Teeter Bed Separation Applications

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Declaration

I declare that this dissertation is my own, unaided work. It has been submitted for the Degree of Master of Science in Engineering at the University of KwaZulu Natal, Durban. It has not been submitted before for any degree or examination in any other University.

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Ashma Singh

this the .11.. day of .MARCH...2008

ABSTRACT

Elutriators or commonly known as Teetered Bed Separators (TBS) consist of a column with water being introduced at the base (known as teeter water), which rises up the elutriator at a constant velocity. Mineral particles are separated according to their density and size. Particles with a settling velocity less than the velocity of the teeter water will report to the overflow stream, while those with a higher velocity will sink to the underflow. Finer and lower density particles report to the overflow whereas coarser, denser particles report to the underflow.

In commercial mineral processing by gravity concentration, the intermediate size range (-2mm+75 μm) has not been effectively processed due to industries lack in knowledge of equipment that are capable of effectively beneficiating this size material.

This project involved testing the effectiveness of the elutriator with regards to fines beneficiation as well as the development of a prototype unit.

Regarding coal (-2.0+1.0mm), the Eriez Crossflow unit produced the best results with an E.p. of 0.095, D_{50} of 1.52 and a product ash content of 8.3%. For the -1.0+ 0.5mm fraction the Eriez Crossflow elutriator was also utilized yielding best results at an E.p. of 0.06, D_{50} of 1.6 and ash content of 9.1% (feed ash content of 22.7%).

Regarding ferrochrome ore (-2.0+1.0mm), no noticeable separation occurred using the Eriez Crossflow unit. For the -1.0+ 0.5mm fraction the Linatex elutriator performed the best yielding an E.p. of 0.085, D_{50} of 3.18 and a FeCr grade of 85.1% (feed grade of 28.1%). For this size fraction the Eriez unit only upgraded the FeCr to 39.6%

Regarding hematite ore (-2.0+1.0mm), the Linatex unit produced the best results at an E.p. of 0.15, D_{50} of 3.4 and a Fe grade of 46.7% (feed grade of 32.4%). For the -1.0+ 0.5mm fraction the Linatex elutriator was also utilized yielding best results at an E.p. of 0.45, D_{50} of 3.75 and a Fe grade of 57.9% (feed grade of 32.4%).

The efficiency of separation with regards to different ore types was noticed to be partially dependent upon the feed point to the column. Lighter material was observed to separate more effectively with a tangential feed entry and denser material being separated more effectively with an entry point above the bed.

Test work on a prototype unit constructed was conducted using the -1.0+ 0.5mm ferrochrome material. This unit performed well compared with both the Eriez unit and the Linatex unit obtaining an E.p. of 0.075 as opposed to E.p. values of 0.085. The FeCr material was upgraded from 28.1% to 76.4% with the prototype unit.

A continuous two day run undertaken revealed that the elutriator is capable of operating at steady state for a period of time without loss of efficiency.

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NOMENCLATURE

Symbol	Definition	Units
a	acceleration	ms^{-2}
Cd	drag coefficient	-
d	diameter	m
Ep	Ecart probable (separation efficiency)	-
F	feed rate	kg/hr
g	gravity	ms^{-2}
m	mass of particle	kg
O	Overflow rate	kg/hr
ρ_f	fluid density	kg/m^3
ρ_s	solid/particle density	kg/m^3
Re	Reynolds Number	-
Tw	teeter water	L/min
U	Underflow Rate	kg/hr
u	velocity	ms^{-1}
μ	viscosity of fluid	m^2s^{-1}
u_i	slip velocity	ms^{-1}
u_t	terminal velocity	ms^{-1}
V	volume	m^3
x_F	feed grade	%
x_O	overflow grade	%
x_U	underflow grade	%
ϕ_i	volume fraction of particle specie i	-

CHAPTER 1 - INTRODUCTION

1 Introduction

Teeter Bed Separators have been used industrially and more commonly in mineral processing applications since 1934. Elutriator technology has thus far gained acceptance not only with coal but with regards to iron ore processing, chromite, beach sands, metal from slag industries etc as an effective means of processing fine material.

The process of separation utilises an upward current of water known as teeter water to aid in separation of mineral particles by means of their size or density. [3]

Due to the high amounts of run of mine (ROM) material being processed in South Africa there has been a phenomenal increase in fines (less than 2mm material) generated. Also as better quality reserves are exploited and dwindle lower grade ores are processed, which tend to require further processing in order to meet market grade specifications, hence the increase in fines generation. South Africa has extensive resources in the form of dumps containing fine coal, iron and manganese ore that are currently not being treated for a number of reasons including high operating costs, poor efficiencies and difficulty in downstream processing.

The sustainability of the South African Coal Industry depends to a large extent on the beneficiation of this fine material; in addition increased worldwide demands for metals has seen an increase in fines beneficiation in other sectors of the mining industry.

The objective of the project was to focus on elutriation as an effective gravity separation technique with regards to the beneficiation of fine particles of coal, ferrochrome and hematite, with a particular focus upon coal.

The project commenced by conducting a detailed literature survey on teeter bed separation fundamentals, principles and applications and comparison with the use of other gravity separation devices employed industrially with regards to fines beneficiation.

The test work program focused on optimisation of the TBS with regards to coal processing; the size ranges of interest for separation being -2+1mm and -1+0.5mm.

Also, in order to test the units' stability for industrial applications, other South African ore types namely ferrochrome (FeCr) and hematite (Fe_2O_3) were investigated which allowed testing of operation at densities between 1000 and 4200kg/m^3 dependent upon the feed material.

Design factors including feedrate, feed entry point into the TBS column and pulsing of the bed were investigated with the focus on designing a prototype unit to test the alterations in design parameters. Off site plant visits were undertaken so as to observe the operation of a pilot plant scale elutriator and to determine ways of improving the operation and equipment structure in order to enhance the beneficiation of fine particles.

In addition the operability of the unit over a continuous time period was investigated to ascertain if the unit possessed mechanical defects or required extensive operator input to maintain steady state operation. High tonnages (approximately 35 tonnes) of hematite material were separated to evaluate the performance of a pilot unit on a continuous basis.

A comparison with other commercially used gravity concentration devices (such as spiral concentrators and jigs) was then carried out to determine whether the commercial use of Teetered Bed Separation units is viable in the South African mining industry.

CHAPTER 2: LITERATURE REVIEW

2 Elutriation Fundamentals

Elutriation is a process of separating particles on the basis of size and density by means of an upward current of fluid, usually water. All elutriators consist of a column with water being introduced at the base, which rises up the column at a constant velocity. Feed particles introduced into the column are separated in two components, which are determined by the terminal velocities of the particles. Those particles with a velocity less than the velocity of the teeter water will report to the overflow stream, while those with a higher velocity will sink to the underflow. These velocities can be calculated by Stokes' law. This is a modified form of Stokes' Law if the flow regime is turbulent or intermediate. Stokes' solution is applicable for settling of particles at low Reynolds numbers ($1 < Re < 500$). [6]

When particles are not spherical, deviations from that solution are expected. In general, the larger the cross-sectional area perpendicular to the settling direction, the slower the particle settles. Generally, fine and low-density particles report to the overflow and the coarser and denser particles will sink to the bottom of the column. The particles that sink down the column create a fluidized bed of particles.

Stokes Law may not apply to coarse particles. At the fine end of the scale, separation becomes impractical below about 10 μm, as the material tends to agglomerate, or extremely long separating times are required. [1,19]

The major disadvantage of an elutriator is that the fluid velocity is not constant across the column, being a minimum at the walls of the column, and a maximum at the centre. This may result in some coarse particles being misplaced in the overflow, and some fine particles being misplaced into the underflow.

2.1 Stokes' Law and Newton's Law for Hindered Settling

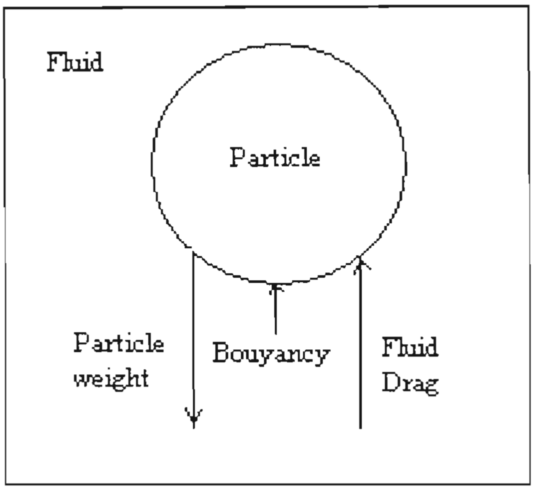

Figure 1: Forces exerted on a particle free falling in a fluid

For well dispersed ore pulps, free settling predominates when the percentage of solids by weight is less than 15%. [1]

Consider a stable non-rotating particle in a static fluid as indicated in Figure 1 of diameter d, density ρ_S and drag coefficient C_d falling under gravity g in a fluid of density ρ_f under free falling conditions. [14]

Three forces act on the particle:

- A gravitation force acting downwards: $(\rho_s g V = \rho_s g \frac{\pi}{6} d^3)$
- An upward buoyancy force due to the displaced fluid : $(\rho_f g V = \rho_f g \frac{\pi}{6} d^3)$
- A drag force D acting upwards: $C_d \frac{\pi}{4} d^2 \rho_f \frac{u^2}{2}$

Thus using Newton's Law, the forces acting on a settling sphere is represented by Equation 1:

$$ma = \rho_s g \frac{\pi}{6} d^3 - \rho_f g \frac{\pi}{6} d^3 - C_d \frac{\pi}{4} d^2 \rho_f \frac{u^2}{2} \qquad \text{.......................................(1)}$$

Where, m is the mass of the particle, a is the acceleration and hence ma is the resultant force.

Stokes showed that for laminar flow, $C_d = \frac{24}{\text{Re}}$

Where Re is Reynolds number and is represented as Re = $\frac{du\rho_f}{\mu}$; where μ represents the fluid viscosity.

At terminal velocity a=0 i.e. no resultant force

Therefore, $0 = \rho_s g \frac{\pi}{6} d^3 - \rho_f g \frac{\pi}{6} d^3 - C_d \frac{\pi}{4} d^2 \rho_f \frac{u^2}{2}$

$$0 = \frac{\pi}{6} d^3 g(\rho_s - \rho_f) - C_d \frac{\pi}{4} d^2 \rho_f \frac{u^2}{2}$$

$$\frac{u^2}{2} = \frac{\pi}{6} d^3 g(\rho_s - \rho_f) * \frac{4}{C_d \pi d^2 \rho_f}$$

$$\frac{u^2}{2} = \frac{2dg(\rho_s - \rho_f)}{3C_d \rho_f}$$

If Stokes' law is followed, i.e for laminar flow, $C_d = \frac{24\mu}{du\rho_f}$

Therefore, $\frac{u^2}{2} = \frac{2dg(\rho_s - \rho_f)du\rho_f}{3 * 24\mu\rho_f}$

$$u^2 = \frac{2dg(\rho_s - \rho_f)du\rho_f}{3 * 24\mu\rho_f}$$

$$u^2 = \frac{d^2ug(\rho_s - \rho_f)}{18\mu}$$

Therefore, by Equation 2 for **laminar flow**, Stokes' law is represented as

$$u = \frac{d^2 g(\rho_s - \rho_f)}{18\mu} \quad \text{...(2)}$$

For **turbulent settling** C_d approximates to 0.44

$$u^2 = \frac{4dg(\rho_s - \rho_f)}{3*0.44\rho_f}$$

$$u^2 = \frac{3.03dg(\rho_s - \rho_f)}{\rho_f}$$

Therefore, by Equation 3 for **turbulent flow**, Newton's law is represented as

$$u \approx \left[\frac{3dg(\rho_s - \rho_f)}{\rho_f}\right]^{0.5} \quad \text{...(3)}$$

Stokes' law is valid for particles below about 50 μm, while Newton's law is valid for particles larger than 0.5 cm in diameter. [14]

The test work for the elutriator involves particles in the size range of less than 2mm. It will be assumed that the terminal velocity of the particles will lie in between Stokes' and Newton's law. Both the laws show that the terminal velocity is a function of the density and particle size. It can be seen that:

- If two particles have the same density, the larger one will have a greater terminal velocity.
- If two particles have the same diameter, the denser one will have a higher terminal velocity.

Consider two mineral particles of densities ρ_a and ρ_b and diameters d_a and d_b respectively, falling in a fluid of density ρ_f, at exactly the same settling rate. Their terminal velocity will, therefore, be the same. The following relationships from Stokes' and Newton's laws can be obtained:

For Stokes' Law

$$\frac{d_a}{d_b} = \left[\frac{(\rho_b - \rho_f)}{\rho_a - \rho_f}\right]^{0.5} \quad \text{.....................}9$$

For Newton's Law

$$\frac{d_a}{d_b} = \left[\frac{(\rho_b - \rho_f)}{\rho_a - \rho_f}\right] \quad \text{..........................}10$$

This is know as the free settling ratio between the two minerals. It can possibly be used to give an indication of the separation efficiency of two minerals being separated by an elutriator.

The general expression can be written as:

$$\frac{d_a}{d_b} = \left[\frac{(\rho_b - \rho_f)}{(\rho_a - \rho_f)}\right]^n \quad \text{...............}11$$

The value of n lies in the range 0.5 – 1 for particles in the intermediate size range of 50 μm -0.5cm.

Stokes' and Newton's laws are valid for free settling particles i.e. particle systems that are very dilute. As the proportion of solids in the pulp increases, the effect of particle crowding becomes more apparent and the falling rate of the particle decreases. The system begins to behave as a heavy liquid whose density is that of the pulp rather than the fluidizing liquid. This represents hindered settling conditions. Hindered settling is the reduction of the settling speed of an individual particle resulting from the fluid upflow generated by neighbouring particles. The average settling speed is reduced as the concentration of the fluid increases. [1]

Due to the high density and viscosity of the slurry, the resistance to the fall is mainly as a result of the turbulence created. Thus Newton's law can be modified to the following:

$$u = \left[\frac{3gd(\rho_s - \rho_p)}{\rho_p}\right]^{0.5} \quad \text{...........12}$$

ρ_p – pulp density

We no longer consider the density of the fluid, but rather the density of the pulp.

As indicated by equation 12, the lower the density of the particle, the more marked is the effect of reduction of the effective density, $(\rho_s - \rho_f)$, and the greater is the reduction in falling velocity. Hindered-settling reduces the effect of size, while increasing the effect of density on classification.

Richardson and Zaki Equation

A theory has been developed by Richardson and Zaki that attempts to model hindered settling. Consider a particle system with species i settling in an unbound liquid at its terminal velocity u_t. As the volume fraction of the species in the liquid increases, the velocity of the species relative to the liquid decreases. This leads to the development of the slip velocity, u_i, which is the velocity of the species relative to the liquid. The slip velocity is a function of the terminal velocity and the volume fraction of the species.

This relationship is described by the empirical equation of Richardson and Zaki. [6]

$$u_i = u_{ti} * (1 - \phi_i)^{(n_i - 1)}$$

$n_i = 4$ or 5 for Re < 0.1, and

ϕ_i is the volume fraction of particle specie i and u_{ti} is the terminal velocity.

$$n_i = \frac{5.1 + 0.27 * \mathrm{Re}^{0.9}}{1.0 + 0.1 * \mathrm{Re}^{0.9}} \qquad \text{For Re} > 0.1$$

For three particle species, the equation is:

$$u_i = u_{ti} * \left(1 - \phi_i - \phi_j - \phi_k\right)^{(n_i - 1)}$$

Where i, j and k represent individual particle species

As the elutriator is effectively a hindered settling separator, the pulp density is used. Slip velocities for different densities and sizes can be generated which can be used to determine the necessary upward current velocity for separation.

2.2 New Technologies for Fine Particle Beneficiation

Due to the increase in Run of Mine (ROM) processing, there has been an increase in fines generation. Also, lower grade material requires crushing and milling prior to processing in order to liberate the valuable minerals and meet market grade required. There is an increasing need to treat fine particles below 2mm. There are many technologies using gravity separation, which have been developed to attempt to treat these fine particles. Traditional separators utilized for beneficiation of fine material include, shaking tables, spirals, centrifugal enhanced gravity separators and magnetic separators. Some of these technologies will be discussed in this section.

