European countries reaches the level of 40–50 bcm/y (with Ukraine, which is opening up to the West of Europe, this volume may even be at the level of 100 bcm/y), such fragmentation and the lack of coordinated regional purchase policy makes the market of Central and Eastern Europe hardly attractive for building new corridors transporting large volumes of gas from new sources. In addition, the existence of expanded transmission infrastructure used for gas transit from the East along the East-West direction and simultaneous lack of connections between these countries on the North-South line do not improve the situation. The decision on abandoning the Nabucco pipeline, diversion of gas supplies from the Caspian Sea to the Italian market coupled with the lack of investment decisions on building other import in-

Source: GAZ-SYSTEM S.A. archive

frastructure (including LNG regasification terminals in the region) deteriorates the situation further.

Having this in mind, integration of the transmission infrastructure in the region and providing conditions for a big regional gas market promoted by the transmission system operators from Central and Eastern Europe takes on a special dimension. Creation of such a market will naturally make global suppliers see this region as more attractive for development of their business and strengthening of their position in respect of gas supply in the region. For the region, new directions of gas supply from the Caspian Sea and the North Sea deposits may be very attractive. Gas could be supplied from there with the use of gas pipelines. Moreover, such a market could also be attractive for other sources such as LNG.

Providing such conditions for gas market operation in the region would considerably increase energy security which – apart from the infrastructural dimension – should be understood as diversified portfolio of gas purchase contracts ensuring flexibility and continuity of supplies to consumers. This would enable acquisition of cheaper energy for the needs of economic development of the countries in the region and would significantly increase competitiveness of enterprises operating in these countries.

Integration of the regional gas market could also be beneficial for the Polish entrepreneurs as they could reach their customers with a new offer and expand the area of their activity beyond the borders. To achieve this, it is necessary, apart from developing the infrastructure, to gradually unify the rules for gas markets` operation. Owing to that, the conditions for operation of enterprises on other than traditional markets used so far will be easier. Such changes have already been introduced in the European Union countries for many years so far, but their dynamics and progress are varying, depending on the country and the region.

Natural gas market in Poland

In the recent years, the Polish natural gas market has also been undergoing transformation. Gradually, the process of liberalisation and development of competitive market mechanisms have been taking place. The Polish customers consume about 15 bcm of gas per year, about 30% of which is covered from domestic resources, while the rest comes from import contracts, mostly from the Yamal contract, binding until the year

2022. For several years, increase in gas consumption has been observed and forecasts indicate that this tendency will continue in the years to come. As there is no possibility to substantially increase gas production from domestic resources in the nearest years, it will be necessary to increase the import.

It requires development of import infrastructure that will ensure the possibility of obtaining gas from new directions and enable gradual stabilisation of gas import conditions. For many years, the currently used transmission infrastructure (designed and built in the previous century) has only been targeted at gas transportation from the East to the West. The main gas import points are located in the East, on the border with Belarus and Ukraine, and also inside the country and on the transit Yamal-Europe gas pipeline. The main gas supplies for Polish customers are made through these entries into the national system. Such condition of gas infrastructure, with its limited technical parameters, restricts the dynamics of gas market development in Poland. That is why it is indispensable to modernise the national transmission system and integrate it with the adjacent transmission systems in the European Union in a way which will enable diversification of import directions and open new possibilities for the operating enterprises.

Activity of Gas Transmission Operator GAZ-SYSTEM S.A. – diversification of sources of gas supply to Poland

Such activity has a special position in the strategy of the Gas Transmission Operator GAZ-SYSTEM S.A., responsible for the development and maintenance of the national transmission infrastructure since 2004 (since 2010, also of the Transit Gas Pipeline System (TGPS) on the territory of the Republic of Poland). The tasks of the company are defined in the energy law and the most important of them include transportation of gas by transmission network all over the country to deliver it to the distribution networks and to customers connected to the transmission system, as well as securing proper transmission capacity – including the cross-border connections – to satisfy the long-term demand of the customers. The company plans that by the years 2018–2019 the conditions for safe transportation of natural gas in Poland should be ensured and new interconnections should be created supporting the integration of the transmission system in Europe.

In consideration of the above plans, one of priority actions taken in the recent years by GAZ-SYSTEM S.A.

Source: GAZ-SYSTEM S.A. archive

Source: GAZ-SYSTEM S.A. archive

are those aiming at connection of the Polish transmission system with the systems of the neighbouring countries. This will facilitate diversification of gas supply sources to Poland and improve the energy security of the country. Simultaneously, such connections will allow to export gas to the neighbouring countries, what will open new possibilities for making use of the national transmission infrastructure.

It is worth mentioning that the first effects of implementation of gas supply diversification to Poland were already observed in 2011. It was then that the connection with the Czech transmission system in Cieszyn was completed and put into service and also connection with the German system in Lasów was expanded. Additionally, accomplishment of these investments enabled the import of about 1.0 bcm/y of gas to Poland. Launching the virtual reverse flow in 2011 allowed further increase in import capacities from the German direction by about 2.3 bcm/y. Consequently, technical import capacities from the European Union countries increased to about 30% of the total demand.

Moreover, in 2014 modernisation of the Mallnow metering station was completed and technical conditions for physical transmission of gas from Germany through the Yamal gas pipeline were provided. This investment was completed, among other things, in connection with the obligation to implement the reverse gas transmission in compliance with the Regulation (EU) no. 994/2010 of the European Parliament and of the Council of 20 October 2010 concerning measures to safeguard security of gas supply and repealing the Council Directive 2004/67/EC. Owing to the above mentioned investments, the present technical import capacity from the European Union countries is at the level of about 7.5 bcm /year, which makes it possible to satisfy about 70% of the demand covered by import.

Construction of one of the most important strategic investments made to improve energy security of Poland – the LNG Terminal in Świnoujście – has been in progress, parallel to the pipeline investments. This terminal, together with developed new transmission gas pipelines in the North and the centre of Poland, will enable the import and transmission of maximum 5 bcm of gas per year. It means that already in the year 2015 there will be technical possibilities to cover the whole gas import demand through the import entries, alternative to the traditional ones, from the eastern direction.

The possibility of importing gas from any independent LNG source is the reason why more and more companies, also from outside Poland, are interested in the access to this source. Companies from Central and Eastern Europe, Germany, Scandinavia and the Baltic countries may be potential recipients of gas from the LNG Terminal in Świnoujście. Therefore, GAZ-SYSTEM S.A. has been engaged in intensive works preparing the construction of the North-South Corridor, which is a significant element of a uniform gas market in Central and Eastern Europe. It will enable connection of transmission networks of the countries in the region i.e. Poland, Slovakia, Hungary and the Czech Republic. This system will facilitate gas supplies from the LNG Terminal in Świnoujście to the countries of the region, potentially also from the Caspian Sea and the North Sea.

The North-South Corridor consists of many bidirectional cross-border interconnections and domestic gas pipelines which are already operating or are at different stages of planning or execution. Construction of the North-South Corridor aims at:

- increased regional integration of the gas markets,
- increased security of supplies,
- providing access to new sources of supply (LNG, Norway) for Central and Eastern Europe,
- coordination of regional infrastructure projects,
- harmonisation/unification of rules binding on the market,
- implementation of regional preventive and emergency procedures.

As part of the implementation of the North-South Corridor project, construction of many new interconnections is planned, including two interconnectors joining the Polish transmission system with the systems of our southern neighbours. By the year 2018, commissioning of a bidirectional connection with the Czech transmission system with capacity of 6.5 bcm/y is planned together with the Czech operator NET4GAS. At the next stage, accomplishment of a Polish-Slovakian interconnection with capacity of ca 5.7 bcm per year is planned, in cooperation with the Slovakian operator Eustream. Apart from these import-export interconnectors, the interconnection Poland-Lithuania is planned in cooperation with the AB Amber Grid, aiming mainly at integration of the Baltic systems and elimination of the so-called energy islands.

The decision of the European Commission on granting the status of Project of Common Interest (PCI) to investments carried out by GAZ-SYSTEM S.A. was a very important event for the projects realized by the company. On 14 October 2013 the European Commission (EC) published the first European list of projects in the natural gas sector which will be granted the PCI status. This decision was preceded by analytical studies carried out by the European Commission in cooperation with the Member States and transmission system operators, among others. Granting the status of common interest to the projects is a confirmation that infrastructural investments in which GAZ-SYSTEM S.A. participates are of key importance for the development of an integrated, effective and competitive natural gas market in Europe. In this way, acknowledgement was made to the contribution towards increased security and natural gas diversification. The projects include:

1. North-South Gas Corridor in Central-Eastern and South-Eastern Europe:

- Western line of the North-South Corridor in Poland together with the interconnection between Poland and the Czech Republic;
- Eastern line of the North-South Corridor in Poland with interconnection between Poland and Slovakia.

These projects are a very important element complementing the strategy of construction of safe transmission system both in Poland and in Central Europe. After they have been implemented, the transmission system in Poland will have high degree of reliability and it will decrease the vulnerability of the Polish market to emergency situations. These interconnections are crucial elements of the concept of the regional North-South Corridor. At present, both projects are at advanced pre-investment stage.

2. The Baltic Energy Market Interconnection Plan (BEMIP):

- Polish-Lithuanian interconnection;
- the Baltic Pipe gas pipeline;
- expansion of the LNG Terminal in Świnoujście;
- expansion of the entry points to the Yamal pipeline in Lwówek and Włocławek.

Implementation of most of the above projects together with construction of national transmission network was included in the Ten-Year Development Plan of GAZ-SYSTEM S.A. in respect of satisfying the present and future demand for natural gas in the years

Source: GAZ-SYSTEM S.A. archive

2014–2023, which was approved by the President of the Energy Regulatory Office on 4 April 2014. This in turn, confirmed the importance of prepared investment projects for the development of gas market in Poland. According to the present estimates, the accomplishment of the investment projects will require engagement of considerable funds. The investment outlays will have reached about PLN 7.124 billion by the year 2018. At present, GAZ-SYSTEM S.A. prepares financing for the new projects, however, a large part of the necessary funds has already been secured.

Bearing in mind the present positive experiences in raising funds from the European Union, as in the previous year, GAZ-SYSTEM S.A. will apply for further support of the infrastructural investments, ensuring increased national energy security and integration of the gas market in the region. The company plans to apply for funding the projects within the new EU financial perspective for the years 2014–2020. In this perspective, funding the gas transmission projects will be granted on the national level from the Operational Program Infrastructure and Environment for the years 2014–2020 and it will include mainly projects for development of internal national transmission network. Moreover, raising substantial funds for the interconnections is also expected within the new instrument – Connecting Europe Facility (CEF). This scheme will enable implementation of these undertakings as planned and will allow to limit its implementation effects on the transmission tariff rate.

Summing up, it is worth emphasizing that all the present activities of GAZ-SYSTEM S.A. are pursued in cooperation with the transmission system operators in the neighbouring countries, which gives regional dimension to the prepared infrastructural projects and it also significantly enhances the prospects of their fast implementation and achievement of full functionality. After their implementation, proper level of the national energy security will be ensured in the field of gas supplies and increased possibilities of operation of gas enterprises which will be able to expand their business areas beyond the present domestic markets. As a result, trust in the gas sector should be gained back in the region. It should be noted that these plans are fully in accordance with the European policy of development of the internal energy market. It is expected that most effects will be achieved already in the years 2018–2019, which is comparatively fast, considering the range of planned investments. On the other hand, it allows the companies to prepare new operational strategies and adapt to newly created long-term market opportunities.

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Implementation of Polish energy policy principles

Świnoujście on the map of LNG market

In 2015, the map of the global LNG market will gain a new, important position. The LNG terminal in Świnoujście designed for imports and regasification of liquefied natural gas is the first project of this type in the East Central Europe and the largest facility situated at the entry to the Baltic Sea from the Danish straits.

Its regasification capacity will amount to 5 billion m^3 and will satisfy one third of the Polish demand for natural gas – with the possibility of expansion of annual capacity to 7.5 billion m^3.

Objective, strategy, benefits

The project, regarded by the Polish government as strategic, will allow to reach the key goals of energy policy, defined as increased security and diversification of gas supplies. Świnoujście will enable our country to import LNG by sea, practically from any direction in the world. By providing liquefied natural gas supplies, starting from the year 2015, the LNG terminal in Świnoujście will have a positive impact on the operation of the national gas market. As an alternative source of supplies, it will support the development of competition and will improve the negotiating position of the national gas trading companies in respect of changing the existing contracts for supplies of the fuel or concluding new ones.

The LNG terminal in Świnoujście will also exert influence on the European market. The Polish participant of the European natural gas transmission system will render services which will make use of the project capacity and will ensure its competitiveness. Owing to diversification and application of clean, safe and modern technologies, the terminal will contribute to the growing dynamics of the global LNG market.

Location of the project

The terminal is located in the north-western part of the West Pomeranian province in the area of Świnoujście City on the Wolin island, in the vicinity of existing installations of the commercial seaport, on the right bank of the Świna river. The facility consists of an onshore and offshore part. The onshore part, i.e. the LNG terminal installations, cover the area of approximately 48 ha, 750 meters from the sea and are connected with the shore by a flyover about 10 m wide. In the offshore part, the terminal`s breakwater extends about 3 km into the Baltic Sea – to the east of the breakwater which is part of the Świna port infrastructure. The pipeline connecting the terminal with the national transmission grid will be extended to Goleniów where gas pumping station is located.

The project is executed by the Polskie LNG. The Company has two basic goals: construction and operation of the LNG terminal in Świnoujście. The first one comprises e.g. the development of technical and economic documentation and obtaining essential administrative permits. The tasks also involve the appointment of the Chief Project Constructor and supervision and coordination of operations related to the construction – including environment-related monitoring and post-investment procedures. The other goal is the operation of the terminal with active support for the security and reliability of LNG import to the Polish and European gas system and effective cooperation with other entities in terms of development of competitiveness on the gas market.

Apart from the Polskie LNG which is responsible for the onshore part (facilities for unloading, liquefied natural gas storage tanks, regasification installations), three other entities are engaged in execution of the project: Maritime Office in Szczecin (construction and maintenance of the external port infrastructure, including the new breakwater, spur, turning basin and approach track and supervision of security of the vessel movements), Szczecin and Świnoujście Seaports Authority (construction of the port infrastructure, including the berth) and Operator Gazociągów Przesyłowych GAZ-SYSTEM S.A. *[Gas Transmission System Operator]* (coordination of the whole project related to the LNG terminal, participation in its financing, construction and operation of the connecting and transmission gas pipelines), which is also the owner of the Polskie LNG Company.

