KPU International Journal of Engineering & Technology
Volume 6, Issue 2, Sep. 2026
e-ISSN:2790-0819, p-ISSN:2790-0800

Date Received: 2025-12-07
Date Accepted: 2026-07-06
Date Published: 2026-09-30

Study of the Physical Characteristics of the Samples to Determine the Quality of the Coal Mine in the Doodkash of Pul-e-Khumri, Baghlan, Afghanistan

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Abstract

This research, titled "Study of the Physical Characteristics of Samples to Determine the Quality of the Coal Mine in the Doodkash of Pul-e-khumri," has been conducted. The main objective of this research is to study and evaluate the quality of coal in this region and to determine its potential for exploitation as an energy source. This research utilized library, field, and laboratory methods. Coal samples were collected from the Doodkash area, and each was analyzed using laboratory methods to assess quality. According to ASTM standards, the results of the analysis showed that this coal falls into the category of high-quality coal based on its physical and chemical characteristics. It is worth mentioning that the specific devices and analytical methods used in this research are as follows: 1- Determination of calorific value using a bomb calorimeter 2- Determination of ash content using a muffle furnace 3- Determination of volatile matter using a muffle furnace 4- Determination of moisture content using a drying oven.
Studies conducted show that the coals of the region have a heating value between 5658 to 6242 kilocalories, an ash content from 17.1 to 24.4 percent, a gas percentage from 25 to 26 percent, and moisture between 4.28 to 4.7 percent. These values indicate the good quality of the coal in the region, which is suitable for use in various industries.
Since the coal Doodkash is located in sedimentary rock layers including gravel stones, conglomerates, argillites, siltstones, and carbonatic-dolomitic rocks, it necessitates deeper studies for a better understanding of these resources and to facilitate their optimal exploitation. This research provides a foundation for future studies and the practical use of this valuable energy resource.

Keywords: Analysis, Bituminous, Exploration, Heating, Laboratory Method.

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https://doi.org/10.68924/33xtcj90

1. Introduction

Underground mines are considered one of the most important natural resources of any country and are recognized as a national asset and a key element of economic infrastructure. The vital role of these resources is particularly evident in countries whose economic growth depends on the exploitation of natural resources. These mines play a central role in the production chain by providing the necessary raw materials and energy for industries. Therefore, the principled and scientific use of them can greatly contribute to the economic prosperity of the country and lead to greater activity in various industrial sectors. Furthermore, underground mines create a platform for job creation, enhance production levels, and foster the development of modern technologies, playing an effective role in strengthening industrial infrastructure. Regarding the background of the subject, it should be noted that the first systematic geological studies of coal in northern Afghanistan, including the Pul-e-Khumri and Doodkash areas, were conducted in the 1960s and 1970s by Russian geologists. These studies primarily focused on geological mapping, identification of coal-bearing layers, and preliminary assessment of reserves [1]. In the 1980s, the Ministry of Mines of Afghanistan, in collaboration with foreign experts, published reports on the active coal mines of Baghlan, including Karkar and Doodkash. These studies addressed the thickness of the layers, slope, extent, underground mining conditions, and industrial use of coal, and introduced the Doodkash mine as one of the important sources of local energy supply. In 2005, the United States Geological Survey (USGS) published an important report titled Assessing the Coal Resources of Afghanistan. In this report, the Baghlan region was introduced as one of the most important coal belts of Afghanistan, and the Doodkash and Karkar mines were mentioned. This study focused on resource potential, coal quality, geological conditions, and the possibility of future development [2].

In 2011, the USGS, as part of the Areas of Interest (AOI) project, published a special report on the Doodkash mining area. This report included a description of the region's geology, the stratigraphic position of the coal layers, structural formations, and the status of traditional mining, and it introduced the Doodkash mine as part of the Pul-e-khumri coal belt. In 2015, an article titled “Coal Resource Potential of Afghanistan” was published in the International Geology Review by Christopher Wnuk, which provided a comprehensive assessment of Afghanistan’s coal geological potential. In this study, the coal belt of northern Afghanistan (including Baghlan) was analyzed in terms of sedimentology, tectonics, and the distribution of Jurassic coal layers, and it strengthened the scientific basis for local studies such as those on Doodkash [5].