2.2.1 Traditional Separators

2.2.1.1 Shaking Tables

Shaking tables operate on the principle of separation according to density, using water as the medium. The table is inclined at an angle dependant upon what type of ore is being separated. Particles of high specific gravity will move more slowly than lighter particles. Particle size plays an important role in shaking table separation. As the range of particle size of the feed increases, the efficiency of separation decreases. The shaking table is generally used for laboratory operations and produces an indication of how effectively a spiral concentrator will work. It produces an ideal solution at which one can benchmark spiral operations. General E.p. values obtainable range from 0.03 to 0.5. Figure 2 is a schematic representation of a typical shaking table operation. [19]

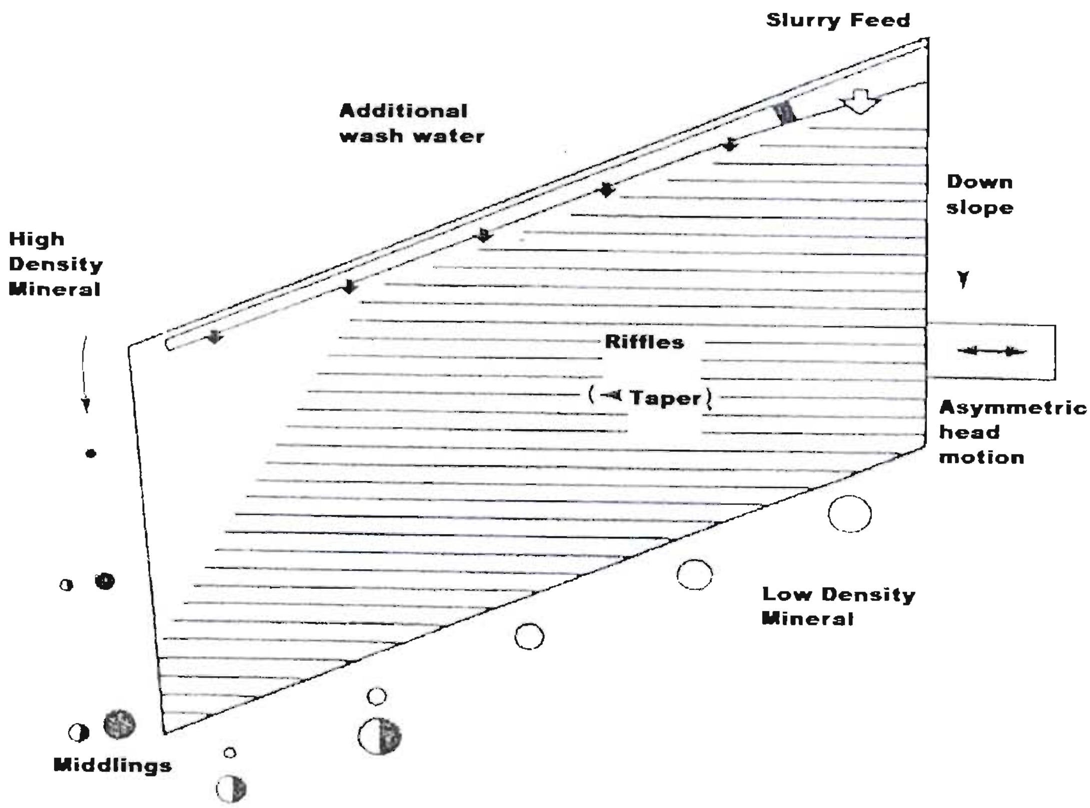

Figure 2: Schematic representation showing the distribution of products in a shaking table. [19]

2.2.1.2 Spiral Separation

Spiral concentrators are used to separate minerals from gangue on the basis of specific gravity differences in the feed material using water as a medium. This process uses the difference in density of minerals to separate fine material (-1 to 30μm). Some size separation also occurs. The standard feed pulp should be maintained between 30-45% solids by weight for optimum separation. Particles tend to segregate down the spiral profile according to fine heavies, coarse heavies, fine lights and coarse lights. The concentrate grade and recovery of samples are affected by the slope and profile of the spirals. A schematic representation of separation along a spiral is presented in Figure 3. [19]

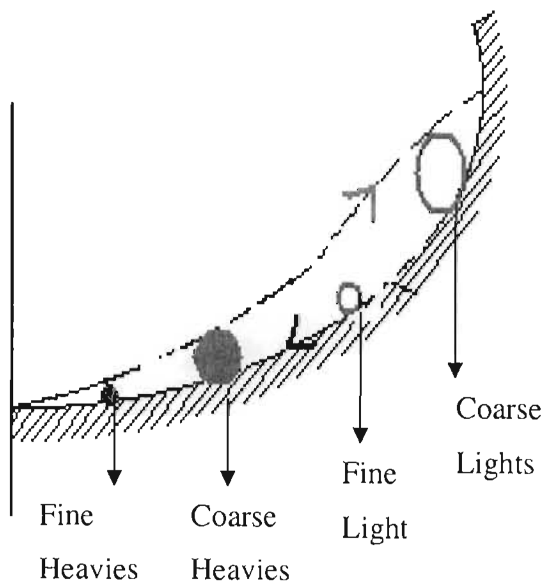

Figure 3: Schematic representation of particle segregation along a spiral

A typical plant setup is where the the rougher spiral is the first spiral where the feed is treated. The concentrate and middlings are then treated through a cleaner spiral for further upgrading. The tailings from both the rougher and cleaner spirals are treated through a scavenger spiral as a final recovery stage. Figure 4 represents a typical spiral circuit setup. Also in general E.p. values obtainable for processing of various ores through a spiral circuit range from 0.03 to 0.5.

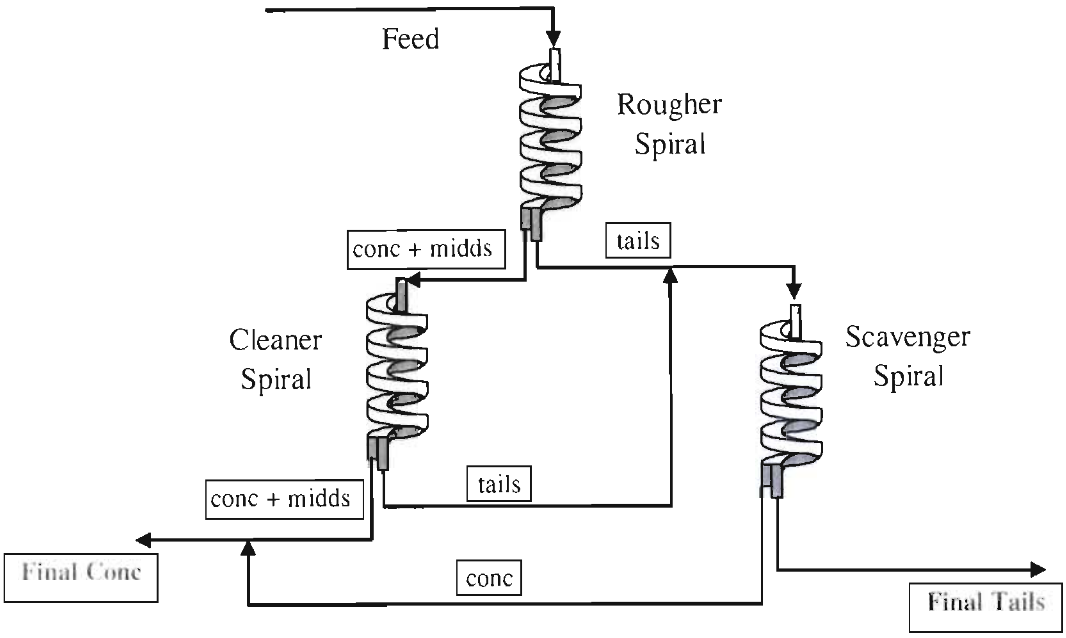

Figure 4: Schematic representation of a rougher, cleaner and scavenger spiral setup

2.2.1.3 Centrifugal Enhanced Gravity Separators

A new generation of centrifugal enhanced separators is capable of upgrading particles that were previous thought to be too fine (<75 μm) for water-based gravity separators. Three of these separators will be discussed namely:

- Falcon Concentrator
- Kelsey Jig
- Mozley Multi-Gravity Separator

Falcon Concentrator

The Falcon concentrator is a gravity concentrator that uses a centrifugal force to separate particles on the basis of density. Figure 5 is a schematic of a Falcon Concentrator.

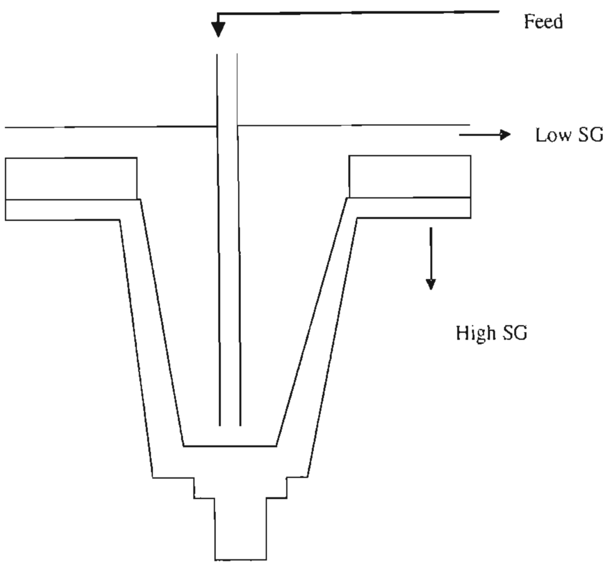

Figure 5: Schematic of Falcon Concentrator

As indicated in Figure 5 the Falcon concentrator consists of a truncated cone that rotates at very high speeds, a discharge valve for high specific gravity (SG) particles and an overflow chamber that removes the low SG particles.

Feed slurry is injected near the bottom of the cone. The slurry is accelerated up the cone wall by the centrifugal field created by the rotating cone. As the cone rotates the slurry forms a thin film in which particles separate on the basis of density. The light particles flow on top of the film layer and are removed over the top of the cone lip. The heavy particles slide along the inner surface of the cone and are discharged through the cone wall via small reject ports. There is no control of the discharge rate.

The Falcon Concentrator treats particles in the −1mm size fraction. Some applications are in the beach sands and chromite industries. It is also used extensively in free gold concentration. They are used in conjunction with a milling circuit to prevent free/liberated gold from being returned in the circulating load. E.p. values for a Falcon Concentrator range from 0.03 to 0.3 with the unit being applicable for ultrafine material with low mass yields to concentrate. [22]

Kelsey Jig

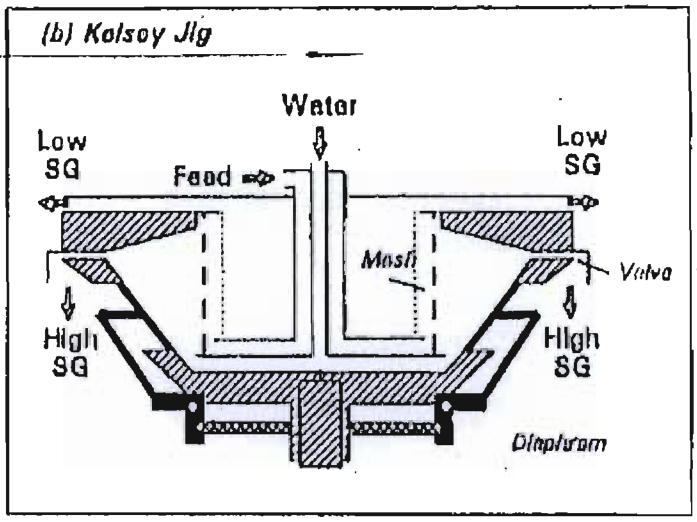

Figure 6: Schematic of Kelsey Jig [25]

As indicated in Figure 6, the Kelsey Jig consists of a series of hutches arranged in a circular structure, a cylindrical screen which is mounted on top of the hutch in an effort to retain the ragging material and a feed tube that penetrates the separation vessel.

The feed slurry enters the unit through a central feed tube and flows outward across the bed of ragging material. The unit also forms it own rag material from the coarse and heavy feed particles. Mechanical pulsators located within each hutch create oscillations in the bed that separate the particles on the basis of density. Low density particles flow across the ragging material and overflow at the top of the unit, while the high density particles pass through the ragging material and are discharged through the actuated valves.

The Kelsey Jig is best suited to –1mm particles. Some common applications are in the chromite and mineral sands (Namakwa Sands) industries. [25]

Mozley Multi-Gravity Separator

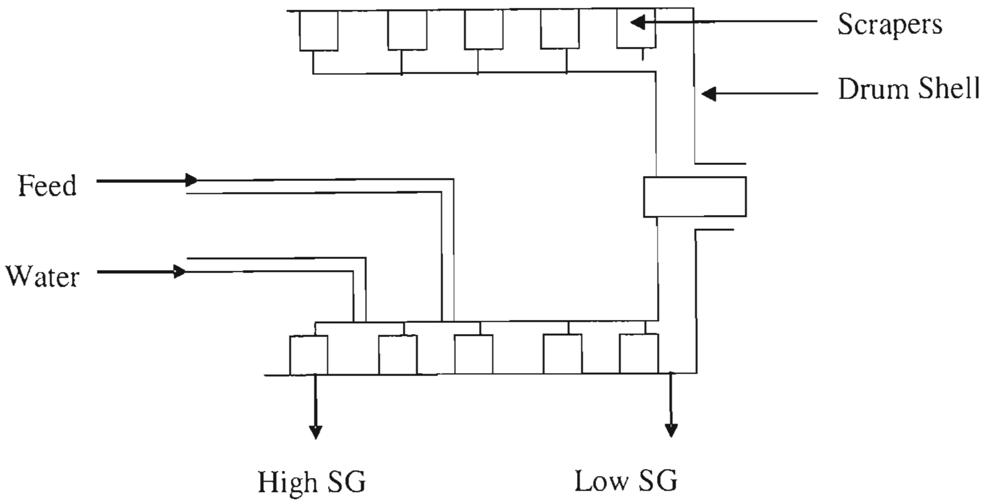

Figure 7: Schematic of Mozley Multi-Gravity Separator

As indicated in Figure 7, the unit consists of a tapered drum shell housing the internal equipment, a feed entry point that deposits feed on the wall of the drum, a water entry point that deposits water near the high particle SG discharge point and rotating scrapers attached to the wall of the drum.

The entire drum rotates to create the required centrifugal force. The feed slurry is distributed along the inner surface of the slightly tapered drum. The light particles are carried by the flowing film to the far end of the drum, while heavier particles become pinned to the inner surface of the drum and are carried by rotating scrapers to the opposite end of the drum. A small amount of wash water is added to the heavy discharge end to remove any entrained light particles.

The Mozley Multi-Gravity Separator is used for –1mm particles. Some common applications are in the fine coal (eg. at the Pittsburgh Energy Technology Centre) and chromite industries. [28]

2.3 Elutriator Development

The following separators will be examined:

- Allflux Separator – a two stage separator developed by Almineral.
- The Reflux Classifier – a separator that combines a fluidized bed and sets of parallel inclined plates.
- Teeter bed Separators – a separator, which uses a hindered settling bed and up current water as its medium of separation.

2.3.1 Allflux Separator

Figure 8 is a schematic of an Allflux Separator.

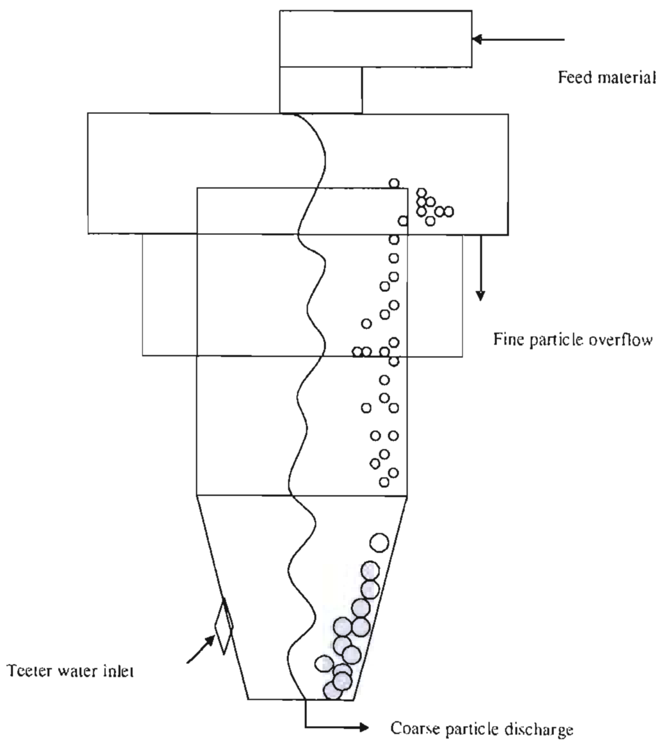

Figure 8: Schematic of Allflux Separator

The Allflux is a two-stage separator. It is a round, centre-feed process vessel that consists of the following components:

An inner circular chamber (Coarse Chamber)

This section has an automatically controlled discharge pinch valve which discharges to remove heavy and coarse particles through the underflow. This valve is controlled via a load cell signal, which is controlled to a setpoint. The setpoint controls the bed-height; as the indicator of the setpoint is increased, the bed-height increases. There is also a water entry point which allows the entry of the upcurrent, water. A feed tube penetrates the top of the vessel. This tube allows for feed to enter the chamber.

