Electrical Separation of Mineral Raw Materials

D.D. Misra

The feasibility of using electrostatic properties to effect separation between different mineral particles was known long back[1], but for two main reasons little progress was made : (a) The electrical equipment was unreliable, high voltage generators (induction types) had small capacities, and were useless under conditions of high humidity; (b) proven applications of the process were limited, and many of the separations could be performed more efficiently and cheaply in other ways.

Electrostatic separation

However, with advances in electrical technology, particularly in the rectification of alternating current to obtain a steady high voltage direct current, electrostatic separation became popular. Instead of feeding the material onto a direct charged rotating cylinder, it was fed onto an earthed rotating cylinder charged by induction, using a charged electrode insulated from the metal framework. Besides simplifying the process from the point of view of the necessary insulation, this changeover made the process safer for the operators. The electrostatic separators which were mainly being used for the separation of metallic sulphides from the silicious gangue minerals, were driven from their primary market with the advent of froth flotation. Concentrated research efforts in U.S.A. on the electrical concentration of rutile from the beach sands during the World War II resulted in the modern electro-dynamic separator, and the renaissance of electrical separation as an important minerals beneficiation technique.

Large-scale applications of the electrodynamic technique are now found in the recovery of heavy minerals from beach sand deposits in the separation of cassiterite, and recently in the upgrading of specular hematitic iron ores[2]. Table 1 gives the types of electrical separation equipments used and the examples of the typical mineral separations for which they are used[1].

Further research efforts will undoubtedly reveal other special areas in minerals beneficiation field where the electro-dynamic method can, alone or in combination with other methods, do a job that cannot be done by the conventional methods alone. The process being a dry one, makes it particularly attractive in areas where process water is scarce and/or costly to process.

Table 1 : Electrical Separation Methods

Types	Electrodynamic (current fields)	Electrostatic (static fields)
Typical equipment	Rotors with discharging electrodes	Rotors with non-discharging electrodes Plates(free fall), Discs., Belts
Typical mineral separation	Hematite - Silicates Rutile - Zircon Cassiterite - Scheelite Columbite - Monazite Chromite - Garnet Tantalite - Microlite	Feldspar - Qiartz Soda spar - Potash spar Barite - Quartz Halite - Sylvite

Charging mechanisms

Electrification or charging mechanisms are of three general types[3] : Contact or frictional, conductive induction and ionic bombardment. In the equipment using contact of frictional charging mechanism i.e., where there is no current flow and the fields are electrostatic, the minerals separate according to any surface charge they may have or may acquire. Electrostatic forces are much less powerful than electrodynamic forces and find only limited commercial application, in the separation of two non-conductive substances from each other after charging by contact electrification. The main problem in using this type of separators lies in finding the most efficient method of charging the surfaces of the minerals to be separated.

Charging by ionic bombardment, sometimes known as 'high tension' is very effective for charging solid particles. Very good separations can be achieved, especially when high tension is combined with conductive induction. These high tension methods, which use a corona discharge as a separating force, are more widely used than the static type methods. The 'electrodynamic' force created by the current flow of electrons and gas ions in the high tension methods, is generally in the range of 1000 times greater than the force available if there is no current flow, such as that in the case of true electrostatic field. This is because of the bombardment of ionized gases in the corona, impinging on the particles undergoing separation.

DIFFERENT TYPES OF HIGH TENSION ROLL SEPARATORS :

In the high tension roll separators, the roll is earthed and an electrode at two O'clock or ten O'clock position causes the electric field. Roll diameters used range from 6" to 14", and the length varies from 0.6 M (metre) to 2.0 M, but 1.5 M, 1.8 M and 2.0 M are the standard lengths. The present tendency is to use higher diameter and larger lengths. The electrode used may be a large diameter (12 mm to 20 mm) rod or a fine wire. In certain cases, a large number of pins are used for the combination effect of rod and fine wire. The speed of rotation of the rolls is usually 120 to 400 r.p.m., depending upon roll diameter, the material treated, and stage of separation. The gap between the rod and the rotor is to be carefully fixed since it can be varied only slightly after installation. If the gap is too much the electrostatic field effect is too small, and if it is too small, sparking due to ion flow will take place. Roll separators can be broadly classified into four types[4] (Figure 1) :