Business and administrative challenges

Installations for receiving and regasification of liquefied natural gas are extremely complicated engineering projects. They are a great challenge not only for investors but also for the governments. Construction of the LNG terminal in Świnoujście is conducted according to the highest quality standards. It is constantly monitored and run in harmony with natural environment, in compliance with strict safety and legal regulations. The investment is situated in close vicinity of the area Natura 2000. It is executed without reservations on the part of environmentalists or community – a compromise was reached when the terminal was moved 750 meters inland. Moreover, careful monitoring of the nature near the project area and Social Dialogue program helped the investor to establish authentic and proven relationship with the neighbours – listening to their needs, creating the platform for local initiatives supported by the Polskie LNG and obtaining unprecedented scale of social support, documented by the survey results.

Equal consideration was given to the issue of safety, conducting e.g. hazard identification study (HAZID), hazard and operability study (HAZOP), analysis of safety integrity level for the installation (SIL) and many more. Moreover, the company remains in contact with all the services responsible for safety and the construction is under Transportation Technical Supervision.

Equally huge is the scale of challenge with respect to financing the investment. Polskie LNG provide the necessary funds in an advantageous way. The key to the success is skillful raising of the funds available on the market and proper expenditure of

the already granted funds. Capital outlay for construction of the LNG terminal in Świnoujście was estimated at approximately PLN 3 billion. Some of the project budget is own capital of Gaz-System company (the owner of the Polskie LNG) and from the EBI funds. Financing from EBI consists in taking out investment credits by the Gaz-System for construction of the LNG terminal in Świnoujście, and then transferring the funds to Polskie LNG company. The latter is the beneficiary of the aid from the EU funds and it covers over 36% of the expenses from the EU funds, including PLN 839.4 m from the Operational Program Infrastructure and Environment for the years 2007–2013 and about PLN 220 m (€ 55 m) from the European Energy Programme for Recovery.

Looking into the future

The objective for the investor of the LNG terminal is to create infrastructure which will ensure uninterrupted diversification of gas supplies to Poland. The imperative of quality is the most important. The terminal, constructed according to the highest world standards, is to operate efficiently and reliably for the next 50 years and the expectations are considerable. Market screening, i.e. market research carried out by the Polskie LNG at the turn of the year 2012 and 2013, whose goal was to determine the needs of entities potentially interested in the LNG market substantiating the expansion of the terminal in Świnoujście, proved significant demand of external clients for increased regasification capabilities and additional functionalities of the terminal: LNG reloading to tankers or smaller vessels and – which is particularly essential – bunkering the ships with LNG fuel. This meets the opinion of the European Commission which considers liquefied natural gas as the most prospective alternative fuel transported by sea.

To support the facts mentioned, there is growing demand for natural gas consumption in Europe and the constantly increasing demand for it provide the terminal in Świnoujście with new opportunities and prospects. The latter appears not only on the regional, European market but also across the ocean – the United States and Canada are planning to export gas to Europe, which will soon make Świnoujście an important player on the natural gas market. ■

The issue of qualitative measurements of alternative gases

How to deal with helium and hydrogen in gas

Marcin Masek

The concept of the Energy Union – exceptionally popular in the recent months and promoted by Poland in a particular way – is based on four main pillars. Some of them, like joint purchase of gas fuel, meet with opposition from some member states. However, one of the pillars stirs up no controversy, what is more, it has the support of the European Commission.

The pillar in question is the expansion of infrastructure, including storage facilities and connections between the national grids. This policy is entirely coherent with the European plans of creating uniform, liberal market for gas.

Discussion of the problem revealed also awkward differences between particular member states. The discrepancies concern the extent of diversification of sources and directions of supplies (own and external), determinants in internal market, binding technical standards and the quality of the gas, as well as strategic plans leading to achievement of targeted goals.

Popularization of biomethane in Poland and Europe

On the margin of the main discussion, an interesting project is run which popularizes biomethane as fuel originating from renewable sources (www.greengasgrids.eu – project supported by IEE – Intelligent Energy – Europe). KAPE – the Polish National Energy Conservation Agency takes part in the project as the representative of Poland. In August 2011, the Polish legislation (Official Journal of Laws of 2011, no. 187, item 1117) introduced the option of including biogas, enriched to biomethane, to the natural gas distribution network. However, this concerns only biogas originating from fermentation of biomass from agriculture and forestry. Other forms of biomethane production are not legally regulated. In Poland, discussion on the topic may seem a purely academic question as only 34 agricultural biogas plants have been built (in total, ca 200 biogas plants, mostly fermenting the sewage residue or rubbish) and no installation to enrich biogas to biomethane has been built. However, in the neighbouring countries, the topic discussed moved long ago from the conception to implementation phase. In Europe, over 200 stations for biomethane treatment are operating, out of which 152 feed the gas networks (source: DENA – biogaspartner).

Other biomethane sources may be installations for gasification of biomass and dry waste paper (a hot process which resembles pyrolysis, consisting of drying, gasification, purification, methanation and enrichment), or the so-called process Power-to-Biomethane which is a variant of the Power-to-Gas (PtG) installation. The solutions described gain increasingly in popularity in Germany and other countries of Western Europe. Their construction is targeted at consumption or storage of the surplus of electrical energy arising from renewable sources (basically unpredictable energy from wind farms) which the national distribution systems are unable to transmit to recipients in other parts of the country. Such solutions increase the efficiency of using renewable energy (in the long-term perspective) and flexibility of the system (storage of energy for peak demands).

In the Power-to-Gas installations, electrical energy is converted to hydrogen in the process of electrolysis of water. When methanation is added, as another stage, we obtain methane and water ($4H_2 + CO_2 \rightarrow CH_4 + 2H_2O$

and $3H_2 + CO \rightarrow CH_4 + H_2O$). In such variant, the GHG (Greenhouse Gases) balance is more advantageous as carbon dioxide, the main greenhouse gas, is bound in the reaction. In order to increase the energy value of biomethane, it is enriched by mixing with propane-butane. At subsequent stage, hydrogen or biomethane is added to the gas network, and high parameters are the best (they guarantee fast mixing). At increased (peak) demands for energy, gas fuel may be converted to electrical energy. There are more and more installations of this kind in Europe and they are no longer experimental objects but integrated biomethane production plants and peaker power plants operating on industrial scale.

Extended analysis of gas composition in distribution network

The new determinants, which appeared with the installations dispensing biomethane and PtG to transmission grids, made the German regulator issue recommendations for operators of transmission systems to run extended analysis of gas composition in the distribution network. For the accurate definition of the coefficient of calorific value in transmission networks, the measurements of hydrogen content (supplied by PtG installation) and oxygen (on account of biomethane which may contain the gas as a result of H_2S removal) are essential.

The company that had to face the challenge of analyzing the gas parameters was Siemens which for many years has successfully been dealing with analysis of gas composition. An unexpected problem that was encountered was the measurement of hydrogen content, disturbed by the presence of another element in the analyzed natural gas. The component which falsified the results in this case was helium.

The gas distributed in transmission grids of particular countries may significantly differ (table 1). The problem described (the presence of helium) occurred because, apart from the Russian gas, substantial volumes of gas are imported to the German transmission network from the Netherlands. The Dutch gas contains a certain amount of helium which – similarly as nitrogen – reduces the calorific value of the fuel. No separate norms regulate the content of helium in the grid. Helium and hydrogen, for their excellent properties of heat reception, are the most popular carrier gases in chromatographic analysis of natural gas composition. Carrier gas fills the pneumatic system aiding transportation and separation of the analyzed sample in chromatographic columns. Difficulty appears when the same gas, used as carrier gas, is present in the analyzed sample. In such case, it is not detected by chromatograph. For simultaneous determination of helium and hydrogen volumes in the analyzed sample of natural gas, a different carrier gas must be used, e.g. nitrogen or argon.

Micro chromatograph SITRANS CV

In measurements of the content of particular hydrocarbons in natural gas, helium or hydrogen are used most often as carrier gases. The problem was solved due to SITRANS CV micro chromatograph

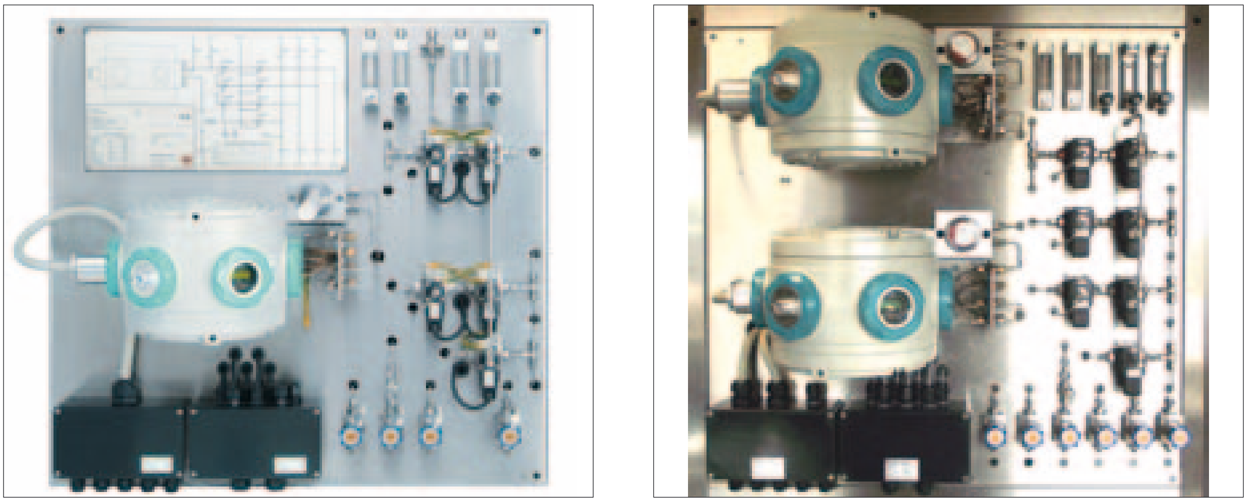

Fig. 1. On the left – standard solution for measurement of natural gas composition based on SITRANS CV micro chromatograph; on the right – measurement using an extra chromatograph working with the other carrier gas.
Source: SIEMENS

Table 1. Similarity of the national norms for biomethane with the natural gas norms

Component	Unit	Austria	France	Belgium	Czech	Germany	Netherlands	Sweden	Switzerland
CH_4	% (vol mol)	≥ 96	≥ 86	≥ 85	≥ 95		≥ 85	≥ 97	≥ 96
CO_2		≤ 3	≤ 2.5	≤ 2.5	≤ 5	≤ 6 (dry)	≤ 6	≤ 3	≤ 6
O_2		≤ 0.5	≤ 0.01		≤ 0.5	≤ 0.5 (wet) ≤ 5 (dry)	≤ 0.5	≤ 1	≤ 0.5
H_2		≤ 4	≤ 6	≤ 0.1		≤ 5	≤ 12	≤ 0.5	≤ 4
CO			≤ 2	≤ 0.2			≤ 1		
S Tot	mg/Nm^3	≤ 10	≤ 30	≤ 30	≤ 30	≤ 30	≤ 45	≤ 23	≤ 30
H_2S (+COS in FR, BE)		≤ 5	≤ 5	≤ 5	≤ 7	≤ 5	≤ 5	≤ 10	≤ 5
mercaptanes		≤ 6	≤ 6	≤ 6	≤ 5	≤ 15	≤ 10		≤ 5 ppmV
halocarbons		0	≤ 1 (Cl) ≤ 10 (F)	≤ 1 (Cl) ≤ 10 (F)	≤ 1.5 (F+Cl)	0	≤ 50 (Cl) ≤ 25 (F)		≤ 1
heavy metals	mg/Nm^3		≤ 1 (µg Hg)	≤ 1 (µg Hg)		≤ 5			≤ 5
siloxanes		≤ 10			≤ 6 (Si)		≤ 5 ppm = 6.2 (Si)		
NH_3 H_2O		technical purity	≤ 3	≤ 3 ≤ 110	none		≤ 3	≤ 20 ≤ 32	≤ 20
dew point	°C	≤ -8. 40 bar	$\leq -5.\ P_{max}$		≤ -10	soil temperature	≤ -10. 8 bar	$\leq t_{min} - 5$	no condensation
odorant		demand. distr.	15 - 40 mg THT/m^3			demand. distr.	>10. 18 - 40 mg THT/m^3	demand. distr.	15 - 25 mg THT/m^3
solid particles		technical purity	technical purity		no solid particles	no solid particles	technical purity	≤ 1 µm	

Source: Mattias Svensson SGC, European Biomethane workshop, Brussels, 11 March, 2014

which uses innovative detectors made with the use of MEMS technology, characterized by high linearity. The capillary columns used in this application have a specific feature: the retention time of specific components is different in the basic analysis and in backflush. A single SITRANS CV chromatograph, working with helium or hydrogen as carrier gases, is able to conduct analysis of hydrocarbons to C6+ or C9+ during a 100-second or 150-second measurement cycle (if the content of oxygen is also measured in the sample). Extended analysis to C9+ does not require changing the hardware of the device, only the software is changed. Each application working with basic analysis to C6+ may be updated to the extended composition analysis (C9+). At the moment when additional micro chromatograph is installed, with extra carrier gas, it will also be possible to analyze the content of hydrogen and helium in the sample, as well as integration of the measurements in the memory of the main chromatograph which will calculate the calorific value and other gas parameters, considering the results obtained by fieldbus, from additional chromatograph. The presented solution is fully scalable, as replacement of the software and addition of a device dedicated to He/H_2 analysis is always possible.

The discussed solution has been implemented and is successfully used, e.g. in Germany (referencial installations are working there). For the Polish transmission network, the existence of proven methods gives some comfort. When gas originating from the installation of biomethane enrichment or from PtG facility appears in our grid, imported from any of the Polish neighbours or from national plants that will be built in the future, the realization of gas composition analysis extended by hydrogen and helium may be implemented in Polish metering stations basing on a ready and proven method.

