ISSN: 2278-4632
Vol-11 Issue-01 March 2021

PREPARATION OF HIGH ASH NON-COKING COAL USING TRIBO-ELECTROSTATIC METHOD

J. P. Giri[1], Ramesh Chandra sidu[2]

[1]Professor, Department of Mechanical Engineering, Raajdhani Engineering College, Bhubaneswar, Odisha

[2]Assistant Professor, Department of Mechanical Engineering, Raajdhani Engineering College, Bhubaneswar, Odisha

ABSTRACT

The triho-electrostatic method is used to process non-coking Indian thermal coal from the Ramagiindain coal mines, which contain around 45% ash. The microscopic examinations showed that the predominant minerals in the coal, aside from quartz and kaolinite, are iron, goetliite, siderite, and pyrite. Different tribo-charger materials made of A1, Cu, bi ass, perspex, and teflon have been used for contact elecir ification of ash-forming minerals and coal matter. The Cu tribo-charger was discovered to be ideal for acquiring differential charge between inorganics that form ash and coil matter. The size of contact char ge acquisition was shown to be significantly affected by the /gmperaiii'e effect. Tests on a laboratory-built electrostatic free-fall separator with a 300 nanometer coal fraction were conducted.

Keyword: *Ash, coal, triho-electrostatic method*

1. INTRODUCTION

Since coal is the most abundant fossil fuel in India, a significant increase in the nation's power production will be based on this fuel in the future to fulfil the rising demand for home, industrial, and agricultural sectors. More than 75% of the non-coking coal generated in India is used to produce electricity. Currently, 200 million tonnes of coal are utilised annually to generate electricity, with an average ash content of above 40%. Because they are of drift origin, the majority of India's non-coking coal reserves are of lower quality. The majority of thick seams are naturally banded. Since there is a lot of ili ash in the coal in these seams, the quality suffers as a result of these bands. The bands themselves typically have a carbonaceous composition.

Given that coal is the most plentiful fossil fuel in India, the country will rapidly increase its power output in the future to fulfil the rising demand for home, industrial, and agricultural sectors. In India, electricity production accounts for more than 75% of non-

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coking coal production. Currently, approximately 200 million tonnes of coal are used annually to generate electricity, and the average amount of ash per coal is consistently over 40%. The majority of India's non-coking coal reserves are of lower quality since they are of drift origin. The majority of thick seams have bands in them. Because of the high levels of ili ash in these seams, the quality of the coal deteriorates. Typically, the bands themselves are of a carbonaceous composition.

The power plants mainly use pulverised coal instead of lump coal for greater efficiency of boilers and the coal fired plants in India are among the most polluting sources as indicated by environmentalists and pollution control agencies. Recent environmental regulations prohibit using high ash coals in power plants due to the generation of huge quantities of fly ash effecting the atmosphere and aesthetics of the nearby plant area. With this background, a project on “Electrostatic Beneficiation of Indian Thermal Coal5” has been undertaken at Lulea University of Technology, Lulea, Sweden, in collaboration with Regional Research laboratory, Bhubaneswar and National Thermal Power Corporation, Noida, financially supported by the department for research c0operatIon of the Swedish international Development Cooperation agency (SIDA). In this paper, the results achieved on coal with 45% ash content by tribo-electrostatic method have been presented and discussed the methods potential for the beneficiation of non-coking thermal coals.

2.THEORY OF TRIBO—ELECTROSTATIC SEPARATION

In order to fulfil the rising demand for electricity in the household, industrial, and agricultural sectors, fast increases in the country's power output will be based on coal, the most abundant fossil fuel in India. The production of non-coking coal in India is utilised to produce more than 75% of the country's electricity. The average ash content of coals is generally above 40% at the present time, and nearly 200 million tonnes of coal are used annually for power generation. Since they are primarily of drift origin, India's non-coking coal reserves are generally of lower quality. In nature, most thick seams are banded. Since of these bands, the grade of the coal decreases because the coal content in these seams contains a large amount of ili ash. Typically, carbonaceous material makes up the bands themselves.

