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Some Problems of the Transition to Low-Carbon Fuel

A. A. KALYBAY[1], Z. A. MANSUROV[2,3], V. G. SALNIKOV[3]

[1]*Kazakhstan Highway Research Institute, Almaty, Kazakhstan*

[2]*Institute of Combustion Problems, Almaty, Kazakhstan*

E-mail: zmansurov@kaznu.edu.kz

[3]*Al-Farabi Kazakh National University, Almaty, Kazakhstan*

Abstract

The urgent problems of decarbonization in the power-generating sector are analyzed, along with the potential routes to solve ecological problems connected with CO_2 evolution from the combustion of coal – one of the major kinds of fuel for power generating facilities in the world, and especially in Russia and in Kazakhstan. The technology and equipment of the technological line for low-temperature (not higher than 75 °C) hydroconversion of power-generating coal into high calorific (heat of combustion 45 MJ/kg), ecologically safe (purified from ash) liquid hydrogenated coal fuel (HCF) with low carbon content (less than 45 %) are described. The methods for processing coal fuel in the form of water-coal suspension are considered. The routes to conserve the coal industry are discussed, relying on the production of hydrogenized coal fuel with low prime cost from power-generating coal, which will ensure technologically efficient and ecologically safe transition to low-carbon power engineering with zero greenhouse gas emission.

Keywords: decabonization, coal, hydrogenated coal fuel

INTRODUCTION

It is known that at present more than 80 % of the generated electric and thermal energy is related to the use of coal at heat and power plants [1], which are the major sources of CO_2 emission into the atmosphere. Carbon dioxide is an essential factor in anthropogenic effects on the atmosphere and the enhancement of the greenhouse effect. For this reason, the world community is facing an extremely important goal of reducing the carbon footprint of power engineering.

In 2015, the representatives of 196 countries signed the Paris Agreement on Climate, coming into effect on the 4th of November, 2016. The goal of this agreement is development and implementation of the strategy aimed at the reduction of the emission of greenhouse gases (GG), mainly CO_2, by decreasing the fraction of hydrocarbon sources in the world energy balance due to the transition to renewable energy sources and carbon-free energy carriers, first of all hydrogen.

It is demonstrated in [2] that the world production of energy in 2019 was 160 000 TW·h, however, the world production of energy by all kinds of renewable sources in the same year accounted for only 2 800 TW · h; that is, almost 60 times less than the modern level. Therefore, to achieve the necessary level of renewable energy production, further broadening of the area used for the arrangement of solar panels, wind generators and other transforming facilities on the surface of the planet is necessary, with the corresponding withdrawal of these territories from economic management and natural ecosystems. Possible consequences of these actions can hardly be predicted and include substantial risk of disturbances of thermodynamic equilibrium in the climatic system.

So, an urgent task at present is the search for methods to decrease the carbon footprint from the use of energy coal, substantial resources of which are found in the Republic of Kazakhstan (RK) and in the Russian Federation.

The Concept for the Development of Coal Industry in the Republic of Kazakhstan up to 2020, developed in 2008 and implemented, was approved by the Decree of the Government of RK on the 28th of June, 2008, under No. 644 [3]. The basic amount of energy coal consumed for the needs of power engineering in Kazakhstan for 2008 was 82.83 million t/y. According to the concept, the indicated amount should increase by 2020 to 121.3 million t/y, or by 46.4 % from the basic level [4]. Coal prevalence in power engineering in Kazakhstan caused the total amount of GG emission in CO_2-equivalent up to 20.3 t/y per one inhabitant, which is more than twice as much as the same parameter for European Union (8.9 t/y).

In general, Kazakhstan occupies the 22nd place in the world in GG emissions and is marked as the brown zone in the Global Carbon atlas [4, 5]. In 2019, Kazakhstan was at the fifth place in the world in the energy consumption per the gross domestic product (GDP) and the second place in the carbon intensity of national economy (official site https://energystats.enerdata.net/).

The actual situation in the energy branch of the country and its official policy contradict each other. Thus, in December 2012, Kazakhstan adopted the Strategy for the Development of Kazakhstan up to 2050 [6], supplemented in 2013 with the Concept of the Republic of Kazakhstan for the transition to green economy [7]. The latter document stresses that the low-carbon development of economy should first of all provide energy efficiency and a decrease in the energy consumption per GDP by 30 % in 2030 and by 50 % in 2050 in comparison with the basic level of 2008, and an increase in the fraction of alternative energy sources in the production of electric energy up to 50 % by 2050 in comparison with the level of 2012.