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Gas consumption [billion m^3]

Country	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Change 2013 over 2012	2013 share of total
US	630.8	634.4	623.4	614.4	654.2	659.1	648.7	682.1	693.1	723.0	737.2	2.4%	22.2%
Canada	97.7	95.1	97.8	96.9	96.2	96.1	94.9	95.0	100.9	100.3	103.5	3.5%	3.1%
Mexico	51.4	54.3	61.0	66.6	63.5	66.3	72.5	72.5	76.6	79.6	82.7	4.2%	2.5%
Total North America	**779.9**	**783.8**	**782.2**	**778.0**	**813.9**	**821.5**	**816.1**	**849.6**	**870.6**	**902.9**	**923.5**	**2.7%**	**27.8%**
Argentina	34.6	37.9	40.4	41.8	43.9	44.4	43.2	43.3	45.7	47.3	48.0	1.7%	1.4%
Brazil	15.8	18.8	19.6	20.6	21.2	24.9	20.1	26.8	26.7	31.7	37.6	19.2%	1.1%
Chile	8.0	8.7	8.4	7.8	4.6	2.7	3.1	5.3	5.4	5.4	4.3	–19.4%	0.1%
Colombia	6.0	6.3	6.7	7.0	7.4	7.6	8.7	9.1	8.8	9.8	10.7	9.1%	0.3%
Ecuador	0.3	0.3	0.3	0.4	0.5	0.4	0.5	0.6	0.5	0.7	0.6	–8.7%	‡
Peru	0.5	0.9	1.5	1.8	2.7	3.4	3.5	5.4	6.1	6.8	6.6	–2.7%	0.2%
Trinidad & Tobago	13.4	14.8	16.3	21.2	21.9	21.3	22.2	23.2	23.1	22.2	22.4	1.1%	0.7%
Venezuela	25.2	28.4	27.4	31.5	36.2	34.3	32.3	29.0	29.7	31.4	30.5	–2.5%	0.9%
Other S. & Cent. America	3.1	3.0	3.3	3.9	4.5	4.7	5.0	5.4	5.8	7.1	7.8	11.4%	0.2%
Total S. & Cent. America	**106.8**	**119.0**	**123.9**	**136.0**	**142.8**	**143.7**	**138.6**	**148.0**	**151.9**	**162.3**	**168.6**	**4.2%**	**5.0%**
Austria	9.4	9.5	10.0	9.4	8.9	9.5	9.3	10.1	9.5	9.0	8.5	–5.9%	0.3%
Azerbaijan	7.7	8.3	8.6	9.1	8.0	9.2	7.8	7.4	8.1	8.5	8.6	1.5%	0.3%
Belarus	15.8	17.9	18.4	19.0	18.8	19.2	16.1	19.7	18.3	18.3	18.3	0.3%	0.5%
Belgium	16.0	16.2	16.4	16.7	16.6	16.5	16.8	18.8	16.6	16.9	16.8	–0.4%	0.5%
Bulgaria	2.8	2.8	3.1	3.2	3.2	3.2	2.3	2.6	2.9	2.7	2.6	–3.1%	0.1%
Czech Republic	8.7	9.1	9.5	9.3	8.7	8.7	8.2	9.3	8.4	8.2	8.4	3.2%	0.3%
Denmark	5.2	5.2	5.0	5.1	4.6	4.6	4.4	5.0	4.2	3.9	3.7	–4.1%	0.1%
Finland	4.5	4.3	4.0	4.2	3.9	4.0	3.6	3.9	3.5	3.1	2.8	–6.7%	0.1%
France	43.2	45.1	44.8	43.7	42.4	43.8	41.8	46.9	40.5	42.2	42.8	1.7%	1.3%
Germany	85.5	85.9	86.2	87.2	82.9	81.2	78.0	83.3	74.5	78.4	83.6	7.0%	2.5%
Greece	2.4	2.7	2.7	3.1	3.7	3.9	3.3	3.6	4.4	4.1	3.6	–11.5%	0.1%
Hungary	13.2	13.1	12.2	10.8	13.1	14.0	12.7	12.6	10.3	10.2	8.6	–16.2%	0.3%
Republic of Ireland	4.1	4.1	3.9	4.4	4.8	5.0	4.7	5.2	4.6	4.5	4.5	–0.1%	0.1%
Italy	71.2	73.9	79.1	77.4	77.8	77.8	71.5	76.2	71.4	68.7	64.2	–6.2%	1.9%

Gas consumption [billion m^3]

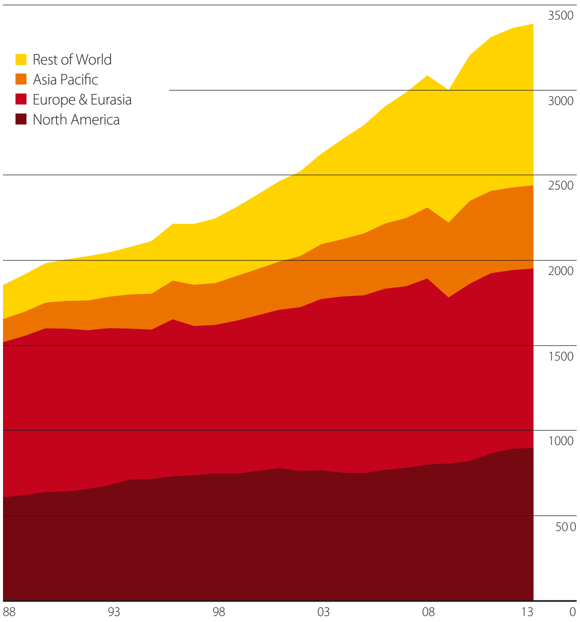
Country	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Change 2013 over 2012	2013 share of total
Kazakhstan	8.8	6.7	8.5	9.0	9.3	8.9	8.6	9.0	9.6	10.4	11.4	9.6%	0.3%
Lithuania	3.1	3.1	3.3	3.2	3.6	3.2	2.7	3.1	3.4	3.3	2.7	–18.3%	0.1%
Netherlands	40.0	40.9	39.3	38.1	37.0	38.6	38.9	43.6	38.1	36.4	37.1	2.0%	1.1%
Norway	4.3	4.6	4.5	4.4	4.3	4.3	4.1	4.1	4.3	4.4	4.4	1.4%	0.1%
Poland	12.5	13.2	13.6	13.7	13.8	14.9	14.4	15.5	15.7	16.6	16.7	1.1%	0.5%
Portugal	3.0	3.7	4.2	4.1	4.3	4.7	4.7	5.1	5.2	4.5	4.1	–9.6%	0.1%
Romania	18.3	17.5	17.6	18.1	16.1	15.9	13.3	13.6	13.9	13.5	12.5	–7.5%	0.4%
Russian Federation	379.5	389.3	394.1	415.0	422.0	416.0	389.7	414.2	424.6	416.3	413.5	–0.4%	12.3%
Slovakia	6.3	6.1	6.6	6.0	5.7	5.7	4.9	5.6	5.2	4.9	5.4	11.5%	0.2%
Spain	23.6	27.4	32.4	33.7	35.1	38.6	34.6	34.6	32.2	31.3	29.0	–7.2%	0.9%
Sweden	0.8	0.8	0.8	0.9	1.0	0.9	1.1	1.6	1.3	1.1	1.1	–1.8%	‡
Switzerland	2.9	3.0	3.1	3.0	2.9	3.1	3.0	3.3	3.0	3.3	3.6	12.4%	0.1%
Turkey	20.9	22.1	26.9	30.5	36.1	37.5	35.7	39.0	44.7	45.3	45.6	1.1%	1.4%
Turkmenistan	14.2	15.0	16.1	18.4	21.3	20.5	19.9	22.6	23.4	26.4	22.3	–15.5%	0.7%
Ukraine	69.0	68.5	69.0	67.0	63.2	60.0	46.8	52.2	53.7	49.5	45.0	–8.9%	1.3%
United Kingdom	95.3	97.4	94.9	90.0	91.0	93.4	87.0	94.2	78.1	73.7	73.1	–0.6%	2.2%
Uzbekistan	45.8	43.4	42.7	41.9	45.9	48.7	43.5	45.5	49.1	46.9	45.2	–3.3%	1.3%
Other Europe & Eurasia	15.3	16.9	17.1	17.8	18.2	17.6	14.7	16.0	16.6	16.1	14.9	–6.9%	0.4%
Total Europe & Eurasia	**1053.6**	**1077.6**	**1098.2**	**1117.4**	**1128.0**	**1133.5**	**1048.2**	**1127.4**	**1099.3**	**1082.6**	**1064.7**	**–1.4%**	**31.7%**
Iran	85.0	98.7	102.8	112.0	125.5	134.8	143.2	152.9	162.4	161.5	162.2	0.7%	4.8%
Israel	†	1.2	1.7	2.3	2.8	4.1	4.5	5.3	5.0	2.6	6.9	168.7%	0.2%
Kuwait	11.0	11.9	12.2	12.5	12.1	12.8	12.4	14.5	17.0	18.2	17.8	–1.9%	0.5%
Qatar	12.2	15.0	18.7	19.6	19.3	19.3	20.0	20.4	23.1	23.5	25.9	10.3%	0.8%
Saudi Arabia	60.1	65.7	71.2	73.5	74.4	80.4	78.5	87.7	92.3	99.3	103.0	4.0%	3.1%
United Arab Emirates	37.9	40.2	42.1	43.4	49.2	59.5	59.1	60.8	62.5	65.6	68.3	4.5%	2.0%
Other Middle East	25.0	26.5	28.4	31.5	32.4	36.5	38.9	44.2	40.6	42.3	44.3	5.1%	1.3%
Total Middle East	**231.1**	**259.3**	**277.0**	**294.8**	**315.7**	**347.4**	**356.5**	**385.8**	**402.8**	**412.9**	**428.3**	**4.0%**	**12.8%**

Gas consumption [billion m^3]

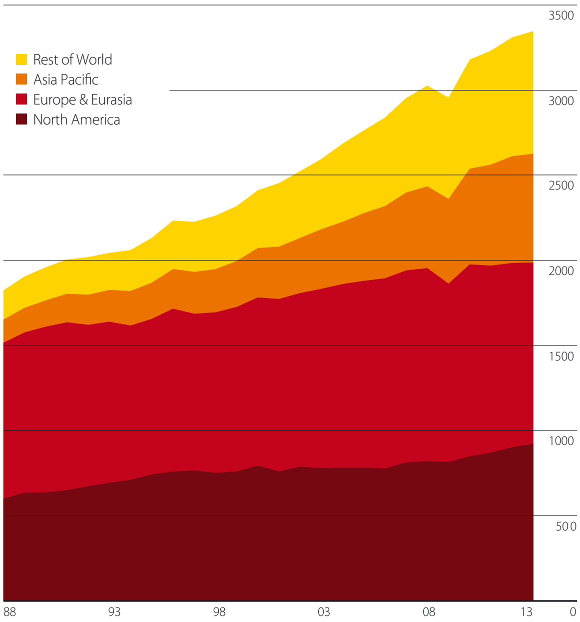
Country	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Change 2013 over 2012	2013 share of total
Algeria	21.4	22.0	23.2	23.7	24.3	25.4	27.2	26.3	27.8	31.0	32.3	4.3%	1.0%
Egypt	29.7	31.7	31.6	36.5	38.4	40.8	42.5	45.1	49.6	52.6	51.4	–2.0%	1.5%
South Africa	1.0	2.1	3.1	3.5	3.5	3.7	3.4	3.9	3.9	4.0	3.9	–1.0%	0.1%
Other Africa	22.7	25.4	27.7	25.6	30.1	31.4	26.9	32.5	33.4	35.4	35.7	1.3%	1.1%
Total Africa	74.8	81.2	85.6	89.3	96.2	101.3	100.1	107.9	114.8	123.0	123.3	0.6%	3.7%
Australia	22.4	22.8	22.2	24.4	26.6	25.5	25.2	25.4	25.2	18.6	17.9	–3.5%	0.5%
Bangladesh	12.3	12.8	13.8	15.1	15.9	17.0	18.5	19.9	20.1	21.1	21.9	4.2%	0.7%
China	33.9	39.7	46.8	56.1	70.5	81.3	89.5	106.9	130.5	146.3	161.6	10.8%	4.8%
China Hong Kong SAR	1.8	2.7	2.7	2.9	2.7	3.2	3.1	3.8	3.1	2.8	2.6	–5.5%	0.1%
India	29.5	31.9	35.7	37.3	40.1	41.3	51.9	63.0	61.4	58.8	51.4	–12.2%	1.5%
Indonesia	35.0	32.2	33.2	33.2	31.3	33.3	37.4	40.3	37.3	35.8	38.4	7.6%	1.1%
Japan	79.8	77.0	78.6	83.7	90.2	93.7	87.4	94.5	105.5	116.9	116.9	0.2%	3.5%
Malaysia	27.3	24.7	31.4	33.7	33.4	33.8	33.0	35.1	31.8	34.7	34.0	–1.8%	1.0%
New Zealand	4.3	3.9	3.6	3.7	4.0	3.8	4.0	4.3	3.9	4.2	4.4	5.6%	0.1%
Pakistan	30.4	34.5	35.5	36.1	36.8	37.5	38.4	39.6	39.2	41.2	38.6	–6.2%	1.1%
Philippines	2.5	2.4	3.2	3.0	3.6	3.7	3.8	3.5	3.9	3.7	3.4	–8.2%	0.1%
Singapore	4.0	5.0	6.8	7.1	8.6	8.2	8.1	8.4	8.8	9.4	10.5	12.3%	0.3%
South Korea	24.2	28.4	30.4	32.0	34.7	35.7	33.9	43.0	46.3	50.2	52.5	4.9%	1.6%
Taiwan	7.7	9.3	9.4	10.1	10.7	11.6	11.4	14.1	15.5	16.3	16.3	0.6%	0.5%
Thailand	28.6	29.9	32.5	33.3	35.4	37.4	39.2	45.1	46.6	51.2	52.2	2.2%	1.6%
Vietnam	2.4	4.2	6.4	7.0	7.1	7.5	8.0	9.4	8.5	9.4	9.8	4.5%	0.3%
Other Asia Pacific	4.2	4.5	5.2	5.5	6.0	5.7	5.2	5.8	6.2	6.6	6.7	1.7%	0.2%
Total Asia Pacific	**350.3**	**365.7**	**397.3**	**424.2**	**457.6**	**480.3**	**497.9**	**562.2**	**593.5**	**627.1**	**639.2**	**2.2%**	**19.0%**
Total World	**2596.6**	**2686.7**	**2764.3**	**2839.6**	**2954.4**	**3027.7**	**2957.4**	**3180.8**	**3233.0**	**3310.8**	**3347.6**	**1.4%**	**100.0%**

