State and Outlooks of Deep Coal Processing

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Abstract

Trends in the development of modern coal-chemical technologies of fuel and non-fuel consumption of coal are considered. For the Kuznetsk basin as example, some directions of deep processing of coal and waste coal materials are proposed; their practical realization is possible even at present in many coal-mining regions of Russia.

INTRODUCTION

Coal is used in the modern fuel and energy complex mainly as a multi-purpose energy carrier and a raw material for the production of metallurgical coke and chemical carbonization products. However, owing to the variable state of the market with respect to world prices for petroleum and the products of petroleum-refining industry, and due to depletion of petroleum resources, the problem of obtaining liquid hydrocarbons from coal becomes urgent. Investigations in the area of chemical technology of coal liquefaction developed especially extensively in the 70–80s of the 20s century after a sharp increase in the price of petroleum at the world market. At present, many countries (China, Japan, *etc.*) possessing no large deposits of petroleum and natural gas develop and carry out semi-industrial tests of the new technologies of obtaining synthetic petrol and raw materials for organic synthesis from coal [1].

ENERGY-GENERATING USE OF COAL

The world consumption of coal is about 3.6 milliard tons of equivalent fuel, among which three milliard is consumed for power generation and 0.6 milliard for the production of coke. Depending on the growth rate of the world economy, an increase in the consumption of fossil coal by about 1 milliard tons is expected for the first decades of the 21th century [2, 3]. An increasing interest to coal as the main fossil energy source is due to its tremendous world resources, which will be sufficient, taking into account the expected needs, for several hundred years. Because of this, with the limited resources of petroleum and gas, the world power engineering is likely to re-direct itself mainly to coal. Thus, even now about 40 % of the world's electricity and 70 % of steel are manufactured using coal.

Within the recent years, substantial attention is paid abroad to the improvement of the quality of coal products, which is explained both by more rigid requirements to environmental protection for the industrial use of coal and by the desire to increase the efficiency of coal processing and burning [1]. Passing from fuel-bed firing to the technologies of deep complex coal processing, we are to solve the problem of ecological safety and economical efficiency of coal power engineering. The technology of coal use for power generation

has been substantially improved due to a combination with gasification, the use of pseudo-fluidized bed at atmospheric and elevated pressure, coal burning in melted slag, in pulverized-coal furnaces or in the form of water-coal suspensions. Thus one minimizes fuel loss due to mechanical and chemical underburning; amounts of nitrogen and sulphur oxides emitted into the atmosphere decrease substantially [4].

COAL GASIFICATION

In addition to power generation, gasification can be used to obtain chemical products. At present, there is only one example of the industrial manufacture of liquid products with the help of Fischer–Tropsch method from synthesis gas obtained by coal gasification (Sasolburg, Republic of South Africa). About 60 developments dealing with coal gasification are known to be planned for implementation; however, no more than 10 of then are meant for chemical processing.

To produce energy-generating fuel and technological gas, more than 350 gas generating stations were in operation in the USSR; about 2500 gas generators were mounted on these stations [5]. Energy-generating and technological gas in the amount of 35 milliard m^3 per year was manufactured at these stations using different kinds of fuel. Works aimed at coal gasification were almost completely ceased in the recent years as a consequence of intensification of oil and gas production.

Boiling-bed gasification [6] is considered as an efficient method to protect environment against energy-generating consumption of coal and can serve as a basis to organise production of synthetic petrol, alcohols and other raw materials for organic chemistry. However, there are no industrial technologies of integrated coal processing in Russia.

Undergroung gasification and underground combustion of coal can be considered as a separate direction of gasification process. This process was spread in the USSR in the 50s on an industrial scale; several installations were functioning in the country. However, their use ceased due to low profitability and ecological reasons. At present, the technology of underground gasification is performed on the industrial scale only in Uzbekistan (Angren station) and is considered as a promising one for the conditions existing in the Kuznetsk basin [7]. According to predictions, it is possible to create a profitable production of ecologically safe gaseous energy carrier for use to obtain hot water, steam and electricity directly in the place of its production.

COAL LIQUEFACTION

The processes of direct hydrogenating liquefaction of coal are not used on an industrial scale due to some reasons connected with complicacy of technology and the difficulties of subsequent processing of liquid products. However, more than 80 experimental installations of coal liquefaction to obtain synthetic liquid fuel were in operation in different countries. The technology of direct coal hydrogenation at relatively low hydrogen pressure was developed in the Institute of Fossil Fuel (Moscow); this technology provides manufacture of a broad range of liquid fuel: petrol, diesel fuel, aviation kerosene, fuel for marine engines, furnace and boiler fuel [8].

It should be noted that coal hydrogenation processes implemented in all the known technologies are still insufficiently perfect; artificial liquid fuel obtained in the experimental industrial plants is not competitive with oil products [9]. The modern level of developments in chemical coal processing, taking into account the raw material resources and research potential, allows us supposing that the industrial production of synthetic liquid fuel can be implemented within the nearest 15–25 years.

Preparation of coal nanodispersions in mixture with alcohols, heavy residues of oil processing, other organic wastes and water can be considered as one of the promising routes to transfer coal into the “liquid state”. The best developed technologies are those of preparation and transport of water-coal fuel [10].