1. Large diameter electrode :

This is a static field type method and only lifting (of conductors) effect is present. Here, the separation of particles is on the basis of their ability to assume different degrees of surface charge. It is capable of separating particles with the same relative conductivity but different affinities to surface charge. Separation efficiency is low (10-20 per cent) and hence repeated passes are necessary. At least four to five passes are necessary before a commercially acceptable product is obtained. The performance of this machine is very sensitive to temperature, humidity, presence of slimes etc. The voltage used is in the range of 0-20 KV and current flow is 0.20 microamperes per 1.5 M length.

2. Wireline electrode :

Here, a wire of about 3 mm diameter (usually made of tungsten) is used as the electrode. The pinning effect (clinging of non-conductors to the roll surface) is present in this case, and the separation is mainly on the basis of difference in conductivity rather than the ability of the particles to assume different degrees of surface charge. Higher degree of separation (80-95 percent) is achieved in this case compared to the first type. High recirculating load (30-50 per cent) is necessary. This type of machine is not very sensitive to temperature and humidity. The voltage used is in the range of 0-30 KV and current flow is 15-1000 microamperes per 1.5 M length.

3. Beam type electrode :

This type takes advantage of the above both types, where a wire as well as a rod is used as electrode. If the wire alone is used, it would emit much of its energy in all directions. But, since the rod repels the corona, 'beam' is directed towards the rotor. The charging effect is very strong here and even good conductors will be pinned if not controlled. The separation is based mainly on the different conductivities of the particles. Pinning effect is very much pronounced, but lifting (of conductors) effect is also present to some extent. High degree of separation (85-98 per cent) is achieved in this case, and requires moderate recirculating loads (usually 20-40 per cent). As in the previous type, it is not very sensitive to temperature and humidity.

voltage range is usually 0.50KV and current flow per 1.5 M rotor length is 1-22 milliamperes.

4. Beam type electrode in parallel position :

Most modern electrical separators use this type or modifications of this type of electrode. This special electrode configuration best accomplishes the electrostatic lift plus electrodynamic pinning effect required for most efficient separation. Separation of particles is based on different conductivities only. High degree of separation is attained (85-98 per cent) and low recirculating loads are needed (0-20 per cent). Besides, the machine is not very sensitive to temperature and humidity. Voltage range is usually 0.30 KV and current flow is 0.25 to 1 milliamperes per 1.5 M length.

Commercial electrical separators are based on the above principle (Beam type electrode in parallel position). Here, a grounded rotor revolves in an electric field. The electric field is controlled by the voltage applied to one or more electrodes in the vicinity of the rotor, but not in contact with it, or, by positioning the electrode. Dry particles, subjected to a surface vharge on or before entering an electrostatic field, behave in accordance with their ability to conduct electricity.

The feed is carried by the earthed rotating roll into the field of influence of the charged ionising electrode. The corona discharge causes the mineral particles to assume a charge opposite to that of the grounded rotor, so they are 'pinned' to the rotor. The conductor particles lose their charge to the earthed roll quickly and are thrown from the roll surface by centrifugal force. These conductor particles then come under the influence of the electrostatic field from the non-ionising static electrode (which is large enough in diameter to prevent corona discharge).

Having shared their charge with ground, these particles are now oppositely charged by conductive induction, and are therefore attracted away from the roll surface (Figure 2). The non-conductor particles however, retain their charge and hence cling to the roll surface, and as they are carried on the roll surface, the charges on them decay slowly; the decay is assisted by high frequency AC wiping. The residual non-conductors are then removed from the roll surface by a tentioned brush. The use of such a wiping brush also helps to clean the roll surface of any oxide films, dirt or grease formed, continuously. The non-conductor particles become charged to different degrees while in the influence of the corona discharge, and therefore, are attracted to the roll surface at various rates. Concentration of the component mineral is effected, by proper placement of splitters in the falling grain stream.

