Determination of the Level of Coal and Productivity in a Coal Field with Well Logging Method

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Received / Geliş: 14th March (Mart) 2016
Accepted / Kabul: 1st August (Ağustos) 2016
DOI: http://dx.doi.org/10.18466/cbujos.07887

Abstract

This study uses geophysical well logs (density logs and natural gamma ray logs) in a coal field to determine coal seam roof and floor depth (limits) and to evaluate coal reserves in the field. To determine the calorific value of the coal, changes in ash content (indicated by density), volatile matter content, moisture content and fixed carbon content are recorded. The potential of the reserve as an energy source for power plant facilities is discussed in terms of efficiency. Therefore it is important to have a realistic evaluation of the thickness of the coal seam and the quality of the coal across the area. The accuracy of the evaluations is dependent upon the density, or spacing, of the test wells, and a grid-based method was used to optimize spacing of the wells.

Keywords — Density log, natural gamma ray log, reserve estimation, thermal power plant

1 Introduction

Well logging is the process of measuring and recording certain physical properties (density, radioactivity, resistivity, temperature, acoustic wave speed, etc.) of formations penetrated by boreholes that are drilled to explore underground resources, as a function of borehole depth. Depending on the physical parameters of the studied formations, different measurement tools are employed for well logging. Physical parameters determined by these tools are used to identify certain characteristics of formations such as porosity, dip, thickness and temperature.

To sustain scientific and efficient methods of mining, well logging applications are mandatory at each stage of mining activities (exploration and operation). Successful results can be obtained in determination of continuity, orientation, and extent of a coal seam using well logging methods, as long as the coal seam is not interrupted.

2 Geology And Tectonics Of The Study Area

2.1 Formation of the Deposit

The region has been affected by a series of tectonic uplift and subsidence events that occurred during the middle Eocene–Pliocene period. This initially resulted in NW–SE-directed, regional-scale gravity faulting and was followed by development of NE–SW-oriented tectonic lineaments, modifying the morphology of the area similar to what is observed today. Neogene sediments were deposited within subsided areas bounded by morphologic ridges corresponding to peneplained old lithologic units.

During the early stage of sedimentation, a period characterized by active tectonism, coarse-grained clastic sediments were deposited along the basin floor and particularly along the basin edges, whereas fine-grained clastic material was deposited in the central portions of the basin. Subsequent slowing down and quiescence of tectonic activity resulted in a predominance of rocks of chemical sedimentary origin, most significantly at the upper levels of the succession. This sedimentation was also accompanied by local volcanic input during the Miocene and more extensively during the Pliocene.

2.2 General Geology of the Study Area

Magnesite that has been identified within the study area is of sedimentary cryptocrystalline origin. It is hosted by dolomite and dolomitic marl lithologies that lie conformably with the surrounding country rocks.

The entire study area is composed of Neogene sediments, and it is characterized primarily by dolomite and dolomitic siltstone lithologies of the Neogene (Upper Miocene–Pliocene) Basin. The succession starts with dolomite, dolomitic marl, tuff, and sandy-silty-clayey rock intercalations. Dolomite at this level appears to be loose and earthy, and it comprises at least 20% clay minerals. Some dolomite strata contain abundant freshwater gastropod fossils. In addition, dolomites have frequently been silicified, most probably due to volcanic activity. These silicified strata occur 5 to 10 m apart, and their thicknesses locally range between 1 and 1.5 m. This section of the succession is characterized by abundant intercalations of dolomite with acidic tuff and sandstone containing volcanic material.

The upper levels of the succession additionally comprise dolomitic marl and detrital sandstone with silty-clayey levels.

White-colored, loose magnesite overlies the aforementioned units. This is followed by intercalations of dolomite and dolomitic marl containing two distinct sepiolitic layers. The top of the succession is characterized by micritic dolomite with a thickness greater than 10 m.

Dolomite observed in the upper parts of the succession is white-gray in color, is thin- or medium-bedded and contains abundant conchoidal fractures. It is micritic, highly fractured and locally brecciated, and it contains clayey (sepiolitic) infillings, particularly along root traces. Brown-colored, organic material-rich clayey levels, which form sepiolite deposits, have dolomite contents of 5% or lower. The color of this unit grades to white with increasing dolomite content. This implies that the color variation observed in the clayey dolomite depends on the relative "clay plus dolomite plus organic material" content.