When two metals of different work functions, \$p, and \$p, (eV), are brought into contact and then separated, the Fermi levels of the two metals coincide and a potentla1 difference V_c is establlshed across the interface. Harper (1951) suggested that they will exchange electrons by tunnelling so that thermodynamic equilibrium is maintained. The contact potential difference is given by:

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V_c =(___") where e is the electron charge 1.6 x 10 " C

e

The charge transfer Q during the contact is:

$$Q = CV_c = C\frac{(\phi_{M1} - \phi_{M2})}{e}$$

where C ls the capacitance between two adjacent bodies. The capacitance C is given by: -

where A is the effective area of contact, z is the separation at contact, s is the permittivity of free space = 8.85 x 10 " Fm '

The surface charge density that can be generated during contact is:

$$\sigma = \frac{Q}{A} = \frac{\varepsilon_0}{z}\frac{(\phi_{M1} - \phi_{M2})}{e}$$

When two bodies are separated after contact the capacitance C decreases and Q decreases until charge exchange by tunnelling ceases. Harper (1951) investigated that at about 1 nm distance the cut off of tunnelling current is abrupt and for a sphere plane geometry, C is given by:

C —4ss,,r 0.577 +0 $2r$

where r is the radius of sphere and z is the distance of at which tunnelling ceases. A semi-quantitative agreement between theory and experiment had obtained by usinp• the tunnelling cutoff distance of z = 1 nm. Lowell (1975) investigated with real material with rough surfaces and showed that the capacitance can be better estimated by taking into account the fact that most of the two surfaces are separated hy much larger distances when closest point of separation is at I nm.

lnculet and co-workers (1982) analysed maceral fractions of electrostatically beneficiated coal and found that different maceral types acquired different charge polarities. By petrograph lc analys is they found that a major portion of the vitrinite charged posltively while inertinite charged negatively. The larger pores present in inertinite are thought to cause the preservation of the original plant cell structure in this inaceral type harbouring negatively charged minerals not liberated by grinding. Several studies showed that clean coal generally charges positively and ash-forming minerals or high- ash coal charge negatively (Carta et al. 1976; Lockhart 1984; Alfano et a1. 1988). Coal matter can acquire negat ive and positive

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charge when the carbonate (e.g., limestone and do torn lte) and s ilicate (e.g., shale, slate or marls) gangue are present respectively. In both cases, good separation was achieved (Ciccu et at. 1991). Test results indicate that a variety of coals and different classes of particle s ize sulphides and silicate impurity minerals can be removed efficiently by triboelectrostatic beneficialion process under appropi iate conditions (Finseth et at. 1993). Temperature and moisture played an important role in charging the coal. Large moisture content reduces the degree of charging, but it is not clear whether the driest materials had the best charging properties (Mazumder et al. 1995; Kwetus 1994).

3.EXPERIMENTAL

3.1.Sample Preparation

Since coal is the most plentiful fossil fuel in India, a significant increase in the nation's power production will be based on this fuel in the future to fulfil the rising demand for home, industrial, and agricultural sectors. More than 75% of the non-coking coal generated in India is used to provide electricity. Almost 200 million tonnes of coal are utilised annually to generate electricity at the moment, with an average ash content of over 40%. The vast majority of India's non-coking coal deposits are of lower quality since they are of drift origin. The majority of thick seams are often banded. Because of the high levels of ili ash in these seams' coal content, the grade of the coal deteriorates as a result of these bands. The bands themselves are typically of a carbonaceous origin.

3.2. Tribo Charging and Charge Measurement

The effect of tribo-charger material on charge acquisition by the independent mineral phases has been studied using a cylindrical rotating drum (diameter 0.095m and length 0.095 m) where the inside lining can be replaced by copper, brass, steel, aluminium, Teflon, Perspex and PVC materials. A 10 g of minus 100 microns size mineral particles are tribo-charged for a fixed time interval and afier contact charging, the particles charge polarity and magnitude are measured by Keithley electrometer.

The coal samples were dried in an oven at l00°C. Then the coal is passed through the vibratory feeder fitted with a copper plate. On sliding through the copper plate, the maceral and mineral particles acquired charge based on their work functions due to frictional charging. The charge acquired by the samples collected at different bins after passing through the electrlc field have been measured using Keithley electrometer fitted with Faraday cup.