† Less than 0.05; ‡ Less than 0.05%

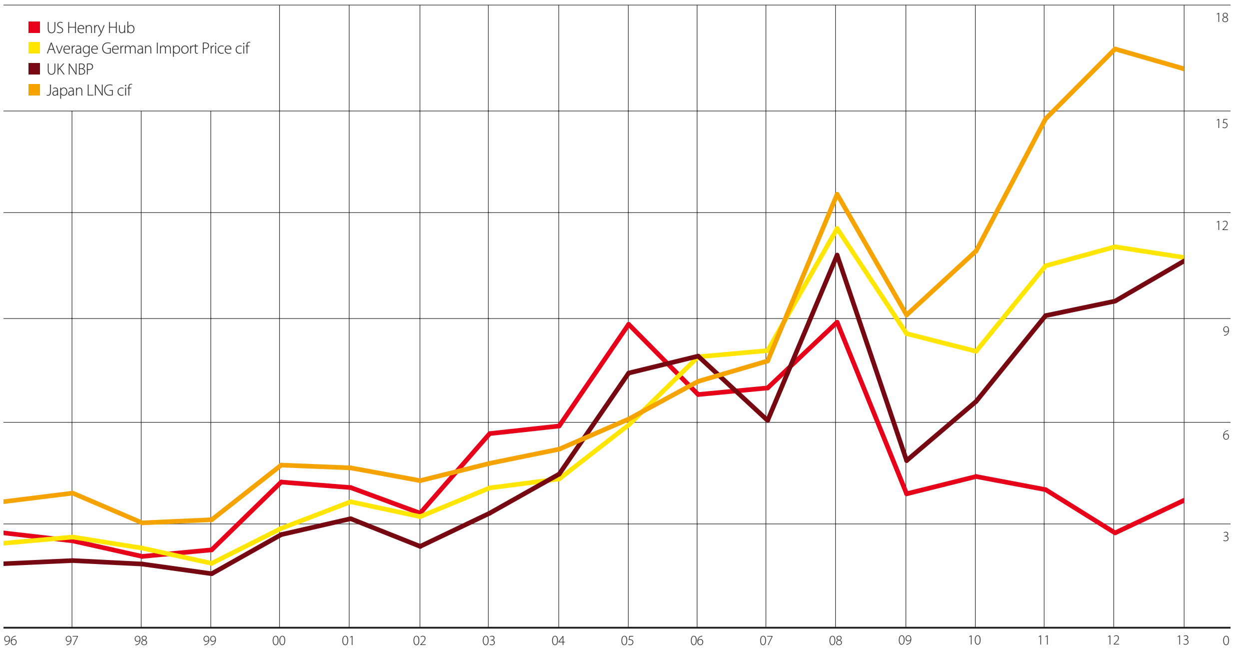
Gas production
[billions m^3]



Gas consumption
[billions m^3]

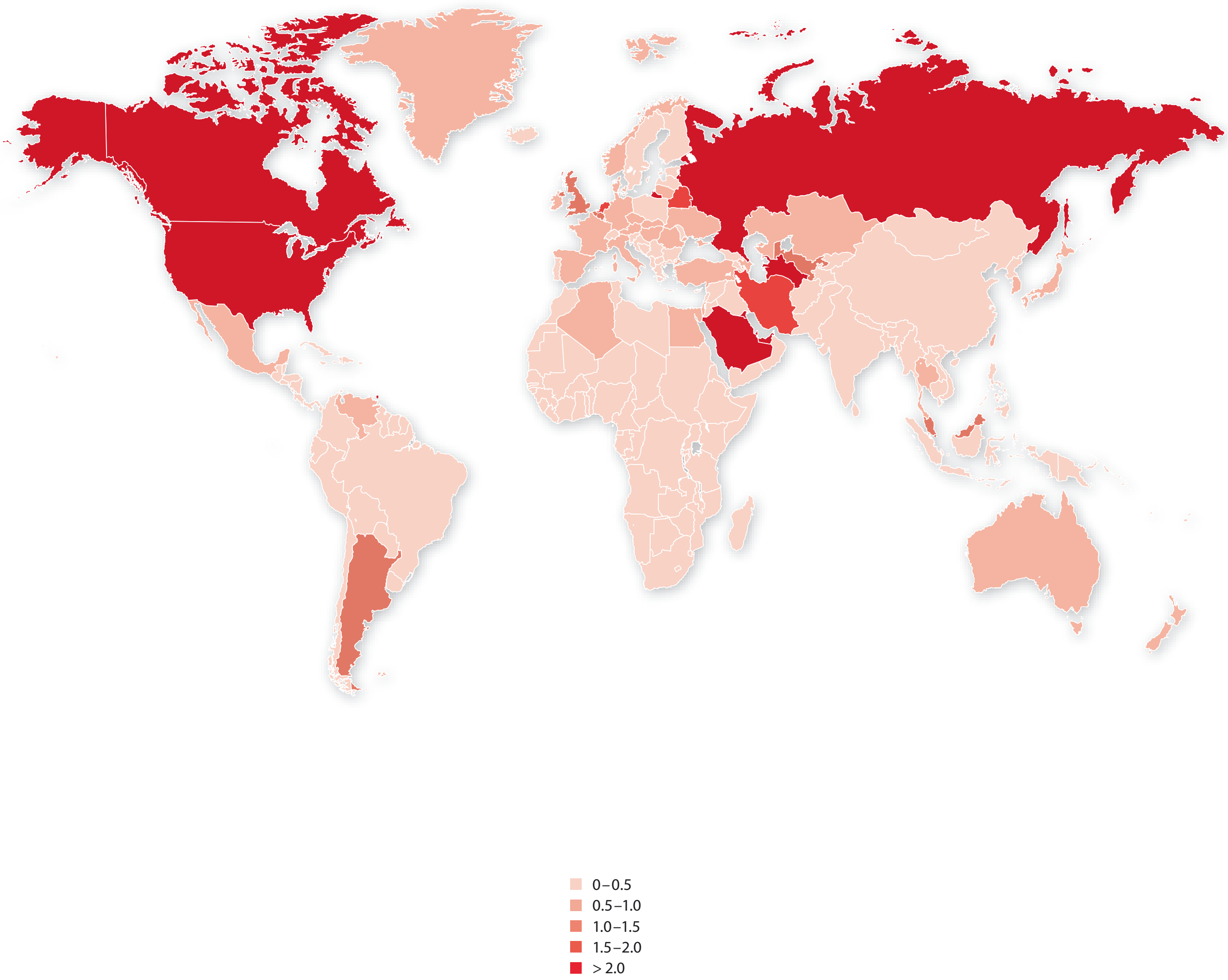


Gas prices
[USD for MMBtu]



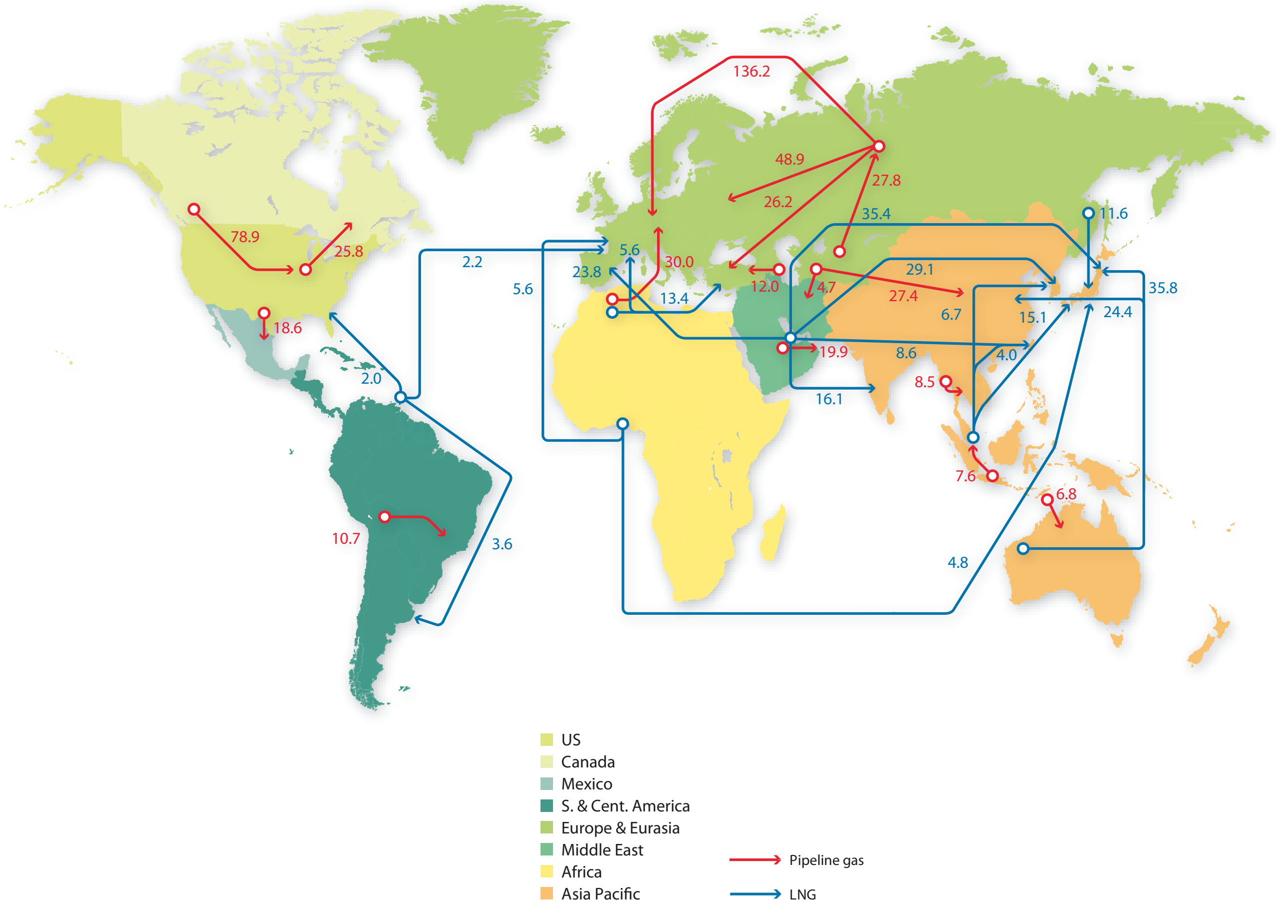
Source: BP Statistical Review of World Energy 2014

Gas consumption *per capita* in 2013 [tons in oil equivalent]



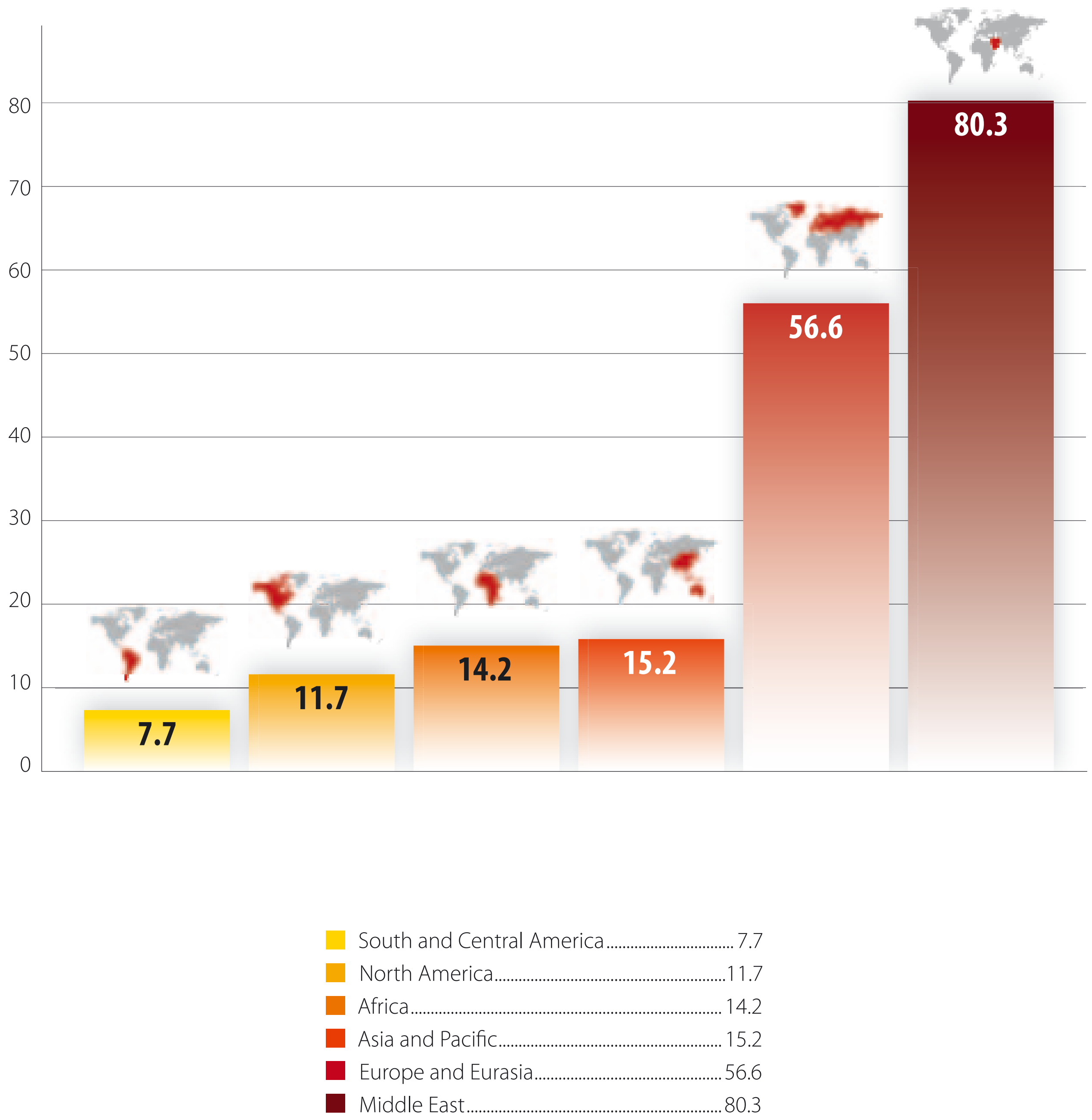
Source: BP Statistical Review of World Energy 2014

The main directions in natural gas trade in 2013 [in bilions m^3]



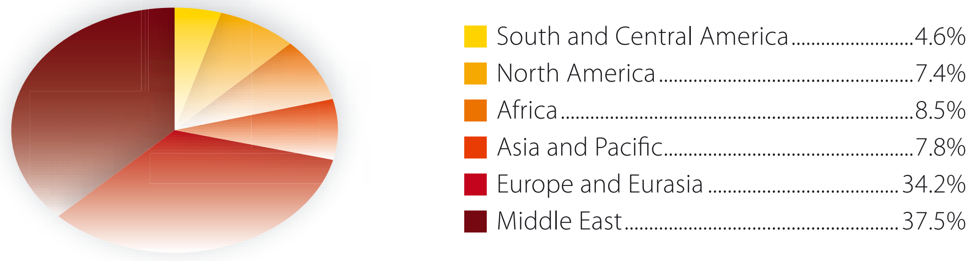
Source: BP Statistical Review of World Energy 2014

Natural gas: Proved reserves at end 2013 [in trillion m^3]

