Oil Shale, 2020, Vol. 37, No. 4, pp. 269–280
doi: https://doi.org/10.3176/oil.2020.4.01 ISSN 0208-189X

Prospectivity analysis of oil shales in Kazakhstan

Sergei Sabanov*, Zarina Mukhamedyarova

School of Mining and Geosciences, Nazarbayev University, 53 Kabanbay Batyr Ave., Nur-Sultan city, Republic of Kazakhstan

Abstract. *Oil shales in Kazakhstan have been studied, to some degree, but have not reached the operational stage. The aim of this study is to conduct a prospectivity analysis of oil shales in Kazakhstan. For this, data on oil shales from over 12 deposits located in the country are used. Based on the analysis, relationships between the ash content and calorific value, as well as oil content and calorific value of oil shales were determined. Prospectivity analysis criteria taking into account the type and quality of oil shales, and mineable reserve tonnages and depth of excavation are proposed. The results of this study may be useful for the estimation of the quality characteristics of oil shales in order to consider their utilization area.*

Keywords: *Kazakhstan oil shales, oil content, ash, calorific value.*

1. Introduction

More than 550 of the known oil shale deposits worldwide are distributed in over 50 countries. According to Knaus et al. [1], oil shale is formed from organic material, which may have different origins. By organic material origin, oil shales are usually categorized into three major types: terrestrial, lacustrine and marine. Marine oil shales (e.g., kukersite, tasmanite, marinate), which are more often used in industry, are derived from salt water algae, acritarchs and dinoflagellates [1]. The kukersite formation is located in Estonia and has been developing over the last hundred years.

Raukas and Punning [2] stated that oil shales are defined as sedimentary rocks containing 10–75% organic matter (OM). Organic matter is characterized by its elemental composition. An important indicator of oil content in organic matter is the ratio of hydrogen to carbon, H/C [3]. Oil yield is dependent not only on H/C but also on the initial material of OM and its degree of decomposition. The mineral part of oil shales may consist of either terrigenous material or carbonates, or both. The terrigenous material is mainly composed of clay

* Corresponding author: e-mail *sergei.sabanov@nu.edu.kz*

and is supplemented by quartz and feldspars. Carbonates are represented by calcium carbonate (calcite) and, in some cases, dolomite [1–4].

Oil shale deposits are located at various depths and have productive seams of differing thicknesses. Oil shale can be developed by either open or underground mining method, or unconventional in situ retorting technology. The prospects for development of an oil shale deposit can be estimated by taking into consideration its geographical location, deposit type, depth, structural features, thickness, and seam orientation [5]. The aim of this study is to carry out a prospectivity analysis of oil shales in Kazakhstan. For this purpose, data on oil shales from over 12 deposits located in Kazakhstan are used. Prospectivity analysis criteria based on the type and quality of oil shales, and mineable reserve tonnages and depth of deposits are proposed. The results of the study may be useful in the estimation of the quality characteristics of oil shales in order to consider their utilization area.

2. Oil shales in Kazakhstan

The oil shale deposits in Kazakhstan were explored in the early 1960s and have been found to be related to the Upper Devonian, Lower Carboniferous, Upper Palaeozoic, Medium and Upper Jurassic, and Palaeogene formations. The most well-recognized oil shale formations are the Kendyrlyk (eastern Kazakhstan) and Baikhozhinskoe (southern Kazakhstan) deposits, as well as the Ural group of deposits (the western part of Kazakhstan), which have been associated with the Turgayskiy lignite basin and the Karatobe oil shale formation. The Turgayskiy formation comprises the Kushmurun and Chernigovskoye oil shale deposits, while the Karatobe formation contains the Algabas, Cherniy Zaton and Tuksay oil shale deposits. Moreover, some of the oil shale deposits occur in conjunction with coal formations, such as the Shubarkol deposit located in the Karaganda region [6].