Coal, as one of the most important mineral resources extracted from underground mines, plays a fundamental role in global energy supply. This valuable substance is actually classified as a type of sedimentary rock that has formed over time from the remains of plants buried in deep layers of the earth under high pressure and temperature conditions. The process of coal formation is very long and complex, taking millions of years to complete. The main composition of this material consists of carbon elements, which play a significant role in its structure [6].

In addition to carbon, water and some minerals also play a role in the composition of coal. For the process of forming this substance to begin, the abundant presence of plant residues

is crucial. Such plant materials typically accumulate in wet and swampy areas like peat bogs. Throughout various geological periods, especially since the Devonian period, these organic materials have accumulated in environments where sufficient oxygen was not available. The lack of oxygen prevents the complete decomposition of plant residues and leads to the formation of peat, which is the first stage in the process of transforming into coal. Over time and under conditions of high pressure and temperature, peat transforms into coal [7].

Coal is formed when plant remains accumulate at a faster rate than decomposition by bacteria in the environment. This process typically occurs in swamps and humid areas with a lack of oxygen. In such conditions, stagnant water and insufficient oxygen prevent microorganisms from fully decomposing plant remains. The activity of bacteria in these environments leads to the incomplete decomposition of plant materials and the formation of a mass of organic material known as "peat". This peat, as a raw material, gradually gets compressed and compacted under the pressure of upper sediments to create the conditions for coal formation [8].

When peat is buried under heavy layers of sediment, high pressure and heat cause it to compress and reduce in volume, and the water and gases present are expelled from it. This process, which takes millions of years, gradually transforms peat into coal. Depending on the intensity of pressure and heat applied to the peat, coal forms in different qualities and grades [9].

When a layer of peat with a thickness of 20 meters is buried under sediments with a thickness of about one kilometer, it is subjected to the high pressure of these sediments and is transformed into brown coal or lignite with a thickness of about 4 meters. However, if the same plant materials are buried at greater depths, for example, around 3 kilometers, 2 meters of peat can convert into a higher quality coal. Under conditions of being buried at very great depths, about 6 kilometers, and accompanied by intense heat, a 20-meter layer of peat will transform into anthracite - the highest quality type of coal - with a thickness of close to 1.5 meters [10].

The amount of carbon present in coal varies between 75 to 95 percent depending on its type and quality grade, and this amount is considered one of the main indicators in determining the quality of coal. In addition, the moisture content in coal can reach up to about 12 percent, which depends on the type of coal and the geological and environmental conditions prevailing at the time of its formation [11].

Coal is recognized as one of the important non-renewable energy sources, and its use dates back to more than two thousand years ago. This mineral has historically held a significant position due to its high energy production capacity, especially in industries such as cement and electricity production. Afghanistan is also considered very rich in terms of natural resources, especially coal. However, comprehensive geological and mineral studies on these reserves have not been conducted yet, and many of the country's coal resources have not been completely identified and explored [12].

According to preliminary geological surveys conducted in collaboration with domestic and foreign specialists, two major coal areas have been identified in Afghanistan: one is the eastern-southeast mining area and the other is the northeastern-southwestern area. Among these, the eastern-southeast area has not yet been studied in a precise and

comprehensive manner. Initial findings indicate that coal extraction in this region is not economically viable due to existing limitations in the quantity and quality of reserves and also current economic and technical conditions [13].

In contrast, the northeastern-southwestern mineral area, which forms a continuous mineral belt starting from Badakhshan province in northeastern Afghanistan and extending through the provinces of Takhar, Kunduz, Baghlan, Bamiyan, Ghor, Samangan, Balkh, Sar-e- Pol, Jawzjan, Faryab, and Badghis to the coal mine of Sabzak in Herat province, is considered one of the most important and coal-rich areas of the country. This mineral strip has considerable potential for industrial exploitation and can play an important role in the economic and industrial growth of Afghanistan with more detailed studies and appropriate investments [14].

