Coal Gasification using clean coal technology

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Introduction

The steadily rising demand for electric power, especially in developing countries such as India or China, has triggered a major shift in the primary fuels consumption structure. Crude oil reserves are estimated to last approx. 45 years, while natural gas will last approx. 60 years. The depletion of hydrocarbon fuel deposits and volatile geopolitical situation contribute to the increasing importance of coal as energy source. According to the forecasts, the global coal consumption will rise from 132 quadrillion Btu (British thermal unit, 1 Btu = 1055.87J) in 2007 to 206 quadrillion Btu in 2035, with the average annual growth rate of 1.6%. [1]. Globally, the coal consumption by industry will increase mainly because of China and the development of steel industry. This increase, along with international agreements on limiting or decreasing greenhouse gas emissions, has forced the development of clean coal technologies. The American *Clean Coal Technology* initiative distinguishes four directions: *Precombustion, Advanced combustion, Advanced postcombustion* and *Conversion. Precombustion* is purifying coal prior to combustion, thus maintaining the pollution limits during combustion. The aim of *Advanced combustion* is to improve the effectiveness of energy transformation. *Advanced post combustion* is purifying the exhaust fumes. In recent years it has been the fourth direction that attracts most attention. Advanced post combustion is related to new coal conversions, i.e.: coal gasification, liquefaction and paralysis. Gasification is steadily becoming the foundation of advanced coal utilization technologies. It enables not only high efficiency in electric power production, but also provides valuable chemical products, such as liquid fuels, methanol and hydrogen. The choice of the appropriate gasification technology concept depends on the development strategy of power engineering and chemical and fuel industry in the given region.

Current situation on global coal market

The documented global coal reserves are estimated at 909 billion tons, of which 53% is hard coal. Coal deposits available for extraction are located in 70 countries. 67% of those reserves are located in four regions: United States (27%), Russia (27%), China (13%) and India (10%). Assuming the coal extraction remains at the current level (approx. 5.5 billion tons/year), the documented coal reserves will last approx. 129 years. Coal reserves according to region and type are presented in Table 1.

In numerous countries coal is the traditional means of ensuring energy security. In the base scenario (economy development similar to the current situation), provided by U.S. Energy Information Administration (EIA) it is clear that the global coal consumption will nearly double between 2003 and 2030, from 5.4 billion tons to 10.6 billion tons - Figure 1. Coal consumption will increase by 3% on average from 2003 to 2015 and then will slightly decrease to 2% annually from 2015 to 2030. Coal is the main fuel used for electric power and its share in the global electric power production will amount to approx. 40%. For comparison, in Poland in 2004 95% of electric power was produced from coal, in RSA – 93%, India – 68% and the U.S. - 51%. Hard coal also plays a significant role in steel works – currently approx. 12% of total coal output is utilized by the steel industry. The rapid development of this industry is the reason behind the increase in coal demand in China and India.

Table 1

Available coal reserves as of 1 January 2008 [1]

Region/ Country	Available coal reserves according to type, in billion short tons				Sufficiency of coal reserves given the current demand, years
	Bitumens and anthracites	Subbituminous coals	Lignite	Total	
Globally	452.9	291.4	165.1	909.4	129
USA	119.6	108.7	33.3	261.6	228
Russia	54.1	107.4	11.5	173.1	543
China	68.6	37.1	20.5	126.2	46
Australia & New Zealand	40.6	2.5	41.5	84.6	195
India	59.5	0.0	5.1	64.6	122
Africa	35.1	0.2	0.0	35.3	127
OECD - Europe	9.3	3.4	19.0	31.7	48
Central and South America	7.7	1.1	0.0	8.8	102
Brazil	0.0	7.8	0.0	7.8	1,182
Canada	3.8	1.0	2.5	7.8	96
Other	54.6	22.1	31.9	108.6	-

Source: World Energy Council and EIA.