An outer circular chamber (Fines Chamber)

This section also has a water entry point that allows water to enter and rise up the column. A screen plate distributes the water flow. There is also an automatically controlled discharge cone valve which allows fine material to flow through.

Overflow Chute

The overflow chute collects all the ultrafine and fine particles.

The separation process uses a unique combination of rising water current and a fluidized bed. It can be divided into three sections:

Coarse Separation Section

The feed should consist of approximately 10-40 % solids. The feed slurry is introduced into the vessel through a centrally positioned feed tube that penetrates the vessel. The feed solids settle against the upstream water, which enters near the bottom of the separator. A bed of solids form at the bottom of the vessel. The bed height is controlled via a load cell attached to the vessel. Once the desired bed height is obtained and maintained, solids begin to discharge from the discharge valve at the bottom of the coarse chamber. The coarse product contains between 80-90 % solids. The fine and light particles are pushed upward and overflow into the second stage outer chamber to undergo fine separation. The overflow from this section contains between 10-20 % solids.

Fine Separation Section

The fine heavy particles that overflow into the outer chamber settle against the rising water that is introduced into the fines chamber at the bottom. There is a screen plate at the botton of this chamber that evenly distributes the water. The fine heavy particles once again form a bed at the bottom of the chamber. Once the bed is maintained at a setpoint, heavy fine particles are discharged through the discharge valve at the bottom. This product contains approximately 40-50 % solids. The ultra-fine and light particles overflow with most of the process water to the overflow chute. [8,13]

Some common applications include the concrete sand industry. The teeter bed separator was introduced into this industry in Germany in 1991. There was an increasing demand for high quality concrete and industrial sands in a market with deteriorating reserve quality. The primary sand contaminants were light impurities such as lignite and roots and varying size distributions in natural sand deposits.

Also the iron ore industry utilizes a teeter bed separator. The iron ore industry uses it to reclaim iron ore from dumpsites of former production operations. Hematite product upgrading from silica and alumina gangue is primarily the basis upon which separation is targeted.

Another application is the treatment of coal fines. Test work has been done on coal fines in the –0.5mm size range at Middelburg Mine, Ingwe coal, South Africa. It is said to get product coal between 13-14 % ash from a feed that contains 30% ash. This method was considered as a means of replacing spirals. [8,13]

2.3.2 Reflux Classifier

The Reflux Classifier is a new device developed by Ludowici MPE which is based on the principles of the hydrosizer i.e. it separates particles on the basis of size and density. It differs from the hydrosizer in the addition of two sets of parallel plates, which are believed to improve the separation of fast and slow settling particles. Figure 9 is a schematic of a Reflux Classifier.

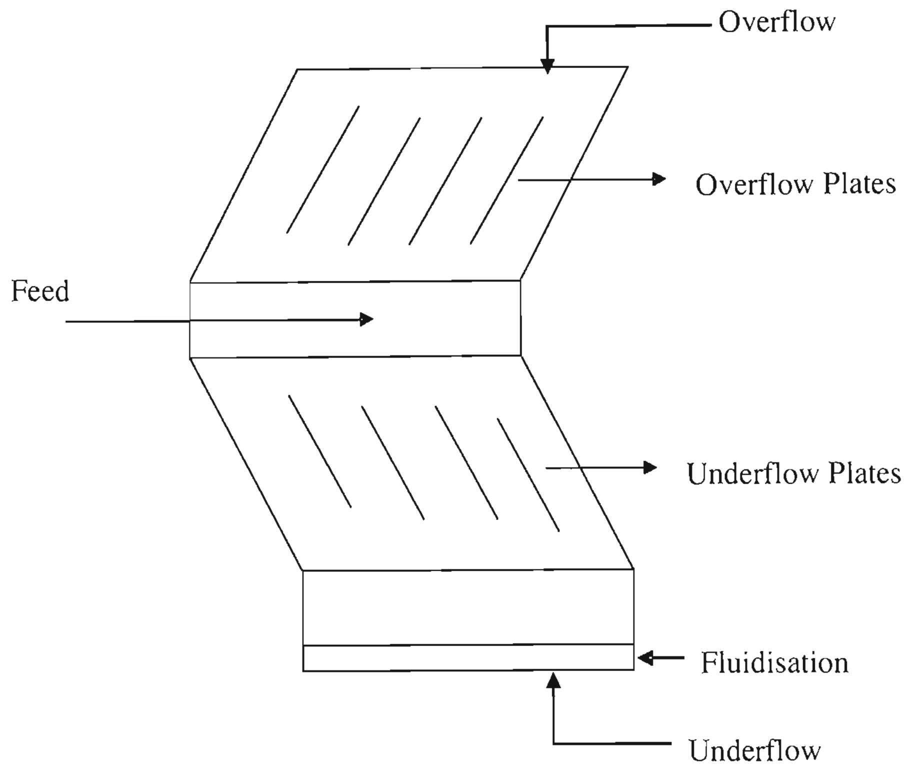

Figure 9: Schematic of Reflux Classifier

As indicated in the illustration the unit contains three sections:

Upper section

This section consists of the overflow launder and a set of overflow plates.

Middle section

This section contains the feed entry point.

Lower section

This section consists of a set of underflow plates, a fluidization water entry point, an underflow exit point and two automated pinch valves.

The operation of the reflux classifier relies on settling of particles in an upward flow of water. The upward water flow is created at a distributor plate in the bottom of the reflux classifier. It has a set of tilted plates above and below the feed entry section. These plates increase the rate of settling of the particles and thereby create two zones of increased slurry density immediately below each set of plates. These high-density zones enable the reflux classifier to sort particles on the density basis rather than particle size. Low density particles float to the top, carried by the water. The denser particles sink through the zones of higher slurry density and accumulate on the distributor plate. Two automated pinch valves control the rate of dense particle discharge. The discharge valves are controlled via a DP cell, which determines the discharge rate. This allows a selected pulp density to be maintained in the reject chamber of the reflux classifier over a wide range of feed conditions. [7,12]

2.3.3 Teeter Bed Separators

These separators permit separation of particles on the basis of particle density and size. This is achieved by subjecting a slurry of mixture to an upward current of water, in a vertical column. Under these circumstances, particles whose settling velocity are greater than the upward current report to the underflow while those of lesser settling velocity report to the overflow. Generally, the material exiting the column is restricted and therefore material builds up at the exit. This bed of slurry acts as a dense medium so that downward moving particles experience a density gradient different from that of the pure liquid. This dense medium effect allows for a sharper separation whilst reducing the effect of size. The height of the bed can be controlled to a setpoint by controlling the underflow discharge rate via an automated valve. The upward current water is referred to as teeter water and the bed of slurry is refered to as the teeter bed. This separation process is commonly refered to as 'elutriation' and there are numerous types of teeter bed separators and elutriators. [2].

Types of Elutriators

Numerous types of elutriators exist. These include the following:

(a) Hindered-settling columns / Hindered Bed columns

(b) Teeter-bed columns

(c) Hydrosizers

(d) Up current classifiers

(e) Eriez crossflow Separators / Stokes' Hydrosizer

(f) Eriez hydrofloat separating column

(g) Magnetically Enhanced HydroSeparator

(a-c) Hindered-settling columns, Teeter bed columns, Hydrosizer

All these gravity separation devices have the same equipment operation and separate on the basis of size and density.

In each case the equipment consists of three sections namely upper, middle and lower sections. The upper section consists of the volumetric feeder and the overflow launder. The middle section of the column contains the entry point of the slurry-water feed i.e. the feed enters in the middle of the column with exception being the Eriez Crossflow Elutriator where the feed enters at the top. The lower section consists of the teeter water entry point, distribution section for the teeter water, pressure sensor and pinch valve. The pressure on the sensor is monitored by a PID controller, which controls the pinch valve for the discharge of the underflow.

The column is initially filled with water. The teeter water flow rate is set to produce the desired cut size. The feed water is adjusted to produce feed slurry consisting of approximately 50% solids by weight. Conditions vary with processing of different ore types. Solids are fed into the feed tube and combined with the feed water and enter the column. The setpoint on the differential pressure sensor can be adjusted to achieve the desired bed height. After the setpoint is reached, underflow solids begin to discharge. Effectively, an autogenous dense medium is set up as the 'teeter bed'. As such, hindered settling predominates and the apparent density of the slurry allows for a sharper separation than by free settling (as noted on page 4). As particles pass through the teeter bed, the apparent density of the bed increases towards the underflow allowing a 're-cleaning' action for misplaced particles.

Some applications of teeter bed separators in South Africa involve the treatment of coal fines. Teeter bed columns were installed at Grootegeluk coalmine, Ellisras. This plant treats coal fines.

Separators can be used to treat silica sand for glass manufacture and moulding sands for foundries and other sands, which are required for more diverse applications. A Hydrosizer is currently being used at Namakwa Sand for processing their beach sand.

An environmental application lies in the units' ability to separate low-density organic material from soil. [20].

(d) Up Current Classifier

The Up Current Classifier has a very similar design and operates as the hindered settling column. The only difference being the utilization of very low teeter water rates. The equipment acts as a gravity separator. Typically, the density of the desired material is considerably different from the undesired material.

Some applications are in the ferrochrome from slag recovery plant at Middelburg ferrochrome and the ferromanganese from slag recovery plant Canon at Witbank. These Up Current Classifiers are manufactured by Atoll and are subsequently named Atoll Apic Classifier. It is also used in the beneficiation of -2mm + 0.5mm hematite ore at Kumba Resourses. [21]

(e) Eriez Crossflow Elutriator / Stokes Hydrosizer

The Eriez Crossflow Elutriator operates on the same principle as the Teeter Bed Separator but differs only on the feed entry point to the elutriator. The feed-water slurry enters at the top of the column. This allows the fines to move across the top of the column to the overflow launder, while the heavies sink to the bottom.

As the name suggests, Eriez Magnetics developed this unit. But numerous South African companies have been commissioning this elutriator in South Africa and Australia.

Some common applications involve the treatment of coal fines. A unit has been installed at Stratford Coal, which is located in the Avon Valley, New South Wales, Australia. It was installed to rewash the primary spiral product to reduce the overall fines ash level. The particle size class treated is –1.2 + 0.35 mm. Bateman Kinhill commissioned the installation of this elutriator. Another unit has been installed at Bayswater's Colliery Coal Preparation Plant (CPP) located in the Upper Hunter Valley of New South Wales, Australia. The elutriator is used to classify a –2 + 0.125 mm coal size fraction.

Another application involves sand production. Silica sand is treated using the Eriez Elutriator to produce high-grade sand for concrete products, glass making or foundry use. Figure 10 is a schematic of the Eriez Crossflow Elutriator.

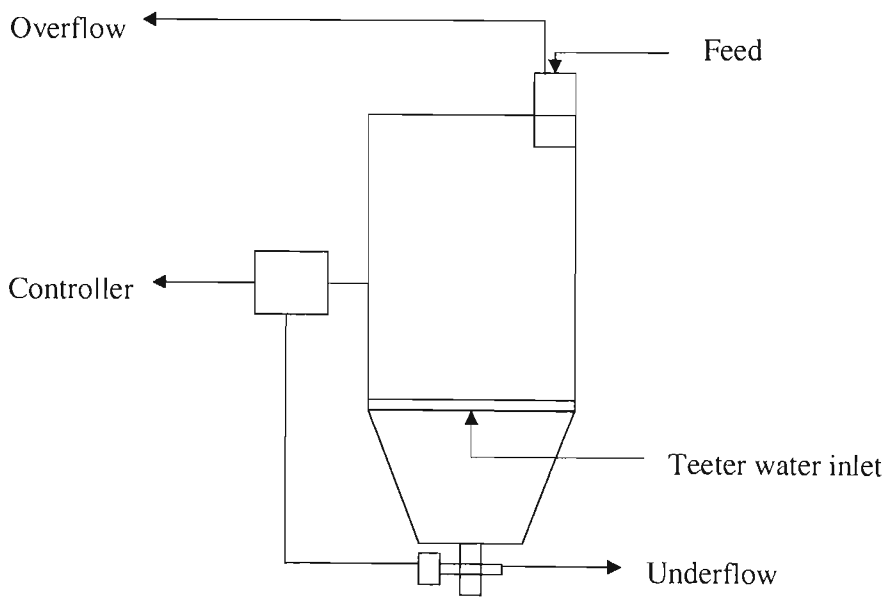

Figure 10: Schematic of the Eriez Crossflow Elutriator

Teeter water is added at a rate that ensures that lightweight particles report to the overflow of the unit. Those particles in the feed that have a settling velocity equal to the upward velocity of the teeter water are held in suspension in the unit thereby creating a fluidized hindered settling bed. The feed is introduced at the top of the unit through a tangential feedwell, which distributes it into the cell. Teeter water is added at the bottom of the cell via a water box and is evenly distributed across the entire area of the cell through a perforated plate – the Teeter Plate. The height of the fluidized bed is continuously monitored by the control system, which ensures that the fluidised bed level remains constant by controlling the rate of discharge from the underflow outlet spigot. Only those particles that are coarser and heavier than the pre-selected point of separation report to the underflow product stream.

The successful operation of the elutriator is critically dependent on the maintenance of the teeter bed. This is achieved by ensuring an even distribution of the upward current water at constant velocity and pressure and by controlling the density of the pulp, at a set height, within the vessel. Control is achieved by allowing the material that has settled at the base of the machine to discharge in response to an increase in density of the pulp. This control allows the operator to set the machine to automatically discharge in order to achieve a pre-set density. The automatic control allows the operator to select the separating density and ensures that the hydrosizer will adjust to variations in feed. [4,24]

(f) Eriez HydroFloat Separator

The Eriez HydroFloat Separator differs slightly from conventional hydraulic/hindered–bed separators but still relies upon particle size and density to separate different types of minerals. The Eriez elutriator uses an aeration system i.e. air is injected into the water line in an attempt to increase the efficiency of the gravity concentration method.

The Eriez HydroFloat separator consists of a main housing (separation zone and dewatering cone), a product collection launder, a process control syste and a water/air injection system. Figure 11 below shows the schematic of the HyroFloat separator.

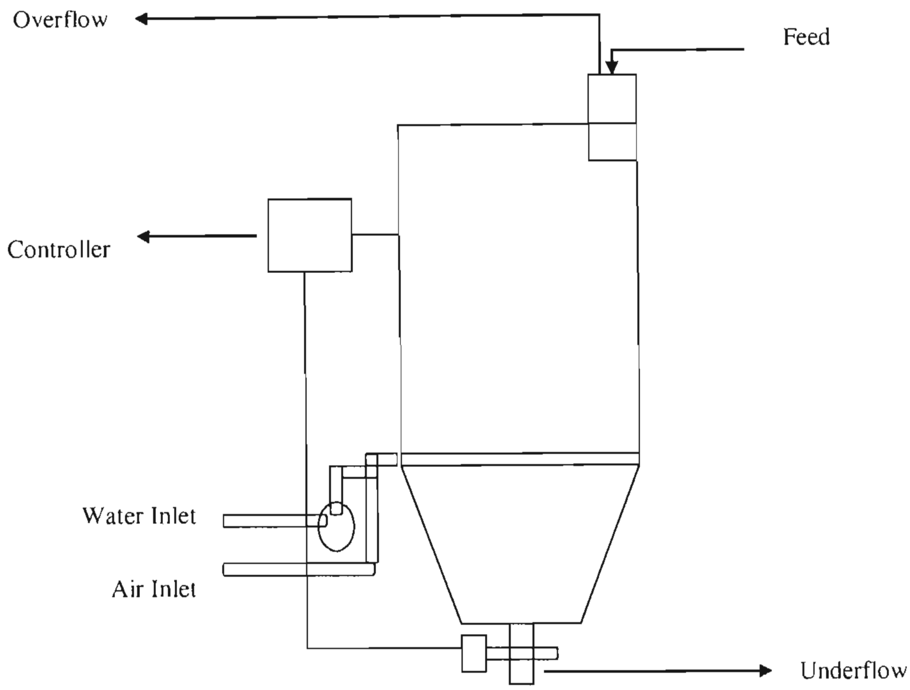

Figure 11: Schematic of the Eriez HydroFloat Separator

The Eriez HydroFloat Separator operates such that fine air bubbles are introduced with the water supply by means of the aeration system. The bubbles rise with the upward water current, meet the suspended particles and selectively attach to the surface of a particular species. Chemical activation can be used to promote bubble attachment to specific minerals. Selective attachment of an air bubble to the coarse, low-density particles reduces the settling velocity of this material. As a result, the effect of particle size on separation efficiency is greatly reduced, which improve process performance. In effect, this is a combination of both gravity separation and froth flotation and relies both on the size and density of particles and their surface properties to achieve an enhanced separation. As a standard teeter bed separator, the Eriez HydroFloat separates using purely water as its medium. No reagent addition is necessary. [5,10,24].