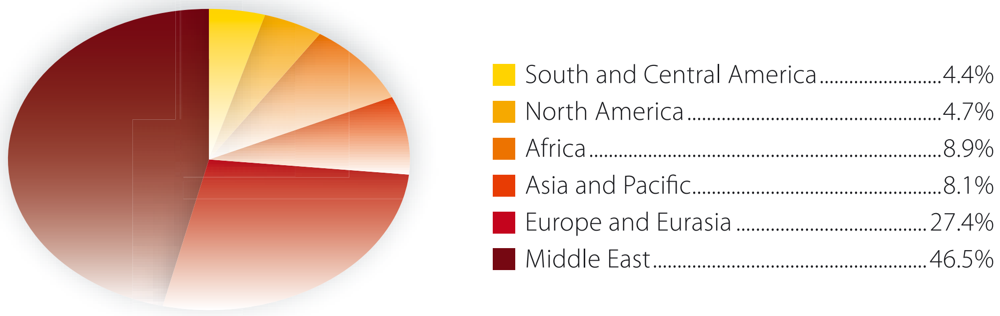


Source: BP Statistical Review of World Energy 2014

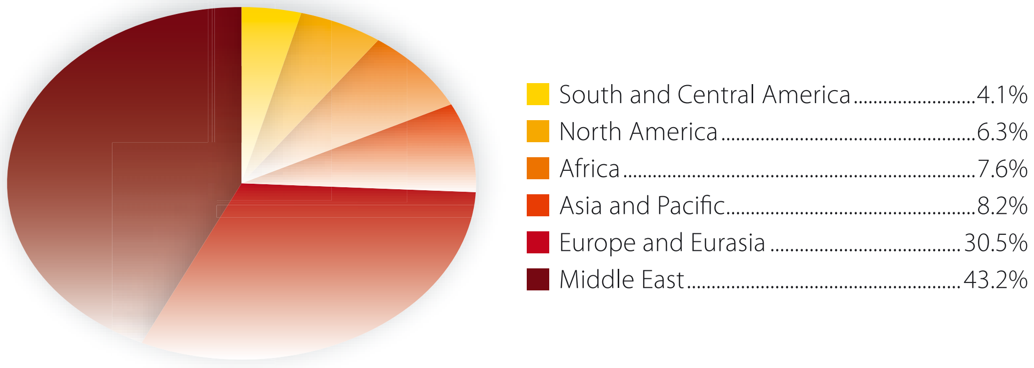
Distribution of proven natural gas reserves in 1993 – 118.4 trillion m^3 total



Distribution of proven natural gas reserves in 2003 – 155.7 trillion m^3 total



Distribution of proven natural gas reserves in 2013 – 185.7 trillion m^3 total



Source: BP Statistical Review of World Energy 2014

Ecology
in the oil and gas industry

Bearing greases

Development trends in the quality of multifunctional bearing lubricants

ANNA ZAJEZIERSKA

In the group of bearing greases the largest group of products are general purpose lubricants, called multi-purpose greases. This name was adopted for plastic greases allowing lubrication of bearings in most common, practically applicable conditions.

The basic characteristics and uses of multi-purpose bearing greases include:

- good rheological properties – particularly at low temperatures, determining the minimum operation temperature of the device,
- lubricating properties, protecting bearings against wear friction under different conditions of load, including dynamic loads,
- anticorrosion properties protecting bearings from corrosion in the conditions of access of water and aggressive atmosphere,
- oxidation resistance,
- high mechanical stability,
- serviceability limit [1–4].

Directions of quality development of multi-purpose bearing greases

Currently, the primary type of general purpose bearing greases are lithium greases produced using lithium 12-hydroxystearate. These greases, first marketed in the 60s of last century, allowed a significant simplification of the lube industry by limiting the range of lubricants.

The progress, associated with the growing demands of users for modern design solutions in devices, caused the need for lubricants with a longer service life; in the case of covered bearings – durability equal to the one of the bearing.

As a result, in the 70s of the twentieth century, alternative multi-purpose bearing greases were developed: aluminum complex and lithium complex. The advantages of these lubricants, especially long service life, caused their widespread use in lubricating bearings. They also replaced lithium and hydroxystearate greases where the stability of these lubricants was insufficient [4–6].

In the 90s of the twentieth century, another, modern type of bearing grease was introduced: polyurea greases. It is a qualitatively distinct group of greases containing organic thickener, resistant to oxidation. Polyurea greases are characterized by their particularly high service life, exceeding that of conventional lubricants containing thickeners, including complex greases [7–11].

The general chemical formula of polyurea grease thickener is shown below.

Special advantages of polyurea greases are evident when applied to high speed bearings operating in boundary conditions for plastic greases. An example of this type of application are small-sized,

$$R - NH\text{-}CO\text{-}[\text{-}NH–R_1–NH–CO–NH–R_2–NH–CO]n - NH–R_1–NH–CO–NH–R_3$$

Formula 1. General chemical formula of polyurea grease thickeners, where:
R and R_3 – alkyl radical or aryl monoamines,
R_1 – alkyl radical or aryl diisocyanate,
R_2 – alkyl radical or aryl diamine, n-1 ÷ 5.

high-speed low-power electric motors, installed in household appliances [10, 11].

Due to high durability and resistance to water, polyurea greases are used as car bearing greases. In Japan, for a number of years, polyurea greases have been applied to bearings operating in particularly difficult conditions, i.e. at high loads and elevated temperatures in the steel industry, metallurgy and paper industry.

In recent years, based on long-term bench and operation studies, polyurea greases have been approved for use in railway wheelset bearings.

The share of polyurea greases in global production is approx. 5%. Their production is developed mainly in Japan and the countries of North America. In Western Europe, the share of these greases in the market is small and amounts to approx. 2% [5, 10, 11].

To ensure correct operation of bearings operating in maximum difficult conditions, at high temperatures and high loads, calcium sulfonate complex thickened-greases are applied. The basic utility feature of the greases is their high water resistance, high mechanical stability and very good antiwear and antiscuffing properties [12–16]. The advantageous operation properties of calcium sulfonate greases are obtained through proper thickener synthesis which allows to transform overbased calcium sulfonate into the desired crystallographic form (Fig. 1).

Calcium sulfonate greases are mainly used in the bearings of machines and devices operating under high loads and high temperatures as well as at the access of water and mechanical impurities, i.e. in mining, metallurgy, building equipment and maritime transport. Calcium sulfonate greases produced with the use of a specialized group of base oils, have been approved by the United States Office of the Food and Drug Administration for use in devices operating in the food industry [15]. Global production of greases produced with the use of overbased calcium sulfonate has been at a stable level for a few years and amounts to approx. 2%.

Their largest share of the global market of plastic greases is observed in North America and is approx. 6.5%.

Research conducted in the Oil and Gas Institute – National Research Institute [INiG – PIB]

In the Oil and Gas Institute – National Research Institute, for many years, research on the issues of

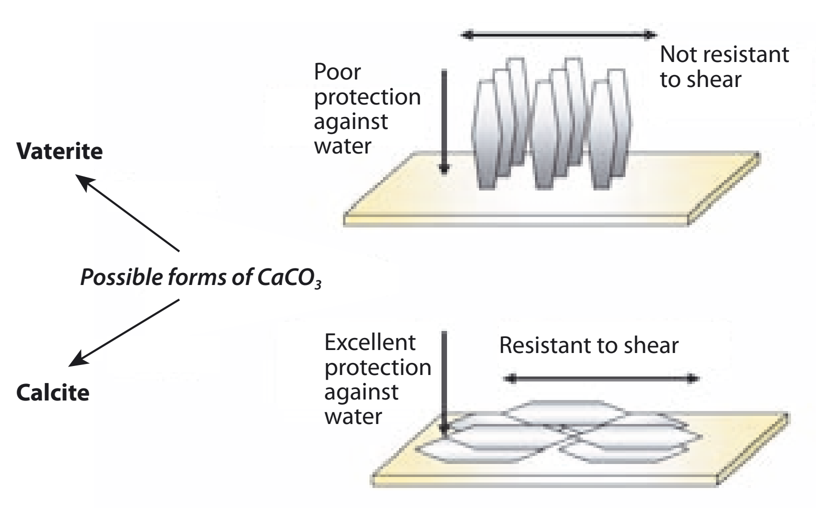


Fig. 1. Crystalline calcium carbonate $CaCO_3$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plastic greases has been conducted. The scope of work covers a wide range of products used in industry, transport and communications.

In addition to the technology work on innovative lubricants, research has also been conducted on quality parameters of lubricants based on international standards and quality specifications using modern equipment.

The Oil and Gas Institute – National Research Institute closely cooperates with Polish oil companies: Lotos Oil and Orlen Oil. This cooperation includes both production processes of lubricants, as well as issues of technical advice on the application of bearing greases in the industry.

In recent years, in the Department of Oils, Lubricants and Bitumen Resources of the Oil and Gas Institute – National Research Institute, with its own funds and under projects co-financed by the European Union from the European Regional Development Fund, projects have been implemented related to the subject of biodegradable lubricants destined for railways. The developed products have been quality-approved and are used in vehicles operated in Polish traction vehicles.

The Oil and Gas Institute – National Research Institute is a leading research centre in the country implementing a full range of issues related to plastic greases meeting the needs signalled by the producers and users of plastic greases.

Summary

Over the past few years, the ongoing research and technical development has made significant progress in terms of the quality of bearing greases. The modern generation of new lubricants for bearings, i.e. polyurea greases and calcium sulfonate complex-thickened greases, are characterized by high stability in the bearing in maximum operation limits at temperatures of 180°C, several times exceeding those of conventional lubricants containing high molecular fatty acids' salts. Operational advantages of modern bearing greases allow much longer lubrication intervals, and in the case of covered bearings – ensure high reliability of devices.

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Plastic greases

European classification standards and quality requirements of plastic greases

Anna Zajezierska

Plastic greases are a specialized group of lubricants used in cases where there is a need for a good friction pair seal against water and mechanical impurities, and the requirement for good adhesion to metal surfaces.

The scope of application of greases is wide and includes: roller and sliding bearings (the main group in terms of quantity), unsealed gears, joints and other friction surfaces. Lubricants are applied to the friction pairs operating in diverse conditions and within a wide range of quality parameters – in conditions of high and low temperatures, high speeds and at variable loads [1-5].

Diverse operating conditions require the use of a wide range of products with different chemical composition, hence unification of nomenclature and establishing a uniform system of classification is much more difficult.

Until now, the generally accepted classification of greases is the classification based on consistency, proposed by the American National Lubricating Grease Institute.

In European countries, for the purposes of classification of greases, ISO 6743-9 is mostly used, whose counterpart in Poland is ISO 6743-9:2009 [6].

Classification and quality requirements for greases are also included in the European national standards: the German standard DIN 51825:2004 [7] and the Swedish standard SS 155470:2003 [8].

ISO 12924:2010 [9] is an international standard combining the plastic greases classification system with their quality requirements [9].

Currently, the Technical Committee no. 222 on Petroleum Products and Lubricants carries out standardization aimed at introducing a national equivalent to ISO 12924:2010.

Discussion of classification standards and quality specifications

PN-ISO 6743-9:2009 *Lubricants, industrial oils and related products (class L). Classification. Part 9: Group X (Plastic greases).*

This standard is a translation of the English version of ISO 6743-9:2003. The basis for classification of greases are the following performance characteristics: the minimum and maximum temperature, the ability of grease to ensure proper lubrication in the presence of water and proper corrosion prevention and the ability of grease to ensure proper lubrication of friction pairs under great loads.

Individual characteristics of greases are encoded with successive symbols. This allows a concise defi-

Table 1. Quality classification of greases according to ISO 6743-9: 2003

Symbol 1 – the minimum operating temperature		Symbol 2 – the maximum operating temperature		Symbol 3 water resistance			Symbol 4 ability to carry loads	Grease consistency
Designation	Temperature [°C]	Designation	Temperature [°C]	Designation	Conditions	Anticorrosion properties		
A	0	A	60	A	L* – no	L*	Symbol A –	Consistency
B	–20	B	90	B	humidity	M*	greases	Class acc. to
C	–30	C	120	C		H*	with no EP	NLGI
D	–40	D	140				properties	
E	below –40	E	160	D		L*	required	
		F	180	E	M** – constant	M*	Symbol B –	
		G	Above 180	F	humidity	H*	greases	
							with EP	
				G		L*	properties	
				H		M*	required	
				I	H*** – access	H*		
					of water			

L* – no anti-corrosion properties,
M** – anticorrosive properties in the presence of distilled water,
H*** – anticorrosive properties in the presence of salt water.

nition of the level of quality of the grease and the intended use (Table 1).

DIN 51825:2004 *Lubricants – Lubricating greases K – Classification and requirements*

This standard is the basic classification and specification standard concerning greases for industrial applications. It applies to products intended for application in rolling and sliding bearings, operating at varying conditions, temperatures, loads and speeds.

The following quality parameters have been adopted as grease criteria for the classification: consistency, maximum and minimum temperature of operation and grease resistance to water.

The temperature range of greases included in this standard, comprising maximum operating temperatures of +60°C to +240°C and taking into account the minimum working conditions of greases in the range from –10°C to –60°C, was divided into 14 grades marked with symbols from C to U.

The basic quality requirements laid down in this standard are: service life of the grease in the bearing dynamic test, rheological properties at low temperatures (torque, pressure, flow) and anticorrosive properties.

The DIN 51825 standard may also be used for biodegradable greases – the degree of biodegradation determined according to DIN 51828-1 and DIN 51828-2 was adopted as a criterion in this case. This group of plastic greases, according to the quality requirements specified in DIN 51825, shall be characterized by biodegradability at a level above 80%.

Quality requirements for greases provided in DIN 51825:2004 are presented in Table 2.

ISO 12 924:2010

The ISO 12924:2010 standard is an international standard specifying quality requirements for greases of automotive and industrial applications.