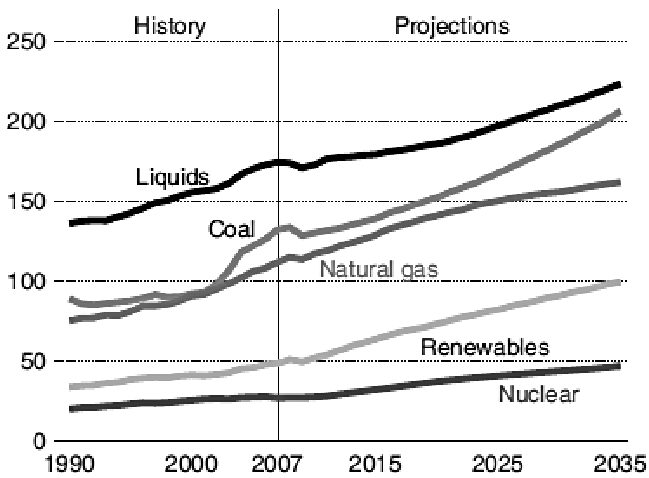

Fig. 1. Global energy trade according to fuel type between 1990 and 2035, in quadrillion Btu [1]

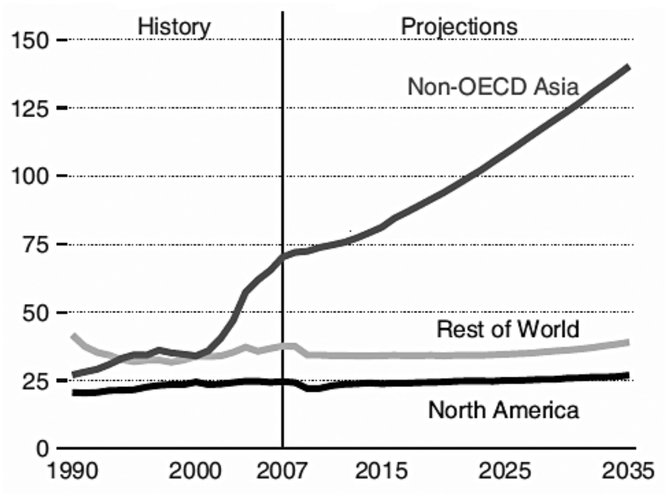

Fig. 2. Global coal consumption according to regions between 1990 and 2035, in quadrillion Btu [1]

Thus far, coal extraction in EU countries has been considered unprofitable and coal was imported from the U.S., China, Australia and North Africa. The necessity to improve energy security forced the European Commission to change their position on the matter. Instead of limiting coal extraction, support for the development of clean coal technologies has been implemented, particularly for the gasification process.

Physicochemical background of coal gasification

Coal gasification is the set of thermal and chemical transformations, occurring at increased temperature between the organic compounds in coal and the gasification agent, i.e. air, oxygen, carbon dioxide and water vapour, or mixtures thereof [2, 3]. The basic reactions in the coal gasification process are as follows (calculated for 850°):

$$C + O_2 \rightarrow CO_{2(g)} \quad \Delta H = -394.9 kJ/mol \tag{1}$$

$$C + 0.5O_2 \rightarrow CO_{(g)} \quad \Delta H = -113.0 kJ/mol \tag{2}$$

$$C + H_2O_{(g)} \rightarrow CO_{(g)} + H_{2(g)} \quad \Delta H = +135.7 kJ/mol \tag{3}$$

$$CO_{(g)} + H_2O_{(g)} \rightarrow CO_{2(g)} + H_{2(g)} \quad \Delta H = -33.2 kJ/mol \tag{4}$$

$$C + 2H_{2(g)} \rightarrow CH_{4(g)} \quad \Delta H = -91.0 kJ/mol \tag{5}$$

$$CH_{4(g)} + H_2O_{(g)} \rightarrow CO_{(g)} + 3H_{2(g)} \quad \Delta H = +226.7 kJ/mol \tag{6}$$

$$CH_{4(g)} + CO_{2(g)} \rightarrow 2CO_{(g)} + 2H_{2(g)} \quad \Delta H = +259.9 kJ/mol \tag{7}$$

