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AN EVALUATION OF THE QUALITY OF METALLURGICAL COKING COAL SEAMS WITHIN THE NORTH BLOCK OF EASTERN PARVADEH COAL DEPOSIT, TABAS, CENTRAL IRAN

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Abstract

The aim of this study is to evaluate the quality of the metallurgical coking coal seams in the north block of Eastern Parvadeh coal deposit located in Tabas, Central Iran. Quality particulars of the main coking coal seams named as C_1 and B_2 , are; thickness, sulfur content and ash content, and have been evaluated by using statistical analysis and 3D modeling based on subsurface hole data including collar, orientation, lithology, stratigraphy and assay taken and analyzed from 87 drill holes. Seams were separated based on USGS (Bulletin 1450-B) and Russian (10583-72 and 7059-75) quality standards. Statistical studies reveal that the amounts of ash content and sulfur content are high considering the USGS standard. This study concludes that the C_1 seam has the highest quality amongst the analyzed seams based on metallurgical quality particulars.

Key words: *Metallurgical Coking Coal, C_1, Eastern Parvadeh coal deposit, Tabas, Iran.*

1. Introduction

Coal is an important component of world mining and will continue to play a significant role in any nation's economy. Increasing petroleum and natural gas prices from one perspective and huge demand on petroleum and gas from the other side are necessitating governments and mining companies to expand their exploration and exploitation of coal resources. Coal mining worldwide was 4.3 Gt in 2000 and is expected to be doubled by 2030 [1]. According to Iran's 4th development program, steel production has to be increased to 50 Mt/y in 2020 [2].

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Also, metallurgical coking coal production has to be raised to more than 3 Mt/y in the next year [3]. Therefore, there are several coking coal exploration projects by the Iranian Mineral Preparation and Production Company (IMPASCO) especially in the Tabas coalfield. Iranian coal resources are estimated to be about 7–10 Gt where most occurs in two main basins, one in northern and another in the central Iran which are well known as Alborz and the Central basins respectively [4]. Tabas coalfield is a major contributor to Iran's metallurgical coking coal deposits due to the fact that the reserve is estimated to be 3-4 Gt of coal. In this study the purpose is to separate the best parts of coking coal seams based on its quality in the north block of the Easten Parvadeh coal deposit.

2. Geological setting of the case study

The Eastern Parvadeh coal deposit is situated some 80 Km south of the Tabas region, Central Iran (Figure1). The Tabas region is part of central Iran's geological classification zones [5]. The Tabas zone is divided into different sub zones namely: Tabas (Parvadeh and Nayband) and Mazinu. The Parvadeh region includes six parts divided by major faults and the Eastern Parvadeh, is depicted in Figure 1. The Eastern Parvadeh coal deposit is divided by the Zenoughan fault which divides the North and South blocks. According to dip, depth and tectonic effects, coal seams in the North block are generally accepted to be better than those in the South block [6].

The coal-bearing strata of the Tabas basin consists mainly of sediments of the Upper Triassic–Middle Jurassic age namely the Nayband formation and Ghadir member [7]. The lithozones include siltstone, sandstone, shale, sandy siltstone and small amounts of limestone and argillic coal. Coal zones in the Parvadeh region are named A, B, C, D, E and F. B and C coal zones are minable based on their quality and quantity. C_1 and B_2 are the major coal seams in these zones.

3. Methodology

87 drill holes were drilled from which 792 samples were collected from coal seams, both from the hanging and footwalls, also chemical analysis for ash and sulfur content were carried out. In addition, the RockWorks software package was employed in order to generate a 3D model of the quality particulars of the metallurgical coking coal [8] and [9]. Additionally, faults in the region of these samples were imported into the software so that effective mapping and interpretation of their critical nature of the faults in terms of economy and safety matters could be assessed [10]. Reserve evaluation and associated boundaries were imported into the software as this was deemed necessary for the full 3D modeling of the coal seams. Finally, the coal seams properties were separated based on the 10583-72 and 7059-75 Russian quality standard and USGS system (Bulletin 1450-B) [11] and [12].

