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A study on thermal and electrical characterization of Barapukuria coal of northwestern Bangladesh

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Abstract

The thermal and electrical studies on the recent discovery of Barapukuria coal of northwestern Bangladesh have been carried out to elucidate the characteristics of this shallow basin coal. In addition to that electrical study, proximate analyses were performed using standard methods for rank classification. Coals are found to have low moisture, low ash, medium–high volatile matter and high calorific values and on the basis of that coals are classified as mixture of medium and high volatile bituminous coal. The dc electrical resistivity has been determined as a function of applied voltage, thickness and temperature using the ASTM standard (D 257-78) methods. For voltage variation measurement from 0 to 200 V both lump and powder compact disc samples were used. The lump samples cut parallel and perpendicular to the bedding planes were used to specify the basic structural unit (BSU) of the micro domains. It is observed that variation of resistivity is not highly affected by voltage but trend to decrease. The resistivity increases as the thickness increases and resistivity is greater when the sample oriented perpendicular to the bedding plane than that of samples oriented parallel to the bedding plane, which implies that the coals are electrically anisotropic. The results obtained have been found very similar to those of some Indian, USA (Illinois basin) and USSR (Lisichansk) in terms of their electrical characteristics. The temperature variation resistivity study reveals that the Barapukuria coals are mostly semiconductor in nature. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Bangladeshi coal; Electrical resistivity; The dc conductivity; Semiconductor

1. Introduction

Coal is the most plentiful resource of conventional energy and it forms the backbone of the modern industrial civilization. The efficiency of the process utilized for development of this resource will depend on an adequate knowledge of the physico-chemical properties of coal. Of the physico-chemical properties of coal, the electrical properties are important for its proper characterization. The coal has revealed the existence of aromatic molecular entities, arranged in micro-domains [1,2]. The number and position of the micro-domains vary when the heat treatment temperature increases [3]. Thus, coal is a carbonaceous material, the properties of which can be changed very easily through the modification of the size and the number of the basic structural units (BSU).

The recent discovery of coal mine in the northwestern zone of Bangladesh provides a major opportunity in studying the coal in some details from the mining and processing point of view. The techno-economical feasibility as well as the precursor states for the graphitization of this coal have already been studied [4–11]. Several researchers [12–20] have

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worked extensively on the electrical resistivity of coal. However, no work has been carried out to date on the electrical properties of Bangladeshi coal. It is from this point of view that the present study is directed towards an investigation of the electrical properties of coals, which might help in mining of coal from Barapukuria shallow basin and as well as for better understanding of electrolinking process. The experiments were made with the bright coals of relatively uniform elemental composition.

2. Experimental

2.1. Sample collection

The Barapukuria coal mine is situated in an area of the shallow basement in northwestern zone of Bangladesh. Coal samples were collected systematically from different boreholes of Barapukuria. Twenty coal samples were collected in the form of cylindrical rod having 6 cm diameter from each boreholes GDH-38 and GDH-39 at different depths (160–450 m depth to top). The samples were preserved in air-tight polythene bags. Proximate analyses were carried out according to ASTM standard D 3172 [21].

2.2. Sample preparation

The electrical resistivity of the coal as a function of applied voltage, thickness and temperature was examined using the standard ASTM (D 257-78) method [21]. For the measurements, cylindrical cores of diameter 30 mm and length up to 100 mm were drilled out from the coal samples. Circular discs 5 mm thick were cut from the cylinders. To minimize the contact resistance, the coal of these wafers were polished smooth and then a thin coating of conducting silver paint was applied.

2.3. Guarded electrode

The coal samples thus prepared were kept in a micrometer jig consisting of a lower 30 mm diameter guarded and a upper 50 mm unguarded copper electrodes. The guard ring around the guarded lower electrode eliminated surface currents, and thus, a uniform electrical field was produced in the sample. A ceramic ring was used as an insulator around the guarded electrode to insulate it from the guard ring. A temperature controller circuit was used to control the temperature of the jig sample holder and one thermocouple was kept in contact with the sample to record the temperature. The electrode system was shielded with a Faraday cage to protect it from the external electrical influences.