While previous studies have outlined the general framework of Afghanistan's coal potential, a comprehensive, up-to-date investigation based on precise laboratory data and international standards is still lacking for the Doodkash mine. This study seeks to fill this scientific and technical gap and to provide a reliable foundation for future extraction planning and industrial development.

2. Research Methodology

In writing this article, various methods and techniques (library, field, and laboratory) have been employed. In the library method, a collection of scientific resources, including books, reports, scientific articles, and reputable journals that have been available in various libraries, were examined and studied.

In the field investigations of the coal Doodkash area, various tools such as GPS for determining precise geographical locations, a measuring tape for accurate distance measurements, a hammer and chisel for extracting samples, a journal for recording observations, a camera for visual documentation, a loop for observing mineral details, and a geological compass for measuring directions and the slopes of layers were used. This set of tools greatly aided in the accurate collection of information and field sampling. The criteria for selecting samples are based on the variability of mineral bodies, their size, and the distance between them. The devices used for measurement (e.g., moisture, ash, calorific value, gas percentage determination) have been calibrated and standardized.

In the laboratory section, the samples were carefully numbered and recorded, and each sample was examined and analyzed using advanced equipment. At this stage, the primary samples of the extracted minerals were analyzed and examined with specialized devices. The results obtained from these samples were compared, showing consistency and confirming the accuracy and reliability of the conducted tests. This consistency of results indicates the precise performance of the equipment and the validity of the methods used in the research process.

Ultimately, the findings from these three stages are comprehensively analyzed, and the final results not only demonstrate the transparency and accuracy of this research but also provide a solid scientific foundation for future studies.

2.1. Field Research

The coal-bearing mining area of Doodkash is located in the northeast section of Pul-e Khumri city, Baghlan province, and is situated 15 kilometers from it. The coal layers of the Doodkash mining area extend from the coal layers of the Karkar mining area. As a result of the excavations that have taken place, three coal seams with thicknesses of (0.6 - 2.5) meters have been exposed in the mentioned mining area. The coal-bearing layers of the Doodkash mining area belong to the Middle-Lower Jurassic geological period, and its coal type is bituminous, with a heat value of (5658 - 6242) kilocalories and an ash content of (20.94).



Fig. 1. The coal mining area of the Pul-e-khumri Doodkash in Baghlan province

It is worth mentioning that the mining area of Doodkash has been surveyed and preliminarily explored locally. However, no detailed exploration has been conducted, and a comprehensive feasibility study has not been carried out to calculate and establish its definitive reserves. Nonetheless, through the drilling of exploratory boreholes and the operation of the mentioned mines, employment opportunities have been created for hundreds of individuals, both directly and indirectly, in the Doodkash mine.

2.2. Laboratory Research Procedures

For the study of laboratory samples, the samples have been taken, packaged, and transferred to laboratories according to a specific geological profile. To determine the quality of the samples, laboratory methods are typically used, and the samples have been subjected to analysis to determine the percentage of purity and quality of the coal contained in the samples.

It is worth noting that, in order to ensure that the coal test results are valid, reliable, and systematically verifiable, the following procedures were carried out:

1. Quality Control (QA/QC): To guarantee the accuracy and reliability of the results, sampling was conducted according to standard procedures. Sample preparation was

carried out following established methods, and control samples were used to verify precision and prevent contamination.
2. Instrument Accuracy and Calibration: For physical and chemical analyses of the coal, periodic calibration of the instruments was performed, and calibration certificates were recorded. Additionally, the accuracy of balances and other measuring devices was checked and confirmed.
3. Repeatability: Each test was conducted at least in triplicate. The mean and standard deviation were calculated, and the relative percent error (RPE) was assessed to evaluate the precision of the results.
4. Uncertainty Analysis: To enhance the scientific validity of the results, measurement uncertainty was determined by considering instrument accuracy, repeatability, and calibration errors.