PHYSICOCHEMICAL COMPOSITION OF POWER-GENERATING COAL

Kazakhstan occupies the 9th place in the world in the confirmed commercial reserves of coal rocks (33.6 billion t), among which 12.3 billion t is brown coal. Outbalance reserves of coal in Kazakhstan are estimated as 28.6 billion t, among which brown coal accounts for 25.3 billion t. In other words, total resources of coal over the basins and deposits of Kazakhstan exceed 62 billion t. Therefore, Kazakhstan cannot reject so large resources of available and cheap energy carriers, but it needs ecologically safe, energy-efficient technologies to transform energy coal into liquid, high-caloric fuel with low carbon content.

The major coal basins are Karagandy, Ekibastuz, and Maykubensk, large deposits are Kushokinsk, Borly, Shubarkol, Karazhyr, while medium-scale (for example, Saryadyr) and small deposits are scattered all over the country except the Kyzylordy Region.

More than 60 % of coal resources in Kazakhstan belong to high-ash coals and are characterized by the degrees of metamorphism (ranks) from gas-fat coal (GZh) to semi-lean caking coal (OS). The average-weighted ash content of energy coal varies within the range from 28 to 42 % and is on average about 38 % per mass (the Ekibastuz basin). Chemical composition of coal ash is, %: SiO_2 60–66, Al_2O_3 24–33, Fe_2O_3 1.56–5.6, TiO_2 0.89–1.5, CaO 0.15, MgO 0.05, SO_3 0.21, P_2O_5 0.01, Na_2O 0.54, K_2O 0.14. Chemical composition of coal includes, %: C 80.24, H 5.66, S 0.53, Cl 0.05, N 0.77, readily volatile substances – 38; moisture – 2.78 %. Readily volatile substances include methane (80–90 %), ethane (8–12 %), propane-butane (1.8–4 %) and other gases (0.2–1 %).

Relying on this information, we may call coal a hydrocarbon compound with a low hydrogen content. Coal is usually characterized by an average hydrocarbon molecule [7] $C_{96}H_{72}$, containing hydrogen in the amount of approximately 5.66 wt. %. The structure of this molecule describes schematically a large number of condensed and non-condensed benzene rings bound with each other by methyl, nitrogenous, sulphurous and other heteroatomic bridges (Fig. 1).