(g) Magnetically Enhanced HydroSeparator

A HydroSeparator is a concentration device that is commonly used in taconite and iron ore producing plants. It is effective in the separation of fine gangue minerals. The selective downward movement of the product is assisted by powerful electromagnets that agitate and hold the strongly magnetic ore preventing it from being flushed out of the system. Laboratory tests have shown that magnetic iron losses can be prevented by applying a magnetic field strength of 0.003 Tesla (30 gauss) to a HydroSeparator [15]. A benefit of this operation lies in the units' ability to obtain greater efficiencies by separating out weakly magnetic middlings particles, resulting in a cleaner value-added product.

Some common applications are in the taconite and iron ore industries. Figure 12 is a schematic of a Magnetically Enhanced HydroSeparator. [15, 16]

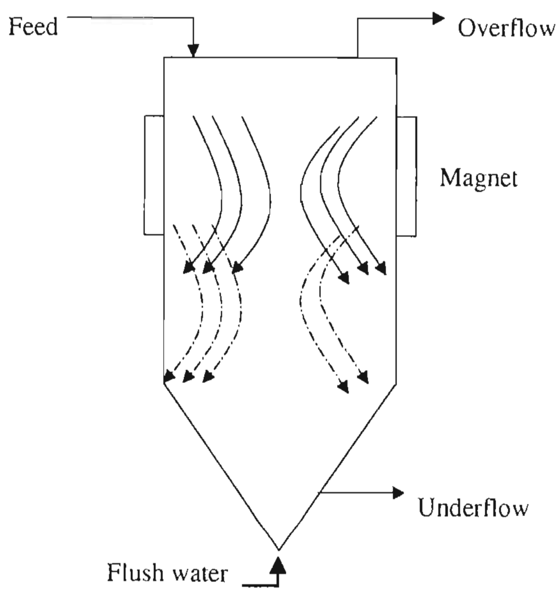

Figure 12: Schematic of a Magnetically Enhanced HydroSeparator

2.4 Advantages of an elutriator over spirals

Some common advantages of elutriators as compared to spirals are that elutriators can process coarser fractions (up until 3mm) whereas the cutoff limit for the spirals is -1mm particles due to the semi-fluidised nature of the spirals compared to the full immersion of particles in fluid in the elutriators.

Specifically with regards to coal processing, lower E.p. values are obtainable (E.p. ~ 0.0025) compared to other density separation processes. Also, lower ash to product is obtainable.[2]

Units are usually fully automated with adjustable controls that allow the operator to adjust the product/refuse ash. Spiral concentrators have multiple points for the removal of tailings and concentrate and these all require adjustment to change the operating conditions. They therefore require less operator attention. Elutriators do not have a complicated feed distribution system, which, unlike those for spirals, is prone to blocking and requires regular attention.

Spirals do not cope well with fluctuations in feed conditions whereas elutriators can operate between 0-100% of their design capacity. Elutriators have an average life span of 15 years as there is little contact between the particles and the unit, whereas spirals need replacement after 3 to 5 years due to the corrosion of the unit when in continuos use. Elutriators are compact and require less floor space per ton processed than a spirals plant, which generally consists of banks of rougher, cleaner, re-cleaner and scavenger spiral stages. Thus elutriators have a lower capital and operating cost on a ton for ton basis. [4,11]

2.5 Differences and Features of the Different Types of Elutriators

Table 1 summarises the novel technologies available for gravity concentration. As can be seen, hindered or teetered bed separators can be used in a range of possible applications across a range of densitites of ores treated by gravity means in South Africa.

Table 1: Comparison between elutriator types

Type of Elutriator	Basis of Separation	Equipment Structure	Discharge Rate Control	Applications
Teeter Bed Sparators Hindered Bed Settlers	Both density and size	Feed tube penetrates the top and deposits feed in the middle of the equipment.	A pinch valve, which is controlled by a load cell input to a PID controller.	1. Treatment of coal fines. 2. Used by sand producers. 3. Hematite beneficiation.
Eriez Crossflow Elutriator	Both density and size	Feed enters tangential to the top of the elutriator.	A ball valve, which is controlled by a load cell input to a PID controller.	1. Treatment of coal fines. 2. Used by sand producers. 3. Chromite industries.

Table 1: Comparison between elutriator types…continued

Type of Elutriator	Basis of Separation	Equipment Structure	Discharge Rate Control	Applications
Up Current Classifier	Largely on density	Feed tube penetrates the top and deposits feed in the middle of the equipment.	A pinch valve, which is controlled by a load cell input to a PID controller.	1. Ferrochrome from slag recovery. 2. Beneficiation of hematite.
Eriez HydroFloat Separator	Largely on density	Feed enters tangential to the top of the elutriator. Air is injected into the water supply to create air bubbles.	A ball valve, which is controlled by a load cell input to a PID controller.	1. Beach sand processing. 2. Coal treatment.
Reflux Classifier	Largely on density but size as well	Contains two sets of parallel plates in the separation chamber. The feed enters through an opening on the side of the classifier in between the two sets of plates.	A pinch valve, which is controlled by a load cell input to a PID controller.	1. Chromite industry. 2. UG_2 processing.
Magnetically Enhanced Hydroseparator	Largely on density	Consists of magnetic coils further up the column, towards the overflow. Feed enters tangential to the column.	A pinch valve, which is controlled by a load cell input to a PID controller.	1. Taconite industry 2. Iron ore industry

2.6 Conclusion

In conclusion, it is clear from literature that elutriators have the potential to be used in a range of mineral processing applications in South Africa. Scientific data however is not readily available to confirm industries need for such a unit. Also its applicability for treating various ore types ranging in specific gravity is not well known. The need for further upgrading of coal, hematite and to an extent ferrochrome within South Africa is rife due to the depletion of current reserves.

By testing separation of these ore types with two commercially available elutriators, it is possible to determine firstly whether elutriators would be appropriate for the South African mining industry, and secondly whether a unit can be developed which can provide separations over a range of densities.

Other commercial equipment for example spirals and centrifugal enhanced gravity separators are specifically utilized for fines beneficiation, however limitations in terms of equipment footprint, processing of material varying in density as well as operability have been identified. The elutriator is a compact unit capable of handling variations in material density. The operability of the unit is easily controlled. The units' applicability as well as design aspect is critically examined within this dissertation.

CHAPTER 3: Experimental Procedures testing the suitability of elutriators for South African Ores

3 Opportunities for Improvement in Teeter Bed Separation Applications

Apart from traditional fines separators currently being utilized (generally spiral concentrator circuits or enhanced gravity separators), elutriators were identified as being a potential unit to treat material within the intermediary size range of -2+0.075mm.

In order to test the suitability of elutriation in a range of applications, three commercial units, the Eriez hydrosizer, the Eriez crossflow separator and the Linatex elutriator were examined using a range of South African ore types. The results of the test work will allow development of a single prototype from an examination of the operation of the existing commercial units.

Coal was identified as the ore type which would undergo primary investigations due to the abundance of coal fines within South Africa having potential for further beneficiation. A network of key industrial coal producers within South Africa was readily available to facilitate indepth research. Also the ease of analysis in terms of determining ash content is quick and non-laborious.

In order to test the efficiency of the teetered bed separator for other ore beneficiation, alternative ore types (e.g. ferrochrome ore, hematite and manganese ore) were examined to evaluate the units' performance at a range of densities.

Also the physical design characteristics were explored to determine further improvements that could be made to the units to allow for imrovements in separation efficiencies. This included addition of a vibration and pulsing dimension to the bed to attempt to prevent possible rat holing, an investigation of the optimum conditions for separation, examination of possible wall effects and the effect of feed inlet positioning, together with improvements in bed control mechanisms.

3.1 Elutriator Test work

The test work involved processing of coal feed using the Eriez Crossflow Elutriator. Offsite tests were conducted at Koornfontein coal plant using the Eriez Hydrosizer. Ferrochrome ore and hematite was tested on the Linatex Elutriator. The test variables examined in detail included (a) bed height setpoints, (b) teeter water addition rate and (c) size classes. These parameters were tested for all ore types.

Ore types were chosen such that a wide range of densities would be investigated in order to determine elutriator performance. Two size ranges were evaluated namely –2+1mm and –1+0.5mm to investigate possible improvements with regards to separation. The test work also involved determination of the separation efficiency and optimum operating parameters of the pilot scale elutriator when processing the above mentioned ore types. Results obtained from offsite and on site test work were evaluated in order to compare the effect of site operations. An examination of design changes and construction of a prototype unit was also conducted. The operation of the elutriator was examined over a continuous two day period and data was collated pertaining to this test run.

3.1.1 Variable Testing Procedure

Bed Height Setpoints

The bed height setpoint was supplied as a setpoint into the controller in an attempt to fix one operating parameter. The elutriator was initially operated at the lowest bed height setpoint. Once the elutriator was at steady state, underflow and overflow samples were taken. These samples were sent for chemical analysis. A new bed height setpoint was supplied into the controller. Similarly, the elutriator was allowed to reach steady state for overflow and underflow samples to be sampled.

Teeter Water Addition Rate

Teeter water fow is directly related to the upward velocity of the water, which relates to the settling velocity and hence separation density of the material. This stage involved varying the teeter water flowrate in order to improve on the product grade. The bed height setpoint that gave the best separation in the above mentioned tests were used for the teeter water addition rate tests. A specific teeter water addition rate was chosen and the elutriator was allowed to reach steady state. Once steady state had been achieved representative sub-samples of the underflow and overflow material was sampled and prepared for analysis.

Size classes

The test work involved testing primarily coal. This feed was split into two size fractions namely the –2+1 mm and the –1+ 0.5 mm fraction to investigate improvements in separation using the Eriez Crossflow unit. Offsite and onsite test work was conducted on -3mm coal fines using the QVA hydrosizer.

3.2 Methodology

3.2.1 Elutriator Mass Balance

The overall mass balance is given as:

$$F = U + O \quad \ldots\ldots\ldots\ldots\ldots\ 1$$

Where F = Feedrate (kg/hr)

U = Underflow rate (kg/hr)

O = Overflow rate (kg/hr)

NB: the feedrate, bed-height setpoint and teeter water rate is set during the running of the elutriator.

A species balance can also be written:

$$x_F F = x_U U + x_O O \quad \ldots\ldots\ldots\ldots\ldots\ldots\ 2$$

Where x_F, x_U and x_O = Grade of feed, underflow and overflow respectively

These two equations form the basis for the mass balance around the elutriator.

Furthermore, equation 1 can be substituted into equation 2 to give the following.

$$x_F F = x_U U + x_O (F - U) \quad \ldots\ldots\ldots\ldots 3$$

This equation can be rearranged to make the underflow rate the subject of the formulae:

$$U = \frac{F(x_F - x_O)}{(x_U - x_O)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 4$$

3.2.2 Recovery

The recovery is calculated using the following equation:

$$\text{Recovery} = \frac{x_U U}{x_F F} * 100 \ldots\ldots\ldots\ldots\ldots 5$$

Where x_U and x_F represents the grade of underflow and feed respectively and

U and F is the rate of underflow (kg/hr) and feedrate (kg/hr) respectively.

<u>NB:</u> The numerator refers to the product, for coal the product is found in the overflow and the numerator will then be replaced with $x_O O$.

3.2.3 Partition Curve

The efficiency of separation of gravity separation equipment can be represented by the slope of a partition curve. It is the percentage of the feed material reporting to either the underflow or overflow within each density class within the ore.

The ideal partition curve shows that all particles having a density higher than the separating density report to the underflow whilst those lighter report to the overflow.

The partition curve for a real separation shows that efficiency is higher for particles of density far from the operating density and decreases for particles approaching the operating density.

Almost all partition curves give a reasonable straight-line relationship between the distribution of 25% and 75% and the slope of this line is used to show the efficiency of the process as follows:

$$E.p. = \frac{SG_{75} - SG_{25}}{2}$$

Where, E.p. is the probable error of separation or Ecart probable.

Therefore, the lower the E.p., the more efficient is the separation. [23]

For lower density material for example coal, Heavy Liquid Separation test work (HLS) was used to determine the mass split of the overflow and underflow within each density class within the ore. HLS test work was conducted in order to obtain mass split at various specific gravity cutpoints. For cutpoints greater than S.G of 2.96 a mixture of TBE and ferrosilicon (FeSi) was used, for density cutpoints less than S.G 2.96 a mixture of tetra bromo ethyl (TBE) and acetone is used. The results obtained were used to plot partition curves indicating efficiency of separation. Tracer tests are another method used industrially that are less cost effective as the tracers are specifically sized particles of exact density. This method is not as accurate as HLS tests due to the uniform shape of the tracers but gives an indication of equipment performance and possible losses of product.

For higher density material (S.G >4.0) for example ferrochrome and hematite, separations of samples were carried out using a shaking table followed by picnometer tests of the concentrates, middlings and tailings streams. The maximum S.G obtainable with regards to HLS test work is 4.0.

3.3 Experimental Procedure

Test work was conducted on four ore types namely:

- Coal from Middelburg Area tested onsite using the Eriez Crossflow Elutriator.
- Coal tested at Koornfontein Coal Mine in Middelburg using Eriez Hydrosizer and test work conducted on the same ore at Mintek using the Eriez Crossflow Elutriator.
- Ferrochrome from Middelburg Area using Linatex Elutriator.
- Hematite from Northern Cape using the Linatex Elutriator.

Each of the above ore types with exception of Coal from the offsite commercial plant was screened into two size fractions namely –2mm+1mm and –1mm+0.5mm. Test work was conducted independently on each of the size fractions.

3.3.1 Coal Test work

3.3.1.1 Middelburg Coal

For the –2mm+1mm-size fraction: six test runs were performed through the Eriez Crossflow Elutriator at varying bed-height setpoints and teeter water flowrates. For the –1mm+0.5mm size fraction: six test runs were performed through the Eriez Crossflow Elutriator at varying bed-height setpoints and teeter water flowrates. Mass splits were determined by heavy liquid separation (HLS) test work of products.

3.3.1.2 Koornfontein Coal (-3mm)

Test work was conducted at Koornfontein Mines by plant personnel using, the Eriez Hydrosizer. The same tests were conducted at Mintek using the Eriez Crossflow Elutriator. A comparison between operations of the unit was evaluated.

3.3.2 Ferrochrome Test work

For the –2mm+1mm size fraction: three test runs were conducted using the Eriez Crossflow Elutriator at varying bed-height setpoints. For the –1mm+0.5mm size fraction: three test runs were conducted using the Eriez Crossflow Elutriator at varying bed-height setpoint.

It was noted that the grade obtained for the product was low; therefore it was decided to process the ore in the Linatex Elutriator and examine the effect thereof. For the –1mm+0.5mm size fraction: 4 test runs were conducted using the Linatex Elutriator at varying teeter water flowrates and bed-height setpoints. Mass splits were determined by HLS test work of products.

3.3.3 Hematite Test work

For the –2mm+1mm size fraction: one test run was conducted using the Linatex Elutriator. For the –1mm+0.5mm size fraction: three test runs were conducted using the Linatex Elutriator. Mass splits of products were determined by shaking table test work.

Based on observation, it was noted that for the hematite ore, the Linatex Elutriator was more efficient in building up a steady bed for test work purposes.

CHAPTER 4: EXPERIMENTAL RESULTS AND DISCUSSION

4 Coal Results

4.1 Middelburg Coal (-2mm+1mm) Data

4.1.1 Elutriation Test work – Eriez Crossflow Elutriator

Six test runs were conducted using the Eriez Crossflow Elutriator. Grades and efficiencies were compared after varying teeter water flowrates and bed-height setpoints. The results of Test Runs 1-6 are presented in Appendix A1-A6.

Figure 13 is a graphical representation of the efficiency of separation when keeping the teeter water rate constant and varying the bed-height setpoint. Similarly Table 2 is a representation of the results obtained and Figure 14 is a graphical representation of this effect.

