High Ash Non Coking Coal Preparation by Tribo-Electrostatic Technique

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Abstract

Triho-electrostatic method is applied to beneficiale non-coking Indian thermal coal front Ramagiindain coal mines contaiHlng nearly 45% ash content. The microscopic studies revealed that quartz- and kaolinite are the dominant iiiinerals whereas illiie, goetliite, siderite and pyrite are the mtrios' inclueion" fn t/ie coal Contact elecir ification of ash forming or inerals and coal matter has been carried out i@fftg different tribo-charger materials of A1, Cu, bi ass, perspex and teflon. The Cu tribo-charger found to be optimum to acquire differ ential charge between ash-forming inorganics and co‹il matter. The /gmperaiiii'e effect on the magnitude of contact char ge acquisition found to be sigiJcant. Tests on a laboratory in-house buili tribo- electrostatic free-fall separator with m Inns 300 ni icrons st-e fraction of coal shov!ed thai the osJi content can be rgducedfrori 45% to about 18% and it is feasible fo obtain a clean coal as judged by the ivashability studies. The results illustrate that the mom-cO#fftQ coals can be beneffciateJ using the scientific knowledge on the response and behaviour of coal and non- coal matters to electric charges.

INTRODUCTION

Coal being India's the most abundant fossil fuel, rapid ilicrease in the county 's future power generation to meet the growing demand for domestic, industrial and agricultural sectors will be based on this fuel. In India, more than 75 % of non-coking coal produced is used for power generation. At present, nearly 200 million tonnes/year of coal is used for power generation and the average ash in coals is invariably above 40%. The majority of non-coking coal reserves in India are inferior in quality becau5e Of drift origin. Most of thick seams are banded in nature. The coal matter in these seams is high ili ash contenl and thus the quality becomes poor because of these bands. The bands themselves are usually in carbonaceous nature and very rarely consist of pure sandstones. As a result the Indian coal seams have basically much higher ash content. It was estimated that more than 65% of recoverable resources of non-cocking coals are inferior in quality and contain about 40-45% ash. The higher ash percentage obviously is correlated with poor calorific value. However, the advantages of Indian coals are low sulphur, chloride, phosphorous, less toxic elements, high ash fusion temperature and refractory nature of ash.

The wet beneficiatioii techniques are accepted for the reason of produce high quality coal product with high recovery. However these techniques are not economical for high ash non-coking coal in fine size fractions. The alternative technique is the dry beneficiation of coal with the advantages like dry handling of coal and retention of high calorific value at same quality of product in comparison with wet process are more attractive. Electrostatic separation is one of such technique. Electrical separation utilises the inherent differences between the minerals in friction charging, electrical conductivity and dielectric constant properties (Manouchehri et al. 2000a and Manouchehri et al. 2000b). The ba.sis for electrical separation is the interfacial resistance offered by different materials to

the flow of electrons. The modify lRg factors are the specific gravity, size, shape, surface state and purity of the particulates as well as the mechanical and electrical attributes of the separator. The composition of the raw material and its electro-physical properties determine the klnd of either conductive induction or tribo-electrification or corona charging mechanism device is applied. Among the known electrical beneficiation methods, the tribo-electric separation process is most suitable for finer materials and minerals with relatively s imilar and varying electro-physical properties (Knoll and Taylor 1984; Mazumder et at. 1994).

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.

THEORY OF TRIBO—ELECTROSTATIC SEPARATION

Tribo-e lectric separation involves charging of particles by contact or friction with other particles or with a third material, usually the walls of a container or pipe, followed by transpoH or free-fall through an electric field that deflects the particles according to the magnitude and sign of their charge. When two disslmilar particles are in contact or rub against each other, there is a transfer of electrons (charge) from the surface of one particle to the other until the energy of electrons in each material at the interface is equal ised. The energy of electrons at the surface of the material is characterised in terms of the Fermi level and a measure of relative affinity for electrons of the material is the work function, which is the energy to move an electron from the surface to infinity. The material with hig•her affinity for electrons gains electrons (i.e., lower Fermi level or higher work function) and charges negatively, while the material with lower affinity loses electrons (i.e., higher Fermi level or lower work function) and charges positively. Thus the particle that is positively charged after the particle-particle charging mechanlsm has a lower work funct an than the part lcle that charges negatively. In the case of wall-particle charging, the work function of the material of the wall should lie in between the work function values of the two types of particles involved for acquiring different polarity. The work function values for various materials such as C, Cu. AI2O,, MgO, and SiO, are 4.0, 4.38, 4.7, 4, 5, and 5.4 respectively (K inn et al. 1997).

