Impact of conditions of coal supply to hard-to-reach northern areas on its useful properties

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Abstract. Hard-to-reach northern areas of Russia are supplied with coal via complex and extended delivery chains. Long-term storage and large haulage distances between the coal production sites and the heat power generation points result in degradation of useful properties of coal and its high quantitative losses. The authors discuss the causes of change in the fuel quality as it travels from production faces to boiler-houses, as the consequences of lower quality fuel burning. The current approaches to alteration of coal properties are reviewed. The influence of oxidation and cryogenic effects is analyzed. Assuming the delivery chains as the integrated systems in blocks and their performance evaluation by the final result allows disengaging new reserves in quality management. An element of the refreshed quality management can be technological and managerial procedures in open pit coal mining and in pre-treatment of coal before shipment.

1. Introduction

Coal remains a major fuel and energy source in the residential sector in the hard-to-reach areas in Russian Far East, in Siberia and European North. These areas feature low density of population, patchy territorial development, deficient infrastructure and limited size of consumption of both local and non-local imported coal.

The Arctic development program 2014 declares the right of any person regardless the place of living to high-quality power supply and power security. Difficult haulage of coal to hard-to-reach areas, for instance, the extreme north in Yakutia, complicates transportation. The aggravating factors include: large producer–consumer distances (2 – 3 thousand kilometers and more), and long delivery period (2–2.5 years); limited or uncoordinated shipment by water or by trucks; low consumption of fuel per communities (5–50 kt); multiple rehandling; high fuel loss; elevated delivery cost, which leads to higher coal price [1, 2]. Coal delivery chains yet hold many disbenefits of the past. Supplies are non-uniform, with periodic failures and force majeure. Expenditures connected with purchasing and delivery of fuel and energy resources, power generation and distribution continuously grow. Comparatively inexpensive local coal, including high grades, is scarcely used. Delivery chains feature high losses. There is a trend of decreasing consumption of solid fuel with its degradation [3].

Russia’s energy security doctrine 2019 sets quite definite landmarks for the remote territories with isolated electricity systems: re-equipment, cost saving and gain in productivity; reduction of inconsistent development of industries and activities in the fuel sector; expansion of mineral mining in
remote areas; enhanced efficiency of use of energy resources; well-balanced spatial and regional development of local sources and power supply and generation using local resources.

2. Coal mining and shipment chains
The analysis of coal delivery to out-of-the-way places exhibits the main modes of transportation by water (rivers and seas) and by trucks. These modes are seasonal: delivery by water lasts for a short warm season, and trucks are used in cold weather period (winter roads). Various length and complexity chains can be straight, from a face to a boing houses, or multi-branch, with numerous points of rehandling and open-air storage of coal (Figure 1).

![Figure 1. Process flow charts of coal mining and shipment, and power generation in hard-to-reach northern areas.](image-url)
The end points of the chains are mostly boiler houses and furnaces which feature low-efficient fuel-bed firing technologies. Low fuel consumption, long-lasting deficiency of finance, shortage of personnel and fixated thinking disable application of better and more effective technologies: pulverized coal combustion; heat and power co-generation; combustion of deeper conversion products of coal dressing, briquetting, pyrolysis and gasification.

In the existing institutional environment, any breakthrough in this respect is unlikely to be expected. Thus, we have to focus on assets implementable at relatively low investment. For instance, it is possible to improve the coal product quality. The integrated coal quality control can ensure maximized consistency of the existing and advanced equipment specifications and useful qualities of fuel in terms of fuel designation, uniformity, persistence and safety.

Toward successful solution of the problem, the system of regional use of fuel and energy resources should be addressed in block. Open pit coal mines and boiler houses should be not individual and independent economic agents but basic components in delivery chains. In integrated operation of all participants, the estimate criterion should not the amounts of coal produced, shipped and burnt, but the amount of heat and power consumed and paid-up at high level of energy preparedness [4]. The relevance of this approach is higher in eastern Russia where the efficiency of fuel and energy at heat power station and boiler-houses of final consumption is lower by 2.6–5.5% than the average figure across Russia [5].

It is important in this regard to comprehend the nature and conditions of change in properties of coal as it moves from a mine to a consumer. An ample review of theoretical studies and in-situ observation data has disclosed a whole set of changes in ROM coal and identified critical areas to be treated carefully in coal supply planning and management (Figure 2). While understanding the complex mechanism of coal quality transformation, we should emphasize that the discussed pattern can vary and should be amended.

| Coal quality factors                        | Deposit | Open pit mine | Warehouses at OPM | Transport | Warehouses at ports and boiler houses |
|--------------------------------------------|---------|----------------|-------------------|-----------|--------------------------------------|
| Ash content, A %                           |         |                |                   |           |                                      |
| Moisture content, W %                      |         |                |                   |           |                                      |
| Combustion heat Q, MJ/kg                   |         |                |                   |           |                                      |
| Particle size composition                  |         |                |                   |           |                                      |
| Impurity with dirt and foreign matter     |         |                |                   |           |                                      |
| Oxidation                                  |         |                |                   |           |                                      |

Figure 2. Influence of coal supply chains on coal qualities: [ ]—strong influence; [ ]—moderate influence.