Figure 15 is a graphical representation of the efficiency of separation when keeping the bed-height setpoint constant and varying teeter water flowrates. Likewise, Table 3 is a representation of the results obtained with Figure 16 being a graphical representation of this effect.

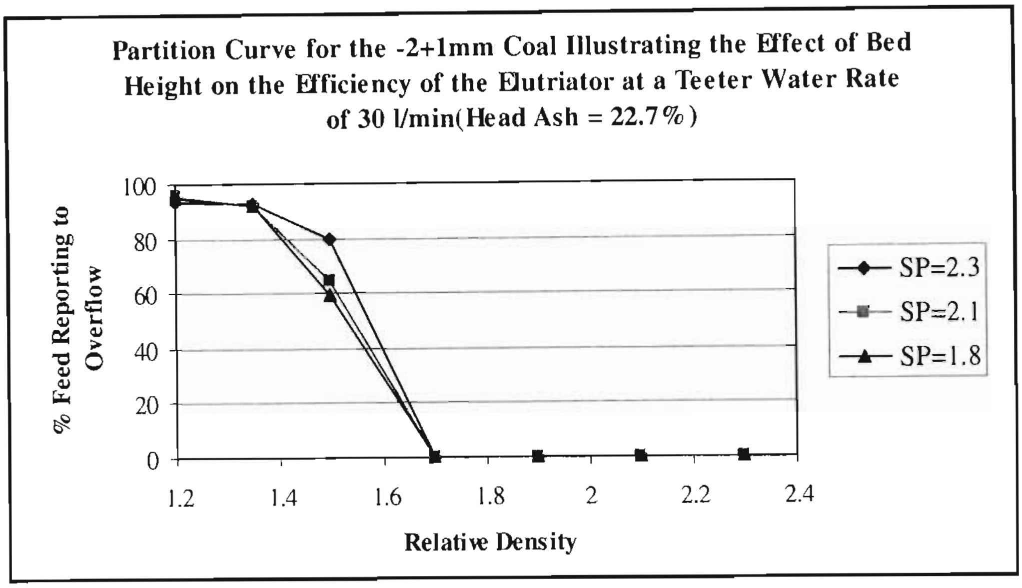

Figure 13: Partition curve of Middelburg coal (-2+1mm) at a constant teeter water flowrate

Table 2: Representation of the efficiency of separation for varying bed height setpoint

Bed Height Setpoint (SP)	E.p.	D_{50}	Ash %	Mass Yield %
2.3	0.060	1.57	10.5	77.7
2.1	0.075	1.55	8.8	73.3
1.8	0.095	1.52	8.3	72.8

For the separation of coal, the percentage of ash which reports to the product is the major criterion. It can be seen that by keeping the teeter water rate constant and increasing bed-height setpoint, with maximum input being 10, the percentage ash reporting to the product as well as the mass yield changes. Figure 14 is a graphical representation for the effect of varying bed-height setpoint. Partition curves constructed is based on a calculated re-constituted feed and compared with the measured feed data represented in the Appendices.

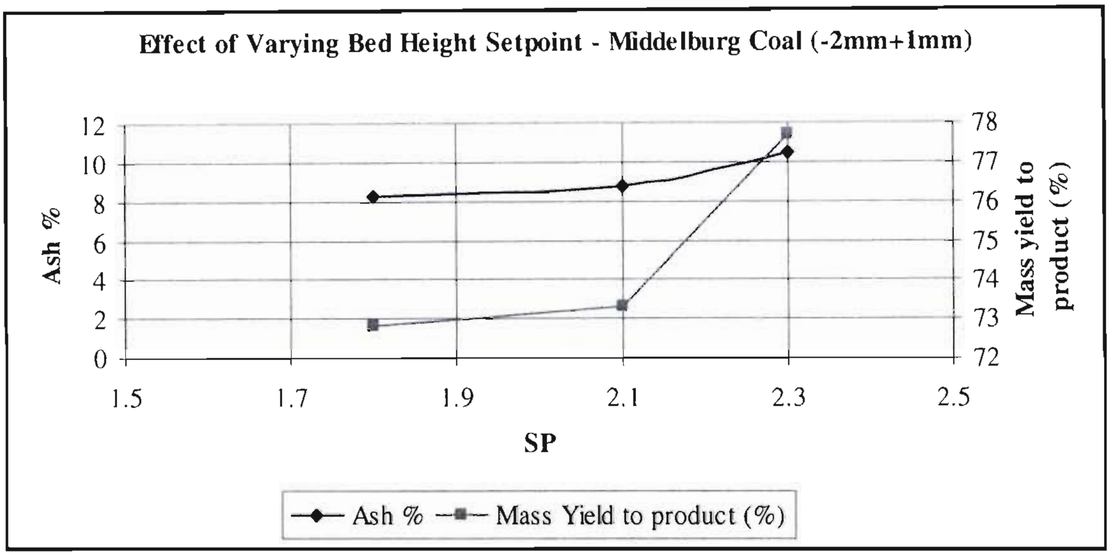

Figure 14: Graphical representation of varying bed SP - Coal (-2+1mm)

A higher setpoint results in an increased solids bed, thus more mass reporting to the overflow and an increased ash content to product. An optimum setpoint is obtained at a minimum ash content to overflow. The overflow ash content can then be optimised All three runs produced good separation efficiencies (E.p. < 0.1). A setpoint of 1.8 however resulted in the lowest ash content (8.3%) reporting to product. Reducing the setpoint further could possibly reduce the ash content to product, however extremely low setpoints will result in no separation being exhibited.

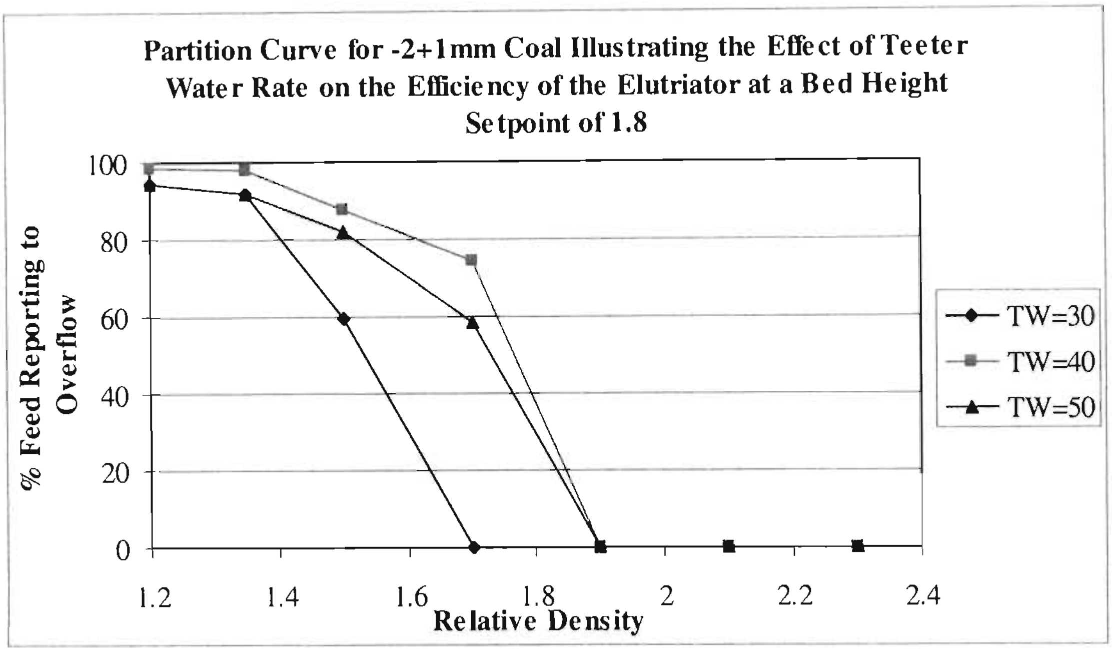

Figure 15: Partition curve of Middelburg coal (-2+1mm) at a constant bed-height setpoint

Table 3: Representation of the efficiency of separation for varying teeter water flowrates

TW (l/min)	E.p.	D_{50}	Ash %	Mass Yield %
30	0.095	1.52	8.3	72.8
40	0.135	1.67	17.1	89.0
50	0.070	1.77	18.2	91.2

It can be seen that by keeping the bed-height setpoint constant and varying teeter water flowrates the percentage ash reporting to the product as well as the mass yield increases as teeter water is increased. Figure 16 is a graphical representation for the effect of varying teeter water flowrate.

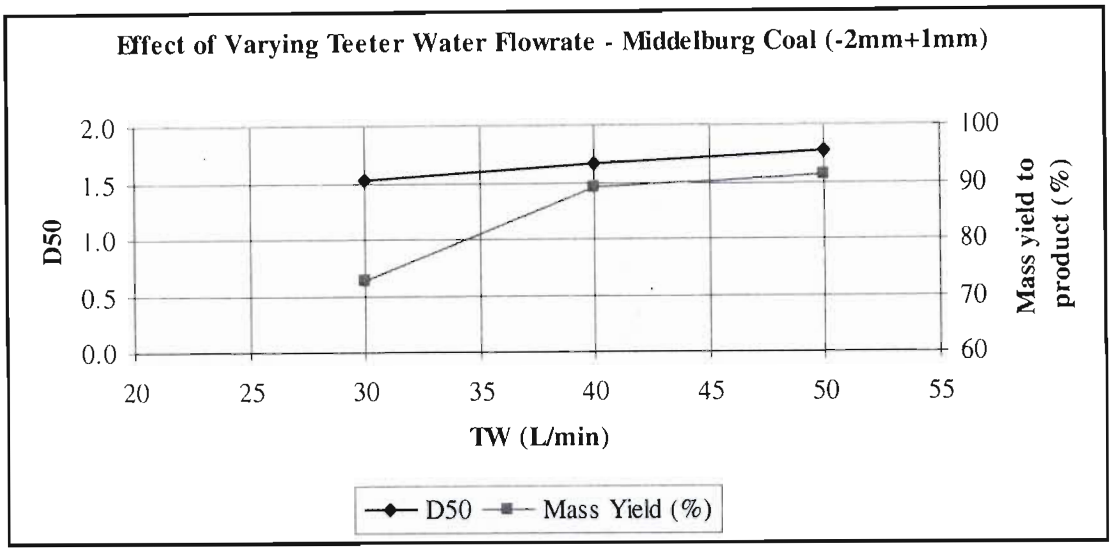

Figure 16: Graphical representation of varying teeter water – Coal (-2+1mm)

Operating at lower teeter water flowrates results in better separation enabling lower ash contents to product stream. By comparing Fig 13 vs Fig 15 we note that the elutriator is much more sensitive with regards to teeter water flowrate than bed-height setpoint with coal. Operating at high teeter water flowrates results in a higher ash content to the product.

4.2 Middelburg Coal (-1mm+0.5mm) Data

4.2.1 Elutriation Test work – Eriez Crossflow Elutriator

Six test runs were conducted using the Eriez Crossflow Elutriator. Grades and efficiencies were compared after varying teeter water flowrates and bed-height setpoints. The results of test runs 1-6 are presented in Appendix A7-A12.

Figure 17 is a graphical representation of the efficiency of separation when keeping teeter water rate constant and varying bed-height setpoint. Similarly Table 4 is a representation of the results obtained and Figure 18 is a graphical representation for the effect of varying bed height setpoint.

Figure 19 is a graphical representation of the efficiency of separation when keeping bed-height setpoint constant and varying teeter water flowrates. Likewise, Table 5 is a representation of the results and Figure 20 is a graphical representation for the effect of varying teeter water flowrate.

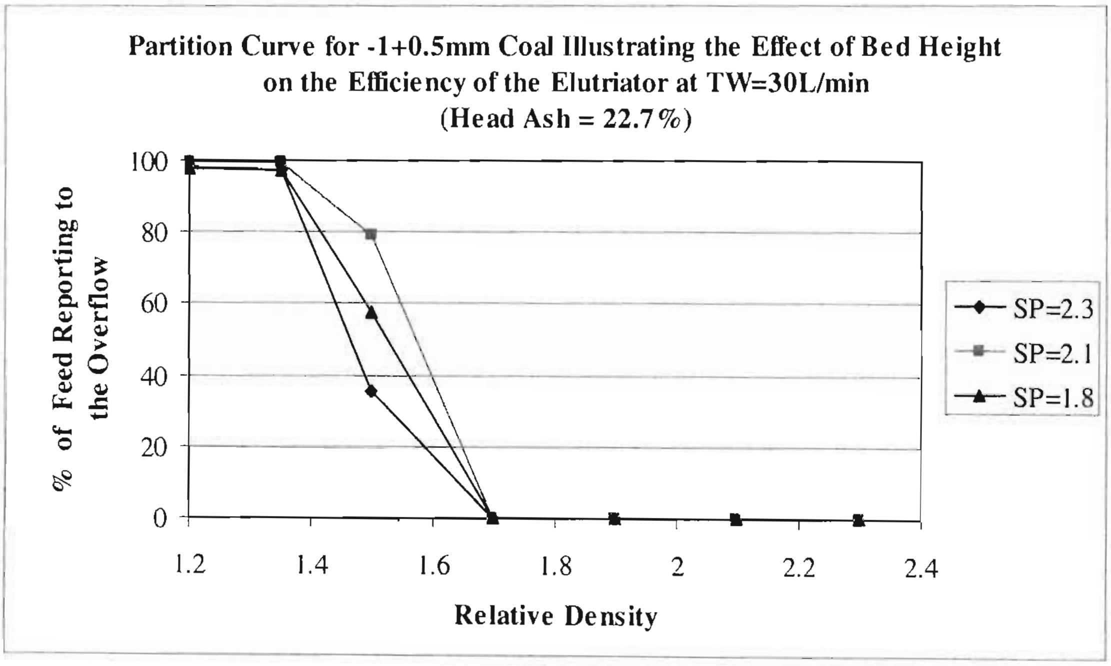

Figure 17: Partition curve representing separating efficiency at a constant bed-height setpoint

Table 4: Representation of the efficiency of separation of the Eriez Elutriator at a constant teeter water flowrates

SP	Ep	D_{50}	Ash %	Mass Yield %
2.3	0.050	1.48	15.3	46.4
2.1	0.060	1.60	9.1	75.3
1.8	0.075	1.57	10.6	70.3

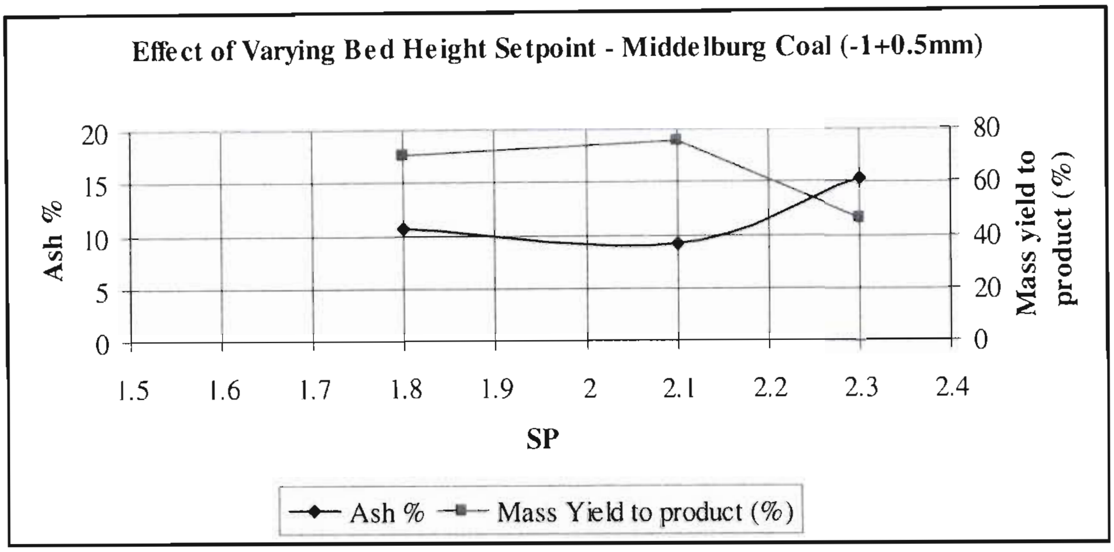

Figure 18: Graphical representation of varying bed SP - Coal (-1+0.5mm)

From the data obtained it was noted that a bed height setpoint of 2.1 produced best results with regards to percentage ash reporting to product stream as well as mass yield. The efficiency of separation is also good at E.p. of 0.06.