2.2.1 Automatic Oxygen Bomb Calorimeter Device

This automatic calorimeter device is used to determine the calorific value or thermal quality of coal (by exploding a specific amount of it), measured in units (Cal/gr).
It is worth mentioning that G.C.V or Gross Calorific Value, is the total amount of calories, that is, the overall thermal value of coal, which is automatically measured and assessed by this device, and the final result appears on the display.
The explosion of a one-gram sample of coal (in tablet form) occurs in a special device called a bomb, which is placed in distilled water, the details of which are provided in Table (1).
Considering that the samples taken from the chimney area contained impurities and the results of the conducted studies indicate that the region's coals have heating values between 5658 to 6242 kilocalories, ash content from 17.1 to 24.4 percent, gas content from 25 to 26 percent, and moisture between 4.28 to 4.7 percent.

Table 1. Characteristics of Doodkash coal samples and their heating values

Sample number	Parameters						
	Gas percentage	Time Analysis	Heating to kilocalories	Percentage of moisture	Ash percentage	Height above sea level in meters	Coordinate
1	26	2025/06/04	5658	4.7	24.4	1066	N=35˚59′ 41″
							E=68˚46′ 40″
2	25	2025/06/04	5870	4.5	22	1064	N=35˚59′ 42″
							E=68˚46′ 41″
3	26	2025/06/04	5748	4.6	23	1066	N=35˚58′ 42″
							E=68˚47′ 40″
4	26	2025/06/04	6242	4.28	17.1	1067	N=35˚59′ 43″
							E=68˚46′ 42″
5	26	2025/06/04	6180	4.3	18.2	1064	N=35˚59′ 41″
							E=68˚46′ 41″

Despite the fact that the samples collected from the chimney area contain some impurities, efforts were made to ensure that the sampling was conducted in a way that represents the

general characteristics of the coal seam in the region. Five laboratory samples were collected from different parts of the seam and from locations with varying lithological and geological conditions in order to account for the natural variations in the composition of the coal. Although the number of samples is limited, due to their selection from different positions within the seam and their relative coverage of the qualitative variations of the coal, these samples can be considered, to an acceptable extent, representative of the general characteristics of the coal seam in the study area.

Based on the results obtained from the analysis of five coal samples, a basic statistical analysis was conducted to better interpret the variability among the samples. The results indicate that the calorific value of the coal samples ranges from 5658 to 6242 kcal/kg, with an average of approximately 5939.6 kcal/kg and a standard deviation of about 251 kcal/kg. This value indicates a relatively moderate variability in the calorific value among the samples. The ash content of the samples also ranges from 17.1% to 24.4%, with an average value of 20.94% and an approximate standard deviation of 3.14%. These results indicate that although the amount of impurities and ash varies among the samples, the obtained values fall within a relatively acceptable range and reflect the general characteristics of bituminous coal in the Doodkash mining area. Therefore, the basic statistical analysis indicates that despite the natural variations among the samples, the obtained data do not show a very high degree of dispersion and can be considered a reasonably representative indicator of the overall quality of coal in the study area.

2.2.1.1 Examining the relationships between coal quality parameters

1. The relationship between calorific value and ash: Usually, there is a negative correlation between the ash content and the calorific value because ash is the non-combustible part of coal. The higher the ash percentage, the lower the amount of combustible organic material (fixed carbon and volatile matter). So, the energy released during burning is also less.