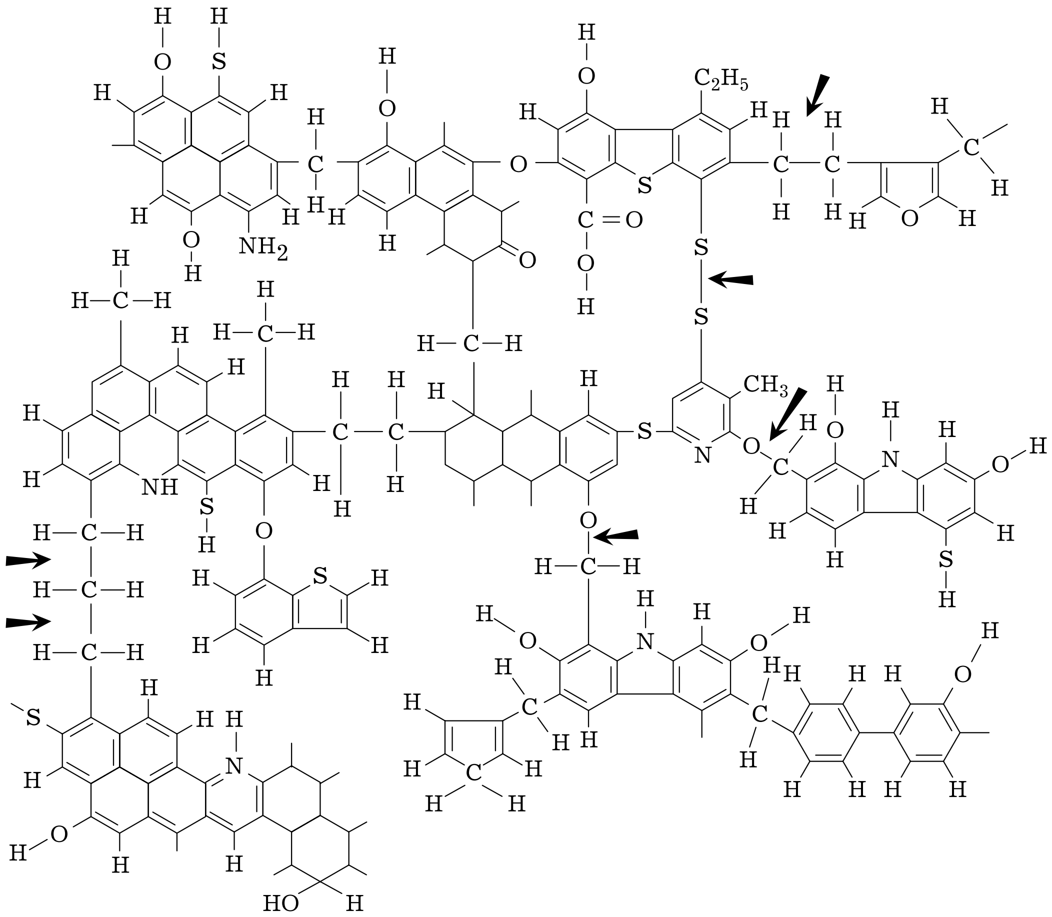

Fig. 1. Coal structure [7].

This structure of coal is formed due to carbon-carbon (C–C), carbon-hydrogen (C–H), carbon-sulphur (C–S), carbon-nitrogen (C–N), carbon-oxygen (C–O) and other carbon-heteroatomic bonds.

ROUTES FOR ECONOMY DECARBONIZATION

It is evident that the technological and economic aspects of civilization development would not allow us to completely reject carbon-containing energy sources at present and in the foreseeable future. We would rather speak of carbon neutrality. However, unlike for most of definitions of carbon neutrality implying complete rejection of carbon emissions, we suppose that carbon dioxide (CO_2) is an essential component of the atmospheric air, favourable for photosynthesis and the formation of biosphere. So, it is necessary to speak not of complete rejection of carbon dioxide emission but of achieving a balance between CO_2 emission and its absorption. It is reasonable to term this balance as carbon neutrality. In this context, in our opinion, there are two promising directions [8]:

1) Development of the promising technologies of combustion for traditional sources of energy (coal, oil, gas) aimed at maximal possible decrease in GG emissions. These technologies of energy generation can be used in the social and economic development of countries during the transition to improved technologies based on alternative energy sources.

2) Inventory accounting and development of natural and artificial reservoirs for CO_2 in order to achieve a balance between its emission and absorption.

In other words, as a compromise, it is possible to consider obligations of countries to reduce CO_2 emissions to a level corresponding to the carbon capacity of a territory. Then the goal of the Climatic Agreement to hold global warming at a level of 1.5 °C would be quite achievable. In the context of the above, according to the general world trend to decrease the emission of carbon-containing harmful emissions, a relevant problem is transition to alternative technologies.

Modern limitations of fuel resources and restrictions concerning environmental pollution have directed research programmes all over the world to the introduction of new methods and procedures that not only provide reasonable fuel consumption but also maintain the low level of emissions from various facilities in which combustion occurs.

In Kazakhstan, possessing enormous coal resources, energy production at coal-fueled power plants accounts for 84 % of the whole amount of energy. Because of this, analysis of developments aimed at the use of water-coal fuel (WCF) was carried out. The world's coal resources are several times higher than the resources of other kinds of fuel. According to estimates, coal resources will be sufficient for 200–250 years. This is a substantial time interval, especially if we keep in mind that resources of oil and gas are to be exhausted much earlier. Most coal is used at electric power stations producing almost 40 % of the world's electric power, and its major consumers are electric power engineering and metallurgy.

The world leader in coal production is China, where more than 3.7 billion t of coal had been mined in 2014. The second place in the world in the amount of coal production is occupied by the USA, where 916.2 million t of coal had been produced in 2014, India is at the third place (668.4 million t), Australia at the fourth (491.2 million t), Indonesia at the fifth (470.8 million t). In Russia, occupying the sixth place in the world in coal mining, and possessing 5.5 % of the world's coal resources (about 200 billion t), 4.4 % of the world's amount of mined coal had been produced in 2014. In 2015, 373.3 million t had been mined in Russia [9–11].

Evaluations of the kinds of energy-generating fuel used in Russian power engineering show that the mass of pollutants formed in combustion of 1 t of conventional fuel (t.c.f.) in the gaseous state is about 5 kg/t.c.f., while combustion of 1 t.c.f. of liquid fuel and coal gives 60 times more, about 3000 kg/t.c.f. So, the listed data show that a substantial negative environmental effect is caused by power plants fueled with coal and fuel-oil residues, which are mainly used to generate electricity.

VACUUM-WAVE HYDROCONVERSION OF COAL INTO LIQUID LOW-CARBON FUEL

It is proposed to use low-temperature (not higher than 75 °C) vacuum-wave hydroconversion of energy coal into liquid low-carbon energy fuel under the effect of high-intensity magnetic and electric field using so-called electrohydraulic effect (EHE) proposed by L. A. Yutkin [12]. We introduced substantial changes into the known electric circuits of EHE production and into new circuits that have found broad industrial application, and supplemented them with new effects accompanying EHE [13].