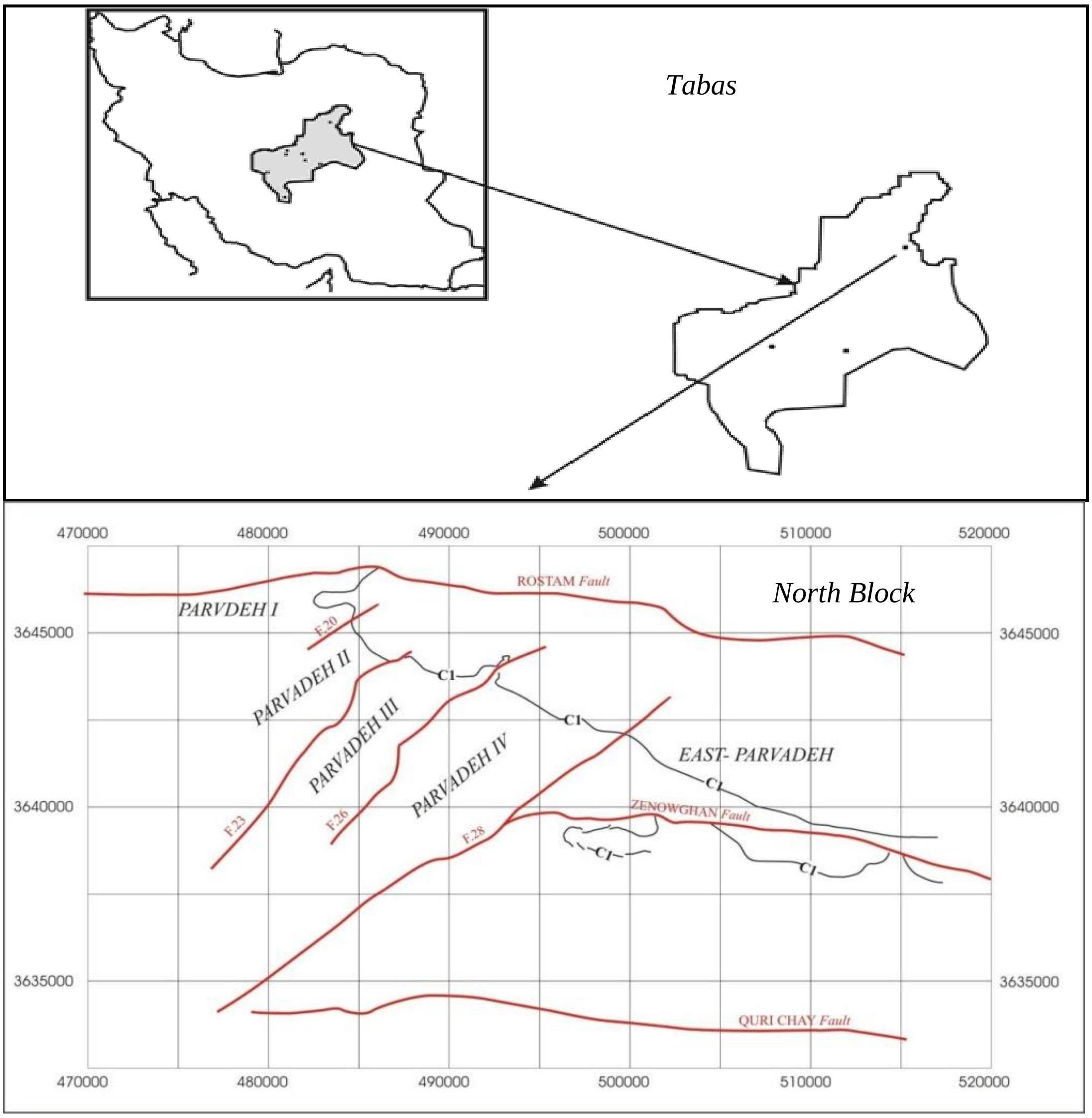


Figure 1. *Parvardeh deposits locations and Eastern Parvadeh blocks in Tabas [6]*

4. Database construction and importing of Data

The resource database consists of information based on and developed from the interpretation of surface and subsurface data [13]. Items were selected based on NCRDS (National Coal Resources Database System) of the USGS from final log reports of the 87 drill holes which were drilled in the north block [14]. It is also noticeable that the coal seams hanging and footwalls were coded on the basis of NCRDS [15].

The selection of block size for a computerized 3D ore body model is an exercise which is fundamentally important [16] according to the area and drill holes coordinates (collar) and project dimensions which were calculated as 14800m, 3000m and 360m for X, Y and Z respectively. Then, voxel dimensions were determined which equated to 200m, 200m and 0.2m for X, Y and Z respectively [16]. It is also noticeable that the acceptable minimum thickness of Iran's coking coal seams is 0.4m [17].

Faults play a fundamentally important role for 3D modeling of coal seams. Undetected or ill-mapped geologic hazards can stop or substantially hinder project development with respect to profit and safety [10]. Two major faults in this area are Zenoughan and F.31 which are located in the southern and western boundaries of the north block. These faults and a few other minor faults were digitized and imported into the software. Finally, boundaries of the north block were digitized and imported into the software for determination of the modeling area.

5. 3D modeling of coal seams

3D models of the lithological and stratigraphical coal seams have been generated using the RockWorks software package in the C_1 and B_2 seams. These seams were deeper in the western part of the area based on their drill holes positions as illustrated in Figure 2. Hanging walls and footwalls of coal seams are generally siltstone, sandstone and sandy siltstone while limestone is found in a few blocks. Ultimately, topographical effects were also entered to produce a comprehensive 3D model.

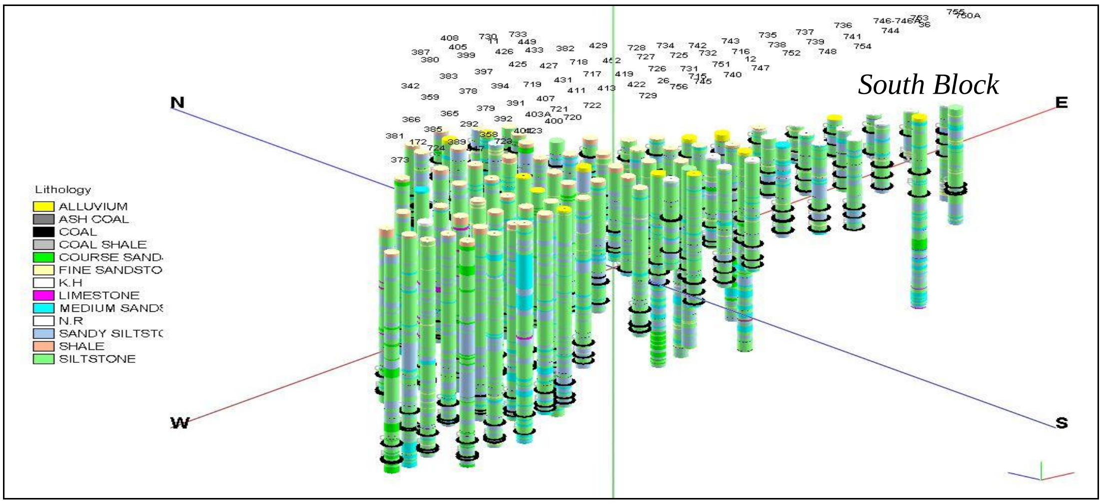


Figure 2. *3D model showing drill holes in north block and C1 and B2 seams based on lithological units*

Based on the NCRDS system, other strata were coded and named as A and B for the 3D modeling of the coal seams [14]. Based on a stratigraphical model of these coal seams, depths are greater than 300 m in SW of this block. The seam C_1 exists in all parts of the block but is not well presented in the central block. B_2 is present in many parts of the west, south and several eastern parts especially in the SE portion of the block, as depicted in Figure 5. These seams have a trend from the NE to SW and have outcrops in the NE part of the block.

6. Chemical quality of coal seams

The chemical quality of metallurgical coking coal in seams C_1 and B_2 was determined based on subsurface data. 141 samples were collected from drill holes with 87 samples from seam C_1 and 54 samples from seam B_2. Both the Russian and USGS standards were used as the Russian standard is common in Iran and the USGS standard has an associated environmental element. The most important difference between the two standards is the environmental consideration which is present in the USGS standard. USGS standard Russian standards (10583-72) and (7059-75) are presented in tables 2 and 3 [10].