Classification of greases is consistent with the scheme set out in ISO 6743-9, in which individual features are described with appropriate symbols:

- symbol 1 is a measure of the minimum temperature of application, from A to E;
- symbol 2 is a measure of the maximum application temperature, from A to G;
- symbol 3 is a measure of water resistance and anticorrosion properties, from A to I;
- symbol 4 is a measure of the ability of grease to ensure proper lubrication under high loads, from A or B;

Table 2. Quality requirements for greases for industrial applications according to DIN 51825:2004

Grease, designation	C	D	E	F	G	H	K	M	N	P	R	S	T	U
Water resistance acc. to DIN 51807-1	0÷40 1÷40	2÷40 3÷40	0÷40 1÷40	2÷40 3÷40	0÷90 1÷90	2÷90 3÷90	0÷90 1÷90	2÷90 2÷90						
Maximum operation temp. [°C]	60	60	80	80	100	100	120	120	140	160	180	200	220	≤ 240
Dropping temp. acc. to DIN ISO 2176 [°C]	> 90	> 90	> 110	> 110	> 130	> 130								
Service life - FAG FE9 apparatus, A/1500/6000, acc. to DIN 51821-1, DIN 51821-2, minimum 100 h in a specific temperature	Not required						120	120	140	160	180	200	220	Not req.
Low temp. properties [°C]	−60		−50		−40		−30		−20		−10			
Flow pressure acc. to DIN 51805 [hPa]	≤ 1400													
Torque at low pressure: • static [mNm] • dynamic [mNm]	≤ 1000 ≤ 100													
Anti-corrosion properties acc. to DIN 51802	≤ 1									Not req.				
Impact on copper acc. to DIN 51811	≤ 2 w 60°C		≤ 2 w 80°C		≤ 2 w 100°C		To be given upon request							
Content of impurities (acc. to DIN 51813) above 25 pm [mg/kg]	≤ 20													
Water content DIN ISO 3733, DIN 51777-2 [%]	≤ 3.0				≤ 0.4									
Oil separation, DIN 51817 [%]	To be given upon request													
Basic oil, DIN 51820-1	To be given upon request													
Degree of biodegradation, DIN 51828-1, DIN 51828-2 [%]	≥ 80													

Table 3. ISO 12924:2010 –
The minimum application temperature – Symbol 1

The minimum application temperature [°C]	Torque [mNm]			Flow pressure [hPa]		Penetration [0.1 mm]	
	Value	Operation torque [mNm]					
		Symbol 1	Value	Value	Symbol 1	Value	Symbol 1
0	≤ 1000	A (L)	≤ 100	≤ 1400	A (F)	≤ 140	A (P)
−20		B (L)			B (F)	≤ 120	B (P)
−30		C (L)			C (F)	≤ 120	C (P)
−40		D (L)			D (F)	≤ 100	D (P)
< −40		E (L)			E (F)	≤ 100	E (P)
–	Test method: ASTM D1478 or NFT60-629			Test method: DIN 51805		Test method: ISO 13737	

Table 4. ISO 12924:2010 – The maximum application temperature – Symbol 2

The maximum application temperature [°C]	Symbol 2	Dropping temperature [°C]	Bearing service life [h]
60	A	≥ 90	Not determined
80	B	≥ 130	
120	C	to be given	F_{50} > 100 h at the maximum temperature of application
140	D		
160	E		
180	F		
> 180	G		
-	-	Test method: ISO 2176, ISO 6299, IP 396 or NFT60-627	Test method: DIN 51821-1 and DIN 51821-2; using a grease test bench FAG FE 9, procedure A/1500/6000

- symbol 5 – consistency class according to the NLGI scale, and defined by determining penetration in accordance with ISO 2137.

Symbol 1 – the minimum temperature of application

The minimum temperature of application should be determined according to the following three criteria:

- torque: starting and dynamic, in accordance with ASTM 1478;
- flow pressure according to DIN 51805;
- penetration at low temperatures, in accordance with ISO 13737.

Depending on the criterion adopted, symbol 1 is completed by a suffix in the form of letters in brackets:

- (L) – in the case of torque;
- (F) – in the case of flow pressure;
- (P) – in the case of low penetration temperatures.

Specific requirements are shown in Table 3.

Symbol 2 – The maximum temperature of grease application

The maximum temperature of application should be determined according to the following criteria:

- dropping temperatures for symbols 2A and 2B;
- service life according to DIN 51821 for symbols from 2C to 2G.

For greases with the maximum temperature of application higher than 120°C, the service life of the F_{50} bearing should be more than 100 hours.

Specific requirements are shown in Table 4.

Symbol 3 – Contact with water and anticorrosion properties

Symbol 3 is a combination of the level of water resistance of grease, determined using a dynamic water washout test method in bearings according to ISO 11009 and corrosion prevention determined during a test of anti-corrosive properties using a static method in accordance with ISO 11007.

Specific requirements are shown in Table 5.

The classification includes the following parameters: minimum and maximum operation temperature range, corrosion protection ability, the ability to

Table 5. ISO 12924:2010 – contact with water and anticorrosion properties – Symbol 3

Symbol 3	Water washout resistance		Degree of anti-corrosive properties
	Requirements [% (m/m)]	Temperature [°C]	
A	No requirements	38	No requirements
B	No requirements	38	max. 1–1, distilled water
C	No requirements	38	max. 2–2, salt water ISO 7120
D	< 30	38	No requirements
E	< 30	79	max.1–1, distilled water
F	< 30	79	max. 2–2, salt water ISO 7120
G	< 10	79	No requirements
H	< 10	-	max.1–1, distilled water
I	< 10	-	max. 2–2, salt water ISO 7120
-	Test method: ISO 11009		Test method: ISO 11007

Table 6. ISO 12924:2010 – ability to lubricate under high load – Symbol 4

Symbol 4	Weld load, four-ball apparatus [kg]	Test method
A	No requirements	ASTM D 2596 lub IP 239
B	≥ 250	

Table 7. Consistency classes according to the NLGI scale

NLGI consistency class	Penetration (after 60 work load at 25°C) 1/10 mm	Test method
000	445÷475	ISO 2137
00	400÷430	
0	355÷385	
1	310÷340	
2	265÷295	
3	220÷250	
4	175÷205	
5	130÷160	
6	85÷115	

Table 8. SS 155470:2003 – The minimum application temperature – Symbol 1

Minimum temp. range [°C]	Torque: static and dynamic [Nm]	Symbol 1	Test method
above –10	Starting torque: max. value 1.0 dynamic torque: max. value 0.02	1	ASTM D 1478
–10 do –20		2	
–21 do –30		3	
Below –30		4	

Table 9a. SS 155470:2003 – The maximum application temperature – Symbol 2

Maximum temp. range [°C]	Dropping temperature, [°C]	Symbol 2	Test method
< 100	130 or lower	1	SS-ISO 2176
100÷120	131÷170	2	
130÷150	171÷229	3	
> 150	230 or higher	4	

Table 9b. SS 155470:2003 – The maximum application temperature – Colloidal stability

Oil separation [% weight]	Structure durability	Class degradation	Test method
< 1	High	0	DIN 51817
1÷5	Normal	0	
5÷10	Low	–1	
> 10	Very low	–2	

Table 10. SS 155470:2003 – Grease ability to provide corrosion protection – Symbol 3

Grade 1	Corrosion protection requirements	Symbol 4	Test method
	Not required	1	SS-EN ISO 11007
0–0 (3.a)	Protection in contact with water	2	
0–0 (3.b, 3.c)	Protection in contact with salt/acidic water	3	

provide lubrication under high loads and impact on the environment (Table 10).

Symbol 4 – The ability to lubricate under high loads

The study aimed at determining the ability to lubricate under high loads should be carried out using a four-ball apparatus, taking into account only the weld load, and assuming a positive result of the measurement in the presence of ER additives.

Specific requirements are shown in Table 6.

Grade consistency

Grade consistency should be determined by worked penetration according to ISO 2137 (Table 7).

SS 155470:2003 *Lubricants, industrial oil and related products – (Class L) Specification for X family (Greases)*

This standard is a classification and specifications standard relating to a broad group of greases for industrial applications, greases for the needs of the automotive industry as well as those operating in the maritime sector.

The SS 155470:2003 standard, as in the previously cited standards, assumes a classification system in which testing and quality parameters, suitable for a given application, are assigned to individual operating parameters, marked with symbol letters.

To determine the minimum grease operation temperature it is necessary to study torque according to ASTM D 1478. For certain categories of grease, marked 1-4, the standard gives maximum torque under static and dynamic conditions. Specific requirements are shown in Table 8.

Determining the maximum grease operation temperature according to SS 155470:2003 requires measuring its dropping temperature and determining colloidal stability, i.e. grease tendency to separate oil.

The SS 155470:2003 standard, as the only European standard, recommends to determine the stability of the colloidal structure of greases at high temperatures and determines numerical values assigned to individual categories.

Specific requirements regarding the requirements for determining the maximum application temperature (Symbol 2) are shown in Tables 9a and 9b.

Corrosion protection ability is determined using the test according to ISO 11007. In this respect, the standard provides for three classification symbols, depending on the criterion for the absence of corrosion on the tested elements:

- in the absence of water access,
- under the conditions of testing in the presence of distilled water,
- in the presence with salt or acidic water

Table 11. SS 155470:2003 – Lubricating properties – Symbol 5

Weld load [N]	Note	Symbol 5	Test method
< 2200 or wear greater than 0.8 mm at 400 N	no EP	NEP	EPI test: DIN 51350-4 or 2 Wear test: DIN 51350-5 or 3
2200÷5000 or wear below 0.8 mm at 400 N	EP	EP	
> 5000 or wear below 0.8 mm at 400 N	Gear grease	GC	

Lubricating properties: anti-wear and anti-seizure ones are determined using the four-ball apparatus according to DIN 51350-4 or 2 and DIN 51350-5 or 3.

As, in the case of the previous category, the standard provides for three classification symbols. Quality parameters assigned to symbols are presented in Table 11.

The SS 155470:2003 standard is the only European standard containing specific requirements concerning the impact of greases on the environment and human health.

This standard covers three groups of greases, marked with A, B and C. The symbols are the basis for marking lubricants as acceptable for the environment.

Class A – applies to products with a low content of hazardous substances to both human health and the environment. This class of products is also required to be characterized by a high degree of biological degradation, as well as the content of rotating components in lubricant composition.

Products acceptable to the environment are marked B and C and required to be characterized by a low content of substances hazardous to health.

Requirements for products classified as B in the range of concentration of hazardous substances and the degree of biological degradation are more strict than the requirements laid down for Class C.

Summary

Standardization work conducted for a number of years led to the development of an international standard for greases. This document covers both the classification system of greases intended for use in varying conditions, as well as quality parameters, making it possible to assess the level of grease quality.

The basis of the classification system for greases and their operating characteristics are the following standards: ISO 6743-9 (and its subsequent editions) and the German standard DIN 51825, for many years used in European countries as the only standard provided for the evaluation of plastic greases for industrial applications.

The ISO 12924 standard was introduced in 2010 and is a modern standardization document, which can also be used by users of lubricants for appropriate application of a lubricant to a friction pair.

Particular emphasis is given to introducing specific requirements covering environmental impact of greases on the environment and human health in the current edition of the Swedish SS 155470 standard.

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7) DIN 51825:2004 *Lubricants – Lubricating greases K – Classification and requirements.*
8) SS 155470:2003 *Lubricants, industrial oil and related products – (Class L). Specification for family X (Greases).*
9) ISO 12924:2010 *Lubricants, industrial oil and related products – (Class L). Specification for family X (Greases).*

ABC of new technologies in heat exchangers

Heating and cooling – at a profit

Modern industrial processes require great capital outlays and involve high operational costs the largest part of which are expenses related to heating and cooling.

Modern technology of plate and spiral heat exchangers allows significant reduction of costs and easier servicing. Even small increase in the efficiency of heat exchangers means substantial savings and improved effectiveness. Economics of this process is particularly important in the following sectors: energy, refining, oil and gas industry and chemical business.

The construction of Alfa Laval heat exchangers facilitates the servicing and maintenance jobs, including chemical cleaning in place (CIP) or cleaning with high-pressure cleaning devices.

Saving on money and space out of concern for environment protection

Higher heat efficiency as the effect of countercurrent flow and crossover temperatures means the application of fewer heat exchangers. Plate or spiral Alfa Laval's heat exchangers are best for this specific task giving smaller consumption volume of the cooling or heating factor than in the case of traditional shell and tube exchangers. The existing installations may be modernized in a simple way by introducing to them plate and spiral Alfa Laval heat exchangers characterized by compact construction which does not require much space. Smaller size and lower weight reduce also the installation costs. Application of more expensive materials with higher corrosion resistance, e.g. titanium or nickel alloys allow cost effectively give smaller area of heat exchange and smaller size. Plate and spiral Alfa Laval heat exchangers are designed so as to achieve considerable turbulence level of the flow in order to avoid blocking the exchanger due to accumulated contamination. As well as in operation it also increase the effectiveness of subsequent chemical cleaning. In this type of exchangers, after opening, larger part of the heat exchange area is easily accessible for mechanical cleaning, which means fewer servicing jobs and easier maintenance than in the case of shell and tube exchangers.

Alfa Laval solutions from upstream to downstream

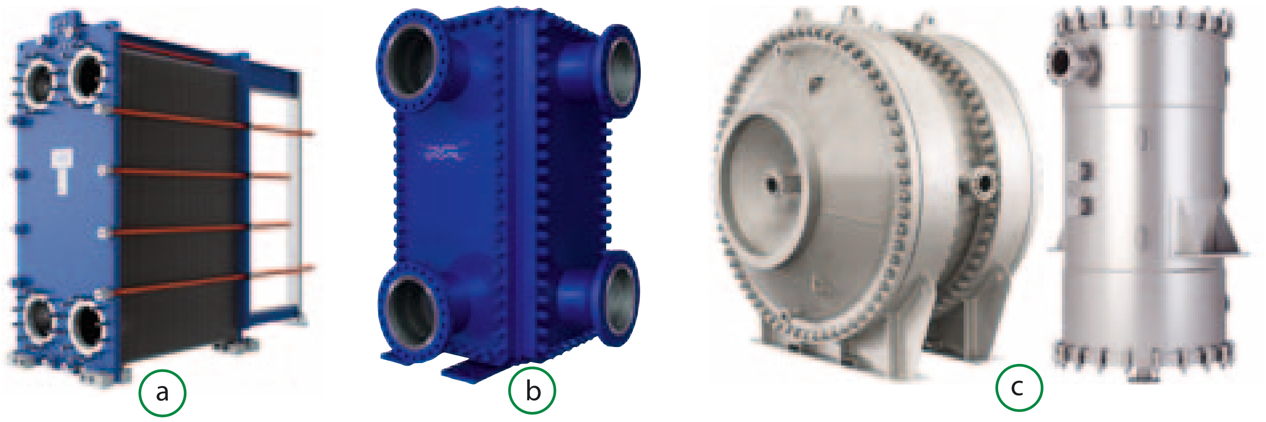
Gasketed plate heat exchangers

Plate heat exchanger ensures the highest heat exchange effectiveness. It consists of a pack of profiled metal plates planted on a frame between the front and pressure plates. The rubber gaskets between the plates ensure water tightness of the pack as well as the possibility of dismantling the exchanger in order to clean the surface of the plates or restructure the device. Specially corrugated plates cause highly turbulent flow, maximal heat exchange effectiveness and prevent the accumulation of deposits in the exchanger. Different types and sizes of indentation are available, depending on the requirements of the process. Flange connections are placed on the front plate or – in multistage exchangers – on the front and pressure plate. Depending on the process requirements, the plates may be made from materials of suitable corrosion resistance, e.g.: acid proof steel, titanium alloys, nickel alloys, tantalum and also specially prepared graphite or PVDF composite with graphite. Operating pressure – to 32 bar, operating temperature – to 180°C.