2.4. Electrometer

A digital keithley electrometer model 614 of keithley Instrument Inc., Cleveland, OH (USA) was used for the direct measurement of resistance at different temperatures. For temperature variation, an inbuilt heater (of the jig) chamber was fabricated using nichrome wire as heating element.

2.5. Electrical resistivity

The electrical resistivity is defined as the electrical resistance offered by as homogeneous unit of cube of material to the flow of a direct electric current of uniform density between two opposite faces of the cube. When the dimensions are in meters the resistivity is expressed in ohm meter. The electrical resistivity is determined by the formula

$$\rho = \frac{RA}{d}$$

where ρ is the electrical resistivity, R the electrical resistance, A the cross-sectional area of the guarded electrode and d the thickness of the sample used.

2.6. Temperature–voltage dependence of dc electrical resistivity

To determine the temperature dependence of electrical resistivity, the first observation was made at room temperature. The sample was then heated up to 573 K at a rate of 1 K min^{-1}. In a similar manner, the voltage dependence of the electrical resistivity was determined for a coal sample orientated parallel to the bedding planes.

To facilitate comparison of the electrical resistivity results with those for USA and USSR coals reported by Dindi et al. [12] and Bondarenko et al. [22], respectively, the same heating rate (1 K min^{-1}) was maintained.

Table 1
Physical properties of GDH-38 of Barapukuria coal[a]

Borehole	Depth (m)	Moisture (wt.%)	Ash (% db)	Volatile matter (% daf)	Fixed carbon (% daf)	Calorific value ($kJ\,kg^{-1}$)
GDH-38	200	3.57	12.15	36.08	48.20	26757
	202	3.20	11.76	35.56	49.48	27567
	205	3.33	9.57	35.55	51.55	28332
	339	2.95	4.45	36.45	56.15	29256
	340	2.60	4.20	36.75	56.45	30814
	345	2.25	3.30	37.25	57.20	28948
	348	2.95	3.67	36.50	56.88	29201
	354	2.15	3.26	33.62	60.97	28995
	365	2.10	2.95	35.26	59.69	29650
	366	2.17	7.25	34.33	56.25	29727

[a] db: Dry basis; daf: dry ash free; GDH: geological drilling hole.

3. Results and discussion

3.1. Proximate analyses

The results of proximate analyses for the coal samples of boreholes GDH-38 and GDH-39 are shown in Tables 1 and 2, respectively. The proximate analyses reveal that Barapukuria coals are classified as the higher rank of bituminous coal.

3.2. Thermogravimetric analysis

The TGA and DTG scans were carried out from room temperature to 800°C under nitrogen flow at a heating rate of $10°C\,min^{-1}$. A Mettler M3 balance, TG 50 furnace and microprocessor TA-3000 system were used for TG analysis.

Fig. 1 shows the TGA and DTG traces of GDH-39 coal sample. There are two temperature regions observed for weight loss: one in the low temperature region from 35 to 120°C, where water loss is expected and the total moisture content is calculated to be about 2.0–3.5% and in the temperature region 250–800°C, where weight loss is due to the removal of volatile material of about 17–27% by primary and secondary volatization.

3.3. Effect of thickness

Fig. 2 shows the variation of dc resistance versus thickness for coal samples cut parallel and

Table 2
Physical properties of GDH-39 of Barapukuria coal[a]

Borehole	Depth (m)	Moisture (wt.%)	Ash (% db)	Volatile matter (% daf)	Fixed carbon (% daf)	Calorific value ($kJ\,kg^{-1}$)
GDH-39	172	3.25	6.75	32.85	57.15	29131
	176	3.40	7.86	30.95	57.79	29115
	179	3.45	8.75	29.75	58.05	28556
	182	2.95	9.25	27.56	60.24	28325
	183	3.10	7.36	30.36	59.18	29230
	186	3.33	5.76	30.77	60.14	28193
	189	2.76	7.28	30.76	59.20	29989
	192	2.85	6.87	28.67	61.61	29387
	193	3.20	9.67	29.45	57.68	28596
	195	3.28	10.25	29.48	56.99	28978

[a] db: Dry basis; daf: dry ash free; GDH: geological drilling hole.