Table 1. *Coking coal categorization based on the USGS standard*

Category	**Low ash**	**Medium ash**	**High ash**
Ash (%)	0-8	8-15	> 15
Category	Low Sulfur	Medium sulfur	High sulfur
Sulfur (%)	0-1	1-3	> 3

Table 2. *Coking coal categorization based on the Russian standards (10583-72) and (7059-75)*

Category	**Very low ash**	**Low ash**	**Medium ash**	**Relatively high ash**	**High ash**	**Very high ash**
Ash (%)	0-10	10-15	15-25	25-31	31-40	> 40
Category	Very low sulfur	Low sulfur	Medium sulfur	Relatively high sulfur	High sulfur	Very high sulfur
Sulfur (%)	0-1	1-1.5	1.5-2.5	2.5-3.5	3.5-5	> 5

6.1. Statistical studies

The chemical quality histogram parameters were generated and are presented in Figure 3. The ash content histogram shows that the ash content mean is 26.89% which is high-ash based on the USGS standard while based on the Russian standard, these coals are considered to have relatively high-ash content. Also, many parts of the coal seams have high ash content based on two of the standards. The sulfur content histogram shows that the mean sulfur content is equal to 3.3% which is a high-sulfur content based on the USGS standard but based on the Russian standard these coals have a relatively high-sulfur content as illustrated in Fig. 3. Most parts of the coal seams have more than 1.5% sulfur content which is poor from both an environmental and coal washing plant perspective.

The thickness frequency distribution diagram shows a mean value equal to 41.5cm which indicates that it is a ‘good’ thickness based on NISCO principles

(National Iranian Steel Company) as depicted in Fig 3. [18].

The positive correlation coefficient between ash content and sulfur content is 0.36 for the two harmful materials in the deposit. Also the correlation coefficients between ash content-thickness and sulfur content -thickness are 0.08 and 0.05 respectively which show very little correlation between these two parameters. Therefore, there is a serious problem due to the fact that both the ash content and sulfur content increases where coal thickness increases. Means of thickness, ash and sulfur in C_1 and B_2 seams are show in table 1.

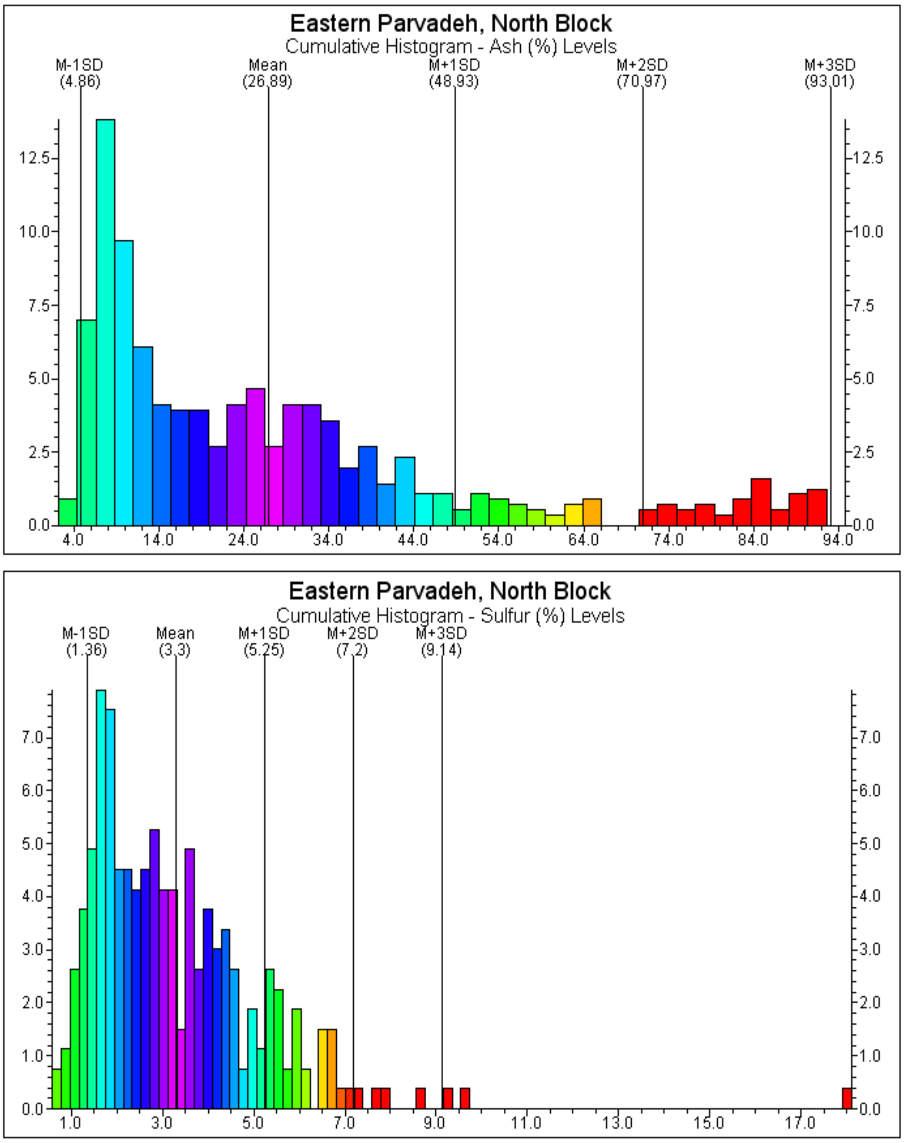


Figure 3. *Ash, sulfur content and thickness histogram in economic coal seams in north block of eastern Parvadeh deposit*

6.2. C_1 seam

Quality particulars of the C_1 seam were calculated based on 87 collected samples from drill holes. Thicknesses in all parts of this seam are over 0.4m and can be considered as a 'good' value (Figure 4 and Table 1). This seam has coal with high ash content when based on USGS standard but with the Russian standard this coal seam is categorized as medium-ash content, as depicted in Figure 4. The sulfur content mean is equal to 2.19% which is deemed as coal with medium-sulfur content based on both the USGS and Russian standard and is over 1.5%, as presented in Figure 4 and Table 1.