The Kendyrlyk oil shale deposit is located in the eastern part of Kazakhstan, near the city Ust-Kamenogorsk. The deposit consists of four seams: Kalyn-Kara, Luchshiy, Karaungur and Saikan. The Luchshiy seam is 0.9–1.2 m thick and oil shale oil content is 4.6–6.5%. The yields of kerogen oil fractions are the following: gasoline fraction 25%, diesel 36% and ligroin 10%. The Kendyrlyk deposit contains about 175 million tonnes of oil shale at an average depth of 260 m [6–13]. The properties of oil shale in the deposit seams of Luchshiy, Kalyn-Kara, Karaungur and Saikan are presented in Table 1 [6–13].

The Kushmurun deposit of the Turgayskiy formation is composed of alternating layers of sandstone, siltstone, mudstone, coal and oil shale. The properties of Kushmurun oil shale are given in Table 2 [6].

Table 1. Properties of oil shale in the Kendyrlyk deposit seams

Characteristic \ Seam	Luchshiy	Kalyn-Kara	Karaungur	Saikan
Moisture, %	4.0	3.4	1.0	2.9
Ash, %	71.0	51.6	76.4	77.2
Sulphur, %	1.0	1.0	1.4	0.5
Carbon, %	75.0	72.0	75.6	70.6
Hydrogen, %	8.2	7.9	10.7	9.8
Nitrogen, %	0.1	1.8	2.3	3.5
Oxygen, %	15.0	17.3	10.1	15.6
Oil, %	16.2	9.7	13.6	5.6
Calorific value, kcal/kg	1430			

Table 2. Properties of Kushmurun oil shale

Characteristic	Value
Moisture, %	7.0
Ash, %	58.0
Sulphur, %	2.6
Volatiles, %	66.0
Carbon, %	66.0
Hydrogen, %	7.2
Calorific value, kcal/kg	1852

The Kushmurun deposit contains approximately 73 million tonnes of oil shale at an approximate depth of 300 m. The Chernigovskoye deposit is located in the Semiozerniy district of the Kustanai region. The main properties of its oil shale are listed in Table 3 [6].

The Chernigovskoye deposit is confined to a narrow and long downwarp extending in the northeast direction. The length of the downwarp is 20 km, with a width of 1–2 km and depth of about 100 m. The total thickness of the oil shale layers is about 23 m. The Chernigovskoye deposit has been estimated to contain about 48 million tonnes of oil shale [6].

The Algabas deposit in the Karatobe formation consists of brown shales, which are usually calcareous, slabby, and of high calorific value (1900–3250 kcal/kg), with an ash content of 33–73%, a high content of volatile matter substances (42–75%), and an oil content up to 23%. Its oil shale amount has been estimated at 5.6 million tonnes [14].

Table 3. Properties of Chernigovskoye oil shale

Characteristic	Value
Moisture, %	6.0
Ash, %	56.0
Sulphur, %	0.4
Volatiles, %	64.0
Carbon, %	63.6
Hydrogen, %	6.7
N + O, %	29.6

The shale-bearing stratum of the Tuksay deposit consists of six formations. The main oil shale seam has a thickness of 1.05–2.0 m at a depth of 25 m. Along the strike, the shale seams are traceable up to 5 km, with the width varying from 65 to 600 m. The average ash content reaches 50.19%, and the average calorific value is 2625 kcal/kg. The amount of oil shale in the deposit has been estimated at about 5 million tonnes [14].

Located at a depth of 30 m, the oil shale seam in the Cherniy Zaton deposit is 2.0–2.9 m thick. Oil shale contains 24.6% oil, 7.5% moisture, 52.86% ash, 37.44% volatiles and 62.19% semicoke. Its amount has been estimated to reach 0.412 million tonnes. The main properties of Cherniy Zaton oil shale are presented in Table 4 [14].