3.3.Tribo-E lectrostatic Test Procedure

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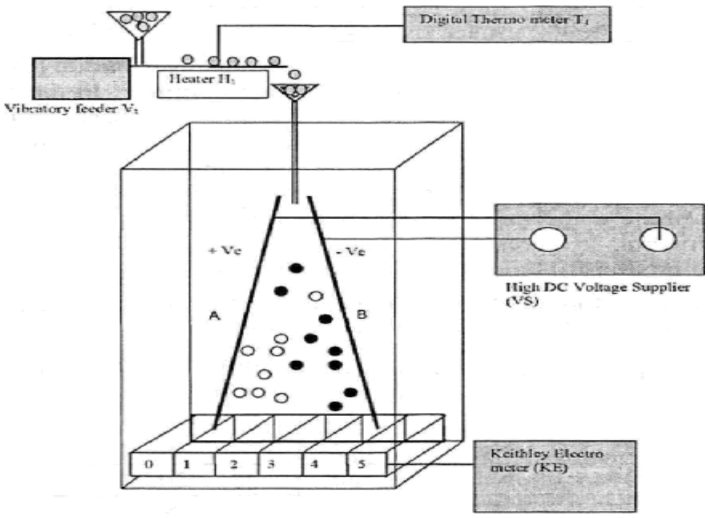
Fig. illustrates the tribo-electrostatic experimental setup for separating coal macerals from ash-forming minerals. 1. It comprises of a Perspex box with two copper plate electrodes attached, a high voltage Dc voltage source, a vibratory feeder with a hopper, a heater, a



digital thermometer, and a Keithley electrometer (KE). There is a setting that allows you to

hange the degree of inclination and the distance between the copper electrodes. You can choose from a variety of tribo-charger plates composed of Cu, Al, Steel, Perspex, PVC, and Teflon to replace the vibratory feeder plate. The tribo-charger is kept at a constant temperature by a thermostat located beneath the feeder plate, and a digital thermometer has been used to track the temperature. For the present investigation the top and bottom electrode plate gap is maintained at 0.075 and 0.325 m respectively. The electrode A has been connected to *ve supply source while electrode B is connected to —ve supply source. The electrodes can be charged with a high DC voltage power supply. There are six collecting b ins of 0.52x0.065x0.008 in size below the electrode plates to collect the material after passing through the electric field.

Ramagundam coal of -300 micron size fraction has been used in the present investigations. The D9 size is 238 microns and the mean diameter of the particles is 88.91 microns. The coal sample was dried at l00°C in an oven before subjecting to the vibrating feeder (V,). A copper plate on the top of vibrating feeder plate acts as copper tribo-charging medium. The feed rate was slow enough that only a single layer of particles sliding over the tribo-charger. Then the particles travel through the funnel shaped copper pipe and fall between the electrode plates. The negatively charged particles are attracted by the positive

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electrode and collected at bin 1 while the positively charged particles are attracted towards negative electrode and collected at bin 4. The uncharged and weakly charged particles are collected at bin 2 and 3. The collected samples in all the bins are subjected to proximate analysis. Te5ts were conducted at three electrode voltages of 10, l5 and 20 KV. The temperature maintained during tribo-charging was in the range of 18-78°C (18, 63, 78^{0} C).

4.RESULTS AND DISCUSSION

4.1.Coal Characterisation

The proximate analys is of Ramagundam coal is presented in Table 1, which shows a h igh ash content of 43.2%. Washability studies for two coal size fractions of -150 mm and -1 mm were performed to evaluate the potential of clean coal separation and the results are showR In Fig. 2. It can be seen that a clean coal with only 25% ash and about 65% yield is obtainable from both the coal samples, illustrating the non-liberation of coal at these s ize ranges. Accordingly, a finer coal size fraction of - 300 microns is prepared for the tribo-electrostatic separation tests.

Table 1: Proximate Analysis of Coal Samples

Name of coal	**Moisture,** %	**VolatiIe** Matter, %	Ash, %	**Fixed Carbon,** %
Ramgundam coal	5.79	23.52	43.22	33.26

Microscopic study reveals that all three maceral groups of vitrinite, liptinite (exinite) and inertinite are present in the coal. The col]ote1inite of vitrinite groups are dominant in the coal. V itrinite group of inacerals includes very fine grains of mineral matter. The mineral phases in the coal detected under visible light with decreasing order are quartz, clay, pyrite, magnetite and goethite. However, the mineral matter identified by XRD includes quartz, illite, kaolinite, montmorillonite, goethite, siderite and pyrite. The relative proportion of mineral phases in coal is presented in Table 2. Quartz is the most dominate mineral phase and found to concentrate in both float and sink fractions of washability studies. Though clay minerals are present next to quartz, only illite is detectable in size fractions of bulk coal. Kaolinite and montmorillonite are also found in both float and sink fractions.