In the gasification reactors the exothermic and endothermic reactions run parallel, with the latter reactions dominating. In order to complete the thermal balance of the process it is necessary to provide heat, usually 20÷35% of C element in the fuel is oxidized to CO_2. From the viewpoint of composition of the resulting gas, secondary reactions are undesirable, particularly the conversion of carbon monoxide with water vapour, since in consequence the content of industrially unusable CO_2 in the products may exceed 25% of the gas volume. Undesirable products include also H_2S, NH_3, HCN, COS, emerging as a result of oxidation and reduction of heteroatoms in the organic compounds of coal. The gasification process of porous coal using the gasification agent is a heterogeneous one. The total process velocity depends on the velocity of the two fragmentary processes: correct chemical reaction of the gasification agent with the organic compound of the carbonization product and the diffusion of gas particles to and from the external surface of the carbonization product's grains, as well as to and from the inside of its pores.

The composition of gasification products depends on the gasification parameters (pressure, temperature, type of reactor), the type of gasification agent and the quality of coal undergoing the process. Basically, gasification with the use of oxygen and water vapour yields fuel gas of medium calorific value or natural gas substitute of calorific value exceeding 33.5 MJ/m^{3}n. Low calorific value gas (3.8÷7.6 MJ/m^{3}n) can be acquired with the use of air and water vapour as the gasification agent.

Gasification raw materials

Nearly half of the industrial gasification reactors are powered by various types of lignite and hard coal. Other gasification batch materials include the petrochemical by-products (heavy oil, tar, deasphalting and visbreaking process remains) (37%), as well as waste industrial gases, petroleum coke and biomass. The share of coal in gasification processes will reach as much as 75% due to the construction of six coal plants planned in China.

In order to achieve high thermal and process efficiency, gasification should utilize coal with relatively high calorific value (preferably above 24 MJ/kg) and low ash content (preferably below 10%). High sulfur content does not interfere with the gasification process and the gas products are purified in modern Claus plants. In order to reduce the ash content the raw material is enriched beforehand. At the moment, coal with preferable quality parameters in sufficient quantities is unavailable in Poland. The analysis by the Polish Geological Institute indicates that coal with appropriate parameters for the gasification process can be found in the mines of Ziemowit, Piast, Bogdanka and Janina.

Table 2

The properties of hard coal in selected Polish coal mines [5]

No.	Designation	Coal mine			
		Janina	Bogdanka	Piast	Ziemowit
Technical analysis					
1	Q^r_i, MJ/kg	18.16	21.28	18.0-20.0	19.83
2	A^r, %	17.53	19.73	20.0-25.0	18.52
3	S^r_t, %	1.82	1.00	0.91-1.40	1.30
4	W^r, %	19.06	11.32	13.0-16.0	14.77
Elementary analysis					
1	C^a	54.00	55.81	55.26	56.01
2	H^a	3.58	3.26	3.56	3.50
3	N^a	0.83	1.18	0.82	0.69
4	O^a_d	9.40	7.70	14.32	11.40

Utilization of gas from the gasification process

Nearly 70% of the process gas acquired through coal gasification is currently used in Fischer-Tropsch process (Sassol plant in RSA) and in the production of synthetic natural gas (SNG plant, Great Plane, USA) [3]. The remaining 30% of gas produced from coal is used in the chemical industry (11%) and in the production of gas fuels (11%) and electric power (10%). Frequently, systems producing „clean" energy are integrated with the production of chemicals, thus creating the so-called „energoplexes".

In the integrated gasification combined cycle (IGCC) coal is transformed into high calorific value syngas. After purification the gas is combusted in a gas turbine. The thermal energy of exhaust fumes emerging from this process is used to create water vapour to power further turbines and generators and finally to provide heating. The energy conversion efficiency of the IGCC plant is approx. 45% and the cost per unit of energy production in this technology is approx. 25% lower than in modern pulverized fuel firing.

Another way of utilizing the gas from coal gasification process is the production of vehicle fuels and chemical materials using the Fischer-Tropsch synthesis. The type and share of the products depends on the technical operation of the process, the used physicochemical parameters and the hydrogen to carbon monoxide ratio in the syngas. In order to acquire petrol hydrocarbons, it is preferable to use an iron catalyst at high temperature (300÷350°C) in a fluidized reactor. In order to acquire higher hydrocarbons (for Diesel fuel), the process should be conducted in a suspension reactor with a cobalt catalyst at 180÷240°C.