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:

$$V_c = \left(\frac{\qquad}{e} \right)$$ where e is the electron charge 1.6×10^{-19} C

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:

$$C - 4ss_{,,}r\ 0.577 + 0 \quad ^{2r}$$

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 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 size 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).

EXPERIMENTAL

Sample Preparation

Ramgundam coal was ground, classified into different size fractions and a representative sample from each size fraction was prepared by standard sampling procedure. The washability study was carried out for each size fraction by slnk and float method by using a mixture of acetone and bromoform medium at different specific gravities ranging from 1.3 to 2.0. The sink and float products were washed thoroughly with acetone, dried and analysed for ash. The proxImate analysis of boat and s ink products were carried out with Thermo Graviiuetric Analyser (TGA-60 1). The TGA was operated under N$\rangle$ atmosphere for moisture and volatile matter analysis whereas $ox_{ys}en$ atmosphere is used for

ash analysis. Approximately 10 mg sample was used for proximate analysis. The heating rate was maintained at l0°C min ' while air flow rate was maintained at 6 litre min '.

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.

Tribo-E lectrostatic Test Procedure

The tribo-electrostatic experimental set-up for the separation of coal macerals from ash forming minerals is presented in Fig. 1. It consists of Perspex box fitted with two copper plate electrodes, high voltage Dc voltage supply source (VS), vibratory feeder with hopper (V,), heater (H t), digital thermometer (T) and Keithley electrometer (KE). There exists a provision to adjust the distance between the copper electrodes and the angle of inclination. The vibratory feeder plate can be replaced with different tribo-charger plates made up of Cu, Al, Steel, Perspex, PVC and Teflon. The thermostat beneath the feeder plate maintains the tribo-charger at constant temperature and the temperature has been monitored with digital thermometer. The rectangular Perspex box height, width and thickness are l m, 0.52 m and 0.52 m respectively. Two electrode copper plates A and B of length 0.84 m and breadth 0.43 m have been fixed within the box. The electrode plate is connected in such a way that its top and bottom gap between the plates can be adjusted.
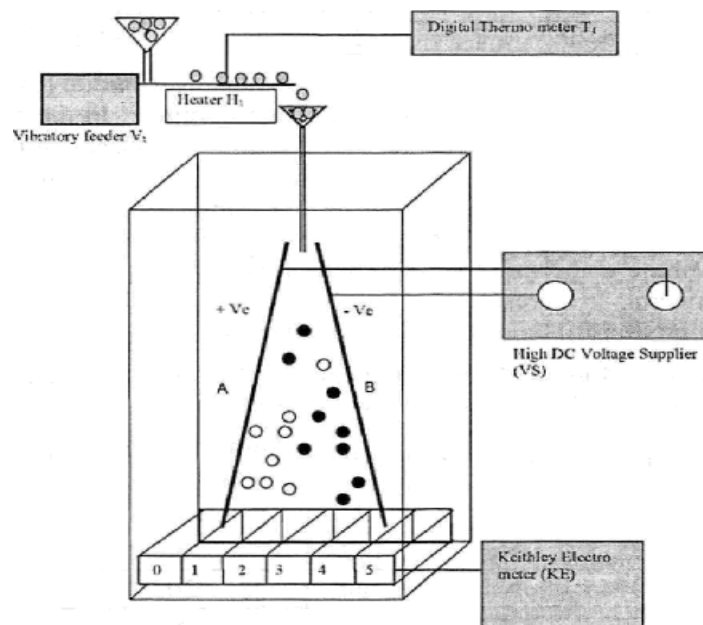

Fig. 1: Schematic Diagram of Experimental Set Up

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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 D_9 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 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°C).

RESULTS AND DISCUSSION

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, %**	**Volatile 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.

