EFFECTS OF SURFACE FINISH AND MATERIAL OF CONSTRUCTION OF THE SEPARATING SURFACE
ON HIGH TENSION ELECTRICAL SEPARATION

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Abstract: The results of work involving minerals passed over a conventional electrostatic separator using rolls of different materials and surface finishes are presented. These show that the separation achieved is affected by the material of construction of the separating surface and also its surface finish. The machining process by which the surface finish is produced also appears to have a significant effect upon the separation.

Experimental work with mineral mixtures designed to eliminate ballistic effects, or with single minerals, shows that advantage may be gained by using an optimum material/surface finish combination for the construction of the roll.

Possible explanations of the results obtained are put forward.

Introduction

The basic work from which the investigation described here originated is described in the paper read to the IEE-IAS annual meeting at Toronto in 1978. As a result of that study it was considered worthwhile conducting tests on a roll type electrostatic separator to discover whether the forces found to operate when electrical contacts separate could be applied to improving mineral separation.

Since the force was dependent upon the capacitance between the contacts, it appeared that the configuration of the roll and particles might give rise to useful differences in the separation characteristics. Although the final departure of the particles from the roll occurs in an electrostatic field, the initial electrical action, when the particles are under the influence of a corona discharge, is taking place under conditions of current flow and is therefore analogous to the phenomena previously described.

In its commonest form, the electrostatic mineral separator incorporates a rotating cylinder which often has a chromium plated or polished stainless steel surface. Little emphasis is placed upon the effects of the surface on the separation of minerals, or on the effect of particular separating surfaces.

Gilbert & George investigated the effect of different metal surfaces, including brass, chromium, dureham and stainless steel. Of these, chromium was considered most suitable for electrostatic separation.

Hudson investigated electrostatic plate type separators and compared shellaced brass, brass, solid copper, mild steel, copper plated brass and chrome plated brass. He attributed the differences found to alteration in contact potential between different materials and to the degree of tornish on the surface of the plate.

Johnson adapted his electrostatic separator for particle sizing by roughening the surface to 'diminish sliding', i.e. to increase the amount of friction between the particle and the roll. None of these investigators related the surface finish quantitatively to the results observed.

The initial aim of the authors' work was to investigate the effect of different materials for the construction of the roll.

Differences in the surface finish of the separating roll surface will arise during manufacture. These differences will be governed by the nature of the manufacturing process and the properties of the metals used. Except for Johnson, previous workers did not attempt to control and measure the actual finish, but in this work the finishes were controlled and measured by the stylus profilometer method using the Centre Line Average convention (CLA).

A laboratory electrostatic separator was loaned by Boxmag-Rapid Limited for the study.

Experimental Procedure

Distribution Analyser: The system of trays and splitters supplied with the separator was unsuitable for obtaining a detailed picture of the distribution of the products. A method of accurately analysing the distribution of the products is described in the literature. Consequently, a distribution analyser consisting of sixteen 25 mm wide trays was deployed. These trays were clipped together underneath the separator to collect the products (Fig. 1).

![Laboratory Separator as modified showing tray numbering and typical product trajectory.](attachment:image)

Selection of Minerals: In choosing the mineral feed to be used in the experimental work, two factors were considered:

1. The minerals should be easily obtainable in a clean state and be devoid of any surface contaminants such as flotation reagents which could alter their surface conductivity as compared with the natural state.

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2. The specific gravity of the various minerals should be similar so as to minimize ballistic differences and enable results to be compared.

Based upon these criteria the following minerals were chosen - magnetite, barite (non-porous), cassiterite, barite (porous), ilmenite and garnet.

Preparation of Minerals: Every precaution was taken not to contaminate the samples with other materials, grease, etc. The size range -0.85 +0.70 mm was chosen for study since it is suitable for electrostatic separation and large enough to observe visually whilst narrow enough to avoid separation due to ballistic effect. Before crushing and sizing, the material was hand-picked to maintain maximum purity.

Roll Speed: A standard roll speed of 100 rpm was selected.

Moisture Content of the Mineral Samples: The presence of moisture on the surface of the particles affects the surface conductivity and hence the rate of loss of charge, which is an important separation factor. In order to ensure that all traces of moisture were removed from the surface of the minerals, the heater above the feed chute was employed. Experiments indicated that the role of the heat in removing moisture was more important than its heating effect as such.

Electrode Position: The directing wire - roll distance was fixed at 45 mm.