The dimensions of a latest design of high tension four roll type Carpco machine (manufactured by the Carpco Research and Engineering. Inc., U.S.A.) are : Roll diameter 14" (36 cm); Electrode position: 45° and 20° from horizontal; Gap between the roll and wire line : 6 cm; Drive motor H.P. : 0.15 per roll (usually 3/8 H.P.); Distance between rolls : centre to centre - horizontal 80 cms, vertical 100 cms; Overall dimensions of the four roll machine (1.5 metre roll) are : height 2845 mm, width 1829 mm and length 1778 mm.

The current is provided from a rectifier which draws power from a variable voltage auto-transformer plugged to the standard 3 phase, 415 volts supply. Electronic, oil-immersed rectifiers designed for high peak wave form, with controllable voltage output and designed to avoid dust and moisture trouble are generally used. The combined equipment called the power pack, is uaually rated for 20 milliamperes on the high tension side. The mineral treatment capacity for such a four or six roll machine is upto 5.0 tonnes per hour per 1.5 metre length. The figure is dependent upon the nature of the mineral treated and the performance desired from the machine. For example, a Carpco 12 rotor machine of 3 metre rotor length can handle upto 120 t.p.h. of specular hematite ore in a single pass operation.

Evidently, particle size will influence the separation behaviour in the case of the high tension roll separators, since the surface charges on a fine mineral grain are higher in relation to its mass, than that in the case of a coarse mineral grain. Thus, the fine particles, which will be most influenced by the surface charge that they accept, will tend to report preferentially into the non-conductor fraction, whereas the coarse grains will be more readily thrown from the roll surface by centrifugal force. Also, in the multiple grain layer feed, the fine conductor grains will tend to be trapped by non-conductors due to their lower mass, and will report in the non-conductor fraction. Hence, it is desirable to take a middling fraction, so as to be able to produce clean non-conductor fraction (which preferentially contains fine non-conductors) and clean conductor fraction (which preferentially contains coarse conductors) simultaneously, and a middling, which will contain coarse non-conductors and fine conductors. The separation of these middling, necessitates the use of large circulating loads.

Screen and Plate type Separators[5] :

In this type of separator, the mineral is fed onto an earthed vibration plate or screen. The conducting minerals are attracted towards a large oval cross section charged electrode, placed above the vibrating plate or screen. By proper placement of the splitter, conducting and non-conducting mineral fractions are obtained (Figure 3). In the case of screen type separator, a screen (20 or 30 mesh) is placed in horizontal position and the non-conductor material falls through the sieve. The cross section of the electrode, which is parallel to the place or screen is usually 160 mm x 80 mm, and the minimum gap from the plate or screen is 20 to 50 mm. The plates and electrodes are 1.8 metre long.

In these separators, the feed gravities are as particulate stream down an earthed plate or screen, into the divergent electrostatic field induced by the large curved electrodes. The conductor mineral grains move towards the charged electrode, but thenon-conductors are poorly affected by the field. Due to the low magnitude of the forces involved, there is a tendency for the coarse mineral particles to report into the non-conductor fraction. The fine grains being the most affected by the forces involved, the conductor product preferentially contains fine conductors. Thus, this type of separators, the non-conductor product preferentially contains coarse non-conductors; the middling fraction contains coarse conductors and fine non-conductors, unlike that in the case of the high tension roll separator.