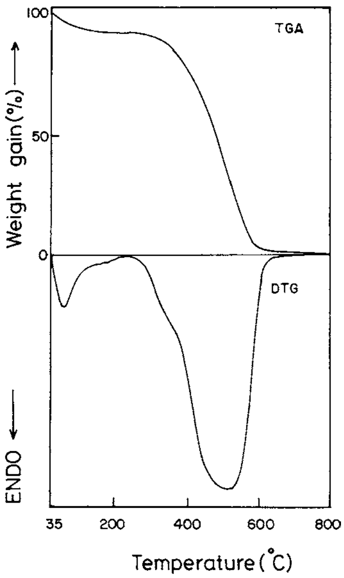

Fig. 1. TGA and DTG traces of GDH-39 coal sample.

perpendicular to the bedding planes from which R_c can be inferred. From the intercept of a plot of resistance and sample thickness, contact resistance (R_c) was determined which must be subtracted from the measured resistance in order to calculate the resistivity. The value of R_c is found higher for samples cut perpendicular to the bedding planes relative to those cut parallel implies that the coals are electrically anisotropic and the number of BSU of the microdomains is more in that parallel position.

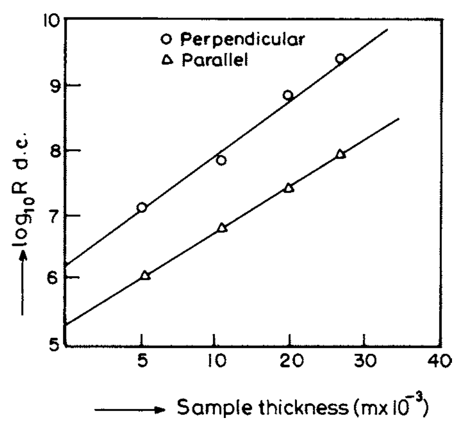

Fig. 2. Variation of dc resistance with sample thickness: sample (GDH-38, D-348) oriented perpendicular (○) and parallel (△) to the bedding plane.

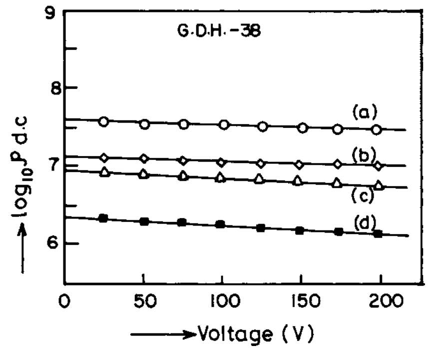

Fig. 3. Variation of dc resistivity of lump sample with voltage. Sample oriented parallel to the bedding plane at depth: (a) 200 m; (b) 205 m; (c) 339 m; (d) 345 m.

3.4. Effect of voltage

Voltage versus dc electrical resistivity (in log scale) is plotted in Figs. 3 and 4. The applied voltage has practically no effect on the resistivity in the region 0–200 V but trends to decrease while the temperature has serious effect on the variation of resistivity. For compact powder disc sample, the same trend was observed. Considering the effect of voltage on the electrical resistivity of the coal samples, it is clear from the Figs. 3 and 4 that the effect of voltage up to 200 V is not very significant, with a voltage increases from 25 to 200 V causing the dc resistivity to change from 7.58×10^7 to 6.40×10^6 Ω m for GDH-38 samples and 8.2×10^8 to 6.15×10^6 Ω m for GDH-39 samples only.

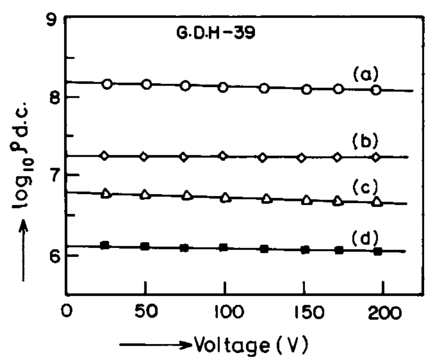

Fig. 4. Variation of dc resistivity of lump sample with voltage. Sample oriented parallel to the bedding plane at depth: (a) 172 m; (b) 179 m; (c) 192 m; (d) 195 m.