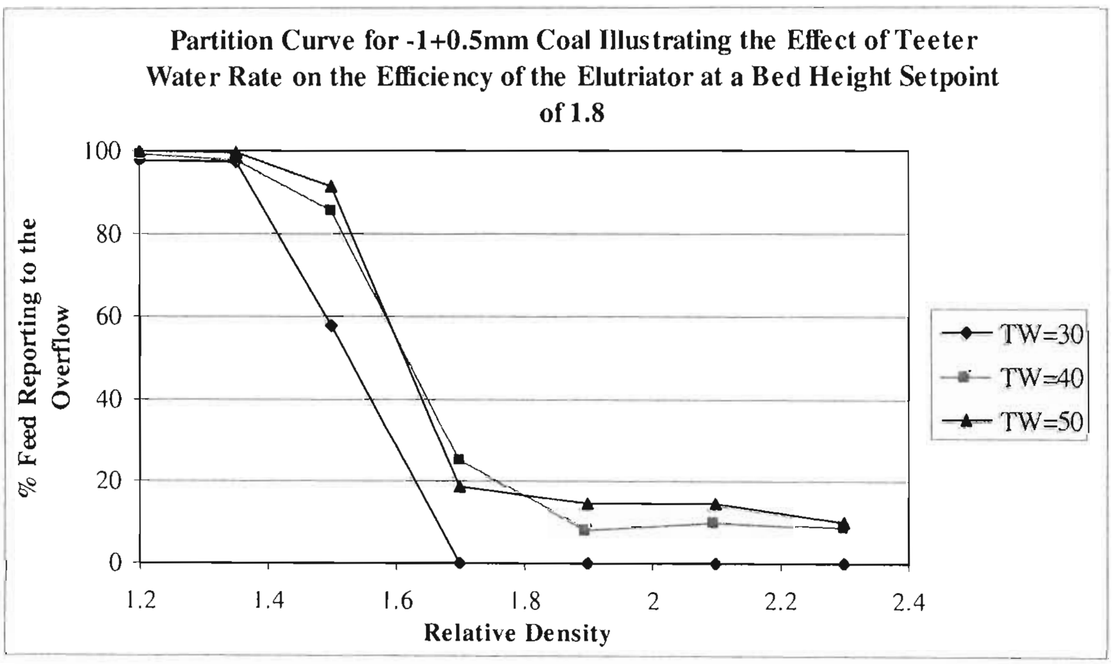

Figure 19: Partition curve representing the efficiency of separation at a constant bed-height setpoint

It can be noted from Figure 19 that as teeter water flowrate is increased, the effect of material bypass; that is misplacement of gangue to product fraction becomes more pronounced. With coal separation, teeter water flowrate is a critical operating parameter that contributes to the ash content reporting to product fraction.

Table 5: Representation of the efficiency of separation of the Eriez elutriator at a constant bed height setpoint

TW (l/min)	E.p.	D_{50}	Ash %	Mass Yield %
30	0.065	1.53	10.6	70.3
40	0.060	1.63	14.8	83.3
50	0.050	1.65	15.8	86.0

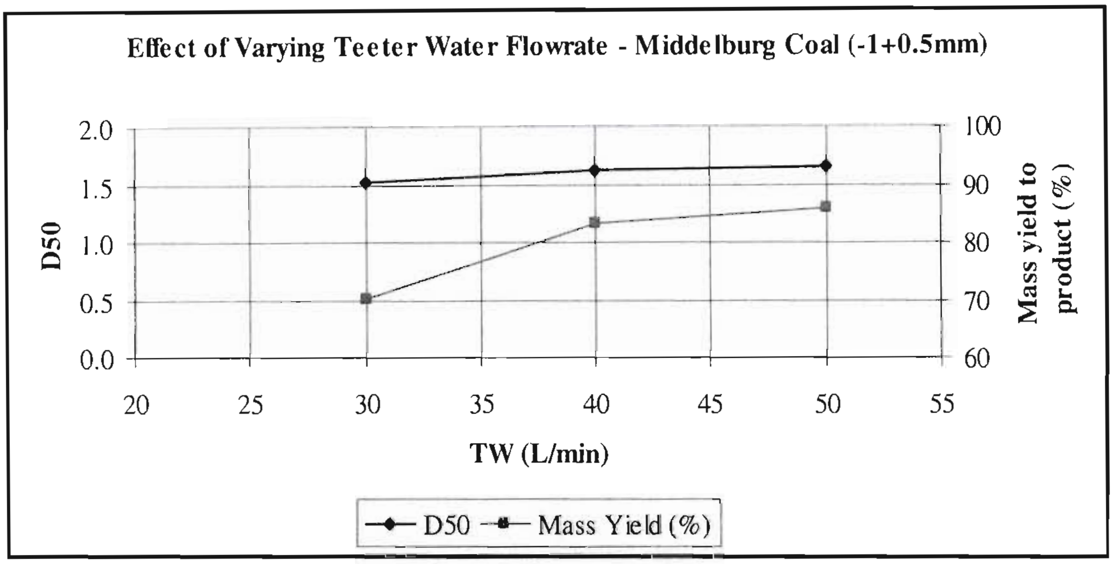

Figure 20: Graphical representation of varying teeter water – Coal (-2+1mm)

The percentage ash reporting to the product stream is the most important criterion with regards to coal processing. It was noted that with increases in teeter water flowrate, the percentage of ash in the product increased. It would thus be advisable to operate at 30L/min, in order to minimise ash % reporting to product. Also, increased teeter water flowrates results in bypass of high density material to the overflow as represented in Figure 19.

4.3 Koornfontein Coal

4.3.1 Elutriation Test work at Koornfontein Mine – Eriez Hydrosizer

This entailed a plant visit to Koornfontein mines and observing test work conducted on site. Four test runs were conducted using the Eriez Hydrosizer. Table 6 represents data obtained for each of the test runs.

Table 6: Data obtained for Koornfontein site test work

	Feed	Run1	Run2	Run3	Run4
Product Grade (Ash %)	22.5	19.8	19.2	20.3	20.0
S.P		1.4	1.4	1.45	1.5
TW (m^3/hr)		2.0	2.5	2.0	2.0
Mass Yield %		79.5	84.2	89.9	86.3
Combustible Rec %		82.3	87.9	92.4	89.2

Combustible recovery is directly related to the quality of coal. The lower the ash content, the higher the combustible recovery. The data obtained revealed that Run 2 produced best results with the lowest ash % to product, possibly due to the increased teeter water flowrate. Runs 3 and 4 resulted in an increased combustible recovery and mass yield due to the higher bed height setpoint, creating a more unstable bed. Feed ore was sent to Mintek to conduct test work on the Eriez Crossflow elutriator. This was to compare the efficiency of both the Eriez Hydrosizer and the Eriez Crossflow elutriator as well as of the current operation.

4.3.2 Elutriation Test work at Mintek – Eriez Crossflow Elutriator

Approximately 1 ton of –3mm Koornfontein coal was sent to Mintek to process on the Eriez Crossflow elutriator. Three test runs were conducted at a constant bed-height setpoint of 1.14 and at varying teeter water flowrates. The results of test runs 1-3 are presented in Appendix B1-B3. Figure 21 is a graphical representation of the efficiency of separation at a constant bed-height setpoint of 1.14 and at varying teeter water flowrates. Similarly Table 7 is a representation of the results obtained and Figure 22 is a graphical representation for the effect of varying teeter water flowrate.

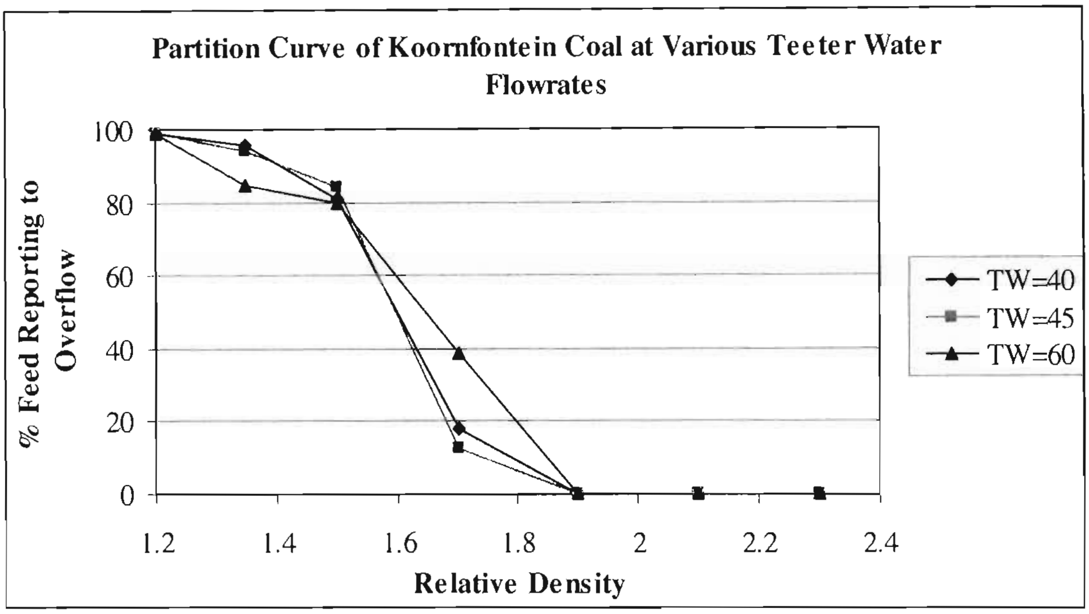

Figure 21: Partition curve representing the efficiency of separation of the Eriez Crossflow elutriator at a constant bed-height setpoint.

Table 7: Representation of the efficiency of separation of the Eriez Crossflow Elutriator

TW (l/min)	E.p.	Ash %	Mass Yield %
40	0.350	16.8	89.6
45	0.300	17.7	90.9
60	0.400	17.2	84.1

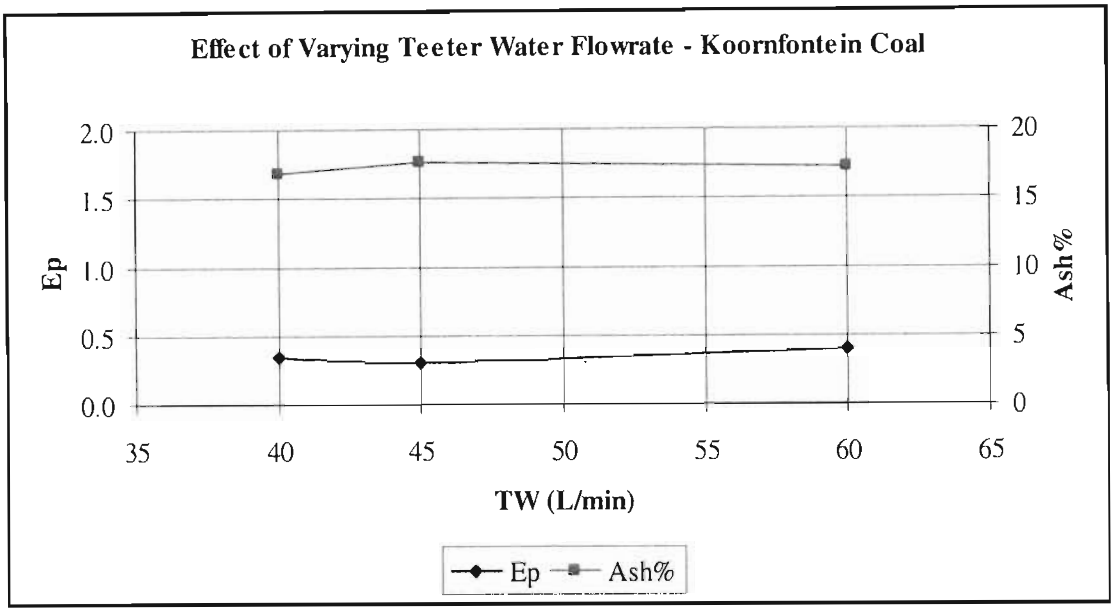

Figure 22: Graphical representation of varying teeter water – Koornfontein Coal

It was observed that the Eriez Crossflow elutriator produced higher recoveries than the Eriez Hydrosizer with respect to the Koornfontein coal. Also, the ash % reporting to the product decreased. It was noted however that the efficiency of separation was poor (E.p. >0.3). This can be attributed to a wider size range being processed (-3mm), with no desliming of material.

5 Ferrochrome Results

5.1 Middelburg Ferrochrome (-2mm+1mm) Data

5.1.1 Elutriation Test work – Eriez Crossflow Elutriator

Three test runs were conducted at a constant teeter water flowrate of 80l/min at varying bed-height setpoint. Table 8 represents the results obtained for test work on the Eriez Crossflow Elutriator with Figure 23 representing the data graphically.

Table 8: Effect of Bed Height on the Separation of FeCr (Head Grade = 28.1%)

SP	U/F Grade %	Recovery %
10.0	28.3	97.0
8.0	27.8	99.2
6.5	27.2	99.8

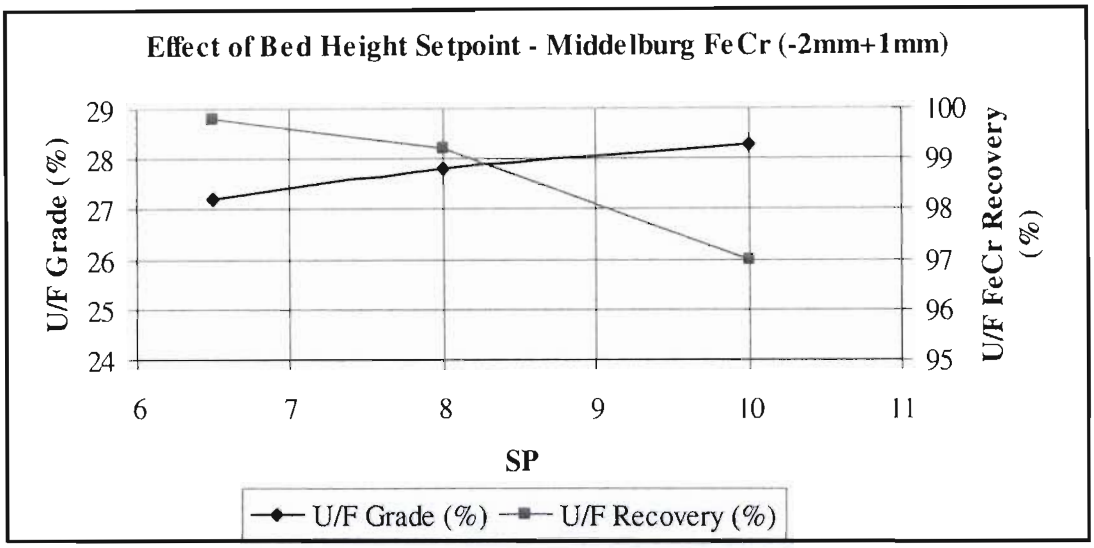

Figure 23: Graphical representation of varying bed SP – FeCr (-2+1mm)

It was noted that although the recovery was high, the grades obtained were similar to the head sample. These grades are possibly due to a stationary bed of ferrochrome ore with some channelling of teeter water up the bed. The head grade compared to the underflow product grade suggests that no separation occurred. It was thus decided to process the ferrochrome in a Linatex Elutriator to determine if the grade could be improved by improving separation.

5.2 Middelburg Ferrochrome (-1+0.5mm) Data: Eriez

5.2.1 Elutriation Test work – Eriez Crossflow Elutriator

Three test runs were conducted at a constant teeter water flowrate of 60l/min at varying bed-height setpoints. Table 9 represents the results obtained for test work on the Eriez Crossflow Elutriator with Figure 24 being a graphical representation of the results.