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

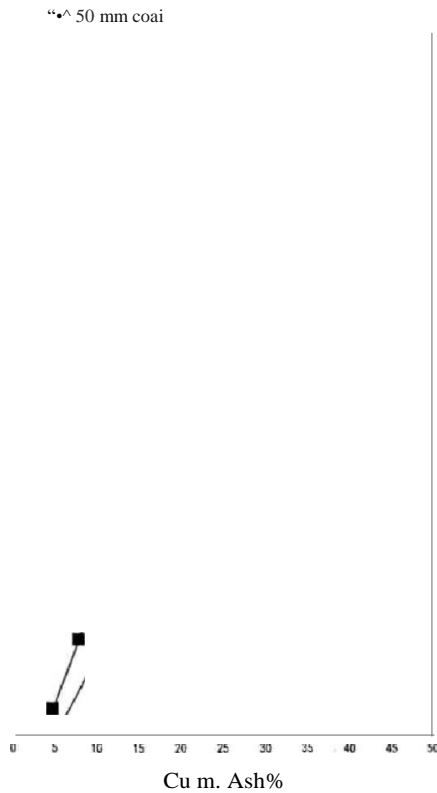| Details of sample	Quartz	I llite	Kaolinite	bOOtNtOl lOWEO	Goethite	Siderite	Pyrite
Bulk	3588	142	Nil	Nil	117	Nil	Nil
+l50mm 1.8Sink	3318	Nil	1183	Nil	196	110	67
+l00mm1.8F1oat	3745	Nil	449	202	Nil	Nil	42
+l00mrn1.4F1oat	2704	Oil	756	Nil	Oil	Nil	48

"•^ 50 mm coai

Cu m. Ash%

Fig. 2: Washability Study of Ramagundam Coal
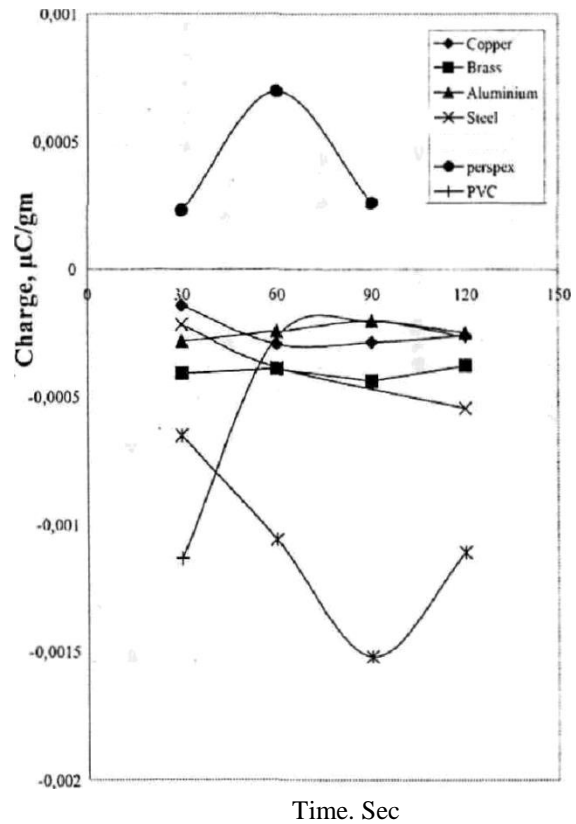

Time. Sec

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

Effect of Tribo-Charging Medium

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 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.

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
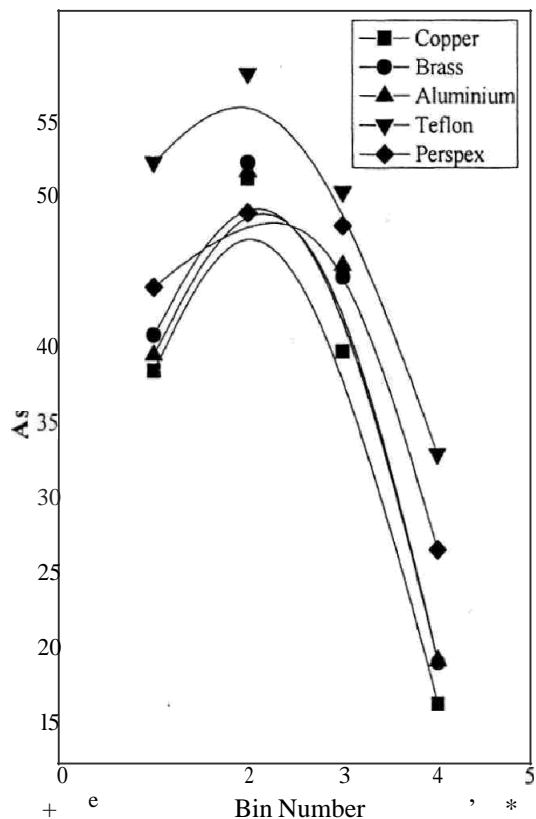
Fig. 4: Bin Number Verses Ash% of Coal Collected at 15KV Applied Voltage After Tribo Charging with Different Materials
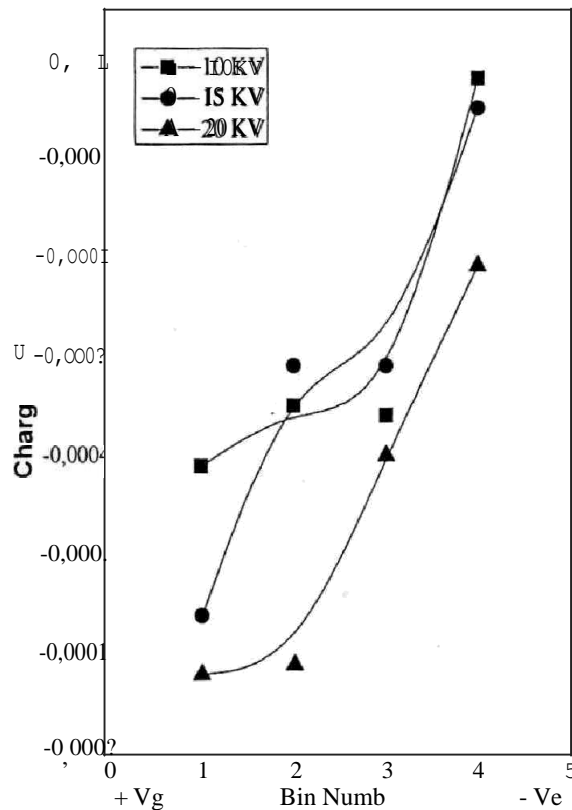