On the basis of their color properties, clays were classified as green and white clays. Green clays are characterized by smectite-illite-chlorite group clay minerals, and they form bentonite-type clays. Green clays are found as intercalations with pure dolomitic units. These dolomitic units locally contain limestone levels, which occur repeatedly in the northwestern portion of the study area. White-colored clays identified in this facies are sepiolitic clays. Sepiolitic clays usually occur in varying amounts together with dolomites, and they rarely occur as pure layers.

Magnesite that has been exposed within the study area extends from northwest to southeast. It strikes in the NW–SE direction, and dips 10–15° to the southwest.

3 Well Logging Methods Used During Coal Exploration

3.1 Density Logs

3.1.1 Working Principal

The density log consists of a source emitting medium-energy gamma rays into the formation, along with two detectors. The portion containing the radioactive source emits medium-energy gamma rays into the formation while pressed against the borehole sidewall.

These gamma rays are high-speed particles, and they get scattered as they interact with electrons. Once they lose their energy upon interacting with electrons, they are counted by a detector placed at a set distance from the source. Counted gamma rays give an idea about the density of the formation. When the formation density is high, the count rate at the detector will be low since the gamma rays emitted into the formation will be held by electrons, which in turn corresponds to a lower value in the porosity scale [1].

Another critical issue for density logging is that it is more effective when the borehole diameter is small. This parameter is controlled by mounting electrodes on the caliper arms [2]. Figures 3.1 and 3.2 show the caliper arms of the density log and the opening of a caliper during logging, respectively.

Figure 1. Single-arm caliper portion of a density log that is used for diameter measurements

Figure 2. Opening of a caliper during density logging

3.1.2 Bed Resolution Density (BRD)

The BRD log is a high-resolution, short-spaced (0.15 m) density measurement method. This method removes the adverse effects caused by drilling mud and pushes the source toward the wall of the formation. Under favorable borehole conditions, BRD provides the highest accuracy in terms of thickness measurements. This method is always employed in combination with caliper logging, which serves as a quality control for interpreting thickness measurements [1].

3.1.3 High Resolution Density (HRD)

In this method, measurements are taken by pressing against the borehole sidewall, which improves measurement reliability.

3.2 Natural Gamma Ray Log

Some of the naturally occurring elements undergo radioactive decay. Radioactive decay occurs slowly but continuously, and it takes place by the emission of gamma, beta, and alpha rays. Alpha and beta rays only travel distances that are shorter than 2.5–4 cm, whereas gamma rays travel longer distances. All the geological formations in nature contain at least minor amounts of radioactive isotopes of potassium, thorium, and/or uranium. Because of their properties, gamma ray sensors can be used during borehole measurements to classify the lithology on the basis of its radioactivity. Through gamma ray logging, sedimentary lithologies can be divided into rocks and clays. Regardless of porosity all rock units have lower radioactivity values compared to clays. On the other hand, limestone has lower radioactivity than dolomite, and dolomite has lower radioactivity than sandstone. The difference between the radioactivities of shale and clean reservoir rocks can be used to distinguish between those two distinct zones [1].

One of the most important features of a gamma ray log is that the measurements can be made through casing. As a result, this tool can be used for correlation purposes during installation of the borehole as well as during the production stage [3].

4 Geophysical Logs Conducted In the Study Area

Study area and borehole profiles are shown in Figure 4.1.

Figure 3. Study area and borehole profiles

Within the study area, coal seam roof and floor depths (limits) and coal densities (Table 5.1) at seven boreholes were determined using Formation Density and Natural Gamma Ray Logging.

Because of the loose nature of the geological units within the study area, some of the boreholes collapsed during installation. Therefore, density and gamma ray logs were measured through borehole casings, and no caliper was used during measurements.

Measurements recorded included Natural Gamma Ray Logs, Borehole Temperature Logs, High Resolution Density Logs, Bed Resolution Density Logs, and calculated density values. The figures below highlight data from some of the boreholes.