Compabloc heat exchangers

Welded plate Compabloc heat exchangers are intended for work in particularly hard conditions in which gasketed plate heat exchangers cannot be used, e.g. on account of extremely high temperatures for rubber gaskets or substantial chemical aggressiveness of the medium.

The heart of the exchanger is a pack of suitably shaped and welded plates made of acid proof steel or from "exotic" metals and their alloys which may be shaped cold and welded, e.g.: nickel alloys, titanium and its alloy, tantalum, etc. Covers with gaskets made of graphite or PTFE enable access to the exchanger`s inside for inspection and cleaning. Compabloc exchangers are available with a variant of heat exchange area to 840 m^2. The operational pressure – from complete vacuum to 40 bar, the operating temperature – to 400°C.



Heat exchangers: a) Gasketed plate heat exchangers, b) Welded plate Compabloc heat exchangers, c) spiral.

Spiral heat exchangers

Spiral heat exchangers (SHE) by Alfa Laval are designed for work with contaminated fluids, suspensions (type 1) or as vacuum condensers and evaporators (type 2). Type 1 spiral exchangers are produced in version for work at low pressure (10 to 16 bar) or high-pressure HPSHE (100 to 250 bar).

Spiral heat exchanger (SHE) has two concentric spiral channels, one for each medium. In type 1 SHE there is full countercurrent flow of the media, which allows to obtain very high heat recovery (crossover temperatures). The stream of each fluid flows turbulently at constant velocity through the only one spiral channel, which prevents the accumulation of contaminants (self-cleaning).

However, when it is necessary to clean the exchanger, it is easy to open and/or take off the cover, and then clean the channels with high-pressure water stream.

Compact SHE type 1 heat exchanger can replace several large shell and tube exchangers, which reduces the costs of installation, piping and also maintenance work and cleaning.

SHE type 2 involves crossover flow (condensed vapours move along the axis and the cooling fluid runs along the spiral from the inside to outside). Spiral axis is always in vertical position. Broad channels on the side of the vapours ensure minimal pressure drop during the fluid condensation and the cooling medium flows turbulently in the closed channel. The exchanger is an ideal solution for application in condensation under very low pressure – "in full vacuum".

Why Alfa Laval?

Alfa Laval is the world supplier of specialist engineering devices and solutions. Delivered components, complete technological lines and servicing ensure optimal and failure-free operation for the clients.

Innovative solutions make possible processing and treatment of most of the media, products and half-finished products, such as oils, water solutions, various types of chemicals, liquid or half-liquid food products.

Alfa Laval has been present in Poland since 1924, when the first branch of the company was established in Poznań. Since then, we have introduced innovative products and patented solutions to the Polish market, based on three key unit operations which are the basis of almost all processing. The operations comprise: separation (separation and filtration), heat exchange, pumping and flow control.

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The KZR INiG System – the first Polish Certification System of Biocomponents recognized by the European Commission

Amendment to the Biocomponents Act – new requirements for biofuels

DELFINA ROGOWSKA

Highly developed countries pay great attention to the environmental performance of products used in all life aspects. Due to the fact that natural products are recognized as environmentally friendly, the sector for goods of total or partial biological origin has been developed. Similar trends are observed in the fuel and petroleum products market, but in this case the phenomenon has a broader scope.

The introduction of biocomponents to engine fuels does not only pertain to "being eco", the addition of ethanol to engine fuels significantly increases the octane number. Moreover, the addition of biocomponents allows to decrease the demand for fossil resources and this in turn decreases dependency on these energy sources. It is also significant to note that the introduction of new components to fuels, sometimes despite possible negative effects on the fuel quality, is also a driver of economic development, innovation and the need to seek new solutions in the fuel and motorization sector by creating new job opportunities.

At the same time we should mention of the "dark" sides of biofuels and about the fact that the excessive expansion of energy crops may result in negative changes in ecosystems and thus yield an adverse effect, which is the opposite of that expected.

Sustainable development criteria

An increase of energy from renewable sources in the European market was planned to last until 2020 and is effective under Directive 2009/28/EC [1], commonly referred to as the RED Directive. However, awareness of the danger which is brought about by uncontrolled agricultural production development for energy purposes caused the regulatory body to add provisions for meeting the sustainable development criteria (SDC). These criteria refer to the protection of land, in particular ecologically rich lands, on which energy raw materials are cropped, pursuant to the good agricultural practice requirements and the requirements for greenhouse gas limitation in the biocomponent life cycle, in comparison to the fossil fuel comparator.

Biofuels Certification

Art. 18 sec. 3 of the RED Directive requires the Member States to take measures to ensure that economic operators submit reliable information about meeting the SDC. The provisions of this article state that Member States shall require economic operators to arrange for an adequate standard of independent auditing of the information submitted and to provide evidence that this has been done. The detailed principles for biofuels certification were issued in the notice of the

The five major requirements are defined:

I. The greenhouse gas emission saving from the use of biofuels and bioliquids shall be at least 35%.

Starting from January 1, 2017, the greenhouse gas emissions saving from the use of biofuels and bioliquids taken into account for the purposes in sec. 1 let. a), b) and c) of the RED Directive shall be at least 50%. From January 1, 2018 the reduction in greenhouse gas emissions shall be at least 60% for biofuels and bioliquids produced in the installations which started production on or after January 1, 2017.

II. Biofuels and bioliquids shall not be made from raw material obtained from land with high biodiversity value, namely land that had one of the following statuses in or after January 2008, whether or not the land continues to have that status (whether or not this status still exists):

a) primary forest and other wooded land, namely forest and other wooded land of native species, where there is no clearly visible indication of human activity and the ecological processes are not significantly disturbed;

b) areas designated:
   - » by law or by the relevant competent authority for nature protection purposes; or
   - » for the protection of rare, threatened or endangered ecosystems or species recognised by international agreements or included in lists drawn up by intergovernmental organisations or the International Union for the Conservation of Nature, subject to their recognition in accordance with the second subparagraph of Article 18 sec. 4 second paragraph,
   - » unless evidence is provided that the production of that raw material did not interfere with those nature protection purposes;

c) highly bio diverse grassland that is:
   - » natural, namely grassland that would remain grassland in the absence of human intervention and which maintains the natural species composition and ecological characteristics and processes; or
   - » non-natural, namely grassland that would cease to be grassland in the absence of human intervention and which is species-rich and not degraded, unless evidence is provided that harvesting the raw material is necessary to preserve its grassland status.

III. Biofuels and bioliquids shall not be made from raw material obtained from land with high carbon stock, namely land that had one of the following statuses in January 2008 and no longer has that status:

a) wetlands, namely land that is covered with or saturated by water permanently or for a significant part of the year;

b) continuously forested areas, namely land spanning more than one hectare with trees higher than five meters and a canopy cover of more than 30 %, or trees able to reach those thresholds in situ;

c) land spanning more than one hectare with trees higher than five metres and a canopy cover of between 10% and 30%, or trees able to reach those thresholds in situ, unless evidence is provided that the carbon stock of the area before and after conversion is such that when the methodology laid down in part C of Annex V of RED Directive is applied, the conditions of reduction in greenhouse gas emissions would be fulfilled.

The provisions of this paragraph shall not apply if, at the time the raw material was obtained, the land had the same status as it had in January 2008.

IV. Biofuels and bioliquids shall not be made from raw material obtained from land that was peatland in January 2008, unless evidence is provided that the cultivation and harvesting of that raw material does not involve drainage of previously undrained soil.

V. Agricultural raw materials cultivated in the Community and used for the production of biofuels and bioliquids shall be obtained in accordance with the requirements and standards under the provisions referred to under the heading 'Environment' in part A and in point 9 of Annex II to the Council Regulation (EC) No 73/2009 of January 19, 2009 establishing common rules for direct support schemes for farmers under the common agricultural policy and establishing certain support schemes for farmers (Journal of Laws 30 of 31.1.2009, p. 16) and in accordance with the minimum requirements for good agricultural and environmental condition defined pursuant to Article 6 sec. 1 of that Regulation.

Moreover, Article 18 of the RED Directive requires economic operators to use a mass balance system.

These requirements are not directly obligatory, but need to be met in order to assign biocomponents to the assumed purposes of the share of renewable energy sources and to receive financial aids. This obligation refers to biocomponents, raw materials and to their production, whether they were produced in the Community or outside of it. Due to the fact that the specified requirements are set, it was necessary to determine a verification method for the SDC criteria.

European Commission in June 2010 [2]. In accordance with the present legislation, the economic operators are required to evidence that the biocomponents/biofuel met the sustainable development criteria in three ways:

- By providing the relevant national authority with data, in compliance with the requirements that the Member State has established (a 'national scheme').
- By using a 'voluntary scheme' that the Commission has recognised for this purpose;
- In accordance with the terms of a bilateral or multilateral agreement concluded by the Union with third countries and which the Commission has recognised for the purpose.

Member States implementing the provision of the RED Directive are required to establish the domestic certification scheme.

Amended Act on biofuels

In Poland, the provisions of the RED Directive were implemented into the national legislation within the amendment of the Act on biocomponents and liquid biofuels [3] in 2014. This Act reviewed the currently applied definitions and implemented many new ones. The new regulations include requirements on proving compliance with the sustainability development criteria, implemented in section 4a of the Act, and also the regulations on conducting business activity pertaining to granting consent for the use of a recognized certification system and the performance of business activity in the field of delivery of the certificates (section 4b). Pursuant to the implemented provisions, the entities running the business activity in the field of biocomponent production, biomass processing, purchase, import or in-Community purchase of biomass or biocomponents, which are to be classified to achieve the National Index Target[1], are obliged to obtain such certificate.

Thus all entities in the biofuels supply chain – starting from the agricultural producer, up to the biocomponents producer – which trade biomass/processed biomass/biocomponents, need to pass the certification process in order to conduct the activity pertaining to biofuel purposes. The legislator also determined the conditions for such a process. Firstly, the certification is carried out only on the basis of the voluntary schemes, recognised for this purpose by the European Commission, and the entities entitled to the relevant scheme are named the Administrator of certification system. The certification system is a set of procedures described in the system documents, which assure that the requirements specified in the RED Directive are met. This set includes requirements regarding: the production of biofuels consistent with the sustainable development criteria, keeping the mass balance system for the assurance of the traceability of biomass streams and audit requirements. However, it should be noted that the role of the certification system is to develop detailed requirements which depend on the adopted certification scope and the audit process, and the delivery of certificates is within the competence of the independent certification bodies. These certification bodies need to meet the system requirements regarding high professionalism and at the same time obtain consent from the system administrator to issue certificates. Act [3], implementing the aforementioned requirements, came into force on May 9, 2014. From this moment on, the certification processes gained momentum.

The activity in the aforementioned scope is under regulation and requires to be entered into the relevant register. The Agricultural Market Agency (AMA), as the registering body, keeps a list of both the system administrators and the certification bodies. The advantage of this solution is that, if the entrepreneur obtains certification as part of the system, through the certification body which is listed by the AMA and acts under the scheme recognised by the European Commission, he will be entitled to produce for domestic biofuel purposes and to export products to other EU countries under the single certificate.

In the field of certification for compliance with the sustainable development criteria, Polish entrepreneurs have at their disposal the foreign schemes and also – so far the only Polish certification system developed by the Oil and Gas Institute – National Research Institute: KZR INiG System, which under the decision No. 2014/325/EU of June 3, 2014 was recognised by the European Union in reference to proving compliance with sustainable development criteria pursuant to the Directives of the European Parliament and Council No. 98/70/EC and 2009/28/EC.

The KZR INiG Certification System

Having worked for many years in the biofuels sector, the Oil and Gas Institute – National Research Institute started works connected with the certification system to be recognised by the European Commission. The initial works on the system started in 2010. In July 2011 an application was submitted to the European Commission for authorisation of the KZR INiG System. The first stage of the authorisation process – quality assessment – lasted until October 2013, and on June 3, 2014 the Commission's executive decision authorising the system [4] was issued. This system was developed on the basis of the RED Directive [1] requirements. Its implementation is to provide entrepreneurs, in particular the domestic ones – acting in the biofuels, bioliquids and biocomponents supply chain – with confirmation of compliance with the requirements for sustainable development pursuant to the requirements of the RED Directive and thus compliance with the requirements of the amended act on biocomponents and liquid biofuels.