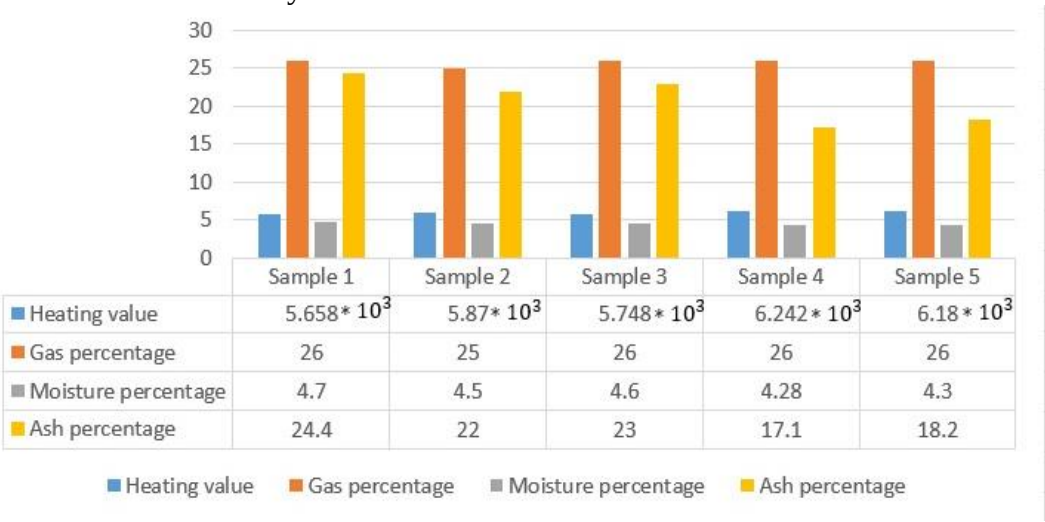
2. Correlation between calorific value and moisture: There is also a negative correlation between moisture and calorific value. Part of the energy from the combustion process is used to evaporate the water present in the coal. Increasing moisture reduces the net usable energy (Net Calorific Value). Even if the gross calorific value (Gross CV) is high, high moisture lowers the practical efficiency.

3. Correlation between ash and moisture: In many coal deposits, a weak positive correlation is observed between ash and moisture. The presence of clay minerals and fine-grained minerals (like shales) can increase water-holding capacity. More polluted layers usually have both higher ash content and absorb more moisture. However, this relationship depends on the geological conditions of the deposit and isn't always strong.

2.2.1.2 The combined effect of three factors on coal quality and its usability and exploitation

The quality of coal is directly linked to its calorific value and inversely related to its ash and moisture content. Higher ash and moisture reduce the combustible material, lower the calorific value, decrease combustion efficiency, and raise operating costs. Since these two factors often increase at the same time, their negative impact on coal quality is intensified. So, coal with high calorific value, low ash, and low moisture has better quality, higher energy efficiency, and greater economic value.

The usability of coal depends on the combined effects of calorific value, moisture, and ash content. Coal with high calorific value, low moisture, and low ash has better quality, higher energy efficiency, and lower operating costs. On the other hand, high moisture and ash reduce the usable energy, lower combustion efficiency, increase fuel consumption, and raise transportation, processing, and waste disposal costs. So, the higher the calorific value and the lower the moisture and ash content, the more technically and economically favorable the coal's usability will be.



	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Heating value	$5.658 * 10^3$	$5.87 * 10^3$	$5.748 * 10^3$	$6.242 * 10^3$	$6.18 * 10^3$
Gas percentage	26	25	26	26	26
Moisture percentage	4.7	4.5	4.6	4.28	4.3
Ash percentage	24.4	22	23	17.1	18.2

Fig. 2. The rate of changes in the characteristics of Doodkash coal samples

The collected samples have been studied using the analysis device, and as observed, in the evaluated samples from the results of the coal quality study, it can be seen that all studies will present the same result. As seen from the studied sample, its heating is good. Therefore, from the comparison of the studies, it becomes clear that the Doodkash coal in the Pul-e-Khumri area of Baghlan province is among the types of coal that contain gases in varying percentages.

3. Discussions

In order to investigate, analyze, and evaluate coal and adjacent minerals, conducting comprehensive and detailed studies is of great importance. Therefore, samples have been taken from the area of interest and have been carefully examined.

This article analyzes and examines coal samples, where the results obtained from laboratory analyses are presented in detail. The mentioned samples are considered one of the most important and valuable samples in laboratory studies and have been collected from the range of coal deposits.

The comparison of the quality parameters of the Doodkash Pul-e-Khumri coal with national and international standards based on the criteria of ASTM International and the International Organization for Standardization (ISO) indicates that the physical and chemical characteristics of this coal are largely influenced by geological factors controlling the formation of coal-bearing layers. The relatively low moisture content of the samples (4.3–4.7%), which falls within the globally acceptable range (approximately

2–10%), may indicate depositional conditions in relatively stable swamp environments, as well as a certain degree of diagenetic evolution during which part of the original moisture was reduced in the early stages of coalification [4].