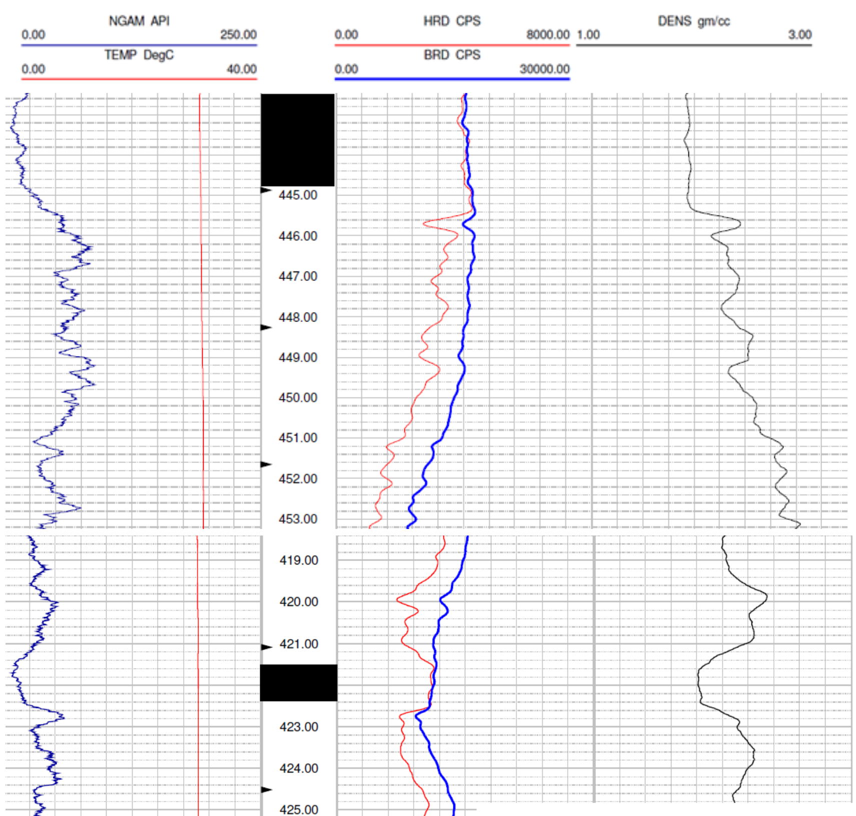

Figure 4. Logging daa of borehole 1

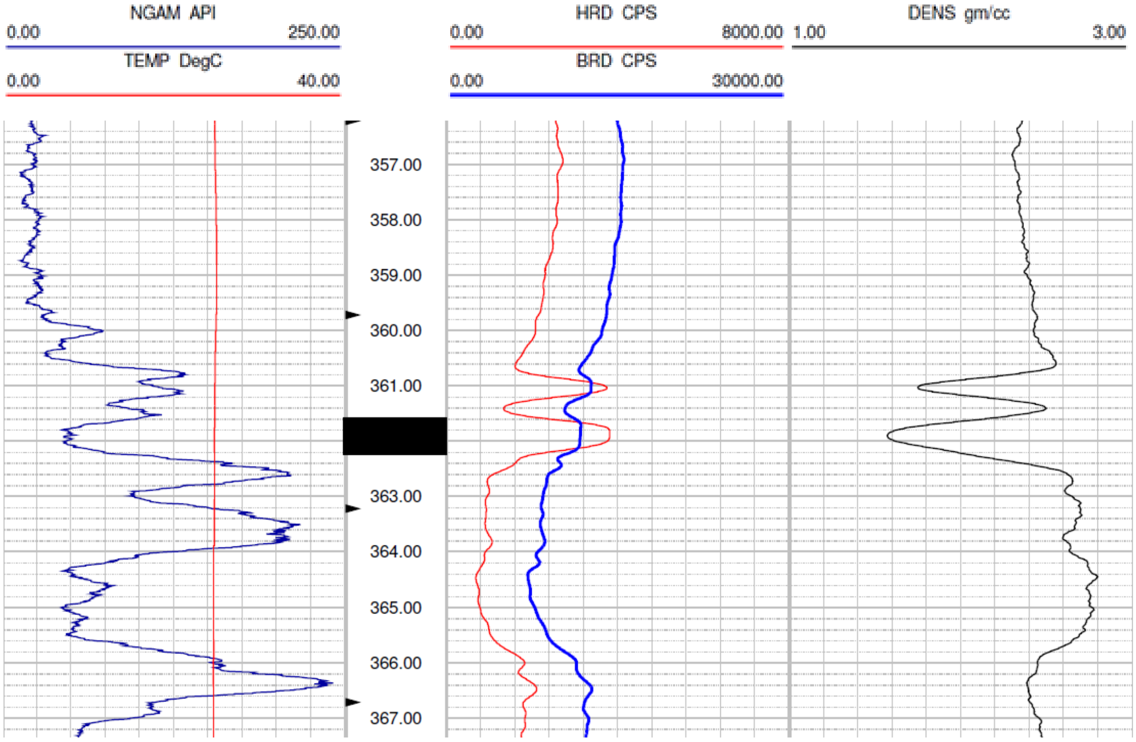

Figure 5. Logging data of Borehole 2

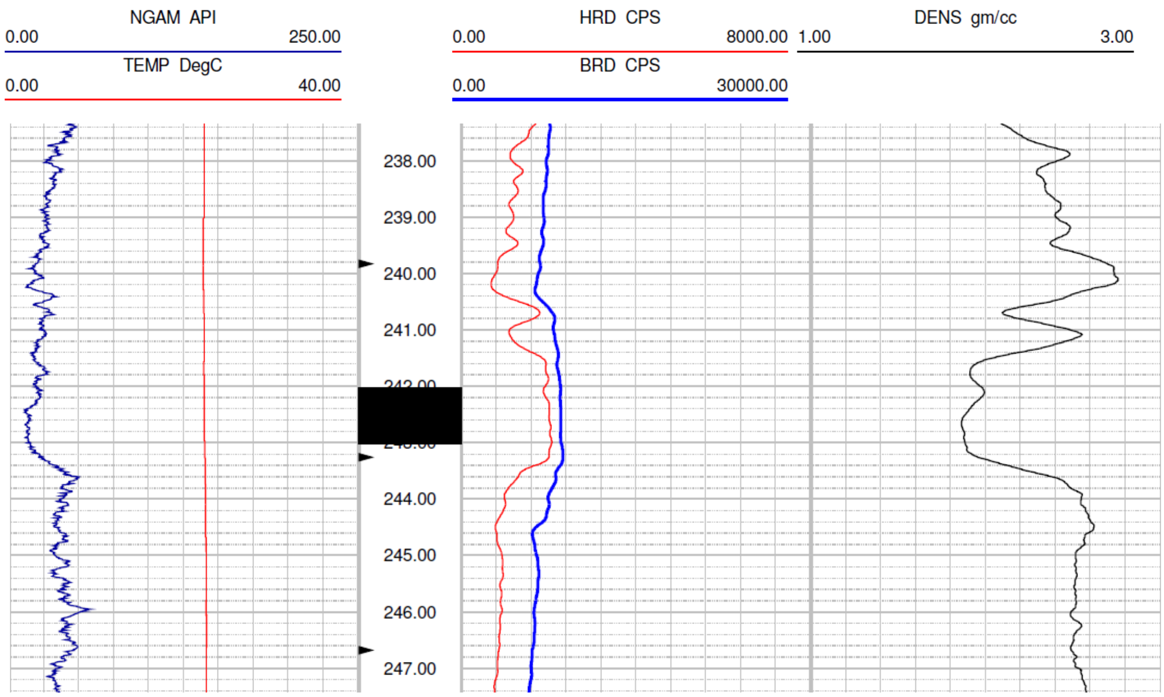

Figure 6. Logging data of Borehole

Logging data of Borehole 1 (Figure 4.2), which has a depth of 477 m, indicates that coal seams are intersected at depth intervals of 421.5–422.5 m and 442.5–445 m.

Logging data of Borehole 2 (Figure 4.3), which has a depth of 376 m, indicates that a coal seam is intersected at a depth interval of 361.5–363 m.