Hydrogen, which is considered the fuel of the future, is acquired on industrial scale mainly through the conversion of natural gas. However, due to the rise in natural gas prices and the volatile market, the concept of hydrogen acquisition through the gas originating from coal gasification is becoming increasingly popular. The acquired hydrogen gas is enriched in pressure swing adsorption (PSA) systems. Also, gas originating from coal gasification is gaining prominence in the production of methanol, as nearly 10% of the global production of this alcohol is currently based on coal syngas.

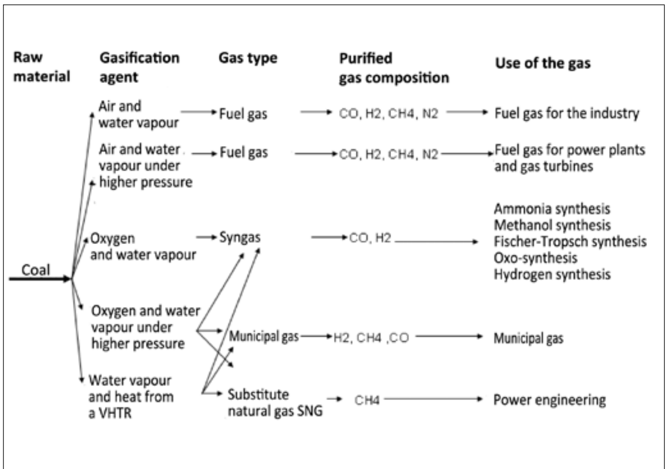

Fig. 3. Utilization of gas from the gasification process [4]

Industrial coal gasification technologies

There are three gasification technology variants, differing in terms of process operation (flow type) and the construction of gas generator:

- gasification in moving bed – the gas flows bottom-up through coal deposits with granulation of 5÷80 mm. In the deposit characteristic layers are formed in which the subsequent gasification stages take place: starting from the bottom, those include: ash layer, combustion layer, coke gasification layer, carbonization layer and coal drying layer. The temperature in the combustion layer reaches as much as 1 800°C, exhaust gases have the temperature of 400÷500°C; the process is conducted under approx. 3Mpa. An example of industrial application of this technology is the Lurgi method, utilized in Sasol plants in RSA
- gasification in fluidised bed – coal with granulation of 0.5÷5 mm is fed to the gasification agent stream. The batch residence time is 10÷100 s and the reactor temperature reaches 1050°C. Recycling is required to increase coal conversion. Currently this process is conducted in gas generators made in Winkler, U-GAS and KRW technology
- gasification in entrained flow – coal dust is delivered in a stream of oxygen with two burners to the reaction chamber, where it comes into contact with water vapour fed by separate nozzles. The process takes place at 1200÷1600°C and under 2÷8 MPa. This is the most popular gasification process at the moment, applied i.a. in the technologies of Shell, GE-Texaco, E-Gas, Hitachi, Koppers-Totzek (unlike the other processes it is conducted under atmospheric pressure).

The comparison of selected gasification technologies is provided in Table 3.

Table 3

Comparison of selected gasification technologies [6]

Technological parameter or indicator	Lurgi process	Winkler's process	Koppers-Totzek process
batch granulation, mm	6-40	1-8	70% < 0.075
max. water content, % of mass	up to 30	8-12	2-8
max. ash content, % of mass	up to 35	up to 46	up to 40
working pressure, MPa	2-3	0.12	0.105
max. temperature, °C	1200	850-1000	1900
coal residence time	1-2 h	20-30 min	0.5-10 s
coal conversion degree, %	99	60-90	90-96
Gasificator's thermal efficiency	75-85	50-75	75-76

Currently there are 144 industrial-scale installations in operation or under construction. Most frequently applied in the industry are the processes by Shell (28% of production), GE (31% of production) and Lurgi (34%).