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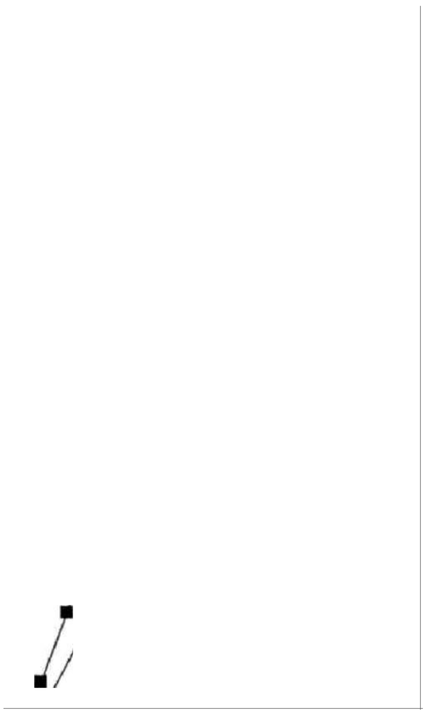
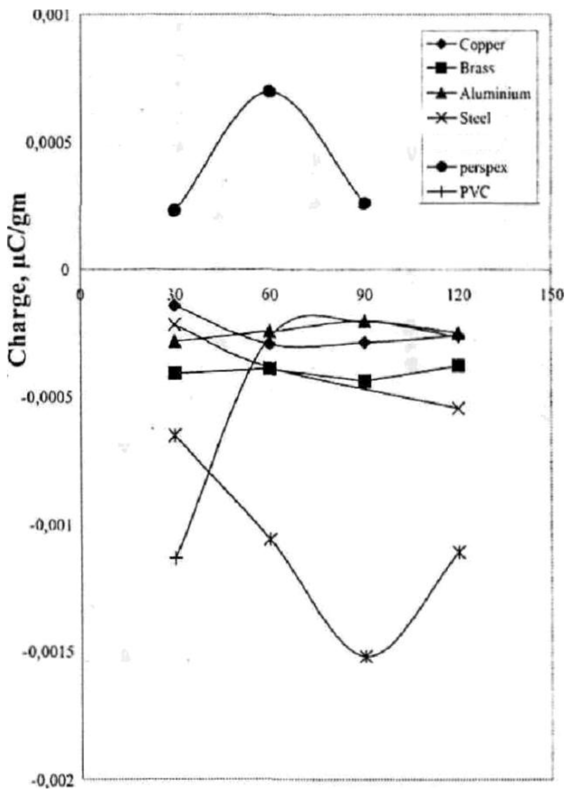
Table **2: Mineral** Matter of Ramgundam Bulk **Coal Ash** (LTA) (Peatt Intensity Given to

Details **of sample**	Quartz	I llite	Kaolinite	bOOtNtOl lOWEO	Goethite	Siderite	Pyrite
Bulk	3588	142	Nil	Nil	117	Nil	Nil
+l50mm 1.8Sink	3318	Nil	1183	Nil	196	110	67
+l00mm1.8F1oat	3745	Nil	449	202	Nil	Nil	42
+l00mrn1.4F1oat	2704	Oil	756	Nil	Oil	Nil	48

Indicate the Relative Quantity)



“•^ 50 mm coai



Cu m. Ash%

Time. Sec

Fig. 2: Washability Study of Ramagundam Coal Effect of Tribo-Charging Medium

Fig. 3: Influence of Tribo-C hzrging Time on Charge Acquisition by Quartz Particles

The results obtained for quartz after contact electrification with different tribo-charger materials are shown in Fig. 3. It can be seen that quartz acquired negative charge while

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contacting most of the materials except Perspex where it acquired positive charge. These results are in good agreement with the reported work function values of copper, brass, steel, aluminium and PVC of 4.38, 4.28, 4.10, 4.28, and 4.85 respectively (Davies 1969; Trigwell et al. 2001). Quartz has higher work function 5.4 (Kim et a1. 1997) than the tribo-charger materials and accepted the electrons from these materials and charged negatively whereas it charged positively with Perspex which has higher work function than quartz. The results also show that with increasing the contact charging time the charge acquisition increased marginally for copper, brass and steel.