Electrostatic forces used in plate and screen type separators have a lower magnitude than those of the charging mechanism used in high tension separators, and hence, the efficiency of separation is lower. Due to this reason, these separators are invariably arranged in multi-pass type and usually in nonconductor cleaner type arrangement (Figure 3). The clean conductors are drawn from each stage, and thus the tonnage of non-conductors to be treated in the subsequent stages of separation decreases gradually, with resulting increase in selectivity. The areas of application of the two types of machines overlap, but in general, the following characteristics serve as guidelines in choosing a particular machine :

a. Plate machines are more tolerant to varying operating conditions such as the feed rate.

b. Screen machines are more selective under optimum operating conditions.

c. It is preferable to use the plate machines on a pre-dominantly conductor feed and screen machines on pre-dominantly non-conductor feed.

Operational features of high tension roll separators

A single pass of material through the high tension roll is usually insufficient to give either pure concentrate or pure reject. Therefore, the separations are always of multipass type with four or six rolls arranged in two vertical rows in each machine. The machine can be constructed with suitable chutes, so that it is possible for a single unit to operate in conductor cleaner type, non-conductor cleaner type or hybrid type of arrangement[6]. Thus, a single machine can be used for any function in a dry mineral separation circuit.

Factors that affecting separation

Separation that minerals in a high tension roll separator is very much affected by factors like humidity, temperature, particle size, presence of slimes etc., which affect the surface property of the mineral grains with respect to their ability to assume a surface charge.

1. Humidity and temperature :

When moisture is deposited on a mineral particle, it behaves like a conducting mineral, irrespective of its original properties. Therefore, to keep the mineral particle surface free from moisture it is common practice to preheat the feed to a high tension roll separator, such that the temperature of the particles when they are on the rolls is not less than 100°C. However, too high a temperature can affect the conductivity of the minerals, and may also cause surface finish damage to the steelwork of the separator. Normal operating temperature of rougher duty is of the order of 120°C. Moisture in the particle caused by humidity does not directly affect above 100°C, but can alter the nature of the electrostatic and corona field between the roll and the electrode. However, the effect of such variation can be neutralised by the operator by a small change in the applied voltage and thereby the current of ion discharge. Control of applied potential is highly desirable, because the sparking voltage at a definite spacing of electrodes varies with the relative humidity.

2. Particle size and specific gravity :

High tension roll separation is effective for particles from 20 to 250 mesh. However, different sizes of particles behave differently, and close sizing of the feed (with maximum to minimum size ratio not more than three) together with corresponding controls of the roll speed is desired for effective separation. Larger particles, because of their higher mass tend to be thrown off the roll and go into the conductor mineral fraction, even though they are non-conducting in nature. This effect is reduced to certain extent by decreasing the roll speed. But, at very low roll speeds, the mineral particles tend to be deposited on the roll in more number of layers, and the fine conductor mineral particles are more likely to be trapped within the non-conducting particles, as that would be the case at high feed rates. Thus, lower r.p.m. for roll is preferred when the particle size treated is large and higher r.p.m. is preferred when the particle size treated is small. Tramp oversize coarser than one millimetre should be removed from the machine feed, and the machine surge bin should contain a screen to remove occasional trash.

The specific gravity of various minerals in an ore can greatly increase or decrease the efficiency of separation of conductors from non-conductors. For example, in the separation of specular hematite from silica, hematite being the conducting mineral[7], it is thrown from the rotor. In addition, the fact that hematite is of much higher specific gravity than silica only aids in the separation. On the other hand, in the separation of monazite from ilmenite, the non-conductive monozite has a greater gravity than the conductive ilmenite, making the separation more difficult.

3. Conductivity of minerals :

When the feed consists of predominantly conducting minerals and the purpose is to eliminate all non-conducting minerals by a conductor cleaner mode of arrangement, low roll speeds are preferable (240-280 r.p.m. with 6" diameter roll). However, lower roll speed reduces the capacity of the machine, and therefore, with a predominantly non-conducting feed and a non-conductor cleaner mode of operation, the speed can be increased by about 20 per cent. Maximum speed that can be used with a 6" diameter roll is about 320 r.p.m. For roughing and scavenging operations, speeds upto 400 r.p.m. are used to obtain higher capacity.