Environmental aspects of coal gasification process

The increasingly strict environmental policy continues to pose new challenges to the chemical and energy industries. Aside from restrictions on the emissions of SO_2, NO_x and dusts there is also the requirement to reduce pollution with heavy metals and dioxins. Given the situation, the necessity to develop high-efficiency and low emission coal technologies appears inevitable. A typical example of „clean" coal technology is the integration of gasification with electric power generation, which not only increases the overall process efficiency, but also enables the elimination of environmentally harmful substances during the process. The energy conversion efficiency of the IGCC plant is approx. 45%, while for coal combustion in pulverized-fuel boilers at subcritical parameters reaches 40%. The installation can be powered with lower quality coals, such as highly sulfated lignites. Atmospheric emissions are at the level of < 10mg SO_2/m^3, < 60mg NO_X/m^3, < 3mg of dust/m^3. The capability of eliminating dust and gas pollution from gasification products prior to combustion allows for reducing the cost of exhaust fumes purification. Compared to the installation of combustion under supercritical conditions, the water consumption and production of sewage in the ICGG plant is reduced nearly by half. The comparison of pollution levels of different electric power and heat generation processes is provided in Table 4.

Table 4

Comparison of different electric power and heat generation methods [8]

System characteristics	Coal combustion in pulverized-fuel boilers (coal combustion + water vapour turbine)	Coal combustion in pulverized-fuel boilers (coal combustion + water vapour turbine + CO_2 elimination)	IGCC plant (coal gasification + "hot" gas purification)
Net power, MWe	396.8	283	400.4
Net efficiency, %	38.86	27.72	49.4
Investment costs, $/kWe	1,268	2,373	1,354
NO_x emissions, kg/MWh	2.04	2.87	0.165
SO_x emissions, kg/MWh	1.56	2.08	0.04
CO_2 emissions, kg/MWh	918	64	1,431

Conclusions

1. Coal gasification technology should be classified as one of the so-called Clean Coal Technologies. Atmospheric emissions are considerably lower with gasification processes instead of conventional combustion.
2. Coal gasification allows for achieving high electric power generation efficiency and yields valuable chemical products.
3. Given its resource base, Poland has the chance to become a European leader in deployment of coal gasification technologies and in the future also in hydrogen production from coal.

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After the crisis EU companies plan to increase spending on research and development

EU-based companies largest in terms of R&D investments expect that their spending on research and development in 2011-2013 will grow by 5 percent per year, according to recently published European Commission study. This means that during this period the growth rate of R&D expenditures will be twice higher than the forecasts from last year. European Commission survey also revealed that on average 27 percent turnover of these companies is generated by innovative products marketed in the last three years. According to Geoghegan-Quinn spokesman, Mark English, investments induce growth and well-targeted investments (in research and development) ensure growth of competitiveness of enterprises and the economy. He noted, however, that investments in innovation of European companies are much lower than those of U.S. companies, which invest about 66 percent more in terms of GDP. Although the companies surveyed by the EC assume to have 75 percent innovative investment in the EU, the growth rate of investment in the EU will be lower than in other regions. In the EU, R7D investments of these companies will increase by 3 percent per year for the next three years, in China by as much as 25 percent, in Japan by 17 percent, in India by 8 percent. The nominal spending on research and development over the next three years is expected to grow by 2.2 billion euros in the EU and by 2.7 billion outside the EU. Based on this trend, already visible in the results of three out of four recent studies, it can be assumed that companies based in the EU wish to benefit from growth in developing economies, while maintaining a significant involvement in the EU, according to the EC. In the survey investors indicated that they invest in research and development in regions with available skilled personnel, public support in the form of grants and tax incentives, and the possibility of cooperation with higher education institutions. Discouragements include high costs of enforcing intellectual property rights and a long waiting time for having these rights protected. The EC hopes in the EU the situation will improve with a standardised EU patent, which has been agreed upon after years of disputes between the EU countries. The EC questions about R&D plans have been answered by 205 of 1000 firms, which, according to the European Commission, is a representative sample. These 205 companies will spent a total of almost 40 billion euros on research and development, which constitutes about 30 percent of total funds spent for this purpose by the 1,000 companies included in the EU ranking.

(http://www.naukawpolsce.pap.pl/6.09.2011)