Table 9: Effect of Bed Height on the Separation of FeCr (Head Grade = 28.1%)

SP	Grade %	Recovery %
10.0	39.6	80.5
8.0	29.2	95.2
6.5	28.2	97.1

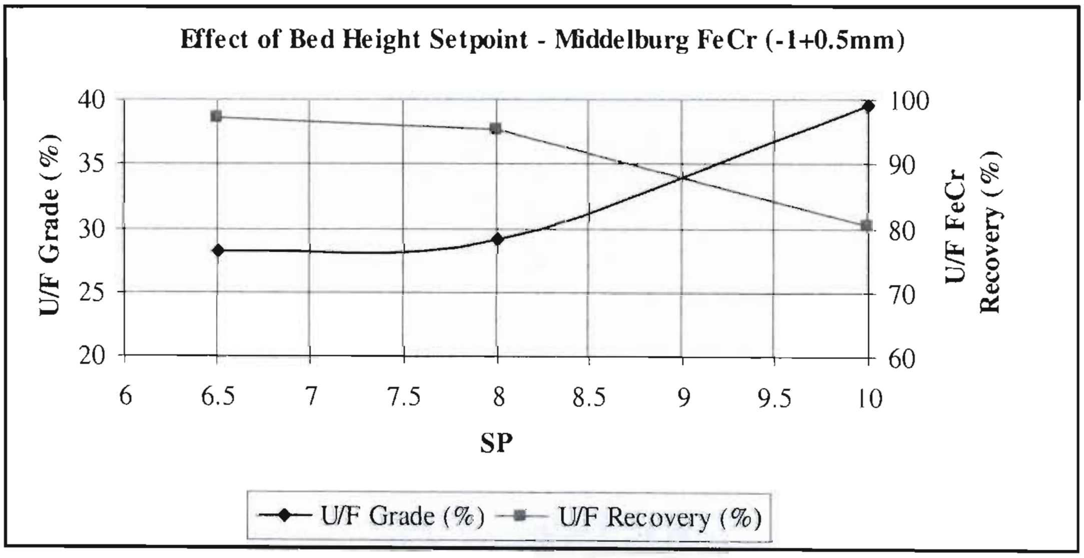

Figure 24: Graphical representation of varying bed SP in Eriez Crossflow – FeCr (-1+0.5mm)

It was noted that although the recovery was high, the grades obtained were low. There is a noticeable improvement compared to the previous test results as at a bed height setpoint of 10, it is evident that upgrading is occurring. It was decided to process the ferrochrome in the Linatex elutriator in an attempt to improve the grade further.

5.3 Middelburg Ferrochrome (-1+0.5mm) Data: Linatex

5.3.1 Elutriation Test work – Linatex Elutriator

Three test runs were conducted using the Linatex Elutriator at a constant teeter water flowrate of 60l/min and at varying bed-height setpoints. The results of test Runs 1-3 are presented in Appendix C1-C3. Figure 25 is a graphical representation of the efficiency of separation when keeping teeter water rate constant and varying bed-height setpoints. Similarly Table 10 is a representation of the results obtained and Figure 26 is a graphical representation of these results.

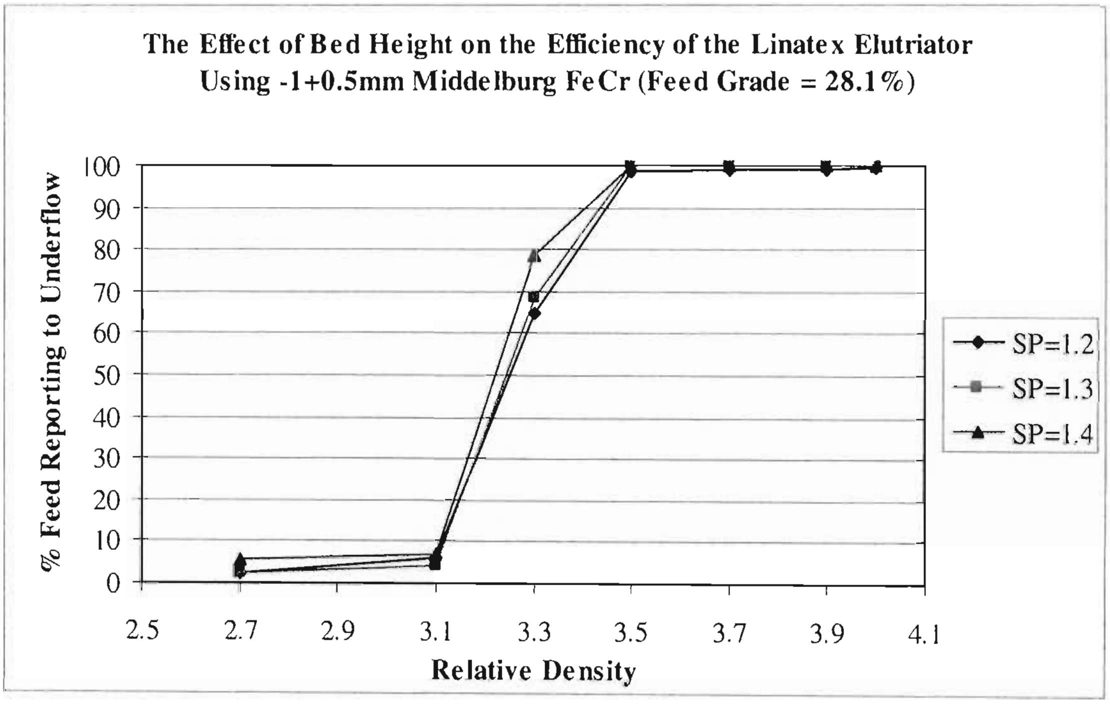

Figure 25: Partition curve of Middelburg FeCr (-1+0.5mm) at a constant teeter water flowrate

Table 10: Representation of the efficiency of separation for varying bed height setpoint

SP	E.p.	D_{50}	Grade %	Recovery %
1.2	0.060	3.23	74.0	89.2
1.3	0.085	3.28	76.6	85.8
1.4	0.085	3.18	85.1	83.8

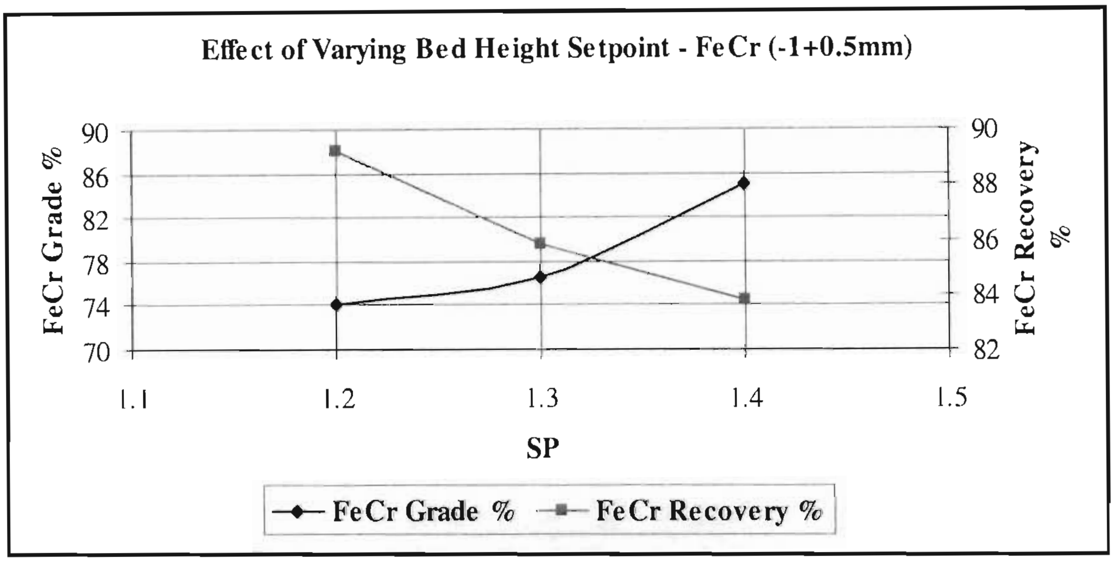

Figure 26: Graphical representation of varying bed SP in Linatex – FeCr (-1+0.5mm)

Observed differences between the Eriez Crossflow Elutriator with regards to the processing of FeCr ore is that at a teeter water rate of 60l/min and at high bed height setpoint, the overflow rate of the Linatex was twice that of the Eriez. The feed entry point arrangements differ in that the Linatex feed penetrates the bed whereas the feed enters tangentially at the top of the Eriez Crossflow elutriator. Due to the higher density of the FeCr material, it was noted that in the case of the Eriez, product material reports to the overflow due to the feed point entry as well as particle size.

Therefore, with respect to the FeCr ore, it was noted that the Linatex elutriators' performance was the best as the Eriez unit did not effect any separation at various conditions.

6 Hematite Results

6.1 Northern Cape Hematite (-2mm+1mm) Data

6.1.1 Elutriation Test work – Linatex Elutriator

Due to the density of hematite (2.8 – 4.5 kg/m^3) the building up of an ideal bed for elutriation test work was crucial because of the near density of the material. One test run was conducted in the Linatex elutriator at a constant bed-height setpoint of 1.66 and a teeter water flowrate of 80l/min. The results of test Run 1 are presented in Appendix D1. Figure 27 is a graphical representation of the efficiency of separation at a bed height setpoint of 1.66 and a teeter water rate of 80l/min. Similarly Table 11 is a representation of the results obtained.

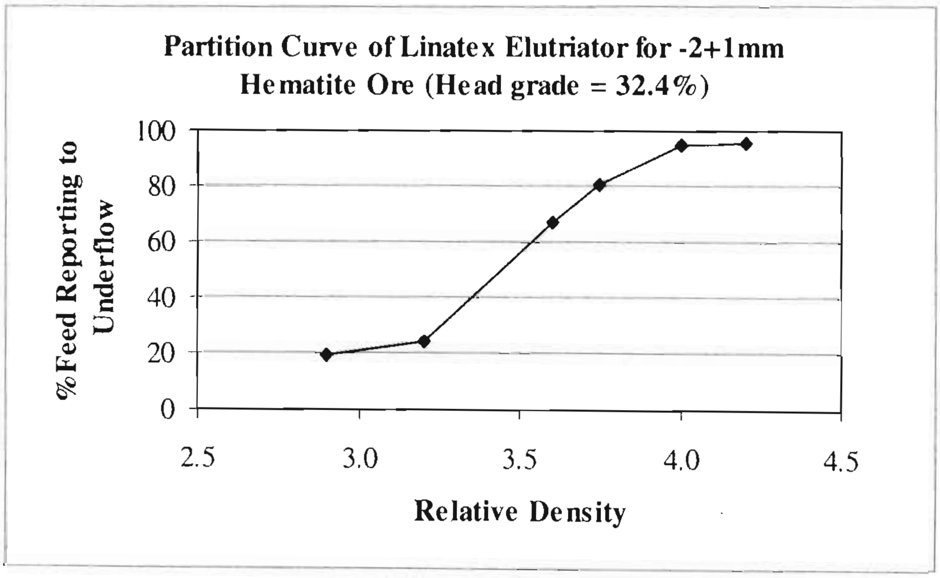

Figure 27: Partition curves of hematite (-2+1mm) at a bed-height setpoint of 1.66 and teeter water rate of 80l/min

Table 11: Representation of the efficiency of separation for –2+1mm hematite ore

SP	TW (l/min)	E.p.	D50	Grade %	Recovery %
1.66	80	0.150	3.4	46.7	84.3

Test work on the hematite ore with the Linatex elutriator served to upgrade the feed material as well as produce a high recovery of 84.3%. The hematite material is classified by a narrow density band of 2.9 kg/m^3 to approximately 4.2 kg/m^3. Thus, the poor E.p. value may be attributed to the near density of the material.

6.2 Northern Cape Hematite (-1mm+0.5mm) Data

6.2.1 Elutriation Test work – Linatex Elutriator

Two test runs were conducted with the Linatex elutriator at a constant bed height setpoint of 1.75 and varying teeter water flowrates. The results of test Runs 1-2 is presented in Appendix D2-D3. Figure 28 is a graphical representation of the efficiency of separation at a constant bed-height setpoint of 1.75 and varying teeter water flowrates. Similarly Table 12 is a representation of the results obtained.

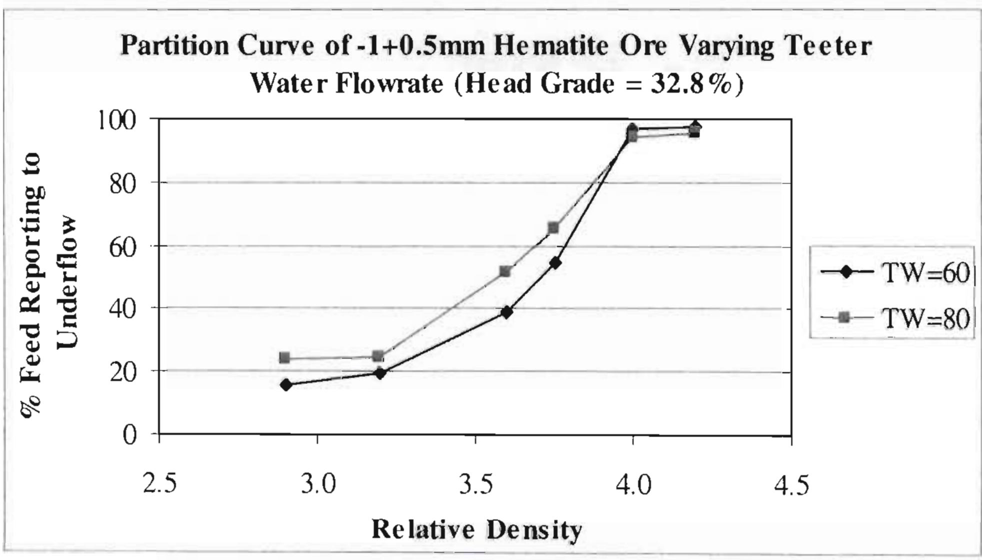

Figure 28: Partition curve representing separating efficiency at a constant bed-height setpoint of 1.75.

Table 12: Representation of the efficiency of separation of the Linatex elutriator at constant bed-height setpoint of 1.75

SP	TW (l/min)	E.p.	D50	Grade %	Recovery %
1.75	60	0.450	3.75	57.9	76.7
1.75	80	0.350	3.6	46.7	79.4

The most important criterion of hematite processing resides in the grade of the product. It was noted that further increases in teeter water flowrate resulted in a decreased product grade. Also, E.p. values dropped significantly from 0.15 to 0.45 upon processing of the finer size fraction range of -1.0+0.15mm.

7 Observed Differences between the Eriez Crossflow and Linatex Elutriator

The feed pipe of the Linatex Elutriator penetrates the bed whereas the feed enters tangentially at the top of the Eriez Crossflow Elutriator. The height of the Linatex (2m) is almost thrice the Eriez Crossflow (0.7m) with two thirds cross sectional area.

For test work on the four ore types the following equipment was used:

- Eriez Crossflow Elutriator: For coal processing. Produced better grades and recoveries in this respect. The slimes reported directly to the overflow by means of the overflow launder without penetrating the bed. For this ore, the feed entering tangentially was ideal as there was noticeably less disturbance within the bed.
- Linatex Elutriator: For ferrochrome and hematite processing. Produced better grades and recoveries in this respect. Tangential feed inlet was not appropriate as it resulted in misplacement of product to the overflow, which could be visually identifiable compared to the silicate gangue material.

CHAPTER 5: PROTOTYPE DESIGN AND APPLICATIONS

8 Elutriator Development

The test work conducted on coal, ferrochrome and hematite showed the effectiveness of the elutriator in treating a wide range of fine material. Test work showed that the elutriator is capable of obtaining high grades and recoveries. For specific applications and utilising specific elutriators, a prototype unit was designed using the optimal features of each of the separators tested to attempt to create a standard teetered bed separator which could handle a range of ore types at high efficiencies.

A prototype unit (clear PVC, 890mm in length and 300mm outer diameter) was developed as represented in Figure 29 to examine ways of improving the current performance of a standard teeter bed separator. Ideas in proposing future changes to the design of the elutriator stemmed from the additional test work performed on the ferrochrome ore and these included adding a jigging dimension to the bed by vibrating or pulsing it as well as testing the ideal feed point entries. Also care and consideration needed to be placed on the wall effects prevalent within the unit. A flowsheet of the design is included in Appendix F1.

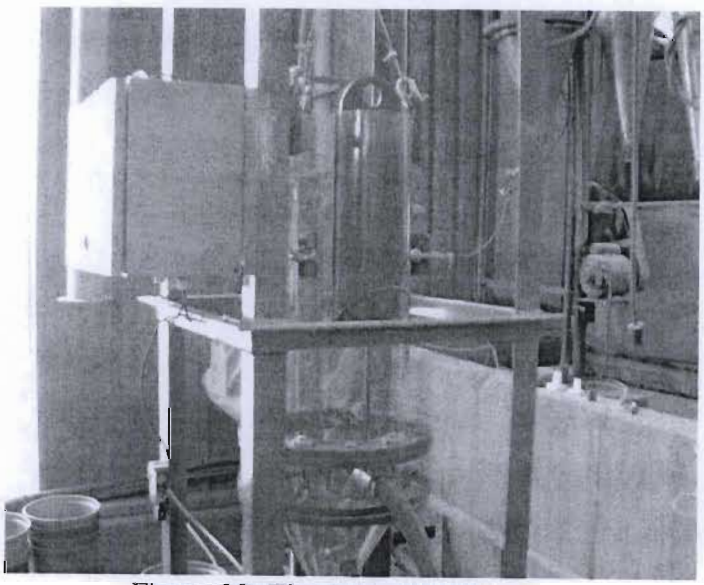

Figure 29: Elutriator test unit

8.1 Test work conducted on the prototype test unit

Test work was conducted using the –1+0.5mm ferrochrome ore, this was in order to determine the efficiency of the prototype unit by comparing the results with test work previously conducted (section 8.4.4). Two test runs were conducted at varying teeter water flowrates and at a setpoint of 10. The results of test Runs 1-2 is presented in Appendix F2-F3. Figure 30 is a graphical representation of the separation efficiency whereas Table 13 represents the results obtained for the test work.