Examining the correlations between thickness, sulfur content and ash content it can be seen that there are positive correlations between these parameters as mentioned above. Correlation coefficients between sulfur content-ash content, sulfur content-thickness and ash content-thickness are 0.20, 0.16 and 0.45 respectively which shows that both the sulfur content and ash content increases with increases in thickness although the rate of ash content increase and sulfur content increase is lower than that of other seams in the deposit.

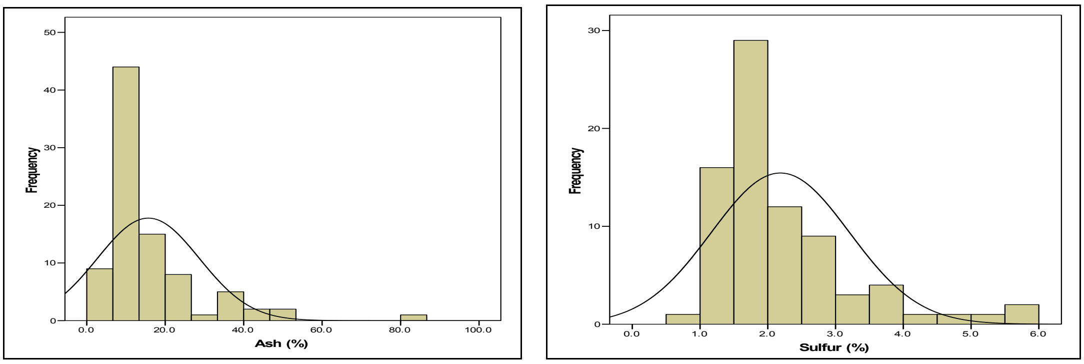


Figure 4. *Ash and sulfur content in C_1 seam in north block*

6.3. B_2 seam

The mean of the B_2 thickness shows that this thickness is 'good' for the mining purposes although parts of the seam's thickness are lower than 0.4m based on 54 collected samples taken and analyzed. The ash mean depicts that the coal is designated with a high ash and a medium-ash content based on the USGS standard and based on the Russian standard, respectively (Table 1). In terms of the sulfur content histogram, its mean is equal to 2.74% which then makes it a coal with medium-sulfur content based on the USGS standard but it categorizes this seam as a relatively high-sulfur content based on the Russian standard, as illustrated in Figure 5 and Table 1.

The examination of correlations based on thickness, sulfur content and ash content shows that there are different correlations between these parameters compared with other seams. Correlation coefficients between sulfur content-ash content, sulfur content-thickness and ash content-thickness are 0.44, 0.09 and 0.13 respectively which show that the sulfur and ash contents decrease as thickness increases. However, the rate of ash content increases as increases in sulfur content occur which is relatively high in this scenario and plays a negative role in terms of environmental issues. It is good to bear in mind that the amounts of ash and sulfur have indirect correlation with thickness.

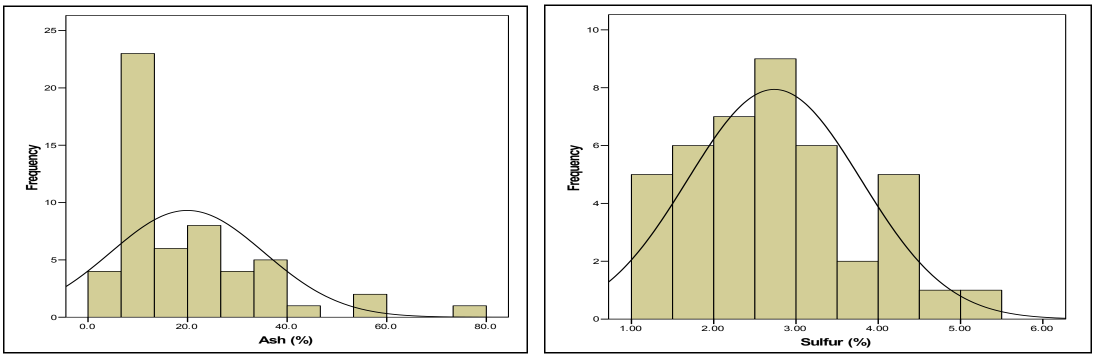


Figure 5. *Ash and sulfur content in B_2 seam in north block*

7. Results

Results of this study show that there are coal resources with thickness of higher than 0.4m in seams C_1 and B_2 in which case seam C_1 has the greater. Based on the USGS standard coal in seams C_1 and B_2 have sulfur of higher than 1% and a few parts of the seams have sulfur between 1.1 to 1.5% in the western, SW and central parts of the north block. Total coal of seam B_2 has a low-ash content based on the Russian standard but most coal has sulfur values greater than 1.5%. High amounts of coal have sulfur grades higher than 5% which are located in the eastern part of the block. Most of the voxels in the central parts of the deposit have sulfur variation between 1.5 to 5%. The ash variation trend is similar to that of sulfur in the seams. Most parts of the coal have ash higher than 15% which are situated in eastern part of the block. Ash amounts increase from west to east. Most of the coal can be utilized in Iranian coal washing plants but is detrimental to the environment.

With respect to sulfur and ash distribution, the chemical quality of the metallurgical coal seams is low in the eastern part of this resource. The best part of the coal in this block within these two seams is located in the central part of the block. According to statistical studies, seam C_1 has the best chemical quality amongst the metallurgical coking coal seams and seam B_2 has the lowest chemical quality amongst the seams. This study shows that ash and sulfur content increases with increase in thickness. The 3D models show that the best parts of seam C_1 are situated in the western part of the seam; especially in the SW. The best parts of seam B_2 are located in the north and the central part of the block.

8. Discussion

A statistical study on the seams shows that seam C_1 has the lowest sulfur and ash contents and also the seam's thickness is greater than B_2 although B_2 has a positive factor since its sulfur and ash contents decrease as thickness increases. As a result of this, seam C_1 has the best chemical quality amongst the metallurgical coking coal seams in the north block, (see Table 3).