The technological line of low-temperature (not higher than 75 °C) vacuum-wave hydroconversion of the organic mass of coal into hydrogenated coal fuel (HCF) is depicted by a flowchart composed of three main and two auxiliary groups of equipment and fittings [1]. The first group consists of combined mechanical mills and electrohydraulic impact grinders equipped with their own electrical power supply units of two types: high voltage source (HVS) and high current source (HCS). Both types of sources have low power (not more than 4 kW) and are fed by relatively small electric power (up to 1 kW · h). This group, with the productivity of 50 m^3/h, consumes electric energy 120 kW · h or 2.4 kW · h per 1 m^3 of processed coal rocks. The group includes a set-up for rough grinding to crush pieces up to 300 mm in size (granulometric size of commercial coal) into particles with the maximal size up to 3 mm; medium-size milling device to grind the particles up to 3 mm in size into particles with the maximal size 0.3 mm (300 μm); an installation (without the mechanical milling part) for fine milling to grind the particles to the size not larger than 0.2 mm (200 nm).

In the first installation (Fig. 2), the time of loading, processing and discharging is 5–6 min, that is, 10 to 12 times per 1 h. Therefore, total productivity with respect to the water – coal mixture with additives is 50–60 m^3/h. In each cycle, treatment time is 3–4 min. Power consumption by the electric motor of the set-up is 45 kW · h, its rotation frequency is 900–1450 r.p.m.; the charging band-type conveyor consumes 10 kW · h and has 300 r.p.m.; a booster reagent pump – 5 kW · h and 900 r.p.m.; the HVS and HCS units together use up to 2 kW · h. Therefore, the electric energy consumed by the first installation is 62 kW · h, and it processes 40 to 48 m^3 of coal during 1 h.

The process takes place in a special vortex-type mixer incorporated into the third group

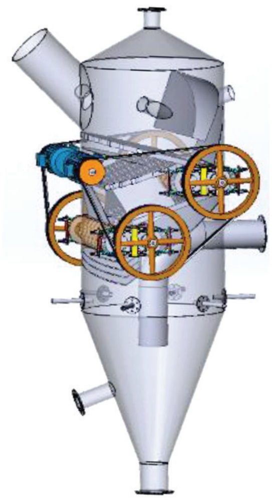

Fig. 2. Mill reactor [1].

of equipment. The group is named a complex of hydrocarbon upgrading (CHU), and its productivity is 50 m^3/h. Total energy consumption by CHU does not exceed 150 kW · h.

The complex of hydrocarbon upgrading produces ecologically safe (with a carbon content less than 45 %), high-caloric (43–45 MJ/kg) liquid hydrogenated coal fuel (HCF). Its fractional composition is close to standard fuel, namely dark household one (Table 1).

It follows from Table 1 that HCF corresponds to stove fuel (diesel fuel) in all parameters [14]. The only difference is low HCF flash point in a closed cup. However, this parameter is not objectionable, and we developed special burning devices for HCF.

TECHNOLOGY OF BURNING THE SOLID FUEL IN THE FORM OF WATER-COAL SUSPENSION

Water-coal suspension (WCF) is a liquid fuel obtained by mixing pulverized coal, water and a plasticizer. This fuel is used at heat-generating objects mainly as an alternative to natural gas and fuel oil, which allows substantial reduction on expenses for the production of thermal and electric energy. To prepare WCF, low-caloric and lean coal is used, as well as wastes from coal concentrating, and various fuel compositions, such as water-peat-coal, water-oil-coal, etc. Investigations showed that the presence of coal nanoparticles in the mixture had a positive effect on the combustion of coal-water mixture.

Drip-flare burning is currently the main method of WCF combustion, especially in small- and medium-productivity boilers [15]. A simplified scheme of the installation for WCF combustion is shown in Fig. 3. Water-coal fuel is supplied to the installation in the form ready for use [7].