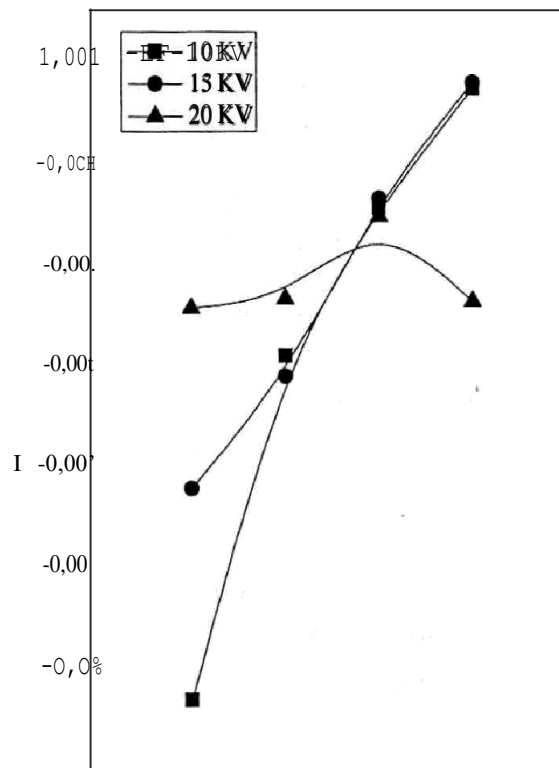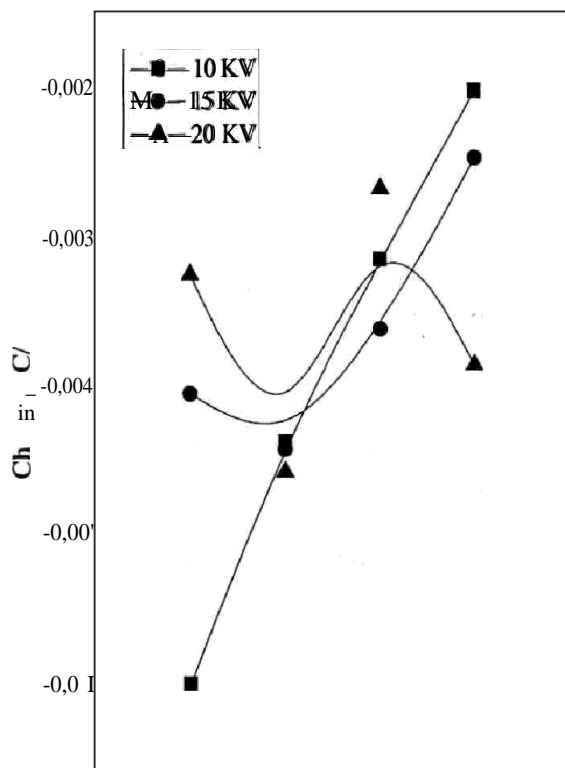Fig. 5: Effect of Votage on Charge Acquired by Particle at Different Bins at 18'c

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| 0 | 1 | 2 | 3 | 4 | | -0,01 | 1 | 2 | 3 | 4 | 5 |

+ Ve   «in Number   ' V@   + "   Bin Number   •>°

Fig. 6: Effect of Votage on Charge **Acquired by**   **Fig.** 7: Effect of Votage on Charge Acquired by
Particle at Different Bins st 63'c   Particle at Different Bins at 76'c

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 durin$_g$ 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 char$_S$e is almost the same. Since all the particles acquired negative charge, there is an optimum voltage for a $_g$00d separation between strong negatively charged paHicles containing more mineral matter and weak negative particles with more coal matter.