The relatively high ash content (17–24%), which is slightly higher than the desirable industrial range (5–20%) and may somewhat reduce the fuel quality, is likely related to the presence of associated mineral materials such as clays, silts, and detrital particles that entered the depositional environment during the formation of peat [3]. This may indicate the influence of continental depositional environments with the influx of clastic materials from adjacent areas. In such environments, fluctuations in the water level and the input of fine-grained sediments into coal-forming swamps can increase the amount of mineral matter and consequently raise the ash content in the coal.

The volatile matter content (25–26%) falls within the standard range for bituminous coals (20–35%) and can be considered satisfactory [15]. This value, characteristic of bituminous coal, indicates a moderate to relatively advanced degree of coalification. It suggests that the original plant-derived organic material underwent thermal alteration during diagenesis and catagenesis, resulting in the partial release of its volatile compounds.

The calorific value of the samples (approximately 5658–6242 kcal/kg) falls within the average range for thermal coals worldwide (5500–7500 kcal/kg) and is consistent with typical values for thermal bituminous coals [16]**.** This energy content largely depends on the ratio of organic to mineral matter as well as the degree of coal thermal maturity. In areas with a higher proportion of associated mineral matter, the calorific value generally decreases, whereas an increase in fixed carbon concentration during coalification leads to a higher calorific value.

Overall, the combination of these parameters indicates that the coals of the Doodkash region were likely formed in continental swamp environments with intermittent input of clastic sediments and have reached the bituminous coal stage through diagenetic processes and thermal maturation. Therefore, the observed variations in ash content, volatile matter, and calorific value can be interpreted as the result of the interaction between the initial depositional conditions, the composition of the plant material forming the peat, and the degree of thermal alteration throughout the geological history of the region.

The overall results from these laboratory studies clearly indicate a strong correlation and consistency among the different findings, confirming the accuracy and reliability of the analyses conducted.

4. Conclusion

Considering that the samples collected from the Doodkash area contained some impurities, the results of the conducted studies indicate that the coal from this region has a desirable calorific value and contains acceptable levels of ash, gas, and moisture. These characteristics suggest that the coal of this area possesses suitable thermal and chemical properties and can be considered a coal with good heating capability for use in various industries. Overall, these findings also confirm the results of previous studies.

In terms of physical and geological characteristics, the coal from this region is in powder form and has a shiny black color, which indicates its purity and high quality.

A preliminary study shows that the coal from Pul-e-Khumri's Doodkash is one of the materials with suitable heat for supplying energy to cement factories. Based on the comparison of laboratory results with industrial standards, the coal from the Doodkash area of Pul-e-Khumri shows good conformity with the technical criteria used in the cement industry. This is because its calorific value is higher than the minimum requirement for cement kilns (about 5500 kcal/kg), its ash content falls within the acceptable range for cement kilns (less than 25%), its volatile matter is within the suitable range for stable combustion (20–35%), and its moisture content is significantly lower than the industrial permissible limit (around 15%). Therefore, this coal can be considered a suitable fuel for cement plants, including the Ghori Cement Factory, as well as other thermal industries, provided that its composition is supplied and controlled consistently. It is also usable, in addition to thermal power plants for electricity generation, in brick-making and pottery industries, lime and gypsum factories, and general industrial thermal uses (boilers and steam engines).

5. Recommendations

- In order to accurately explore the coal reserves of the Doodkash coal mining area, it is necessary to carry out drilling in the mining area where the coal layers have not been significantly folded or fractured due to tectonic movements and where the coal layers have a low dip.
- Conducting detailed geological studies to prevent unintended damage to tunnels.
- Considering that the coal mined is used for the cement industry, increasing production could help supply fuel for local industries and create employment.
- Using new machinery to reduce risks and increase extraction speed.
- One of the major challenges during research is the lack and absence of advanced laboratory equipment in the geology department, so it is recommended that well-equipped laboratories be established in universities to advance research.

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