Within the supply chains, when coal travel from a production face to a boiler-house, coal undergoes oxidation of different complexity and intensity. We are going to discuss this issue in more detail.

Oxidation of coal in a pile changes grain size composition, bulk density, moisture content, sieve fraction composition, combustion heat, etc. Volatile yield is lower in lower rank coal and is higher in higher rank coal [6]. When oxidation period of coal extends, coal loses weight, which is connected with emission of carbon dioxide and water vapor in higher amount than the amount of absorbed oxygen. Because of different coal sensitivity to oxidation, some types of coal grow in weight by 8.5–10.6%, while the other keep their weight unchanged. The change in the fractional makeup can be unrelated to oxidation. As a consequence of non-uniform drying of wet coal, particles diminish in...
volume and the arising internal stresses promote disintegration of particles [7]. Oxidation process includes three stages: initial oxidation (adsorption of oxygen from air); high-rate oxidation (long-term exposure of coal to oxygen, with chemical reactions and with coal–oxygen association); saturation (considerable deceleration of oxidation). The oxidation velocity is different initially in coal of different ranks, and grows with increasing volatile yield [8].

The analysis of alteration of coal in oxidation on open-air stock-piles shows the nonlinearity and two stages of the process. The first stage is the temperature elevation at the rate correlated with the coal rank represented by volatile yield. The rates of reaching transition points between stages in summer and in winter are different in different rank coal. These rates are almost independent of the coal ranks in winter. The extremums in the range of medium-rank coal (Vdaf 27.3–30.5 %) are reflective of different mechanisms of oxidation in different rank coal [9, 10].

When coal is stored in piles for the whole year, its operational combustion heat Q drops [11]. In black coal and lignite with high volatile yield, oxidation of ROM coal with fine fractions intensifies as air contact area expands [12]. Lower rank coal experiences loss of strength and moisture, which degrades the coal qualities [13]. In short-term storage, standard analyses show unaltered qualities of coal, while more accurate studies exhibit continuity of oxidation processes on coal surface. The case-study of Kuzbass coal shows that after storage of coal samples for 30 days, ‘active’ oxygen-bearing groups reduce in number while ‘inactive’ oxygen grows [14].

The regions discussed in this paper are mostly situated in the permafrost zone, which can have influence of alteration of coal quality both during production and storage. Ice-bearing permafrost rock features, with few exceptions, low air permeability, heat and mass exchange, and oxidation rates [15]. Cryogenic disintegration of coal during its storage and shipment, alteration of thermal stresses, oxidation, as well as wedging effect of water and ice under negative temperatures and multiple phase transitions modify composition, structure, texture and properties of the fuel. Even in case of short-term cryogenic disintegration, lignite (in a greater degree) and black coal are incapable to stand cyclic freeze-and-thaw [16].

In-situ observations were carried out in Yakutia, at open pit mines Kangalass, Dzhebariki-Khaya, Kirovsky, Kharbalakh and Kempendyai, and at open-air warehouses of coal (at open pits, in-between, coastal, at boiler-houses and heat-and-power stations) involved in delivery chains of coal to the remote areas of the region. Coal is produced in Yakutia from permafrost and mainly in the coal season. Coal consumption is strongly seasonal. Warehouses accumulate large amounts of fuel to be quickly shipped to remote consumer within a very short shipping season and a limited period when winter roads are serviceable. All coal is shipped as run-of-mine, even in case of a crushing-and-blending plant is available. Warehouses are situated at natural or manmade sites which required minimized preparation. In winter, coal experiences no noticeable alteration.

In warm seasons, particle size composition of coal changes: large and average size particles disintegrate and very many fine sizes appear. This is typical of surface layers in the piles of the first phase storage (at open pits), of the whole volume in the piles remoted from the mining sites. The main cause is the loss of internal and external moisture, and oxidation of lower rank coal (Russian grades D, B3 and B2). Yakutian mines have no quality control services, no monitoring of coal properties is performed, and qualitative estimation of coal alteration is thus very complicated.

Additional knowledge on the mechanisms of transformation of coal qualities in the long production–consumption cycles can be obtained via special-purpose research. It also expedient to implement: lab-scale and full-scale testing of coal properties in long-term storage under positive, negative and alternating temperatures; physical simulation and mathematical modeling of coal storage in open air and in buried warehouses; selection (creation) of coal oxidation ability techniques; development of prediction procedure for qualitative and quantitative transformations in coal of different grades in the shipment chains to remote consumers; feasibility study of improvement and arrangement of supply chains in hard-to-reach and energy-isolated areas, etc.