The effect of tribo-charger medium on coal separation is shown in Fig. 4. In these tests, a particle size fraction of -300*21 0 gm coal was tribo-charp•ed for 5 min with each of the tribo-charger materials of copper, aluminium, brass, tefion and perspex. After tribo-charging with a specified material, the particles are allowed to fall freely between the two electrode plates. The applied voltage is kept con5tant at 15 KV. The results show that copper tribo-charger gave better separation in comparison to other tribo-chargers and therefore the copper tribo-charger has only been used as the tribo-charging medium in further tests.

4.2. Effect of Voltage

The effect of voltage on the electrostatic separation of particles tribo-charged at three different temperatures of 18, 63 and 76°C has been studied. The applied voltages in these tests *â e* 10, 15 and 20 KV. The charge acquired by the particles has been plotted against the particles collected at different bins in Figs. 5-7. As shown in the experimental set-up, bin 1 is close to the positive electrode while ihe bin four is nearer to the negative electrode. The particles collected at different bins are

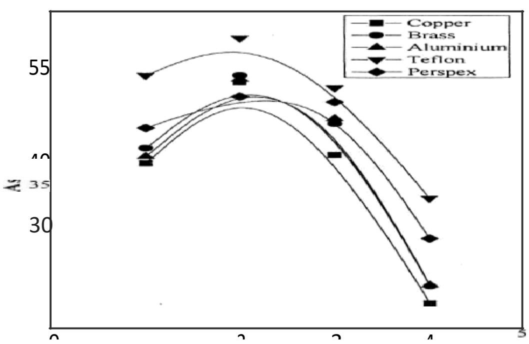

Fig. 4: Bin Number Verses Ash% of Coal Collected

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negatively charged but the magnitude of charge decreases with the bins from positive to negative electrode (Fip•. 5). Generally, the more negatively charged particles are attracted by the positive electrode and collects in bin one while the positively charged particles get attracted towards nep•ative electrode and fall in bin four. The net charge acquired by the particles collected in bin four is found to be negative. This may be due to non-liberated coal particles and/or coating of fine coal particles over mineral particles where the overall charge acquisition of particles became negative and the particles are deflected towards positive electrode. Thus the partIcles are widespread based on the magnitude of particles negative charge. Ciccu et al. 1991 observed that coal matter acqulres negative and positive charge when the carbonate (e.g. limestone and dolomite) and silicate gangue are present respectively. In both the cases, good separation was achieved. lt is interesting to note that with the increase in voltage from 10 to 20 KV, the charge acquired by the particles collected at each bin also increases. With increasing voltage, the electrostatic field generated withln the electrodes also increases which intern pulled more oppositely charged particles and the net acquisition of charge increases. The paHicles collected at bin 2 and are al most constant for 10 and 15 KV voltage where as there is a difference in charge for 20 KV voltage.

Figure 6 shows the results of particles charge collected at different bins when the particles are tribo- charged at 63°C. It can be seen from the figure that at 10 KV voltage, the char•pe acquired by the particles increases with increasing bin number, i.e., the bins from positive to negative electrode. At a higher voltage, the charge of the particles collected at bin one decreases and in bin four, the charge increases. The hijher temperature during ti ibo-charging causes more electron transfer from outermost orbit due to excited electrons and a different map•nitude of negative charge acquisition by the particles takes place leading to a different distribution of particles in the bins.

The charge acquisition of particles collected at different bins after copper tribo-charging at 76'C is shown in Fig. 7. These results are comparable to the results shown in Fig. S. The partlcles negative charge decreases from bin one to four at 10 and 15 KV voltage whereas at 20 KV, the chars e is almost the same. Since all the particles acquired negative charge, there is an optimum voltage for a g o0d

separation between strong negatively charged paHicles containing more mineral matter and weak negative particles with more coal matter.

4.3. Effect of Temperature

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The influence of temperature on charge acquisition by the particles collected in bin 1 (close to positive electrode) and in bin 4 (close to negative electrode) at different voltage is shown in Fig. 8 and 9 respectively. The results show that the char$_g$ e acquired by the particles increases with increasinp• temperature. The increase in temperature during tribo-charging brings about more excited state of electrons in the outermost orbit leading to better electron transfer from the tribo-char•ger to the particles and vice-versa. Similar behaviour of particles charge with temperature also reported by Alfano et al 1985. At l8°C the charge acquired by the particles in bin one at 10 KV voltage is les5 than at 20 KV applied voltage. But with increase in temperature, the charge is higher with decreasing voltage. Similar charge acquisition behaviour with increasing temperature is also seen with the paHicles collected in bin 4 (Fig. 9).