Conductivity of the minerals also affects the current flow through the field. In actual operation with 1.5 metre long, 150 mm diameter, 4 roll machine treating 5 to 6 tonnes of beach sand per hour, the following current flows were recorded : 3 milli-amperes with 80-90 per cent non-conductors in feed. 10 milliamperes with 80-90 per cent conductors in feed.

4. Surface coating :

Particles below 1/20th the size of the largest particles and coatings like saline water or chemicals from froth flotation tend to alter the surface properties of the particles, and should therefore be removed before high tension separation.

Factors to be considered in the design and operation of high tension roll separators :

A few important factors which are very often overlooked at the fabrication stage and during operation, causing bottlenecks in plant operation, are given below.

1. Clearance from the ground level :

As the product from the lowest pair of rolls have to be fed to a belt conveyor or a bucket elevator, it is desirable that the frame is designed to place these roll at least 0.6 metre above the ground level.

2. Feed rate control :

The desired rate of feed with uniform distribution of mineral particles onto the whole active length of the roll is easily achieved by suitable fabricated chutes. However, in the case of power failure, it is very difficult for the operator to manually close all the chute openings before considerable amount of mineral has spilled out. Therefore, solenoid operated additional gates interlocking with power pack and roll drives should be provided to cut off the feed in case of any stoppage.

3. Balancing the rotor :

Effective separation with freedom from vibration and reasonable machine life is possible, only if the roll is properly balanced around its rotational axis. In addition, the roll surface should be machined smooth and taken out of use, as soon as pits by erosion develop.

4. Brush for removal of non-conductors :

This should be checked from time to time to see that all the bristles are pressing on the rotor with adequate pressure. Brush pressure adjustment can be made by means of torsion springs. The machine can be fabricated in such a way that the brushes can be changed while the machine is in operation. After the pressure is eased, the old brush can be removed from the carrier, and a new brush inserted. Brush pressure is reapplied by simple readjustment of the torsion spring. For less frequent brush changes, it is preferable to use brass bristle brushes, instead of ordinary coir brushes.

5. Wire material and tension :

Snapping of the electrode wire is a common cause of trouble in the operation of electrical separators. To avoid sag which causes wire snapping by local arcing, the wire should be kept under proper tension. Tungsten wires are usually found to be better than wires made from other materials.

6. Roll and chute maintenance :

The machines should be fabricated such that the roll and the changeable feed chutes can be removed from the operating end of the machine, so that the machine does not have to be removed from its operating position for maintenance of these items.

7. Preheating the feed :

As the material left over in the feed bin when the machine stops may not retain the heat till the machine is restarted, it is preferable to provide bin heaters. Even then, the bin should be emptied in case of planned shutdowns. It is preferable to have recirculation arrangement for feed passing through the machine at a time not desired.

In actual plant practice, it is essential to establish the nature of the mineral (conducting or non-conducting), so as to be forecast its behaviour in plant by prior laboratory tests, because the same mineral from different deposits can behave differently. Besides, the exact effect of the surface coatings and unliberated other minerals which are invariably present can be established only by actual test work. It is however, important to note that, to avoid scale up error, the same diameter of the roll, speed of rotation and feed rate is used, only with a smaller roll length, for the test work.

Operating features of plate and screen type electrical separators :

Both plate and screen type separators are usually made as two start units (Figure 3). Each such unit has a standard capacity of between 3 to 4 tonnes per hour of mineral sands. This figure is dependent upon the nature of the mineral treated and the performance desired from the separator. Therefore, the capacity should be defined only by prior laboratory testing. The screen and plate separators, as in the case of the high tension roll separators are used primarily for the treatment of heavy mineral sands such as rutile, zircon, monazite and ilmenite. Some of the operating characteristics of these machines are :

a) Feed sizing :

These machines will handle feed grains between 30 to 240 mesh. Tramp oversize that is coarser than one millimetre should be screened from the machine feed.

b) Feed rate and product splitter adjustment :

Feed rate control is achieved in a manner similar to that in the case of high tension roll separator. If the feed rate changes in operation, the screen type separator will behave badly, but the plate type separators are more tolerant to variations in feed rate. The position of the product splitters can be adjusted by using appropriate handles.

c) Feed temperature :

Generally, the screen and plate electrostatic separators must be used at lower temperatures than that in the case of high tension roll separators. Normal operating temperature should not exceed 80°C. Separation can be carried out with feed temperatures as low as 20°C.