Feed Rate: Preliminary tests showed that reproducible results were difficult to obtain at feed rates exceeding a monolayer on the roll. This rate corresponds to 50 kg/25 mm width of roll/24h (for material -0.65 +0.70 mm), approximately a quarter of commercial feed rates.

Applied Voltage: The magnitude and also the polarity of the voltage applied to the active electrode affects the charge acquired by a particle and hence its path through the separator. At all voltages this charge is influenced by the particle/roll electrical contact resistance, size, electrical resistance and the time during which it remains under the influence of the field. At voltages below the onset of corona discharge, the electrical capacitance of the particle is of greater importance than at higher voltages.

When the potential gradient is great enough to give them sufficient charge, non-conducting particles will remain almost totally pinned, while semi-conductors and even conductors, will be pinned for part of the revolution of the roll. In this context, non-conductors are those with a resistance greater than 10^12 ohms, semi-conductors a resistance of between 10^12 and 10^13 ohms and conductors resistances less than about 10^12 ohms rather than the conventional meaning.

In order to assess the performance of different rolls the distribution of mineral in the analyser was determined at 0 kV, 6 kV and then at intervals of 2 kV up to the sparkover voltage, for both negative and positive electrode polarities.

Physical Properties of the Minerals: The physical properties of the minerals, i.e. specific gravity, moisture content and specific surface area, were determined on the -0.85 +0.70 mm size fraction and presented in Table 1.

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### Table 1

| Mineral          | Specific Gravity | Moisture Content | Specific Surface Area (BET method) | % | m^2/g |
|------------------|------------------|-----------------|-----------------------------------|---|-------|
| Magnetite        | 4.87             | 0.174           | 0.414                             |   |       |
| Barite (non-porous) | 4.48            | 0.083           | 0.048                             |   |       |
| Cassiterite      | 6.47             | 0.037           | 0.007                             |   |       |
| Barite (porous)  | 3.88             | 0.030           | 0.520                             |   |       |
| Garnet           | 3.87             | 0.015           | 0.049                             |   |       |
| Ilmenite         | 4.61             | 0.022           | 0.053                             |   |       |

### Table 2

| Mineral          | Fe% | Ti% | Sn% | SiO2% | A1% |
|------------------|-----|-----|-----|-------|-----|
| Magnetite        | 68.92| 0.205| 0.86|       |     |
| (Stoichiometric composition) | 72.4 | -   | -   |       |     |
| Cassiterite      | 0.5  | -   | 74.1| 0.6   | 0.1 |
| (Stoichiometric composition) | -   | -   | 78.6|       |     |
| Ilmenite         | 29.6 | 33.3| -   |       |     |

Chemical Properties of the Minerals: The chemical composition of the three metallic minerals was determined by standard wet chemical analysis, the results of which are given in Table 2.

Mass spectrometric analysis of the two barite samples indicated that the main impurity was strontium which was lower than 0.2%. The actual chemical and mineralogical composition will determine the bulk electrical resistance of the mineral. The presence of trace impurities may control rectifying properties. (In order to avoid confusion, the term 'rectifying' is used here to denote what is in common parlance is termed 'semi-conducting').

Roll Deburring and Surface Finish Measurement: Deburring of the rolls prior to the commencement of tests was carried out with trichloroethylene and the surface finish measured with a Surtronic stylus profilometer immediately after deburring.

Ambient Temperature and Humidity: The atmospheric temperature and relative humidity were continuously measured during each test. Ambient temperature variations were found to have no measurable effect on separation. The relative humidity only affected the distribution of a mineral in the catchment trays when it was outside the range 40 to 70%.

Separating Surfaces: All rolls were manufactured to the same dimensions so that they were interchangeable. For preliminary investigation a titanium roll (surface finish 190 microinch CLA) was compared with a chromium plated roll (surface finish 10 microinch CLA) as normally fitted to Boxmag-Rapid separators.

It was found that the great difference in the surface finish of these two rolls made it difficult to distinguish between the effect of the material of construction of the roll and that of its surface finish.

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In order to differentiate between these two factors, two sets of rolls were manufactured. One set was made of mild steel turned and then lightly polished for surface finishes of 20, 45, 100 and 110 microinches and turned only without polishing for surface finishes of 145, 160 and 250 microinches. The other set made of aluminium only had the turning operation performed, no polishing being used. Surface finishes were 45, 70 and 340 microinches.

Cost prevented the possibility of a similar set of titanium rolls.