Logging data of the Borehole 6 (Figure 4.4), which has a depth of 434 m, indicates that a coal seam is intersected at a depth interval of 242–243 m.

Coal seams identified in each borehole through well logging (density logs and gamma ray logs) within this coal deposit have been verified by comparison with drill core analysis results.

5 Coal Analysis Results Obtained In The Field

5.1 Characteristic Properties of Coal

Major characteristic properties of coal are: [4].

1. Ash content
2. Fixed carbon ratio
3. Relative moisture content
4. Volatile matter content
5. Lower calorific value

These five characteristic properties can be obtained either by drill core analyses and laboratory studies or by using well logs.
Density, normalized density, ash content, fixed carbon ratio, moisture content and volatile matter content data obtained solely by using well logs (density logs and gamma ray logs) for the identified coal seams from the coal deposit are provided in the table below (Table 5.1).

the Lower calorific value:

$$\text{AID} = \frac{(90-\mathbf{R})(90-\mathbf{K})}{(\mathbf{K}+\mathbf{R})+2} \times 32 \qquad (5.6)$$

Where:
ρ_D : Normalized density (gr/cm^3)
ρ_{log} : Log reading density (gr/cm^3)
V_{ash} : Ash content of the coal (% weight)
V_{fc} : Fixed carbon ratio (% weight)
V_w : Moisture content of the coal (% weight)
V_V : Volatile matter in the coal (% weight)
AID: Lower calorific value of the coal (kcal/kg)
K: Ash content (%)
R: Moisture content (%)

5.1.1 Measurement of coal properties and the model

Normalized density values: [4].

$$\rho_D = \rho_{log} \times 0.9 \qquad (5.1)$$

Ash content:

$$V_{ash} \; 0.65 \times (\rho_D - 1) \qquad (5.2)$$

Fixed carbon content:

$$V_{fc} = 0.512 \; (1 - V_{ash}) \qquad (5.3)$$

Relative moisture content:

$$V_w = 0.461 - V_{ash} \qquad (5.4)$$

Volatile matter content:

$$V_V = 1 - V_{fc} - V_{ash} - V_w \qquad (5.5)$$

In this method, the surface area is split into blocks containing only one borehole (Figure 5.1).

These blocks can be square or rectangular in shape. Boreholes should be located on the intersection points of diagonals for each square or rectangular area. Surface area is multiplied by the thickness of the intersected coal seam to obtain the volume of the block [5].

Block volume is then multiplied by the average density of each block to obtain the tonnage.
Because the dip angle of the coal seam could not be determined by dipmeter logging, reserve estimates were done by assuming a horizontal coal seam.
Data for each borehole used in the grid-based reserve estimation is given in the table below (Table 5.2).

5.2 Reserve Estimate for the Study Area

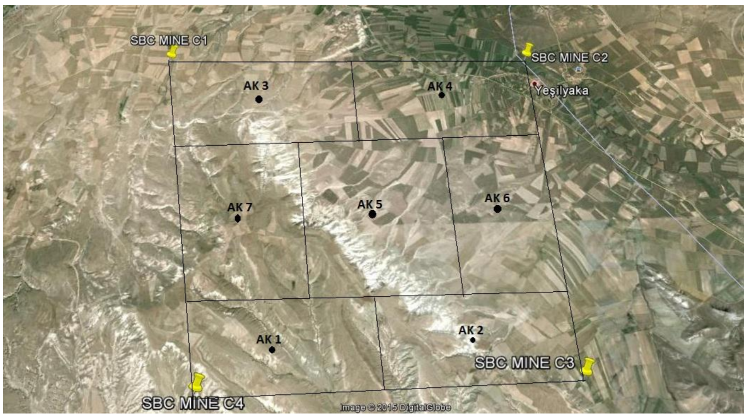

Figure 7. Model of the study area based on the grid method

Table 1. Exploration boreholes and limits, densities, and characteristic properties of the coal seams intersected in these boreholes