Table 3. *Means of thickness, ash and sulfur contents in seams C_1 and B_2*

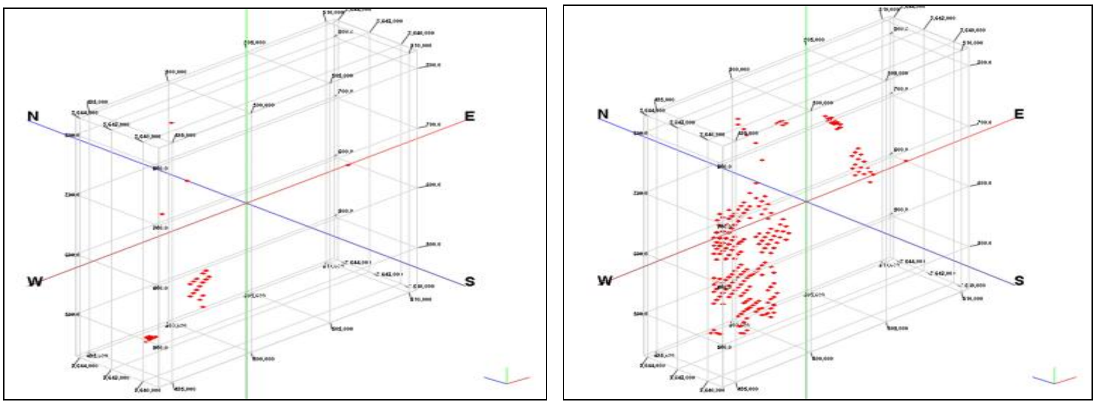
Seam	Thickness (m)	Ash (%)	Sulfur (%)
C_1	0.87	15.71	2.19
B_2	0.75	19.95	2.74

8.1. Modeling and evaluation of thickness, sulfur and ash distributions in seams C_1 and B_2

In this section, the distribution of sulfur and ash contents in thicknesses over 0.4m in seams C_1 and B_2 is demonstrated, also the distribution of ash and sulfur content in the main sections of the coal seams to be mined are determined based on thickness. The interpolation method used was Inverse-distance squared (IDS) from there different sections of the coal seams were separated based on the USGS and Russian standards.

8.1.1. C_1 seam

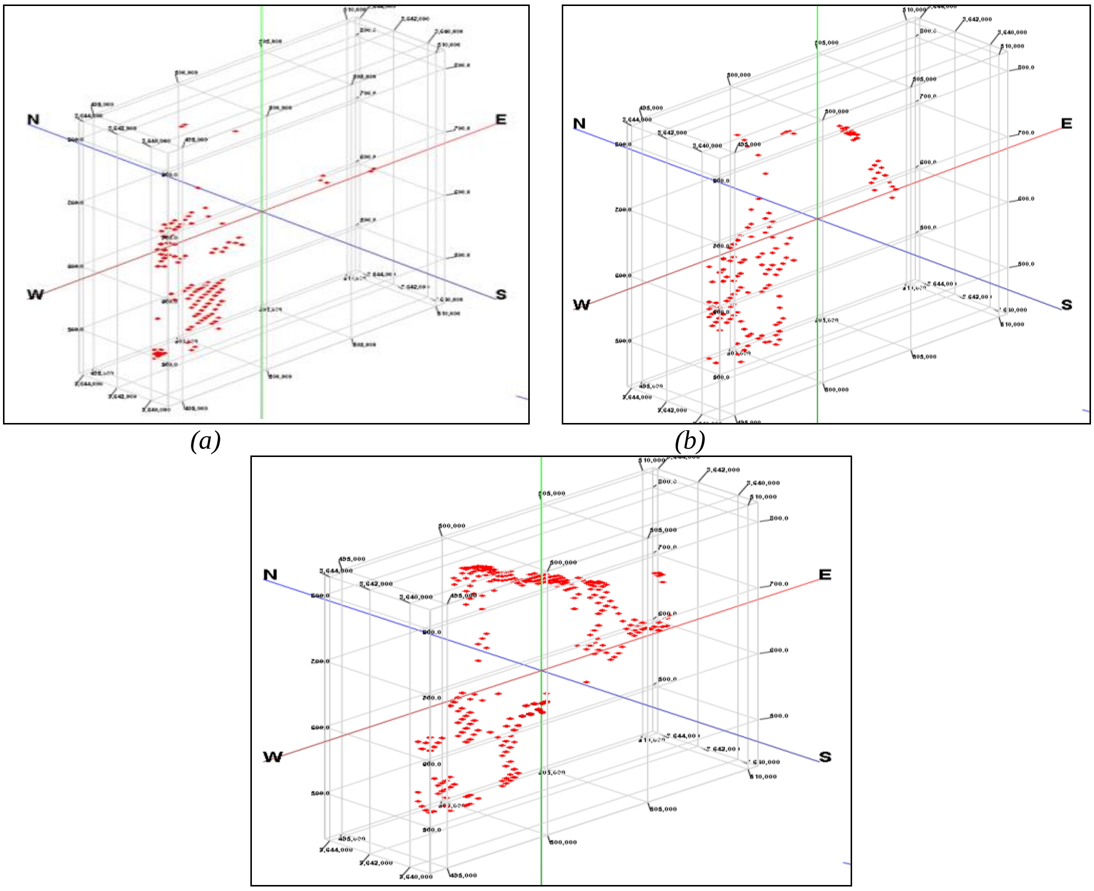
It was mentioned above that all parts of this seam are over than 0.4m in terms of thickness. However, a few parts of this seam are coal with low-ash content based on the USGS standard as presented in Figure 6. According to the ash distribution model in this seam, the ash value is low in the Western part of C_1 especially the SW of north block. Most parts of the seam have a high ash content, that is, more than 15%. In other words, ash amounts decrease in the lower depths of the deposit.