Subsequently, four of the mild steel rolls were chromium plated. The surface finishes of these plated rolls were 11, 15, 50 and 84 microinches.10

**Initial Results**

With the standard chromium plated and titanium rolls, some pinning of both cassiterite and magnetite was observed below the onset of the corona discharge field, which latter was taken as the voltage at which the HT power supply current meter just showed a deflection (for the electrode settings selected, this was about 12 kV for negative polarities and 17 kV for positive polarities), both minerals being pinned more to the chromium roll than to the titanium roll (Fig. 2).

Chromium and Titanium Rolls - relationship between mean tray numbers for Cassiterite and Magnetite and the applied negative voltage.

However, above the onset of the corona discharge both minerals were pinned more to the titanium roll than the chromium plated one.

There was little difference in the behaviour of the non-porous barite on either roll; however, pinning to the rolls at higher voltages was much greater than for cassiterite or magnetite and even at low voltages, the pinning forces were considerable as would be expected for a non-conductor.

The porous barite was thrown from both rolls to the same extent until the voltage was increased to the onset of the corona discharge when the pinning at first increased rapidly, until 18 kV negative polarity and 22 kV positive polarity, after which the rate of increase of pinning decreased. At negative polarities up to 16 kV the barite was pinned more to the chromium roll whereas above 16 kV the difference diminished until there was slightly more pinning on the titanium roll; at 14 kV the difference was at a maximum.

**Discussion of Initial Results:** The higher relative permittivity of titanium oxide was expected to cause greater pinning to the titanium roll than the chromium plated one whilst the difference in surface finish was expected to have the opposite effect. If this expectation is correct it would appear from the initial results that surface finish was the overriding factor.

**Results with Cassiterite on Mild Steel Rolls of Different Surface Finishes**

In Fig. 3 the mean tray number has been plotted against the log of the mean surface finish for different negative voltages above the onset of the corona discharge. It can be observed that at constant voltage, for rolls with a surface finish smoother than 145 microinch, the pinning is proportional to surface roughness. With the rolls of greatest surface roughness, less pinning at a particular voltage was observed. The difference between the mean tray numbers for the 20 microinch and 145 microinch rolls is equivalent to 37.5 mm in the position of the ballistic trajectory of the product at tray level with the voltage just above the onset of the corona discharge. On changing to a positive polarity, little difference due to surface finish is observed.

**Comparison Between the Standard Chromium Roll and Mild Steel Rolls:** Between 12 and 22 kV negative polarity, the pinning on the chromium roll is similar to that on the mild steel rolls. Above 22 kV the pinning on the chromium roll does not increase as fast as on the mild steel rolls so that by 26 kV there is...
less pinning than on any of the steel rolls. On changing to a positive polarity, the pinning of cassiterite on the mild steel rolls was found to be greater than on the chromium roll at all voltages.

Comparison Between the Titanium and Mild Steel Rolls: Between 12 and 22 kV negative polarity there is more pinning on the titanium roll than on any of the mild steel ones; however, above 22 kV the pinning on the titanium roll does not increase by as much as it does on the mild steel rolls and at 28 kV the pinning on the titanium roll and on the mild steel one of similar surface finish is alike.

With a positive polarity, the pinning on the titanium roll is less than on any of the mild steel rolls.

Discussion of Results Obtained with Mild Steel: The surface finish appears to be important in determining the amount of pinning when employing a negative polarity. In the case of the rolls for which a linear relationship was found between pinning and log surface finish, their finish had been achieved by polishing with emery after they had been turned on a lathe, whereas the results obtained with the rougher ones which had been solely turned without any subsequent polishing, no longer lay on the same straight line.

Not only the actual magnitude of this surface finish but also the method by which the surface is achieved and therefore the type of surface appears to be an important consideration. The surfaces of the rolls which had only been turned were observed to consist of circumferential radial lines, whereas those which had been subsequently polished with emery had lateral lines super-imposed on the surface in addition.

Discussion of Results Obtained with Aluminium: It was concluded that, as there was no apparent relationship between mean tray number and surface finish for aluminium, either the oxide film on aluminium was having an over-riding effect due to its resistance, or through some rectifying effect, or else that the relationship found for the mild steel rolls depended principally upon the amount of polishing.

General Discussion

The effect of different surface finishes may be to:

1. alter the actual area of contact between the roll and the particle and therefore alter the particle/roll contact resistance which in turn affects the rate of loss of charge,
2. alter the particle/roll capacitance due to the change in contact area as in (1) above,
3. alter the field configuration and hence the potential gradient close to the roll, thus affecting the total charge received,
4. affect the co-efficient of friction between the particle and roll and therefore the speed of the particles through the charging zone, which will determine the charge received and the point of detachment from the roll. This can be observed by comparing the results at no applied voltage for the different roll surfaces when, in general, particles detach from the roll at an earlier point for the smoother surfaces, rolls, although contact potential and frictional charging make exact evaluation difficult,
5. affect the degree of oxidation in chemical alteration of the surfaces of the roll. It is known that mild steel with a high polish oxidises much more slowly in comparison to mild steel with a rougher finish and this will affect roll/particle contact resistance which will determine the rate of loss of charge as well as the capacitance.