New information and data can substantiate technologies and management activities [1–3] in improvement of coal supplies, including: re-appraisal of proven reserves with their mapping as per
consumer requirements; mine planning in the mode of end-to-end quality control; pre-treatment of coal at open pit mines (blending; bagging of ROM and blended coal, dry cleaning, briquetting, gasification), launching of small-size open pit mining of coal in closer vicinity of the consumers.

3. Conclusions

The complex and long chains of coal mining–haulage–storage–combustion in supplies to hard-to-reach northern areas call for improvement. It may be effective to introduce the end-to-end coal control based on the coordinated and agreed criteria in order that boiler-housing fuel has high useful qualities, with regard to geological potentials of coal fields, technological capabilities of the supply chain participants and high energy preparedness.

Furthermore, it is necessary to account for all actual and currently unrated qualitative losses inevitable in the long-term delivery cycles and connected with segregation and blending, grain size composition changes, impurity of coal with dirt and foreign matter, as well as with physiochemical and cryogenic weathering. For the correct economic evaluation of expediency of certain technological and managerial operations within the chains of coal supply to consumers, it is required to implement additional research, in particular, lab-scale and full-scale testing of change in coal properties in long-terms storage under positive, negative and alternating temperatures, as well as modeling coal storage in open air and in buried warehouses.

References

[1] Gavrilov VL, Tkach SM, Batugina NS and Fedorov VI 2014 Geotechnological aspects of coal mining in the arctic region in Yakutia J. Fundament Appl. Min. Sci. Vol 1 pp 79–85
[2] Gavrilov V and Fedorov V Process chains in the development of remote deposits of the North E3S Web of Conferences Conf. 56, 04014 (2018). VII International Scientific Conference Problems of Complex Development of Georesources (PCDG 2018) DOI: https://doi.org/10.1051/econf/20185604014
[3] Batugina NS, Gavrilov VL and Shepeleva EG 2017 Small-scale coal mine in polar regions of Yakutia: State and prospects J. ECO Vol 2 pp 134–145
[4] Gavrilov VL and Fedorov VI 2019 Mining company as an effective element in coal supply to the regions of the Far North IOP Conf. Series: Earth and Environmental Science 262 012018, doi:10.1088/1755-1315/262/1/012018
[5] Saneev BG, Sokolov AD, Muzychuk SYu and Muzychuk RI 2016 Energy-economic analysis of the existing state of the regional fuel and energy complexes of Eastern Russia Energetich. Politika No 5 pp 14–22
[6] Desna NA and Miroshnichenko DV 2015 Use of oxidized coals in coking (review) Koks i khimiya No 5 pp 2–9
[7] Goryushinsky VS, Gubarev MP and Shulepov VV 2008 Improvement of loading and unloading, transport and storage operations with solid fuel at coal yards Vestn. Transport. Povolzhya No 3 pp 40–46
[8] Miroshnichenko D, Drozdnik ID, Kaftan YuS, Ivanova EV and Desna N 2012 Investigation of the kinetic characteristics of coal oxidation Koks i khimiya No 3 pp 6–15
[9] Miroshnichenko DV, Desna NA and Kaftan YuS 2014 Oxidation of coal in industrial conditions. Report 2: Changes in the plastic-viscous properties of coal during oxidation Koks i khimiya No 10 pp 2–8
[10] Miroshnichenko DV, Desna NA and Kaftan YuS 2015 Oxidation of coal in industrial conditions. Report 4: Coal temperature in the stack Koks i khimiya No 2 pp 2–8
[11] Ravich MB 1977 Fuel Efficiency Moscow: Nauka (in Russian)
[12] Roddatis KF and Poltaretzky AN 1989 Reference Book on Low Efficiency Boiler Installations Moscow: Energoatomshshat (in Russian)
[13] Petrova GI, Bychev MI, Moskalenko TV and Mikheev VA 2011 Briquetting brown coal from the Kirov field with peat Mining Informational and Analytical Bulletin—GIAB Special Issue 10
[14] Fedorova NI, Patrakov YuF and Berveno VP 2010 Changing physicochemical properties of coals under mechanical effects *Vestnik KuzGTU* No 6 pp 137–140

[15] Shesternev DM 2017 Physical and chemical weathering of rock mass in permafrost *Mining Informational and Analytical Bulletin—GIAB* No 3 pp 350–360

[16] Shkuratnik VL, Novikov EA and Oshkin RO 2016 Effect of the cryogenic disintegration processes on the characteristic features of the thermally stimulated acoustic emission in different types of coal *Mining Informational and Analytical Bulletin—GIAB* No 10 pp 368–376