Effect of Temperature

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 charge acquired by the particles increases with increasing 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-charger 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).

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
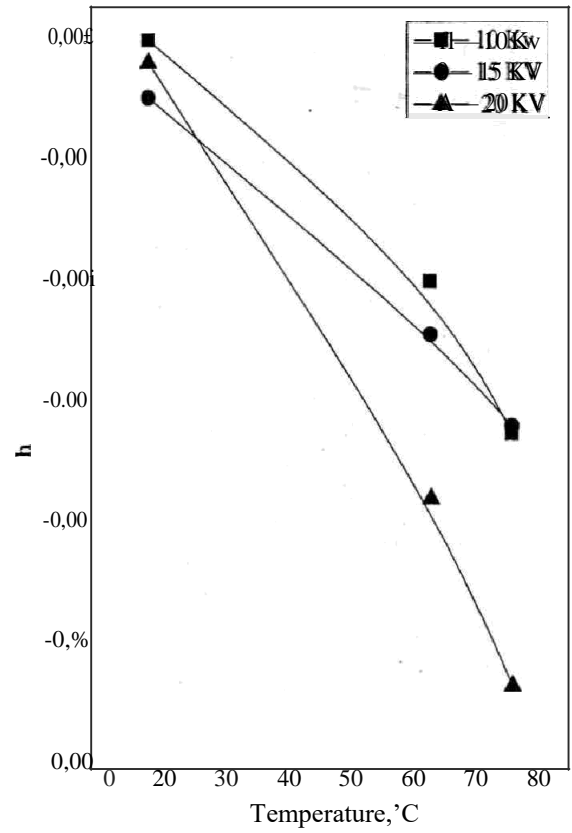
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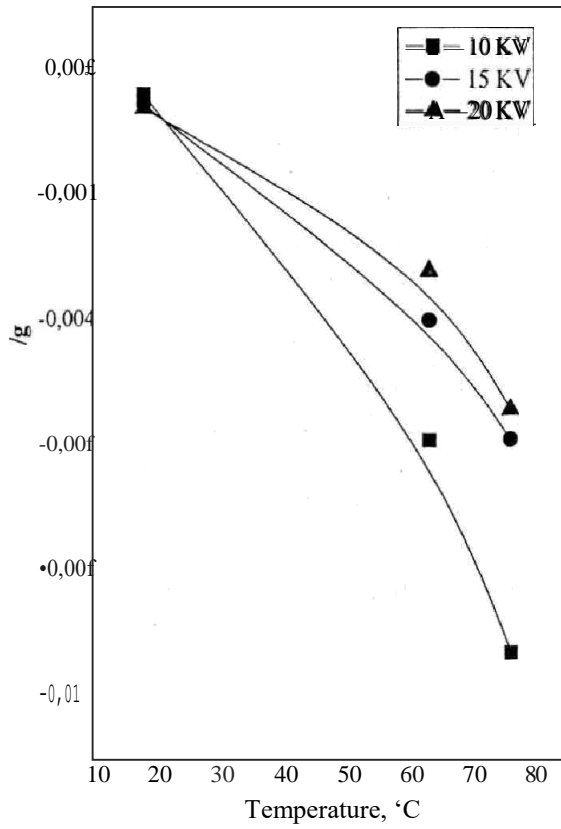**ISSN: 2319-6564**
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Fig. 8: Effect of Temperature on Charge Acquired by Particle at Bin 1
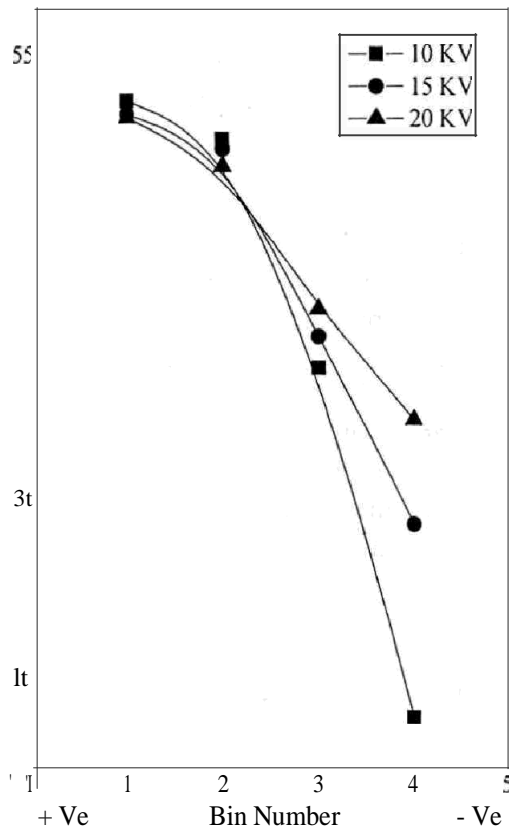
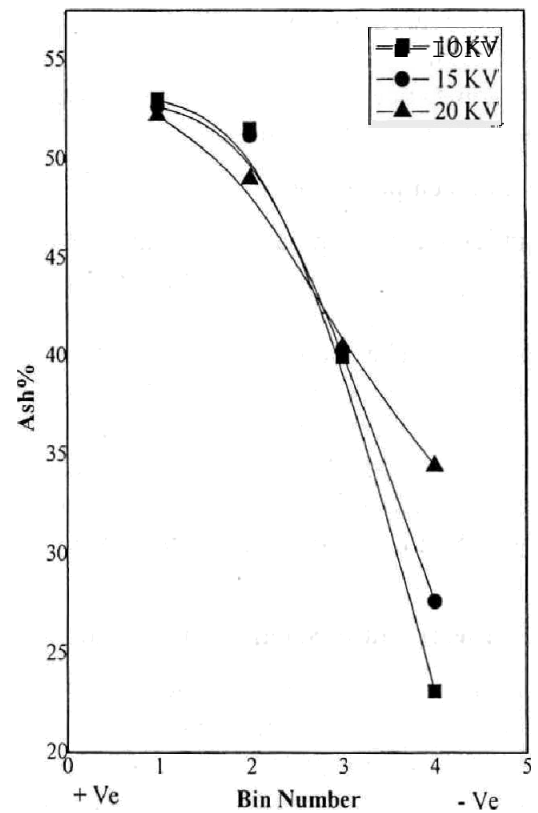Fig. 9: Effect of Temperature on Charge Acquired by Particles at Bin 4