Table 4. Properties of Cherniy Zaton oil shale

Characteristic	Value
Carbon, %	66.2
Hydrogen, %	5.1
Nitrogen, %	0.7
Oxygen, %	19.1
Sulphur, %	8.9
Calorific value, kcal/kg	3404

Figure 1 shows the Fisher assay results for Tuksay oil shale at a temperature of 500 °C [14]. From this oil shale, 14.2% oil, 14.9% pyrolytic water, 54.9% semicoke and 16% gases and losses were produced.

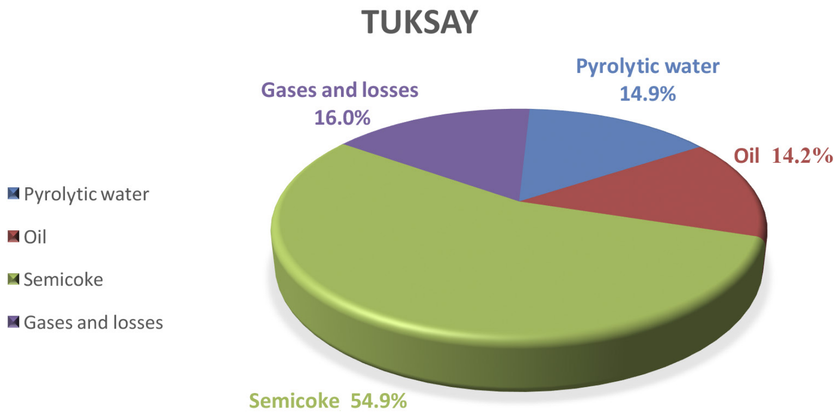

Fig. 1. Fisher assay results for Tuksay oil shale.

The mineral part of Tuksay oil shale has been shown to contain the chemical elements S_t (1.3%), Mn (0.014%), Ni (0.008%), Pb (0.004%) and Cu (0.001%), and compounds SiO_2 (50.6%), Al_2O_3 (20.4%), CaO (11.8%), Fe_2O_3 (5.7%), MgO (2.9%) and V_2O_5 (0.01%) [14].

In the Shubarkol deposit the oil shale bed, which is located at depths up to 150 m, varies in thickness from 1.10 to 7.65 m. This carbon-bearing claystone appears as a massive bed with insignificant or no specific structural features, varying in colour from yellow-white and greyish-brown to dark brown and black. Estimated by the USSR Governmental Committee of Natural Reserves in 1987, the Shubarkol deposit at a minimum seam thickness of 1 m contains 409 million tons of oil shale (off-balance, C2 category) with an average net calorific value of 7.2 MJ/kg (1720 kcal/kg) [14]. The average compressive strength of oil shale is 12.5 MPa at an average density of 1.9 t/m^3 [15, 16].

The properties of Shubarkol oil shale are presented in Table 5 [16].

Table 5. Properties of Shubarkol oil shale

Characteristic	Value
Moisture, %	3.1
Ash, %	67.1
Sulphur, %	1.2
Calorific value, kcal/kg	2030

Figure 2 shows the products obtained during the Shubarkol oil shale coking process (8 hours at a temperature of 900 °C) by Arbuzov et al. [16]. The oil shale afforded 5.7% oil, 9.8% pyrolytic water and 73.5% semicoke.

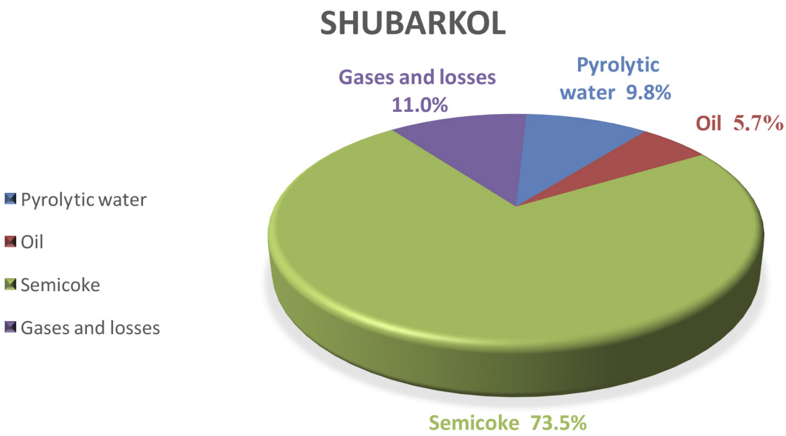

Fig. 2. Coking products of Shubarkol oil shale.