BY-PRODUCT COKING INDUSTRY

By-product coking industry manufactures not only coke, coke-oven gas, but also a broad

range of valuable chemical products. The technology of laminar coking in a chamber furnace with chemical by-product trapping has reached almost the limiting level of its technological significance; the possibilities of further development of this technology have already been exhausted.

At present, we are starting to observe a transition from optimization of the conventional laminar coking process in a multi-chamber system of periodic action to the development of the processes of new generation meeting essential requirements of the high technologies of the future: continuity, complete automation, ecological safety, resource and energy saving [11]. A usual technology of coke gas processing at coke plants is uneconomic, especially if more strict ecological requirements are taken into account. For example, a new technology of processing and use of the raw coke gas is being developed, along with the structure of the coke plant of the future. According to this technology, coke gas will be subjected to cracking to obtain a reductive gas that contains hydrogen (more than 60 %) and carbon monoxide (more than 30 %). The main products of a coke plant, metallurgical coke and reductive gas, will be used as energy source or as a reducing agent in the processes of direct iron production.

In the recent years, technologies of coal carbonization in furnaces without chemical product trapping start to reappear in the USA. In order to increase efficiency, these technologies are combined with the recovery of heat of the waste gas of coking [12].

Coking industry of the metallurgical complex of Russia is represented by four coking plants and eight metallurgical works. Single-ring aromatic hydrocarbons and naphthalene are obtained at coking plants in Russia by processing raw benzene and tar. Broadening the range of products with the separation of individual compounds and improvement of the product quality will allow one to increase profitability and to make the production more flexible and competitive. However, for the majority of plants, the conditions of the operating works of chemical coking product trapping do not meet the requirements of ecological and industrial safety; raw benzene processing is carried out in rectification plants using sulphuric purification technology which is outdated both with respect to technology and due to obsolescence; this technology can be replaced by highly efficient catalytic processes of hydrotreating and hytdrodealkylation [13]. In general, the existing state of coking industry is characterized by low innovation; application of developments is carried out only in the case if it does not require substantial investment. The strategy of coking industry in Russian Federation includes as one of the directions new flowcharts for trapping and for coke gas treatment, elimination of the production of non-deficient products, and special technical and economical developmental work to build coking works without a chemical wing to obtain fuel gas and electric power [14].

COMPLEX PROCESSING OF COAL AND COAL WASTE MATERIAL OF THE KUZNETSK BASIN

The Kuznetsk basin is characterized by diverse and unique grade composition of coal, well-developed energy and transportation infrastructure, coal-processing industry (coal cleaning, semicoking, coking, underground gasification), chemical industry, and extant experienced personnel in coal chemistry. In view of these circumstances, the Kuznetsk basic could become an original testing ground to master and introduce many processes aimed at complex processing of coal into high-calorific, ecologically safe solid, liquid and gaseous fuel, a broad range of valuable chemical products for non-fuel purposes, and construction materials.

The Kuznetsk coal basin in which about 70 % of coking coal in Russia is mined should retain the position of the major supplier of coking coal; for this purpose, it is necessary to build new coal plants, to expand industrial facilities for sorting, cleaning and preparation of the finished coal mixtures for coking. In order to increase the economic potential of the region and elevate the efficiency of coal consumption, it seems reasonable to increase the production of the final commercial product, that is, metallurgical coke, and at the same time to develop coking chemistry and the production of the range of scarce compounds traditionally

related to coking chemistry (benzene, phenol, naphthalene, polyaromatic compounds, nitrogen bases, graphitized carbon materials, *etc.*).

Relatively low quality (humidity, ash content, granulometric composition) of ordinary power-generating coal brings about a number of economic, transportation-related and ecological problems, and decreases the possibility of exporting. So, first of all, it is necessary to develop the technologies of primary coal processing (beneficiation, particle size sorting, utilization of high-ash waste of coal cleaning). The latter also implies the possibility to organize high-technology production aimed at extraction of rare elements and rare earths from coal and coal waste material [15].

The problem of increasing the energy-generating potential of low-grade coal becomes urgent, too; it involves development of the production of high-calorific fuel (thermal coal, thermal briquettes, semicoke) with compulsory complex processing of pyrolysis tar and obtaining the scarce chemical products, components of petrol and fuel oil, organic binder for the production of coal briquettes and road building, electrode materials.

Large-scale production of liquid hydrocarbons as an alternative to those obtained form petroleum, is likely to remain non-competitive in the nearest future. However, it is possible to broaden the production of coking chemicals, which are increasingly needed (pure benzene, naphthalene, anthracene, raw material for the production of pharmaceutical substances, coal tar pitch and so on).

In addition to coal resources of valuable grades, the Kuznetsk basin possesses the deposits of off-grade solid fossil fuel (turf, brown coal and sapromixite, shale oil, oxidized coal) which could find qualified application. With some home-made developments as examples, one may propose an approximate scheme of complex processing of a number of low-grade coal and coal waste kinds of the Kuznetsk basin [16]. Turf and brown coal from the north-eastern deposits of the region, having low energy-generating significance, after relatively simple preliminary thermal [17], chemical [18] or high-energy mechanical [19] treatment, can serve as a raw material for profitable production of valuable extractables (ozocerite, turf-coal tar, brown coal tar, humic preparations); solid residues of extraction can be used in the production of cheap adsorbents and organic-mineral fertilizers.