4.4.Tribo-Electrostatic Separation of Coal

The results of electrostatic coal separdtlon after contact electrification with copper tribo-charger at 18, 6? and 76°C are presented in Fip•s. 10, 1 1 and 12 respectively. The effect of applied voltage on coal separation is also depicted in these figures. It can be seen from Fig. 10 that low ash coal is recovered at the bin close to negative electrode (bin 4) whereas high ash coal is collected at the positive electrode (bin 1) and the ash percentage decreases from bin one to bin four. The results once again illustrate that coat particles are positively charged relative to the inorganic matter and accordingly the low ask coal particles are collected at the negative electrode. A clean coal of 18% ash is collected at bin 4 and it is possible to beneficiate the 43% ash coal by tribo-electrostatic method. The increase in A pp!i$_{I2}$d voltage is seen to increase the ash percentage of clean coal. The results at hig her temperatures during tribo-charging also 5how similar behaviour and the low ash coal is recovered at the negative electrode. I n these cases, a coal with an ash percentage of 23.12 and 24.57 is respectively obtained at 63 and 76°C tribo-charger temperatures. Although the charge polarity of inorganic matter and coal particles expected to be different after copper tribo-charging, the charge measurements on the collected particles in different bins showed only negative charge acquisition with a difference in magnitude. Thus, the applied voltage is an important parameter for the deflection of relative magnitude of highly negative inorganic matter and weakly negative coal particles in the electric field.

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5. SUMMARY

1. The Ramgundam coal has three types of macerals: vitrinite, liptinite, and inertinite, with vitrinite and inertinite predominating. The coal's inorganic mineral composition includes pyrite, goethite, siderite, kaolinite, illite, and quartz. Since the mineral particulates, significantly quariz, observed to be visibly free from coal matter, the Ramagundam coal is suitable for dry electrical beneficiation.

2.The charge acqulsition of quartz after contact electrification with different tribo-charging media has been studied since quartz is the major mineral phase in the coal. The results show that quartz is negatively charged with copper, brass, aluminium, steel, copper, PVC and Teflon materials whereas it charged positively with Perspex. However, the magnitude of negative charge acquired with copper, brass, steel and aluminium is comparable to each other. Evidently the materials having the work function values in between the work functions of macerals and minerals are suitable to acquire different charp•e polarity for the coal and non-coal matter during contact electrification and copper found to be optimum tribo-charger material for coal beneficiation.

3.The temperature of the tribo-charging medium plays an important role in the net charge acquisition of coal particles. With increas ink temperature, the charge acquired by the particles also increases. The electron transfer between the materials of lower work function to higher work function increases with increasing temperature leading to more charge acquisition by the particles. However, the ash percentage of coal in the concentrate adversely effected with increase in tribo- charger temperature. Low ash coal is achieved at 18°C tribo-charger temperature.

4.The applied voltage to the electrode plates has significant influence on the separation of coal macerals from minerals. Although the charge measurement of collected particles at different b ins shows thai all the particles are negatively charged, particles collected at positive electrode measured higher negative charge than particles collected at neg•ative electrode. With increasing voltage there is an increase in the charge of particles collected at both the electrodes at l8°C but at higher temperatures the particles charge collected at positive electrode decreased and reverse is the case with the particles collected at negative electrode. The higher electric field strength caused redistribution of weakly/bipolar charged particles due to conslderable deflection of the particles effecting the separation. Therefore, the effective applied voltage need to be optimum for obtaining good separation.

5. The results clearly indicate that particles collected at negatlve electrode contain low ash

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percent whereas particles collected at positive electrode comprise high ash percent. This shows that the mineral particles are charged negatively with copper tribo-charger while the inacerals charged positively and coilected near the negative electrode. The present studies showed that it is possible to reduce the 45% ash coal to 18% ash clean coal.

REFERENCES

1. Alfano, G., Carbini, P., Ciccu, R., Ghiani, M., Peretti, R., and Zucca, A., 1988, “Progress in riboe lectric Separation of minerals,” Proceedings of XVIIM PC, Stockholm: E. Forssberg, ed., Elsevier Pub B V, Amsterdam, pp. 83?-844.