The mineral part of Shubarkol oil shale has been shown to contain SiO_2 (56.5%), Al_2O_3 (27.3%) and Fe_2O_3 (11%), and trace amounts of CaO. On the basis of these results the researchers concluded that the oil shale had potential for industrial use in Kazakhstan in terms of chemical and oil products [16].

3. Materials and methods

In order to characterize oil shales as industrial commodities, it is necessary to estimate their quality characteristics in accordance with their specific areas of utilization. However, this is related to the oil shale resource quantity and the presence of other competitive commodities. Thus, when deciding on the use of oil shales for production of electricity and heat, or fuel oil, one must take into account their quality indicators such as heat of combustion (kcal/kg or MJ/kg) and semicoking oil yield (%), respectively [17–19]. To characterize oil shales, parameters like conditional organic mass, ash, moisture, kerogen oil, pyrolytic water, gases, semicoke yield and the CO_2 content of carbonates, as well as the chemical composition of mineral part (e.g., SiO_2, Al_2O_3, Fe_2O_3, TiO_2, CaO, MgO, SO_3, K_2O, Na_2O, P_2O_5) and the elemental composition of kerogen oil (e.g., H, C, S, N, O, H/C) are typically used [17–19]. So far, based on parameters oil shales from over 100 deposits located in 27 countries have been analyzed [17]. Over the last hundred years Estonian Kukersite oil shale has been successfully used for the production of shale oil, electricity, heat, and chemical products [18, 19]. This can be explained by its good quality characteristics, on the basis of which a comparative analysis of other oil shales can be performed to estimate their prospectivity. For illustrative purposes, the average oil content of industrially used Kukersite is 23%, ash content is about 50% [20], conditional organic mass

36% and the calorific value about 2700 kcal [21].

Zelenin and Ozerov [7] proposed an industrial classification of oil shales, which represents a set of quality-based estimation criteria characterizing the industrial value of each type of oil shale. Ash and sulphur contents are key parameters for choosing the oil-refining technology.

In this study, it is proposed that oil shale deposits can be characterized by three prospectivity degrees: high, moderate or low, according to oil shale type and quality (Table 6). The prospectivity criteria also include the amount of mineable reserves and the required depth of excavation.

Table 6. Oil shale prospectivity criteria

Prospectivity	Type [7]	Type of quality [7]	Type of commercial mineral [7]	Mineable reserve
High	Sapropelic, 12.5 MJ/kg	Oil > 30% Ash 6% S_{TOTAL} 2%	Carbonate (CaO + MgO 20%) Aluminosilicate-carbonate (CaO + MgO: 10%–20%)	Millions, depth < 75 m
Moderate	Sapropelic-humus, 8.4–12.5MJ/kg	Oil 10–12% Ash 61–70% S_{TOTAL} 2–4%	Aluminosilicate-carbonate (CaO + MgO: >10%)	Tens of millions, depth < 150 m
Low	Humus-sapropelic, 6.3–8.4 MJ/kg	Oil < 10% Ash >70% S_{TOTAL} >4%	Silicate ($SiO_2 + Al_2O_3 > 70\%$)	Hundreds of millions, depth < 300 m

4. Results and discussion

Based on the data collected, oil shales of Kazakhstan are mostly of low prospectivity (Table 6), and a considerable amount of work will be required to make them commercially attractive. The case is opposite with moderate-prospectivity Estonian Kukersite oil shale which has been industrially used for over 100 years already.