Electrode position adjustment

Electrode position for both screen and plate separators can be adjusted safely while in operation, by using an insulated tool. The gap between the electrode and plate or screen is varied, till the best separation is achieved as seen from the colour difference between the products.

Use of high tension roll separators in combination with screen and plate type separators.

The performance of the two new types of electrical separators, i.e., plate type and screen type complements that of the high tension roll separator. As mentioned already, in the case of high tension roll separator, the clean non-conductor fraction preferentially contains fine non-conductors and clean conductor fraction preferentially contains coarse conductors. But, in the case of plate and screen type separators, the clean conductor fraction preferentially contains fine conductors and clean non-conductor fraction contains coarse non-conductors.

Thus, the middling from the high tension roll separator can be treated in plate or screen type separator or the middling from plate or screen separator can be treated in the high tension roll separator for complete separation (Figure 4). But generally, the high tension separators are used as primary separators due to their ability to handle high unit loads, lower cost of treatment per tonne of material processed and their ability to accept higher temperature at the commencement of the circuit. Thus, the products from the high tension roll separators uniquely suit the separation characteristics of the plate and screen separators. As an example, screen type separator can be used as the final cleaning stage in the production of ceramic grade zircon. Because of the large number of dense mineral of widely varying properties occurring in beach sands, it is essential that electrical separation technique is used in conjunction with gravity separation and magnetic separation for most efficient recovery of the products.

Electrical separators except for the power pack (comprising the transformer and rectifier) are low cost equipment that can be easily fabricated in the workshops provided at the mineral dressing plants indigenously. They are also easy to operate with very little training for the operator.

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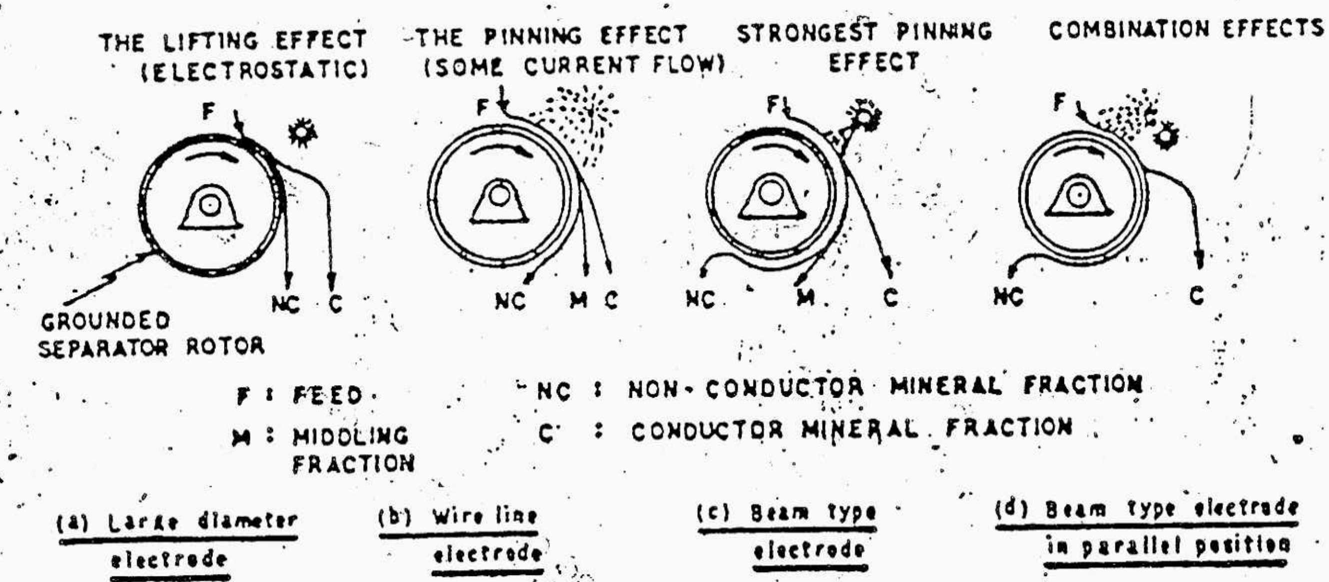
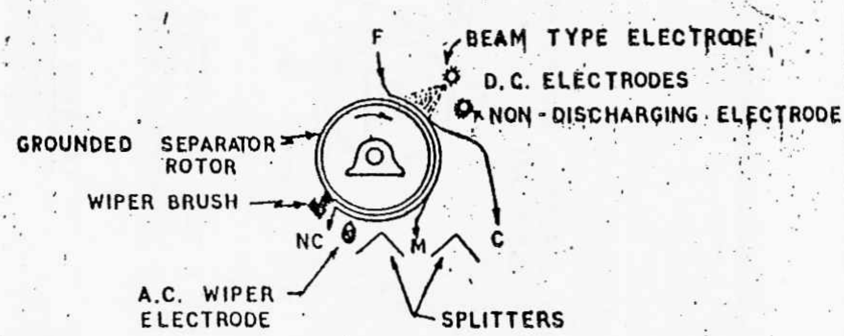