(a) (b)

Figure 6. *Ash content distribution in C_1, coal with low-ash content (a) and medium-ash content based on the USGS standard (b)*

Several parts of this seam in the SW have very low ash content based on the Russian standard as illustrated in Figure 7. Most sections of the coal in this seam have a medium ash content and a relatively high ash content, that is, between 15 and 31%. Coal with high and very high ash contents, that is more than 40%, are located in the eastern section of the north block especially in the NE region. It is noticeable that this ash amount is suitable for an Iranian washing plant but with regards to the USGS standard the ash amount in C_1 seam has potential to create environmental pollution.

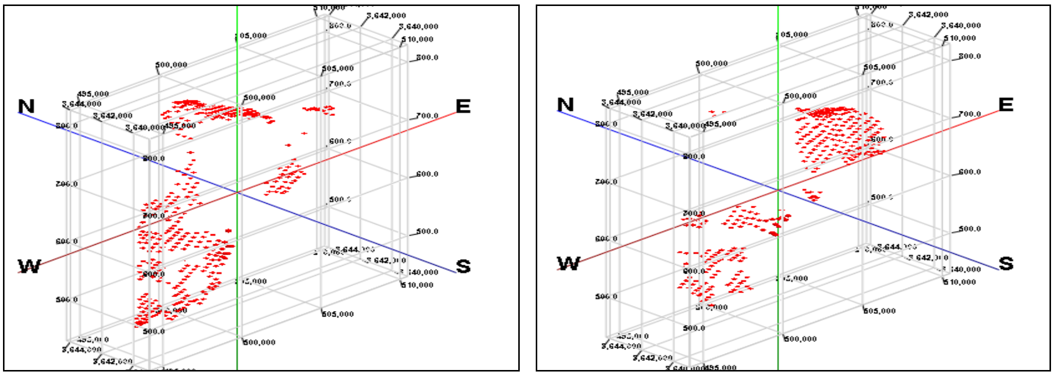


(a) *(b)*

(c)

Figure 7. *Ash content distribution in seam C_1 based on the Russian standard, coal with very low-ash content (a), low-ash content (b) and medium-ash content (c)*

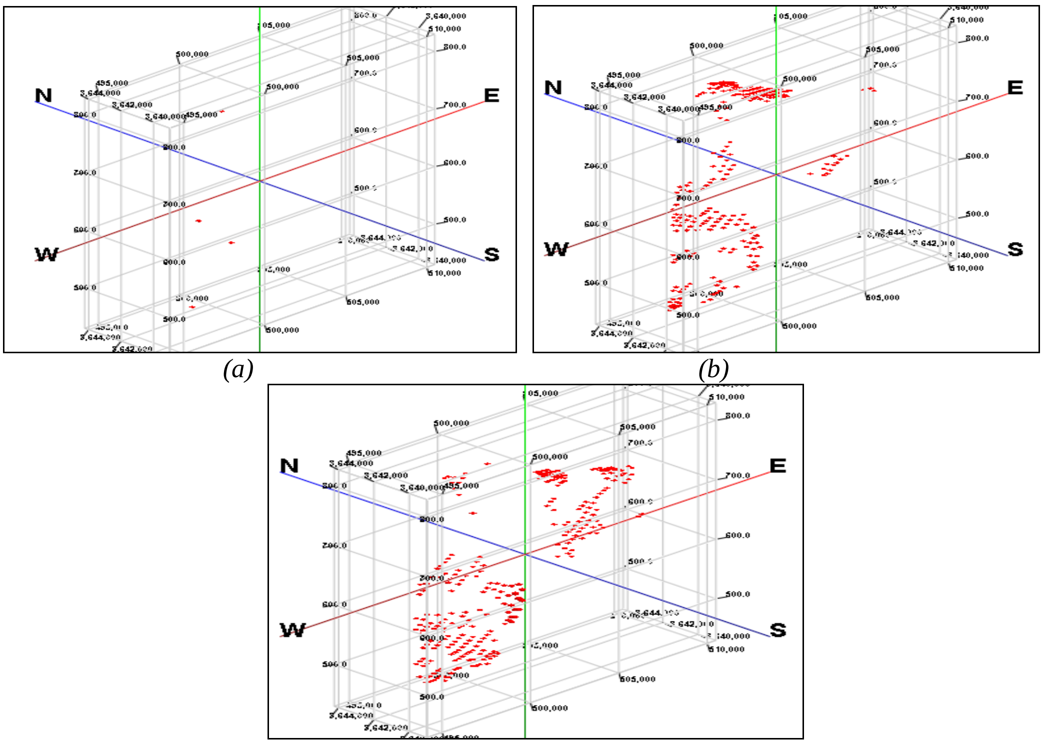
The sulfur content in all metallurgical coking coal seams of the Parvadeh region is high, specifically in this deposit. The sulfur distribution in this seam can be considered by the USGS standard so representing this is not a coal deposit with low-sulfur that is lower than 1%. According to the sulfur distribution model generated in this seam, the sulfur amounts are lower in the Western part of seam C1 especially in the SW of the north block as presented in Figure 8; however in parts of the seam sulfur values are higher than 1%. According to the sulfur limit (1.5%) for steel industries, this coal must be blended with low-sulfur coal (Figure 8).



(a) *(b)*

Figure 8. *Sulfur content distribution in seam C_1 based on the USGS standard, coal with medium-sulfur content (a) and high-sulfur content (b)*

Sulfur distribution in this seam is considered by the Russian standard (10583-72) which shows there is not coal with very low-sulfur content and few voxels exist with low-sulfur as shown in Figure 9.