The price of oil plays a significant role in oil shale resource estimation exercises for fuel projects. Of critical importance is also the amount of mineable reserves. In view of prospectivity criteria, oil shales located at a depth greater than 300 m and with an oil content of 5–10% are deemed to be unsuitable for development. Oil shales with an oil content less than 3% can be considered unsuitable as the current industrial processing technologies allow oil recovery only about 82%. However, to assure this, oil prices and mineable reserve tonnages must be taken into account. Figure 3 shows the conditional organic mass and oil content of oil shales in the different deposits of Kazakhstan. For comparison, the figure also indicates the same data on Estonian Kukersite oil shale, one tonne of which can give about 16% of shale oil.

Analysis reveals that the conditional organic mass quality and oil content of oil shales in the Cherniy Zaton and Algabas deposits are the highest. However, the oil shale amount in these deposits is scarce to render them economically viable. In this sense, the situation is better in the Kendyrlyk deposit whose oil shale amount is sufficient for development. Though, the greater depth of excavation in this deposit is of considerable concern when it comes to mining costs. At the same time, in terms of oil shale amount, the Shubarkol oil shale deposit may enjoy better prospects for development.

Relationships between the ash content and calorific value, as well as oil content and calorific value of oil shales were established (Fig. 4 and Fig. 5, respectively). From Figure 4 it can be seen that the calorific value decreases with increasing ash content. For comparison, data on Estonian Kukersite oil shale are also shown. A preliminary analysis demonstrates that some of the Kazakhstan oil shales studied have a potential for development.

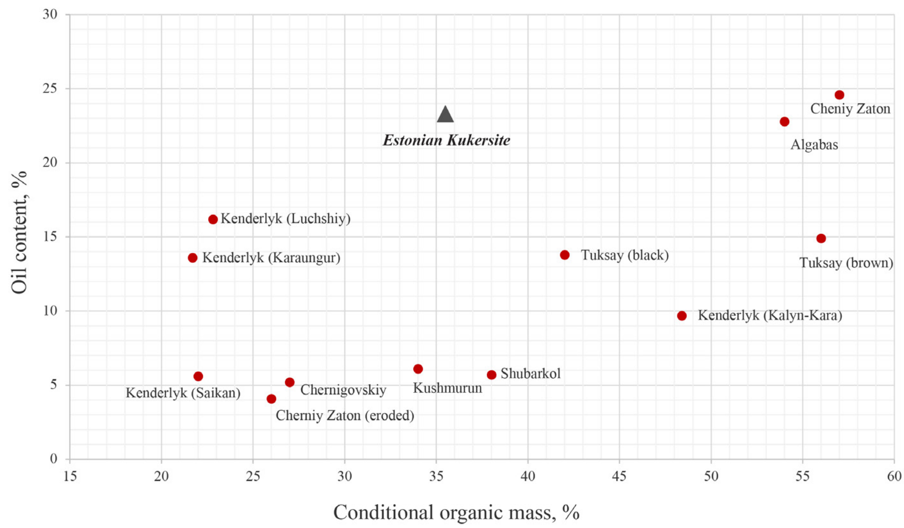

Fig. 3. Conditional organic mass and oil content of Kazakhstan oil shales compared to Estonian Kukersite.

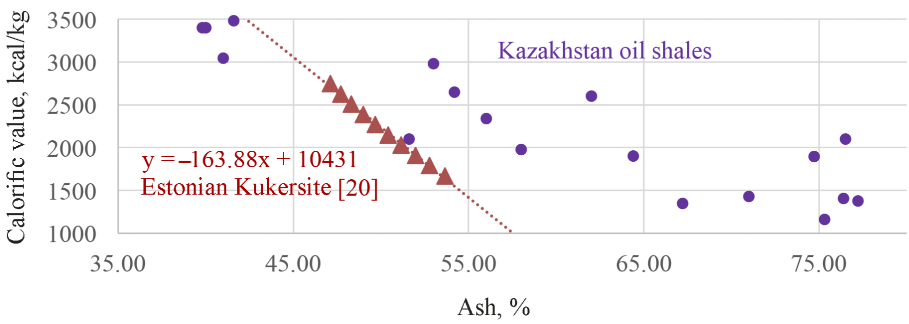

Fig. 4. Plot of the calorific value vs ash content of oil shales.