Fig. 1. Principles of operation of high tension roll separators.



F : FEED

NC: NON-CONDUCTOR MINERAL FRACTION

M : MIDDLING FRACTION

C : CONDUCTOR MINERAL FRACTION

Fig. 2. Modern electrodynamic separator.

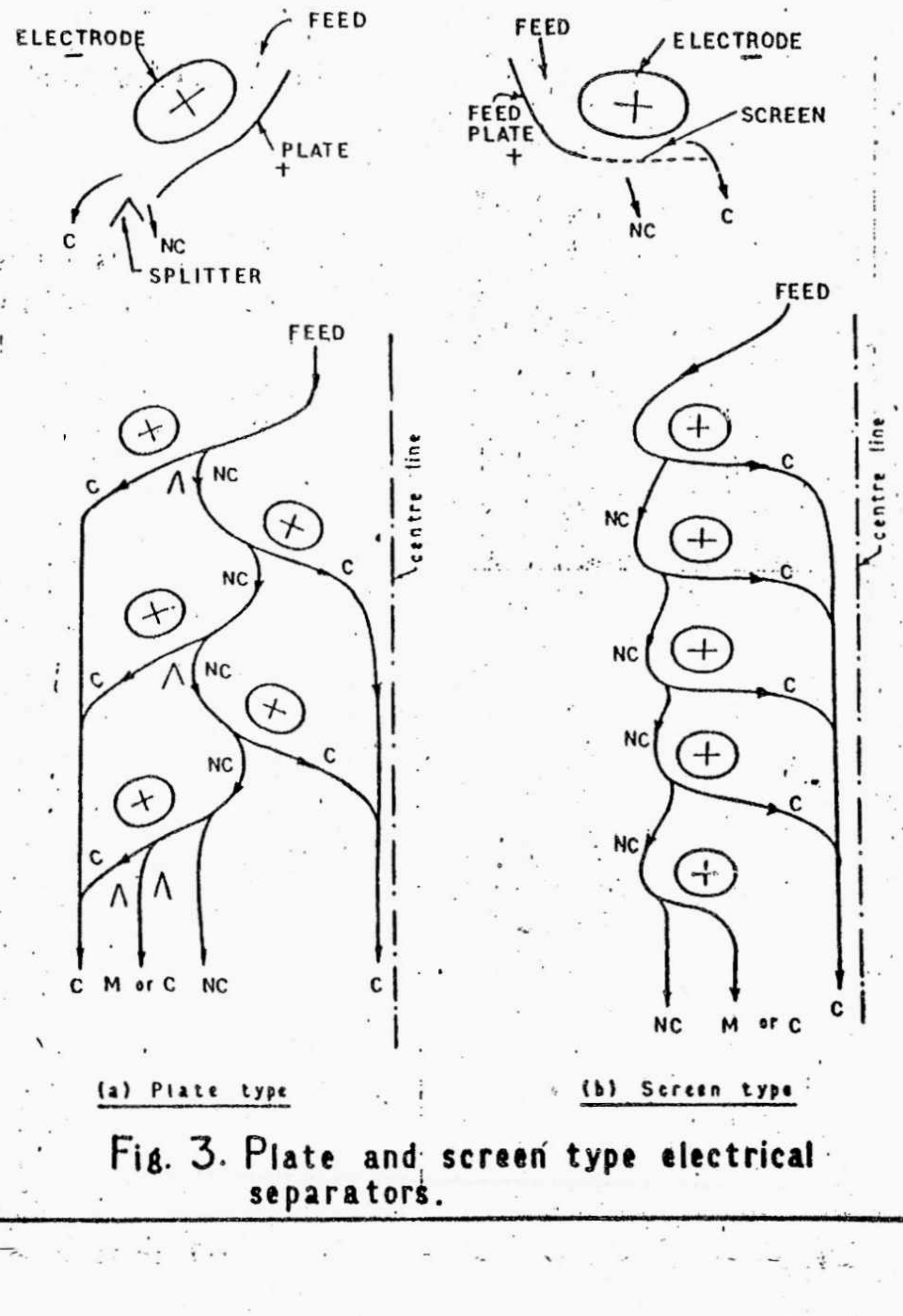


Fig. 3. Plate and screen type electrical separators.

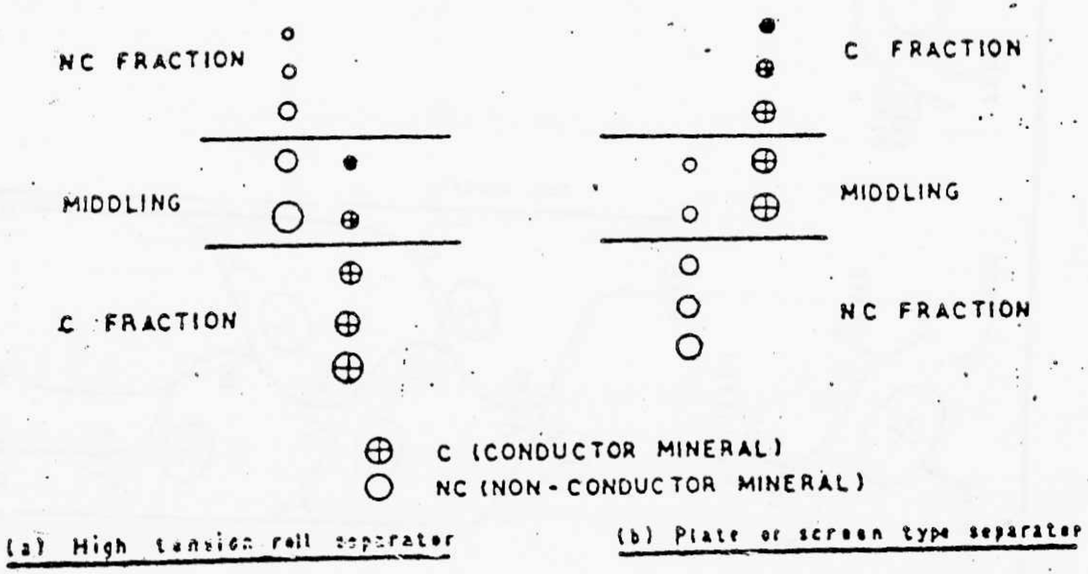


Fig. 4. Mineral separation in high tension and plate or screen type separators.