2. Alfano, G., Carbini, P., Carta, M, Ciccu, R, Del Fa, C. Peretti, R., Zucca, A., 1985, “Applications *of* static electricity in coal and ore beneficiation,” Journal of electrostatics, 16, pp. 315-328

3. Carta, M., Del Fa, C., Ciccu, R., Curreli, L., Agus, M., 1976, “Technical and economical problems connected with the dry cleaning of raw coal and in particular with pyrite removal by means of electric separation,” Proceedings of 7" International Coal Preparation Congress, Australia: A. Partridge, ed., Adept Print ing pvt. Ltd, K.2, pp.1-35.

4. Ciccu, R., Ghiani, M., Peretti, R., Serci, A. and Zucca, A., 1991, “Tribocharging studies of ground coal matter,” Processing and Utilization of high Sulfur Coals IV, P. R., Amsterdam: Dugan, D. R., Quigley and Y. A., Attia, eds., Elsevier Science Publishers B. V., pp. 223,.

5. Davies, d. K., 1969, “Charge generation on dielectric surfaces,” Brit. J, Phys. (J. Phys. D), 2, pp. 1533-1537.

6. Finseth, D,, Newby, T., and Elstrodt, R., 1993, “Dry Electrostatic Separation of Fine Coal,” Processinp• and Utilization of High- Sulfur Coals, Amsterdam: V, B. K. , Parekh and J. G. Gropps,eds., Elsevier Science Publisher, B. V., pp. 91-98.

7. Harper, W. R., 195 1,”The volta effect as a cause of static electrification,” Proc. R. Soc. Lori. A, Math. Phys. Sci., pp. 83- 103.

8. Inculet, 1. I., Bergougnou, M. A., and Brown, J. D., 1982, “Electrostatic Bene ficiation of Coal,” Physical Cleaning of Coal-Present and Developinp• methods, New York: Y. A. Liu (ed), Marcell Dekker, pp. 87-13 l

9. Kim, S. C., Son, N. W., Kim, D. H., and Oh, J. G., 1997, “H ip•h efficient centrifugal and triboelectrostatic separation of unburned carbon from fly ash for ash recycling•,”. The 12* Korea- US joint Workshop Energy & Environment, Oct. 6-11, Taejon, Korea: p 308-313.

10. Knoll, F. S. and Taylor, J. B., 1984, “Advances in Electrostatic Separation,” SME

ISSN: 2278-4632
Vol-11 Issue-01 March 2021

Preprint, pp 84-71.

11. Kweius, B. A., 1994, “Contact electrification of coal and minerals,” 3 of E lectrostatics, 32, pp.

12. 271-276.

13. Lockhart, N. C., 1984, “Review paper. Beneficiation of coal,” Powder Technology, 40, P 17-42.

14. Lowel, J., 1975, “Contact electrification of metals,” J. phys. D, Appl. Phys., 8, pp. 53-63.

15. Manouchehri, H. R., Rao, K. Hanurnantha, Forsberg, K. S. E, 2000a, “Review of electrical separation methods Part 1: Fundamental aspects,” Mineral & metallurgical processing, l7, pp. 23-36.

16. Manouchehri, H. R., Rao, K. Hanumantha, Forsberg, K. S. E, 2000b, “Review of electrical

17. separation methods Part 2: Practical consideration,” Mineral & metallurgical process ing.

18. Mazumder, M. K., Tennal, K. B. and Lindquist, 1994, “Electrostatic Benefic lation of coal,” Proceeding of the Tenth Annual Coal Preparation, Utilization and Environmental Control Contractors Conference, July 18-21, 1994.

19. Mazumder, M. K., Tennal, K. B., and Lindquist, D. A., 1995, “Triboelectric separation of coal from mineral impurities,” Electrostatic society of America 1995. Annual Meeting proceedings, Laplacian press, Morgan Hill, CA, p. 59-70

20. Trigwell, S. and Mazumder, K. M., 2001, “Tribocharging in electrostatic beneficiation of coals: Effects of surface composition on work function as measured by X-ray photoelectron spectroscopy and ultraviolet photoelectron spectroscopy in air,” J. Vac. Sci. TechnoL A, 19 (4), pp. 1454-1459.