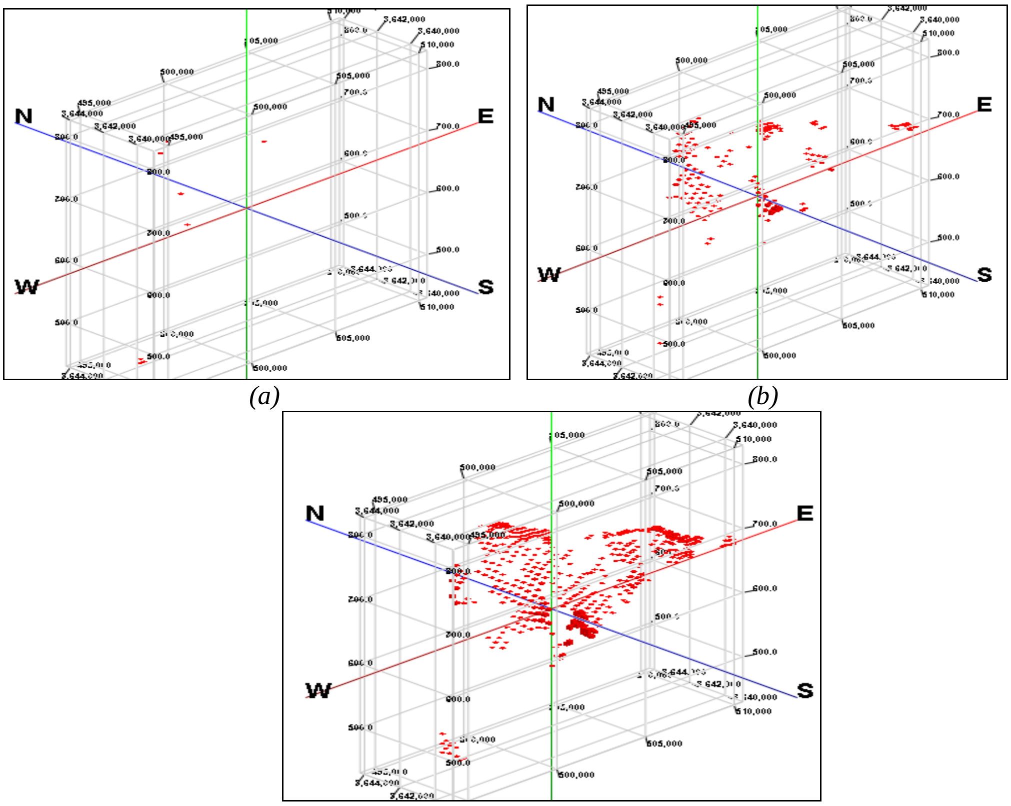
(a) *(b)* *(c)*

Figure 9. *Ash content distribution in seam C_1 based on the Russian standard, coal with low-ash content (a), medium-ash content (b) and relatively high-ash content (c)*

Most parts of the coal are medium-ash content and relatively high-sulfur content which are located in the western part of the block especially in the SW region. Coal with high-sulfur content is located in the eastern part of the north block especially in the NE and a few voxels with a sulfur content of more than 5% in the central part of the block.

8.1.2. B2 seam

Many parts of this seam are over than 0.4m. Ash distribution in this seam is considered by USGS standard which depicted a few voxels within the seam are coal areas with low-ash (Figure 10).

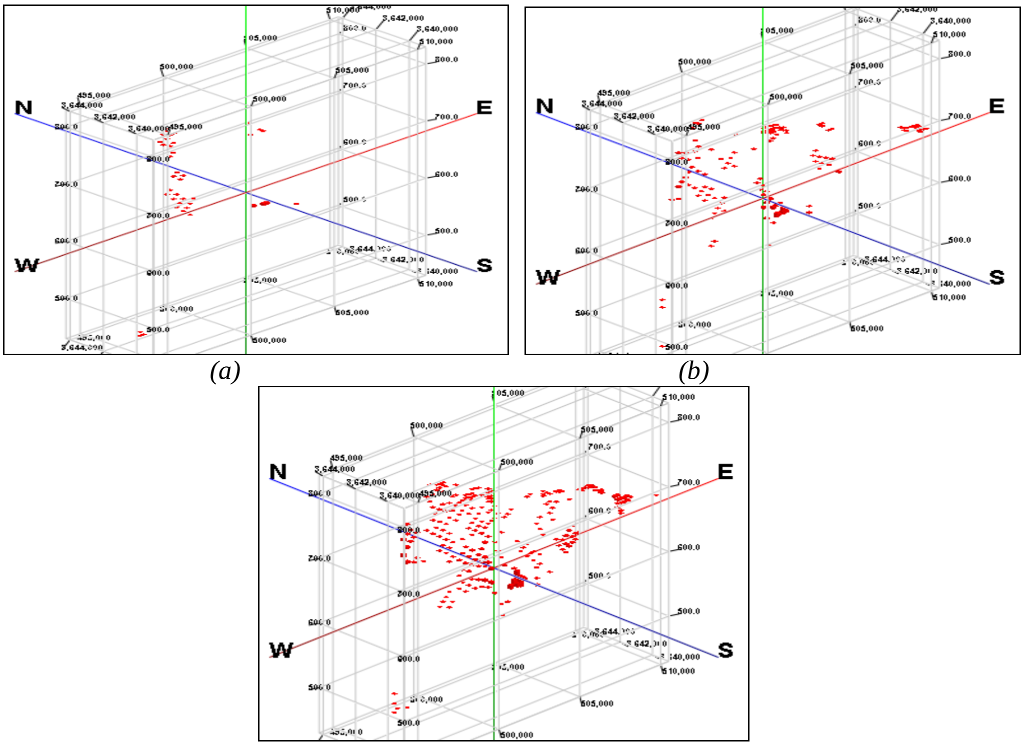


(a) *(b)* *(c)*

Figure 10. *Ash content distribution in seam B_2 based on the USGS standard, coal with low-ash content (a), medium-ash content (b) and high-ash content (c)*

According to the ash distribution 3D model in this seam the ash amounts are lower in the Western part of seam B2 especially in the SW section of the north block. Most parts of the seam have high ash content or more than 15% represented in Figure 10. Fundamentally, ash values decrease in the lower depths of the model.

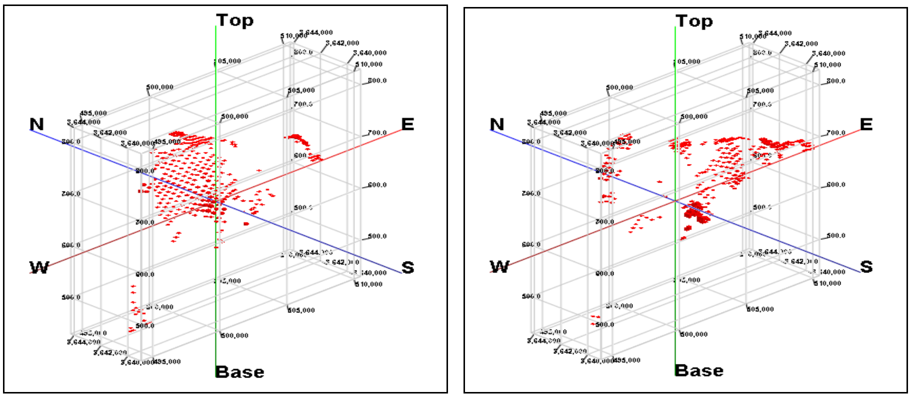
Based on the Russian standard several parts of the seam in the NW and center of the deposit have very low-ash and low-ash content as depicted in Figure 11.