Whereas with negative polarity clear relationships were found on changing to a positive electrode polarity, the difference observed in the behaviour of the minerals on the various mild steel rolls was small. The fact that the surface finish of the mild steel rolls does not appear to have much effect when a positive (i.e. with the active electrode positive with respect to the roll) corona discharge field is employed suggests that either:

(a) the different surface finishes of the rolls result in a different field configuration in the negative corona discharge field but not in the positive field, or
(b) the rectifying properties of the cassiterite result in a different behaviour in the negative field, or
(c) the rectifying effects due to the asymmetrical nature of the electrodes causes a difference in the behaviour of the cassiterite under fields of different polarity.

Kilevuz has subsequently shown that cassiterite exhibits marked rectifying properties whereas magnetite does not and therefore tests should be performed with magnetite & cassiterite under similar conditions to determine whether the rectifying property of the mineral is a controlling factor.

Cobine states that for a negative wire most of the potential drop occurs close to the wire with a similar though much smaller fall of potential at the roll and
over a large region the potential gradient remains more or less zero. With a positive wire there is a pronounced fall of potential at the wire and then a gradual fall to the surface of the roll.

He measured the corona potential distribution for a wire within a tube of 70 mm diameter. The measurements were made by means of an insulating probe and errors in measurement were stated to be insignificant except close to the wire. These potential plots are shown in Fig. 5.

5(a) Relationship between wire to cylinder distance and wire to cylinder voltage when adjusted so as to maintain a current of 1.91 x 10^{-5} amp (wire positive).  
(b) As (a) but wire negative.

Of the five possible effects of surface finish outlined above, the following two would be expected to remain constant in both positive and negative discharge fields:

1. The co-efficient of friction between the particle and roll.
2. The actual area of contact between the particle and roll.

The oxidation state of the surface of the roll would probably not be sufficiently affected by a change in polarity to make a material difference in the results. In any case if an oxidation effect existed it would be expected to be permanent and no permanent change in roll behaviour was observed. Thus, only differences due to the field configuration, which is known to be very different for positive and negative corona discharge fields, together with the roll/particle capacitance and/or resistance which may be a function of the field, remain. Therefore, unless some other effect or effects which have not been considered are responsible, it seems likely that the surface finish is influencing the mineral separation by virtue of its effect upon the field in close proximity to the roll and/or its effect upon particle roll/capacitance/resistance.

Conclusion

Although with negative electrode polarity a correlation was found between the final trajectory of the mineral particles and the surface finish of the separating surface of the roll prepared by turning followed by polishing, this correlation was not manifest with positive electrode polarity. The number of factors involved in the analyses of the observed results were such that further work is required before a rigorous mathematical treatment can be evolved which will enable a more exact interpretation of the results to be made. A preliminary analysis of the mechanical forces acting has already been published but there is insufficient knowledge to incorporate the electrical and other forces acting.

The apparent lack of specific correlation between surface finish and the final trajectory of a mineral particle when the rolls of aluminium are manufactured solely by turning was unexpected and considerable detailed work may be necessary before the true explanation for this can be found.

The observation that the maximum differences due to surface finish occur when the electrode voltage is close to the onset of corona discharge may be of considerable practical importance. This could be due to the fact that at these voltages, small increases in voltage result in larger current increases than those which occur for similar voltage changes outside this region. Small differences in the behaviour of the mineral may therefore be accentuated.

It must be remembered that the onset of the corona discharge will be affected by the relative humidity, temperature and to a lesser extent the air pressure, but Cobine considered the humidity to be the more important effect.

The surface finish of the roll as well as the material of construction of the roll and any oxide layer present may also affect the onset of the corona discharge. However, in the work carried out by the authors, in the range of relative humidities encountered (i.e. between 40 and 70%) no correlation was found between these and the onset of corona discharge. Although some apparent correlation between the material of construction of the roll and the behaviour of the mineral was found, much further work is required before this effect can be satisfactorily quantified in isolation from the other factors influencing the results.

The experimental work described was conducted at the Minerals Engineering Department of the University of Birmingham.

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