According to the prospectivity criteria (Table 6), oil shale with an ash content higher than 70% is considered low prospective. Figure 4 displays that despite their high ash content, over 70%, some oil shales have a calorific value high enough from the perspective of their industrial use. Figure 5 demonstrates that calorific value increases with oil content, while these values greatly differ between different oil shales. For comparison data on Estonian Kukersite are also shown.

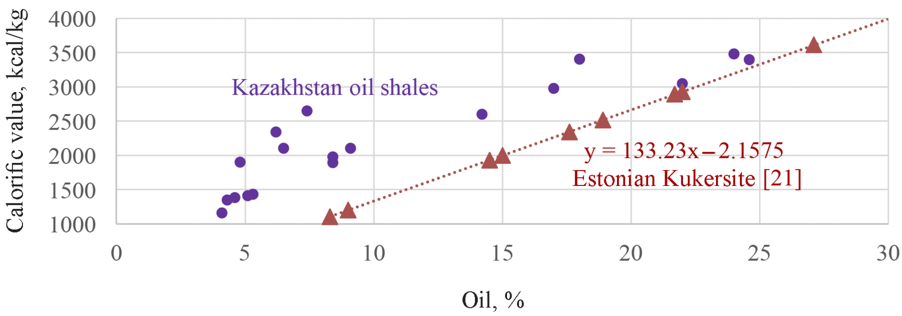

Fig. 5. Plot of the calorific value vs oil content of oil shales.

From Figure 5 it can be seen that the calorific value of Kazakhstan oil shales varies from 1160 to 3403 kcal/kg, the ash content range is 39.8–77.2% and the oil content between 4.3 and 24.6%. Some of the Kazakhstan oil shales are very similar to Estonian Kukersite in properties. The derived relationships can help characterize Kazakhstan oil shales for further exploration potential. In general, Kazakhstan oil shales may have potential for use in the power industry as at lower oil content their calorific values are higher, compared to Estonian Kukerite.

The results of this study may be useful for the estimation of the quality characteristics of oil shales, in order to consider their utilization area. Some oil shale deposits in Kazakhstan have good potential for development, however, their prospectivity needs to be re-evaluated in view of the most sophisticated extraction and processing technologies. Based on the results of this study, Kazakhstan oil shales having suitable organic content and adequate calorific value are fit for use in potential industrial projects. These prospectivity estimation results can serve as a basis for further feasibility studies of oil shale projects in Kazakhstan.

5. Conclusions

In this study, a prospectivity analysis of Kazakhstan oil shales was carried out. For this purpose, data on oil shales from over 12 deposits located in Kazakhstan were used. Conditional organic mass and oil content relationships were derived. Based on the analysis, relationships between the ash content and calorific value, as well as oil content and calorific value of oil shales were established. Oil shales in some deposits have a maximum oil content over 20% and calorific value over 3000 kcal/kg, which gives evidence of their good potential for development. However, this needs to be re-evaluated, taking into account the most sophisticated extraction and processing technologies.

The results of this study may be useful in the estimation of the quality characteristics of Kazakhstan oil shales, in order to consider their utilization area. The organic content and calorific value of the studied oil shales were found to be suitable for their use in potential industrial projects. These prospectivity estimation results can be taken advantage of in the further feasibility studies into oil shale projects in Kazakhstan.

Acknowledgments

This study was supported by Nazarbayev University Grant Programs: Research Grant #090118FD5337 and Collaborative Research Project #091019CRP2104.

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Presented by A. Siirde
Received February 07, 2020