(a) *(b)* *(c)*

Figure 11. *Ash content distribution in seam B_2 based on the Russian standard, coal with very low-ash content (a), low-ash content (b) and medium-ash content (c)*

The coal ash amount of most parts of this deposit within the seam have a medium-ash content, relatively high-ash content and high-ash content varying between 15 and 40%. Coals with high and very high ash are located in the north and eastern parts of the north block especially in the NE.



(a) *(b)*

Figure 12. *Sulfur content distribution in seam B_2 based on the USGS standard, coal with medium-sulfur content (a) and high-sulfur content (b)*

Based on the USGS standard there is no coal with a low-sulfur content. According to the sulfur distribution model within the seam, sulfur amounts are medium-sulfur in the central part of B2 as shown in Figure 12 but in all parts of the seam the sulfur content is higher than 1% and sulfur values of the seam are high in the eastern part of the north block. Based on the Russian standard most of the coal in the seam has a relatively high-sulfur content, that is, (2.6-3.5%). Generally, the sulfur amounts in coals are higher in the eastern part of the seam (see Fig 13).

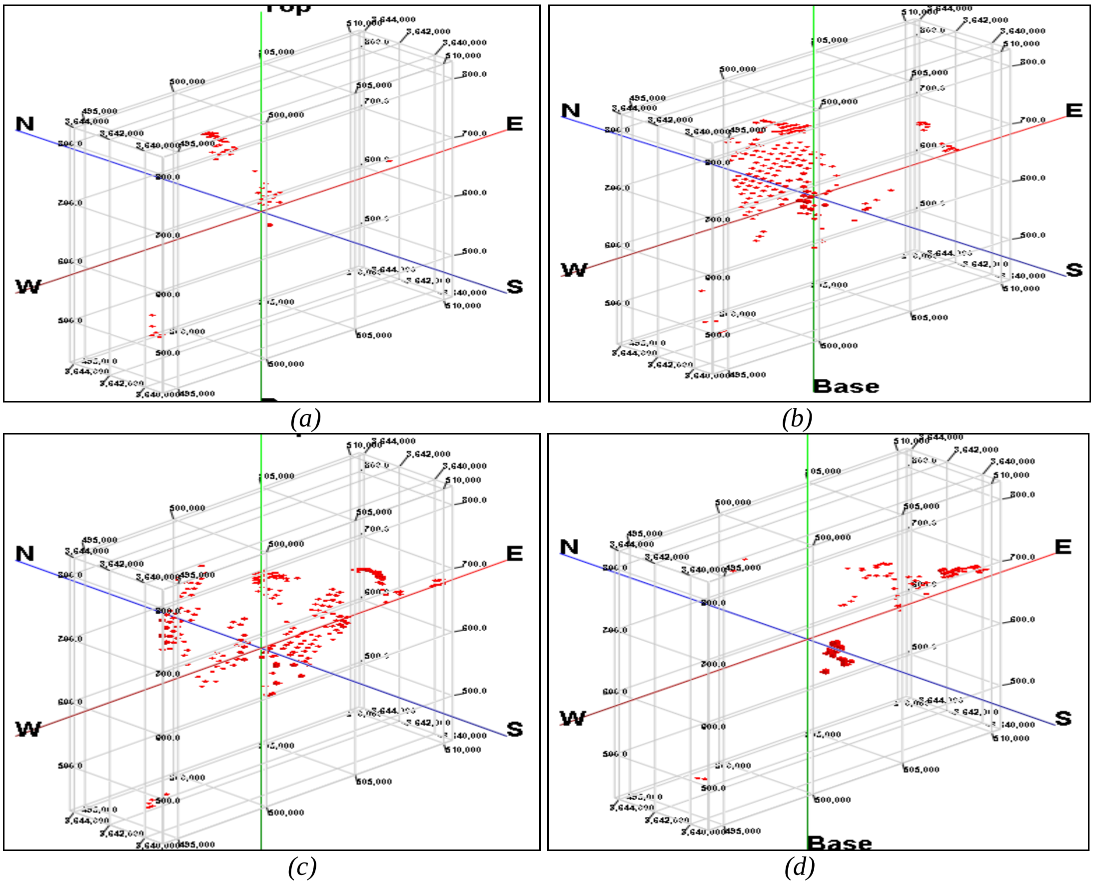


Figure 13. *Sulfur content distribution in seam* B_2 *based on the Russian standard, coal with low-sulfur content (a), medium-sulfur content (b), relatively high-sulfur content (c) and high-sulfur content (d)*

9. Conclusions

Statistical studies, coking coal resource amounts, thickness location and modeling of sulfur and ash distribution based on the USGS and Russian standards illustrate that the C1 seam has the best quality in the north block of Eastern Parvadeh.

Seam B_2 has some positive points but with a negative correlation between thickness-sulfur and thickness-ash. Also, there is 1.6 Mt of coking coals with low-sulfur. The lower tonnage with proper thickness and none sedimentation in the western part of the block are negative points for the seam. The chemical quality of all seams becomes better towards the western part of the deposit. There is an important distinction between the USGS and the Russian standards because the Russian standard does not attend to environmental concerns. This problem is clearly seen in that there are some differences between the USGS and the Russian standards in terms of some factors especially the accepted ash content. Iranian coal washing plants have been designed based on the Russian standard and their associated ash limits for imported coking coals this is 40% therefore this resource is identified as not an environment-friendly, hence ash limits must be changed and also this coking coal has to be blended by coking coals with a low-sulfur content.

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