SHAFTS	COORDINATES			SHAFT DEPTH (meters)	COAL SEAM DEPTH (meters)		SEAM THICKNESS (meters)	LOG DENSITY VALUES (gr/cm³)	VERIFIED DENSITY VALUES (gr/cm³)	ASH CONTENT of COAL (nominal %)	FIXED CARBON RATIO (nominal %)	MOISTURE CONTENT of COAL (nominal %)	VOLATILE SUBSTANCE CONTENT (nominal %)	LOWER CALORIFIC VALUES OF COAL (kcal/kg)
	X	Y	Z		UPPER LIMIT	LOWER LIMIT								
SHAFT #1	39° 18' 3.39"	31° 55' 32.48"	1046	477	421,5	422,5	1	1,8	1,62	40,3	30,6	5,8	23,3	2784.02
					442,5	445	2,5	1,8	1,62	40,3	30,6	5,8	23,3	2784.02
SHAFT #2	39° 20' 26.08"	31° 54' 51.76"	884	376	361,5	363	1,5	1,6	1,44	28,6	36,5	17,5	17,4	2961.49
SHAFT #3	39° 18' 0.93"	31° 59' 14.41"	807	517	466	467	1	1,6	1,44	28,6	36,5	17,5	17,4	2961.49
					488	491	3	1,8	1,62	40,3	30,6	5,8	23,3	2784.02
SHAFT #4	39° 20' 21.46"	31° 58' 48.96"	745	366	291	292	1	1,6	1,44	28,6	36,5	17,5	23,3	2961.49
					303	304,5	1,5	1,7	1,53	34,4	33,5	11,7	20,4	2896.28
SHAFT #5	39° 19' 10.59"	31° 58' 58.11"	769	370	288	289	1	1,7	1,53	34,4	33,5	11,7	20,4	2896.28
					304	305	1	1,7	1,53	34,4	33,5	11,7	20,4	2896.28
SHAFT #6	39° 19' 13.90"	31° 56' 58.80"	856	434	242	243	1	1,8	1,62	40,3	30,6	5,8	23,3	2784.02
SHAFT #7	39° 19' 06.36"	31° 55' 14.38"	1085	551	427,8	428,8	1	1,8	1,62	40,3	30,6	5,8	23,3	2784.02
					447	448	1	1,7	1,53	34,4	33,5	11,7	20,4	2896.28

Table 2. Results for boreholes that were used for reserve estimation

BOREHOLES	EFFECTIVE AREA (m²)	INTERSECTED THICKNESS (m)	BLOCK VOLUME (m³)	AVAREGE DENSITY (tonnes/m³)	TONNAGE
K1	7020000	3.5	24570000	1.62	39803400
K2	9240000	1.5	13860000	1.44	19958000
K3	6600000	4	26400000	1.53	40392000
K4	4320000	2.5	10800000	1.48	16038000
K5	6000000	2	12000000	1.53	18360000
K6	4320000	1	4320000	1.62	6998400
K7	4560000	2	9120000	1.57	14364000

Total coal volume is calculated as 101,070,000 m³ and total tonnage is calculated as 155,914,200t.

5.3 Calculation Method for Thermal Plant Installed Capacity

Thermal installed capacity:

$$Q \ \text{AID} \times \ (1h/3600 \text{ sec})$$

Q = Amount of coal fed to the power plant in an hour (kg/hr)

AID = Lower calorific value (kcal/kg)

For example, to install a 250 mw thermal plant;

On the basis of the obtained data, the average lower calorific value of the coal is 2865.83 (kcal/kg).

$$Q = \frac{250000 \times 3600}{4.18 \times 2865.83} = 75.13 \text{ tons/hr}$$

6 Results

Using Density and Natural Gamma Ray Logs in the study area, the depth of coal in the survey

Drill holes was determined and the thickness and true density of coal intercepts in each drill hole were possible using drill hole log measurements. As well as this, the characteristics of the coal available to be extracted vary and are reflected in the coal quality and reserve of the site. For this reason, the studies to be carried out on drill hole logs of various drill holes and the necessary key steps are given in this study.

Acknowledgements

I would like to thank my student Semin BAYAR for the help in the preparation of the study and I offer my thanks to Mustafa BAYAR for the support data.

7 References

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