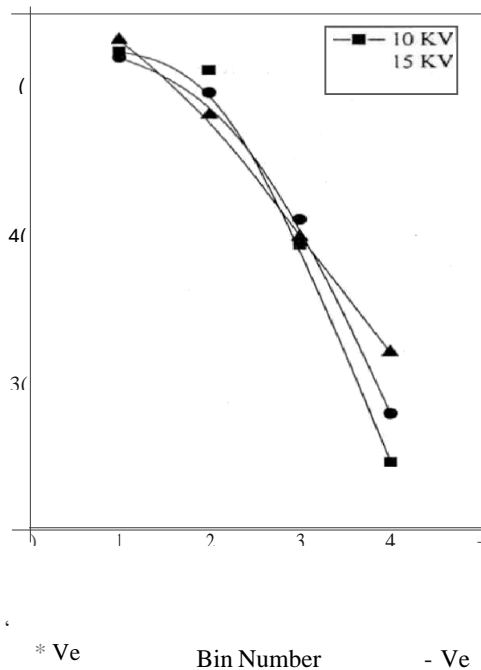Fig. 10: Bin Number Verses Ash% of Coal at 19'c Charger Temperature

Fig. 11: Bin Number Verses Ash% of Coal at 63'c Charger Temperature

Fig. 12: Bin Number Verses Ash % of *Com I* at 76°c Charger Temperature

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bin 4 and it is possible to beneficiate the 43% ash coal by tribo-electrostatic method. The increase in Appli₂d voltage is seen to increase the ash percentage of clean coal. The results at hi8 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.

SUMMARY

1. Three groups of vitrinite, liptinite and inertinite macerals are found in Ramgundam coal where vitrinite and inertinite are predominant. The inorganic mineral matter in the coal contains quartz, ill ite, kaolinite, goethite, siderite and pyrite. 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.

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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 bins 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 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.

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