Rather high requirements to the burning device (injector device) may be related to shortcomings of the technology of WCF combustion. At the early stages of WCF application, high abrasive wear of the injector devices took place [9]. For example, at the Novosibirsk Heat and Power Plant No. 5 the first injectors served for not more than 40 h. Definite limitations of WCF applicability are connected with its trend to get layered within 1–2 days, which requires special plasticizing additives. Since the process of WCF combustion is very unstable, there is a necessity to develop a special geometry of boilers and a special arrange-

TABLE 1

Characteristics of hydrogenated coal fuel [1]

Parameter, units	RD* for test methods	Standardized value	Actual value
Chilling points, °C, not higher, since the 1st of April till the 1st of September	GOST 20287-91	−5.0	−8.0
Flash point determined in a closed cup, °C , not lower than	GOST 6356-75	40	32
Density at 20 °C, kg/m^{33}	GOST 3900-85	Not standartized	871
Mass fraction of sulphur, %, not more than	GOST 19121-73	0.2	0.14
Kinematic viscosity at 20 °C, mm^2/s, not more than	GOST 33-2000	8.0	4.8
Content of mechanical impurities, %	GOST 6370-83	Absence	0.026
Water content, %	GOST 2477-65	Marks	Marks
Fractional composition:			
10 % distilled at a temperature, °C, not lower than	GOST 2177-99	150	158
90 % distilled at a temperature, °C, not lower than	GOST 2177-99	360	343

* Reference document.

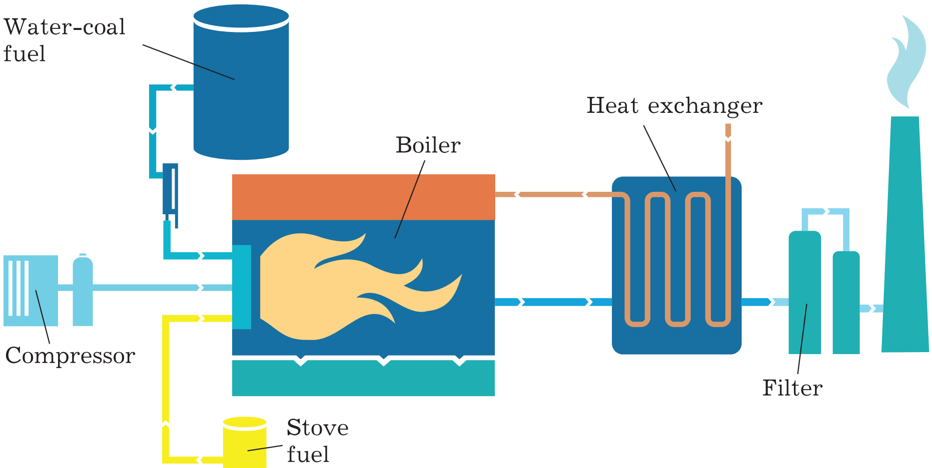

Fig. 3. Typical circuit of a boiler for the combustion of water-coal fuel.

ment of the sites of fuel and air supply in order to provide circulation of hot combustible gases in the ignition zone. One of the major instruments for the optimization of boiler design is the use of numerical methods allowing investigation of aerodynamics, heat and mass exchange processes, and WCF burning in the combustion chamber.

The introduction of water into fuel has two major effects: 1) physical action as a regulator of fuel sputtering, enhancing the mode of preliminary fuel mixing; 2) chemical action as a result of thermal dissociation of water at high temperature into active radicals – hydroxyl (OH) and hydrogen atom (H), and these radicals accelerate oxidation of the products of incomplete combustion, such as solid particles, hydrocarbons (C_nH_m), and CO [16]. Moreover, the interaction of carbon black and hydrocarbons with water vapour leads to the formation of molecular hydrogen (H_2) [16]. In this case, a global positive ecological effect is observed; a decrease in the local temperature (due to energy loss for water evaporation) causes a substantial decrease in NO_x, while the existence of active radicals causes oxidation of CO and carbon black. So, the use of water in fuel has a favourable effect on the ratio carbon black/NO_x.

CONCLUSION

The problem of keeping energy-generating (high-ash) coal, the raw material present in enormous natural resources, as an available and cheap energy carrier for economy and population, and the solution of this problem by means of the transition to ecologically safe, high-caloric, low-carbon fuel (HCF), comprise the basis for the formation of state programme for the development of power engineering in Kazakhstan in the “green” mode.

It should be stressed that an analogue of the fuel developed by the authors exists in Russia. It is called “Hydrogenated energy fuel” of TGE-40 grade, where number 40 means the volume fraction of ionized water added to the fuel (40 %), while hydrocarbon content is 60 %. For this reason, a new, more informative name was adopted to the term low-carbon fuel: “Hydrogenated coal fuel” (HCF), which stresses its origin from coal.

We chose regional boiler stations in Kazakhstan, RK-2 and RK-2 (Kokshetau) and HPP-1 (Stepnogorsk) in which upgrading for the use of HCF is planned.

It is shown that during a possible fuel crisis, coal-water mixtures may play noticeable role as an available, ecologically safe efficient fuel, thus promoting solution to the indicated problems.

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