Each voluntary scheme recognised by the European Commission provides the scope of certification. It also refers to the territory on which the agricultural raw materials are cropped or biofuels are produced and also the production pathway, to the determination of the raw materials for biofuel production and technology. The KZR INiG System assesses, in terms of compliance with the sustainable development criteria, the cropped and harvested biomass within European Union territory, waste and residues collected in EU territory and also the raw materials, biofuels and bioliquids produced on Union territory. The total life cycle of bio-

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[1] *National Index Target defines the minimum share of biocomponents and other liquid fuels and biofuels by the total number of liquid fuels and biofuels used by the farmer for transport purposes within a calendar year (calculated by calorific value).*

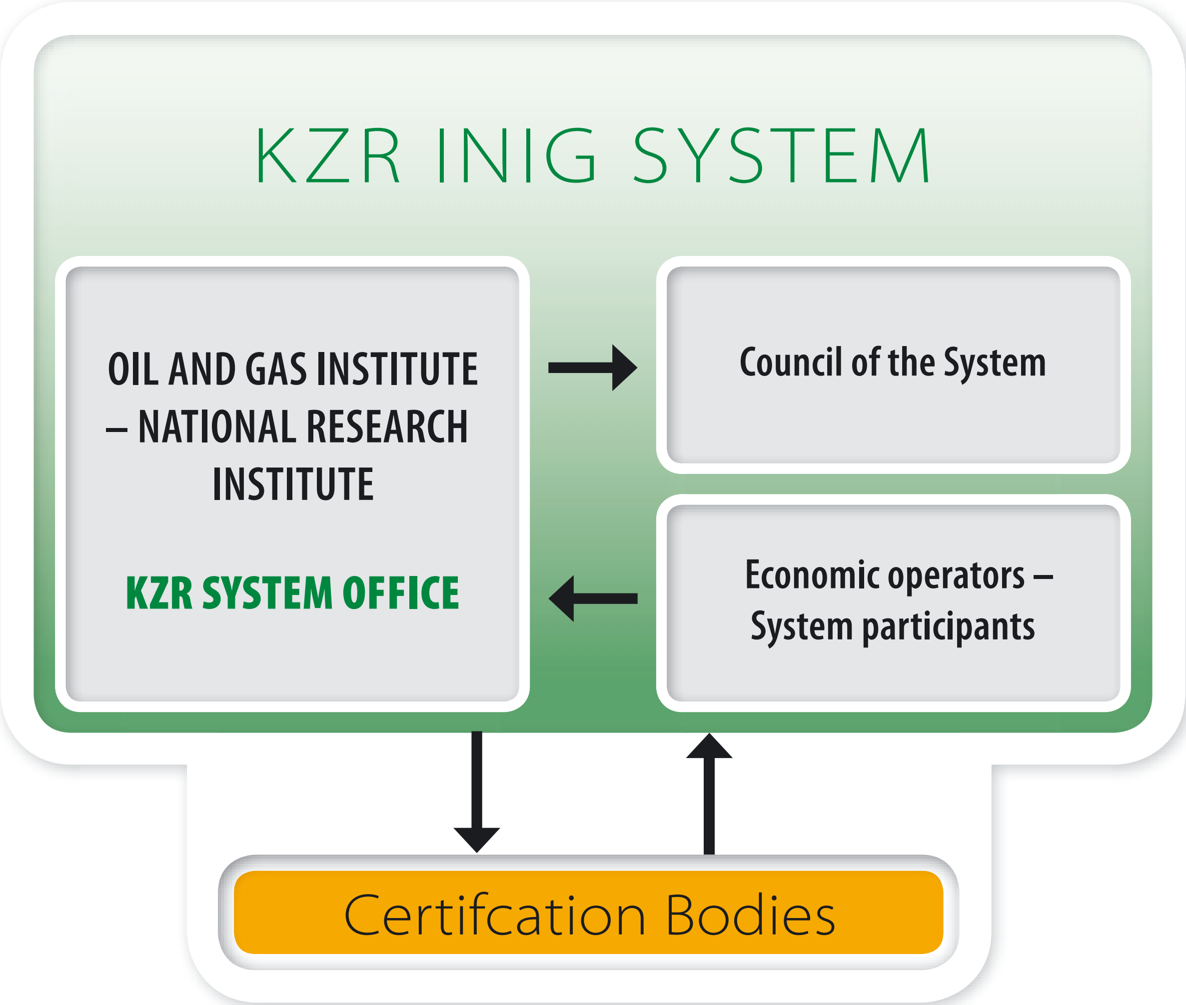

Fig. 1. Structure of the KZR INiG System

fuels, biofluids and biocomponents is assessed – starting from the raw material growing or waste collection points, to the final use of biofuels and bioliquids, origin of waste and residues, including all intermediate stages (biomass purchase, intermediation and processing) So the KZR INiG System does not limit the range of biocomponents, which are authorised to be certified (also such biocomponents not listed in the RED Directive and hydrocarbons biocomponents or other – of advanced generations may be also certified), provided that the sole limit is the crop or production territory.

Structure of the KZR INiG System

The KZR INiG System is the property of the Oil and Gas Institute – National Research Institute and is managed by this Institute (System Administrator) and is represented by the Director of the Institute. The structure of the System is presented in Fig. 1.

The green field presents the KZR INiG System composed of: the Oil and Gas Institute – National Research Institute, the economic operators (manufacturers, sellers), who obtained the KZR INiG certificate and the System Council. Certification bodies are independent entities outside of the System.

The KZR System Council is an entity composed of 5 to 10 members – external experts – representatives of the parties involved in the certification process. The main tasks of the Council include: supervision over independence, transparency, avoiding conflicts of interest between the system participants and certification bodies, examination of complaints and proposals, setting directions for the development of the KZR INiG System.

It is a very important body, because it allows entrepreneurs, through its representatives, to express their

Certification path

1. Decision on certification
2. System implementation
3. Registration to the KZR INiG System
4. Assessment of the application by KZR INiG
5. Signing the agreement on participation in the System
6. Contact with the certification body
7. Following the body's procedure
8. Audit -> Certificate
9. Participant of the KZR INiG System
10. Information on certification on the website: www.kzr.inig.eu

Fig. 2. Relevant stages of certification

opinions in matters related to the certification, including in particular the report and consideration of ambiguous and doubtful issues, to determine needs and development directions etc.

The Institute structure includes also the KZR System Office – the organisational unit responsible for the supervision and development of the System. The main task of this division is to supervise the records and documents of the KZR INiG System and the realisation of the System's resolutions. The System Board manages the Office and has decisive powers. The main tasks of the Office are also recognition and supervision of certifying bodies within the framework of the System, moreover it is responsible for setting directions for the development of the KZR INiG System and communication and cooperation with the System Administrator, system participants, certification bodies, System Council and interested parties.

The System Administrator supervises the System – certificates of compliance with the KZR INiG System are issued by independent certification bodies.

The external elements connected with the System are the certification bodies. The RED Directive [1] imposes clear requirements of the high quality independent audit of the reported information. Such standards may be met only due to the high professionalism of the certification body. And therefore, the entity must meet several requirements and obtain the Administrator's authorisation in order to certify under the KZR INiG System. These requirements include both general body competences and the detailed requirements for the auditing staff. Information on the authorised certification bodies are published on: www.kzr.inig.eu

System Participants – business entities, which obtained the KZR certificate, are the most important element of the system. Being a member entitles to operations with biomass for biofuels purposes and makes the business entity an element of the biofuels supply chain – both produced in Poland and exported to other EU countries. The entity must take several actions in order for this to occur.

Certification path

The certification path is presented in in figure 2.

The first of the aforementioned steps is very important: the obligation of certification of entities in the biofuels supply chain is implemented under the amendment to the Act on biocomponents and biofuels [3]. The selection of certification system and certification body is the most important; in this case, the question is: what are the selection criteria? The answer is obvious for each entrepreneur – the main criteria are cost, time, easy communication, reliability and the scope of the system.

The costs for participation in the KZR INiG System are comparative to those in other rival systems. The

entrepreneur bears the cost of the audit carried out by the independent certification body (at least once a year) and pays fees to the System Administrator. The price list of the KZR INiG System includes two types of fees: the first is a registration fee, depending on the size of the enterprise, paid once upon registering in the System, and the second is a fee from the sale volume in tonnes, settled in a period of three months.

The time needed to obtain the certification is the next important argument supporting the selection of the relevant certification system. Similar to the cost, it is composed of two elements: working time of the certification body and the period upon which the information on the obtained certificate is published on the system administrator's website. It is important, because a client buying raw materials is able to confirm that the supplier's certificate is valid via this website. The maximum time from obtaining information on the certificate to its publication on the website is three working days. Moreover, certificates issued under the KZR INiG System are issued by national certification bodies, it also reduces the waiting time for this document.

Easy communication, availability of documents in Polish language, opportunity of asking questions directly are also very important for the entrepreneurs.

In June 2014, the list of voluntary schemes endorsed by the European Commission increased to 17 items [5], more specifically to 16 because one of them (Biograce) is a calculator. Each of them is equally important; the certificate issued under any of these schemes is of the same importance. But they differ – the scope of certification is defined differently. The Act on biocomponents states that certificate issuance requires registration. So, before the selection of the scheme and certification body, one should confirm whether the products sold under the certificate of the relevant system will be recognized not only on the international market, but also for the domestic purposes. However, holding the certificate issued under the scheme registered in the country (and simultaneously the European scheme) does not exclude the opportunity to purchase raw materials with the exclusively European system certificate.

After the selection of certificate system, its requirements should be implemented. Each system defines requirements to be met by the production in order to be compliant with the sustainable development criteria and provides them in the system documents, which have been analysed by the European Commission. The KZR INiG System includes 10 documents published on the website (www.kzr.inig.eu) and available to be downloaded. For convenience, they are divided by issues. The first document is a general document containing the system description; all material definitions are gathered in the second one. The third document describes the connections of the KZR INiG System with the national and European legislation. Three other documents refer to the requirements for agricultural production, which need to be met pursuant to the criteria provided by the RED Directive. The seventh document is a basic document for each system participant, because it contains requirements for the proper functioning of the mass balance system. The eighth one is dedicated to the determination of the lifecycle per unit values of GHG emissions. The last two documents contain requirements for certification bodies and audit guidelines. Depending on the nature of the activity of the relevant entrepreneur – his place in the supply chain, the scope of requirements necessary for implementation may vary.

The registration in the KZR INiG system and assessment of the proposal are of formal nature, after which the agreement between the business entity and system administration, so the Oil and Gas Institute – National Research Institute, may be signed. It is an essential condition to start cooperation with the certification body.

All certification bodies which have system administration powers granted, are equal and independent, in particular regarding finances of the system administrator so they develop the price list for services considering their own costs and other conditions. The certificate issuance time may vary depending on availability of auditors.

The audit is carried out in compliance with the internal body procedure including system recommendations and pursuant to the checklist which is prepared by the system administrator and applied by all bodies. If the audit is concluded with a positive result, the certificate, valid for one year, will be issued; from this moment this entrepreneur is a participant of the KZR INiG System conducting its activity in compliance with the System requirements. Information about this fact is published on the website.

In order to be able to sell products with confirmation that they are compliant with the sustainable development criteria – as defined by the RED Directive, the raw materials need to have certification that they meet these criteria that they come from a certified supplier. It is also important to be sure at purchase that the certificate of the supplier is still valid, e.g. if this certificate is not withdrawn under the stated material non-conformities – or suspended for other reasons.

Farmers audit

The farmers are the specific group of system participants. They are the first element in the biofuels supply chain and they need to prove compliance with the sustainable development criteria (referring to the land on which the raw materials are grown). Farmers can be audited individually or as part of a group. In the latter case certification, the certification process is carried out in the first gathering point or by the central office of the organisation. But also the subject of the audit is a trial group of farmers supplying to the relevant gathering point or associated in the organisation.

Summary

On May 9, 2014, the amendment to the Act on biocomponents and liquid biofuels came into force, implementing the obligation of biocomponents certification regarding the compliance with the sustainable development criteria. In practice, this obligation includes all entities in the supply chain, starting from the farmer.

Pursuant to Act [3], certification is possible only within those certification schemes which were endorsed by the European Commission. So far, the KZR INiG System is the only Polish system to be recognised.

Due to the fact that the System was developed and is managed in Poland, there are at least two advantages. Firstly: the participation of the producer's representative in the System Council. The Polish entrepreneurs, through their representative, may actively participate in its development, report and solve arising problems. The second advantage is the fact that documents are available in Polish and contact is possible only in the Polish language.

The issuance of the certificate by the national bodies will be positively reflected in the waiting time. Upon receipt, the information will be published on the website within three working days.

Producers, upon payment of the registration fee, will bear only the fees due to the biomass/biocomponents operation calculated under the real sales. If the activity is discontinued, the fees will not be paid and the certificate is valid to its expiry date. So one may return to the "biofuel" activity without any additional fees.

The System is recognised by the European Commission that gives the opportunity to export outside Poland. Products being sold under the KZR INiG System may be classified both to domestic purposes and to be exported to other EU countries.

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Literature

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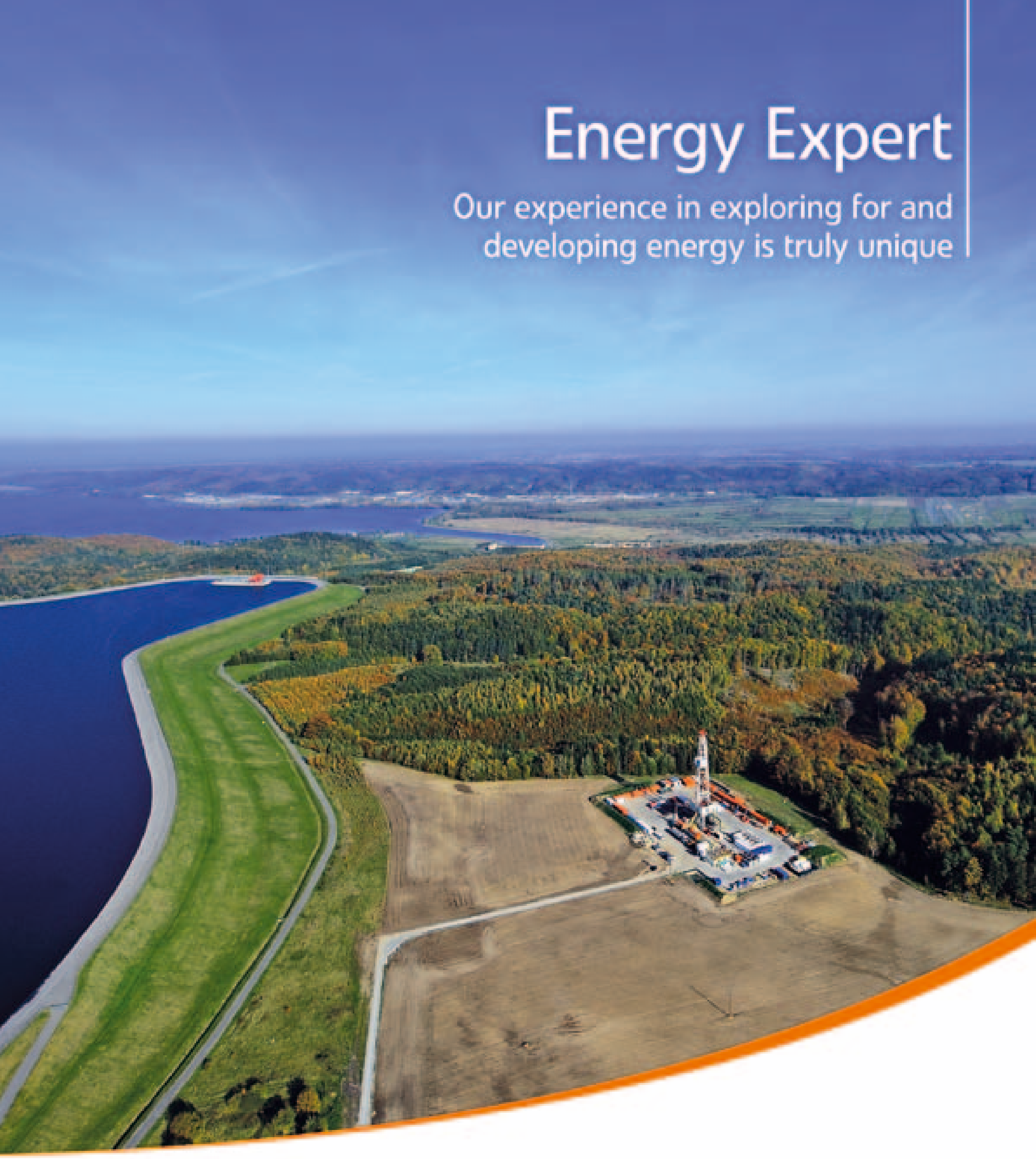
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