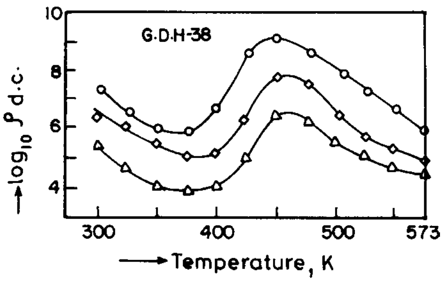

Fig. 5. Variation of dc resistivity of lump sample with temperature. Sample oriented parallel to the bedding plane at depth: (a) 205 m; (b) 339 m; (c) 345 m.

3.5. Effect of moisture

Figs. 5 and 6 demonstrate the importance of moisture on resistivity. At lower temperature resistivity decreases from 7.35×10^7 to 4.11×10^4 Ω m for GDH-38 and 6.8×10^6 to 3.15×10^3 Ω m for GDH-39 coal samples due to the increase in the mobility of current carrying impurity ions and moisture. Since their kinetic energy is raised as a result removal from the lattice becomes easier [23]. The removal of moisture is accompanied by a characteristic change in resistivity. The greater the initial moisture of coal, the greater will be the change in electrical resistivity on evolution of moisture. When moisture removal begins near 373 K, the resistivity increases rapidly reaching a peak near 450 K in the order of 10^8 Ω m, after which it decreases in the order of 10^4 Ω m probably due to devolatization of hydrocarbon gaseous product. The release of gases results in a relative increase in the free carbon content of the residue.

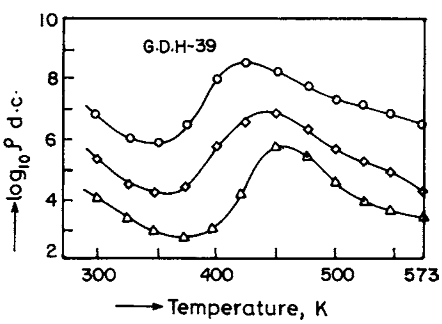

Fig. 6. Variation of dc resistivity of lump sample with temperature. Sample oriented parallel to the bedding plane at depth: (a) 179 m; (b) 192 m; (c) 195 m.

The reduction in resistivity at low temperature can also be explained in a different approach that due to the use of direct current in the measuring circuit, there is some possibility to be the formation of charge transfer complexes between the aromatic or hetero aromatic organic molecules of the coal and some of the ionic impurities.

3.6. Temperature dependence dc electrical resistivity

The relation between the electrical resistivity and the temperature above 373 K for coals may be described by the following formula depending on whether the sample is a semiconductor or a dielectric:

$$\rho_t = \rho_0\, e^{E/2KT} \quad (1)$$

$$\rho_t = \rho_0\, e^{E/KT} \quad (2)$$

where ρ_t the resistivity at given absolute temperature *T*, *E* the activation energy, *K* the Boltzmann's constant and ρ_0 is a constant. Where there is a change in the slope of the curve between the temperature and resistivity, the result may be better explained by the sum of two terms as below

$$\rho_t = \rho_{01}\, e^{-E_1/KT_1} + \rho_{02}\, e^{-E_2/KT_2}$$

The first term of this combined equation corresponds to the mechanism of conduction in the low temperature region while the second term for high temperature.

Coal is complex mixture of organic and inorganic species. Inorganic part is the mineral matter. Thus, the ash content of this coal in an average is 8 wt.%. The difference between the resistivity values for parallel and perpendicular to the bedding plane shows that electrical conductivity of this coal is strongly affected by the presence of aromatic matrix only rather than mineral matter. The lower the resistivity of coal will be ascribed to the condensation of aromatic ring compound materials.