Sapromixite and shale oil, unique in the composition of the organic matter, can be processes by means of alkaline hydrolysis, thermal dissolution and pyrolysis into valuable chemical products: aliphatic carboxylic acids [20], floatation reagents [21], components of petrol and fuel oil, organic binder [22]. Solid carbon-containing residues of thermal dissolution and pyrolysis, together with screening products of energy-generating coal, can be gasified with the formation of energy gas or synthesis gas for subsequent synthesis of valuable chemicals (on the basis of carbon monoxide) and hydrogen for use in hydrogenation processes and as promising ecologically safe fuel for motor transport and power engineering.

CONCLUSIONS

Thus, in the nearest future coal is assigned to play only the role of energy-generating raw material; all the coal processing developments are aimed mainly at the production of different kinds of fuel. However, with exhaustion of the main world oil and gas resources, coal will hold the importance of the main source of organic raw material for chemical industry. Therefore, non-fuel ways of the use of fossil coal need significant development, technological and economic evaluation and wide implementation. This will require a thorough revision of the possibilities of complex use of the natural potential of coal in Russia, both from the viewpoint of fundamental coal science [24] and in view of the most optimal routes of industrial coal processing for each coal-mining region of the country. At present, there are all the technological and economic prerequisites for the improvement of quality of coal mined in Russia, for involving low-grade and off-grade solid fuel into processing, and for utilization of solid wastes of coal mining and processing, which will allow one to obtain additional valuable coal chemical products.

REFERENCES

1 D. A. Tsikarev, *Koks i Khim.*, 9 (2004) 42.
2 V. P. Grebenshchikov, S. M. Gusev, *Ugol'*, 12 (2001) 64.
3 S. G. Gagarin, *Koks i Khim.*, 7 (2001) 32.
4 S. G. Gagarin, *Ibid.*, 5 (1999) 40.
5 A. A. Krichko, V. V. Lebedev, I. L. Farberov, Netoplivnoye ispol'zovaniye ugley, Nedra, Moscow, 1978.
6 Yu. P. Korchevoy, A. Yu. Maystrenko, A. N. Dudnik *et al., Promyshl. Teplotekh.*, 4 (1998) 33.
7 S. N. Lazarenko, E. V. Kreynin, Podzemnaya gazifikatsiya ugley v Kuzbasse: nastoyashcheye i budushcheye, Nauka, Novosibirsk, 1994.
8 A. S. Maloletnev, A. A. Krichko, A. A. Garkusha, Polucheniye sinteticheskikh zhidkikh topliv gidrogenizatsiyey ugley, Moscow, Nedra, 1992.
9 I. P. Krapchin, E. Yu. Potapenko, *Khim. Tv. Tela*, 5 (2004) 59.
10 G. S. Khodakov, *Izv. RAN. Energetika,* 2 (2000) 104.
11 V. I. Rudyka, V. P. Malina, E. T. Kovalev *et al.*, *Koks i Khim.*, 11–12 (2000) 17.
12 G. S. Ukhmylova, *Ibid.*, 8 (1999) 39.
13 V. V. Zamanov, A. A. Krichko, A. A. Ozerenko *et al.*, *Khim. Tv. Tela*, 3 (2005) 67.
14 M. Yu. Posokhov, V. I. Sukhorukov, L. Ya. Rytnikov, *Koks i Khim.*, 3 (2001) 10.
15 B. N. Nifantov, V. P. Potapov, N. V. Mitina, Geokhimiya i otsenka resursov redkozemel'nykh i radioaltivnykh elementov v kuznetskikh uglyakh. Perspektivy pererabotki, Kemerovo, 2003.
16 Yu. F. Patrakov, N. I. Fedorova, *Ugol'*, 2 (2000) 60.
17 V. A. Mikheev, G. I. Petrova, M. I. Bychev, Transformatsiya burykh ugley v guminovye veshchestva pri teplovom vozdeystvii, Yakutsk, 2002.
18 S. I. Zherebtsov, V. I. Losbin, M. F. Polubentseva, *Khim. Tv. Tela*, 2 (2003) 8.
19 O. I. Lomovskiy, A. A. Ivanov, O. A. Rozhanskaya *et al.*, *Chem. Sust. Dev.*, 12 (2004) 353.
20 Yu. V. Rokosov, *Ibid.*, 4 (1996) 525.
21 N. V. Bodoev, S. V. Denisov, A. A. Baychenko, *Khim. Tv. Tela*, 1 (1989) 76.
22 N. N. Ulanov, *Ibid.*, 5 (1992) 17.
23 A. L. Dmitriev, *Int. Sci. J. Alternative Energy Ecology*, 1 (2004) 14.
24 A. M. Gyulmaliev, G. S. Golovin, T. G. Gladun, Teoreticheskiye osnovy khimii uglya, Moscow, 2003.