Although above the 573 K, the resistivity has not been measured but it would appear from the trend of the curve and the formula that the resistivity will go on decreasing with the increase in temperature and the coal would show the semiconductor in nature. These results indicate that there is a great similarity between

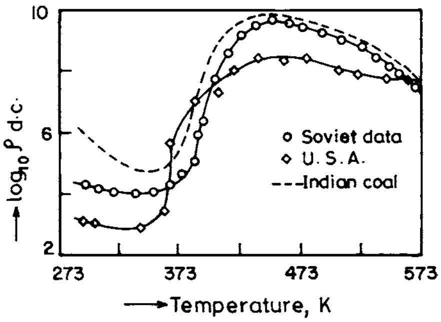

Fig. 7. Electrical resistivity versus temperature for Illinois basin bituminous coal (USA) as compared with Lisichansk (USSR) coal and Indian (Hariajam) coal.

the Bangladeshi, Indian, USA and USSR coals (Fig. 7) interms of the their electrical resistivity characteristics. To some extent, Bangladeshi coal shows semiconducting nature.

4. Conclusion

The voltage seems to have no effect on the electrical resistivity of coal. However, the electrical conductivity of coal is greatly affected by the presence of organic matter, resistivity being lower for organic matter than that of the mineral substance. The electrical resistivity characteristics of Barapukuria coal with respect to temperature are similar to those of USA (Illinois basin), USSR (Lisichansk) and some Indian coals. This property could be useful in determining the electrolinking characteristics of Bangladeshi coal with other similar coals.

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References

[1] P.L. Walters, in: Proceedings of the 5th Conference on Carbon, Vol. 2, Pergamon Press, Oxford, 1963.
[2] A. Oberlin, G. Terriere, J.L. Boulmier, Tanso 80/83 (1975) 29, 153.
[3] F. Carmona, P. Delhaes, G. Keryer, E. Manccau, Stat. Commun. 14 (1974) 1183.
[4] J. Podder, T. Hossain, Kh.M. Mannan, D.A. Begum, Fuel Sci. Technol. 3 (1994) 93.
[5] J. Podder, T. Hossain, Kh.M. Mannan, Thermochim. Acta 255 (1995) 221.
[6] J. Podder, T. Hossain, Thermochim. Acta 284 (1996) 279.
[7] J. Podder, T. Hossain, Indian J. Phys. 71A (2) (1997) 225.
[8] J. Podder, T. Hossain, in: Proceedings of the 9th International Conference of ICCS'97 on Coal Science, Vol. II, Essen, Germany, 7–12 September 1997, p. 909.
[9] J. Podder, T. Hossain, J. Bangladesh Acad. Sci. 22 (1) (1998) 71.
[10] J. Podder, S.A. Tarek, T. Hossain, Indian J. Phys. 73A (3) (1999) 283.
[11] J. Podder, S.A. Tarek, T. Hossain, in: Proceedings of the 10th International Conference of ICCS'99 on Coal Science, Vol I, Taiyuan, China, 12–17 September 1999, p. 93.
[12] H. Dindi, X. Bai, W.B. Krantz, Fuel 68 (1989) 185.
[13] A.F. Baker, G.A. Brady, J.W. Eckerd, US Bureau of Mines (R.I.), 1966, p. 6788.
[14] J.M. Alexander, H. David, J.H. Peter, A.P. Richard, Fuel 73 (5) (1994) 731.
[15] A.J. Sharp, Fuel 66 (1987) 1487.
[16] S.N. Tiwary, Mukhdeo, Fuel 72 (1993) 1099.
[17] A. Duba, Fuel 56 (1977) 441.
[18] A. Duba, Fuel 62 (1983) 966.
[19] K. Rajeshwar, R. Nottenburgh, J. Dubow, R. Rosenvold, Thermochim. Acta 27 (1978) 357.
[20] T. Hossain, N. Zaman, A.B.M. Shahjalal, A. Hossain, T. Hossain, N.Z. Ara Ahmed, Thermochim. Acta 189 (1991) 235.
[21] ASTM Standard Test Method: D 257-78, Annual Book of ASTM Standard, Vol. 10.02, ASTM Philadelphia, 1986, p. 48.
[22] S.T. Bondarenko, B.K.H. Brodskya, S.N. Lyandres, E.A. Meerovich, V.I. Pan-Kovskii, A.D. Reznikov, Academy of Science of the USSR, Moscow, 1959, Lawrence Livermore Laboratory, UCRL-TRANS-11050, 1976.
[23] V. Rzhevsky, G. Novik, The Physics of Rocks, Mir, Moscow, 1971 (A.K. Chatterjee, Trans. from Russian).