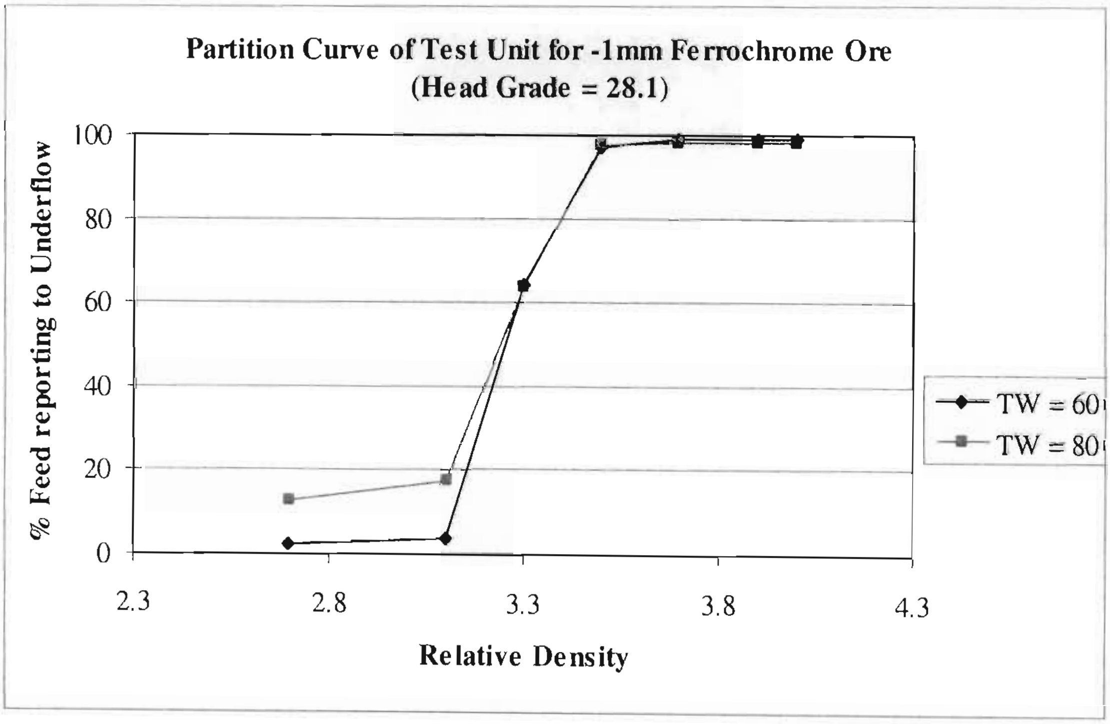

Figure 30: Partition curve representing the separation efficiency of the test unit

Table 13: Representation of the efficiency of separation for varying teeter water flowrates

TW (l/min)	E.p.	D_{50}	Grade %	Recovery %
60	0.075	3.2	76.4	70.9
80	0.085	3.2	74.2	68.3

It was noted that the prototype unit performed significantly better than tests conducted on the Eriez unit. Despite the slight drop in recovery from 80.5% to 70.9% the FeCr material was upgraded from 28.1% to 76.4% (prototype unit) as opposed to 28.1% to 39.6% (Eriez unit). Further modification of the design followed, by widening the baffle plate at the base of the prototype to evenly distribute the teeter water flowrate up the column. Also examination of adding a jigging/pulsing dimension to the bed was explored.

8.2 Design Changes

8.2.1 Pulsing Effect of Column

To determine the effect of pulsing the bed, the –1+0.5mm ferrochrome ore was processed in the Eriez Crossflow Elutriator at a bed-height setpoint of 8 and a teeter water flowrate of 60L/min. The column was run under these conditions for a while in order to form a steady bed. The water supply to the column (teeter water + total water) was stopped and the material was able to settle within the column. The column was then emptied in layers and the density of each layer was determined.

The same –1+0.5mm ferrochrome feed was processed in a Mineral Density Separator (MDS), which introduces a pulsing dimension (water pulse at 1pulse/sec) in order to separate ore by means of density. The densities of each of these layers were determined in order to draw a comparison with the densities obtained from the elutriation test work. Table 14 and 15 represents the densities obtained in each layer for elutriation test work as well as MDS test work respectively. Similarly Figure 31 is a graphical representation of the results illustrating the pulsing effect.

Table 14: Elutriation Test work

Layer	S.G
Elutriator Bed	
1	3.33
2	3.33
3	3.33
4	3.23
5	3.03
6	2.84
7	2.82

Table 15: MDS Test work

Layer	S.G
MDS Bed	
1	4.00
2	3.85
3	3.33
4	3.33
5	3.33
6	2.86
7	2.86
8	2.50
9	2.50

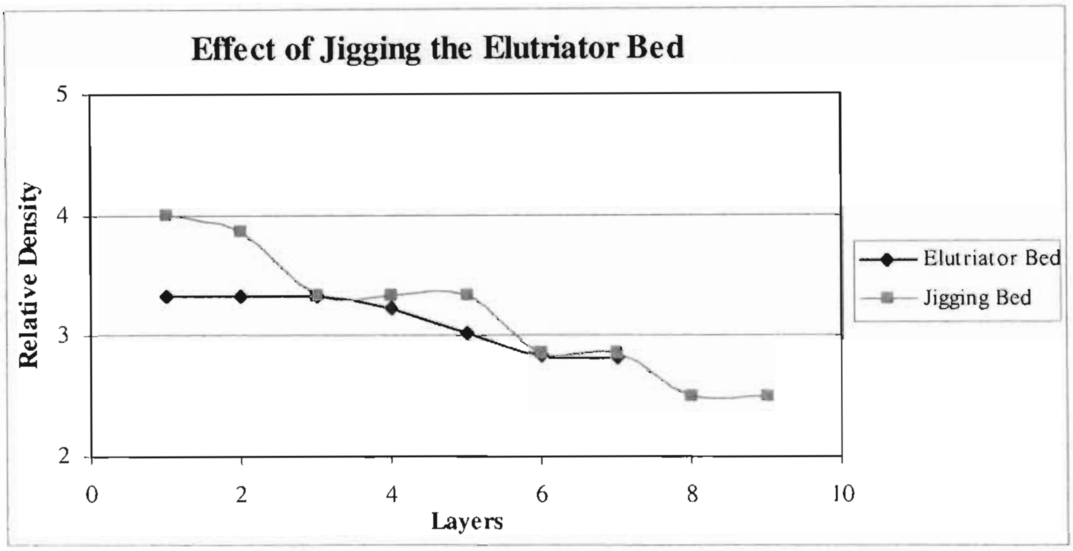

Figure 31: Comparative test work illustrating the pulsing effect

Mineral Density Separation (MDS) test work produced a denser concentrate fraction (Layer 1) consisting of an SG of 4.0 as opposed to an SG of 3.33. Both units perform well with the rejection of gangue. The curves stabilise from Layer 6 onwards. Pulsing of the bed could aid in removal of gangue material trapped within the concentrate layer (Layers 1 and 2), as pulsing is clearly improving the density distribution through the bed, this will add a cleaning effect as the material moves through as the apparent fluid density changes.

8.2.2 Wall Effects

Three test runs were performed on the –1+0.5mm-ferrochrome ore and for each test run sub-samples of the ore was removed from either side of the column and directly in the middle of the column. From this, the density could be evaluated at each of the three points within the bed. Table 16 represents the density of the material for each test run. Likewise, Figure 32 is a graphical representation of the wall effects within the column.

Table 16: Data representing wall effects within a column

Points	SG
Run 1: TW = 60l/min; SP =6.5	
1	4.17
2	4.69
3	4.0
Run 2: TW = 50l/min; SP =10	
1	3.08
2	4.0
3	2.78
Run 2: TW = 60l/min; SP =10	
1	4.05
2	4.65
3	3.95

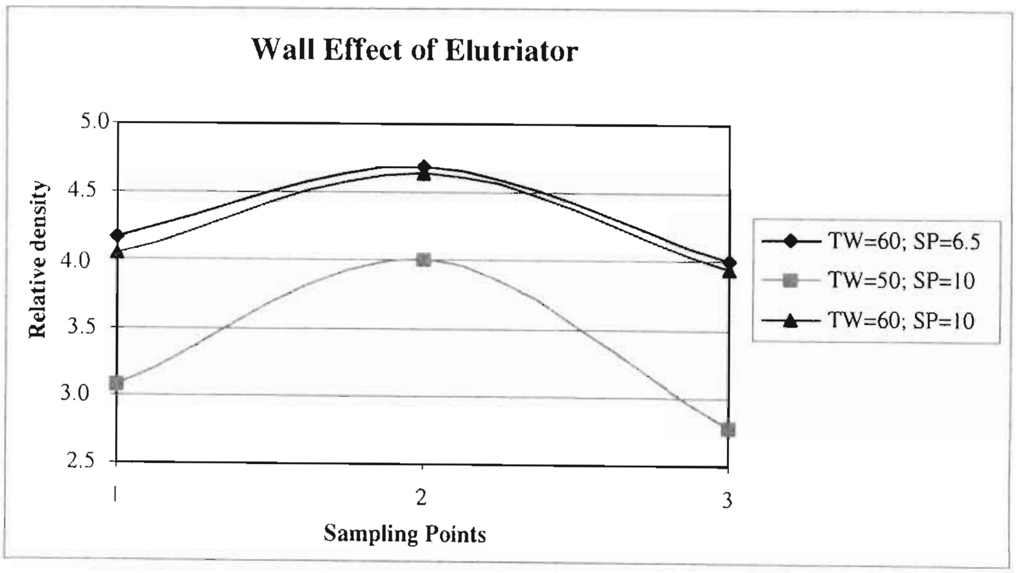

Figure 32: Graphical representation of the wall effects within a column

Points 1 and 3 represent material removed from either side of the column whereas point 2 refers to material removed from the centre of the column bed. It can be noted from the test work that the wall effects are undesirable showing the density profile is considerably higher in the centre of the column than at the column walls. Therefore with increased diameter profiles, the separation efficiency improves.

CHAPTER 6: EXAMINATION OF OPERABILITY FACTORS ASSOCIATED WITH PILOT SCALE OPERATIONS

9 Continuous TBS 2 day test run

Due to many industries' lack of knowledge with regards to operational capabilities of the TBS, many units have been removed from existing plant flowsheets. Test work was carried out at Mintek to evaluate the performance of a pilot scale unit (Linatex) over a continuous two day period.

Approximately 35 tones of hematite fines were supplied to assist with this test work program. The strategy of test work involved taking timed sub-samples of feed, overflow and underflow material during hour intervals taking care not to disturb the bed.

Sizing analysis was conducted at various intervals in order to evaluate if significant inconsistencies with regards to separation occur. Ten timed intervals were evaluated.

9.1 Sizing Analysis

Sampling was conducted at every hour interval during the continuous 2 day run. Ten product samples were chosen and sent for sizing analysis to determine consistency of plant operation. Table 17 represents the operating parameters for 10 chosen samples.

Table 17: Test work parameters for a 2 day continuous test run

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8	Sample 9	Sample 10
Time	07:00 - Day 1	12:00 - Day 1	17:00 - Day 1	22:00 - Day 1	03:00 - Day 1	06:00 - Day 2	11:00 - Day 2	16:00 - Day 2	21:00 - Day 2	03:00 - Day 2
Feedrate: solids (kg/hr)	612.2	691.8	592.0	561.2	652.9	680.6	652.6	636.0	534.2	667.8
% Solids in Feed	49.9	53.0	49.1	47.5	51.3	53.3	53.3	50.8	46.7	53.4
Feedwater (L/hr)	613.9	613.9	613.9	621.0	621.0	596.0	572.6	616.3	609.0	582.0
Wash water/teeter water (L/hr)	2700.0	2700.0	2700.0	2700.0	2700.0	2700.0	2700.0	2700.0	2700.0	2700.0
S.G Setpoint	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65
Underflow flowrate: slurry (kg/hr)	579.8	561.3	627.6	500.7	595.4	593.7	623.4	632.8	574.8	639.1
Overflow flowrate: slurry (kg/hr)	3346.2	3444.4	3278.3	3381.5	3378.4	3382.9	3301.8	3319.5	3268.4	3310.7
Underflow flowrate: solids (kg/hr)	428.5	415.1	473.6	336.7	451.9	408.4	481.9	491.7	386.7	492.1
Overflow flowrate: solids (kg/hr)	183.6	276.7	118.4	224.5	200.9	272.2	170.7	144.3	147.5	175.7
% solids underflow	73.9	73.9	75.5	67.2	75.9	68.8	77.3	77.7	67.3	77.0
% solids overflow	5.5	8.0	3.6	6.6	5.9	8.0	5.2	4.3	4.5	5.3

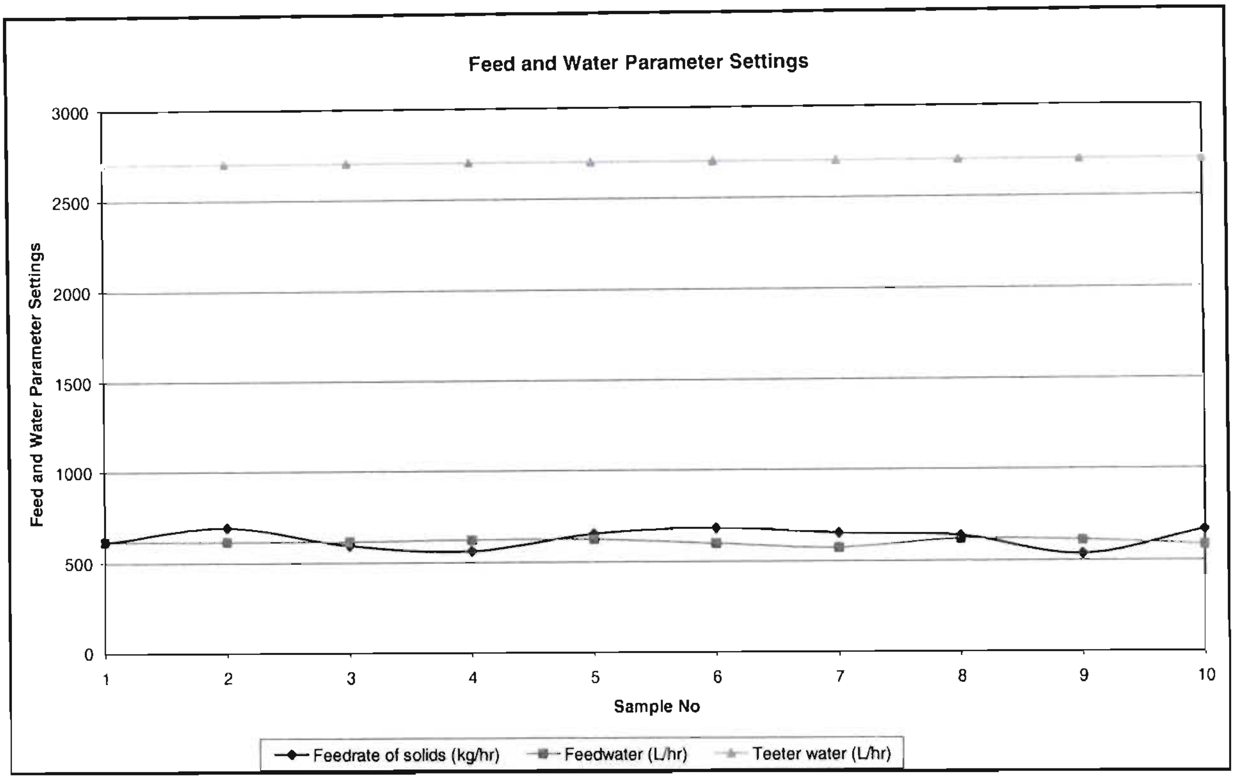

Figure 33: Feed and Water Parameter Settings

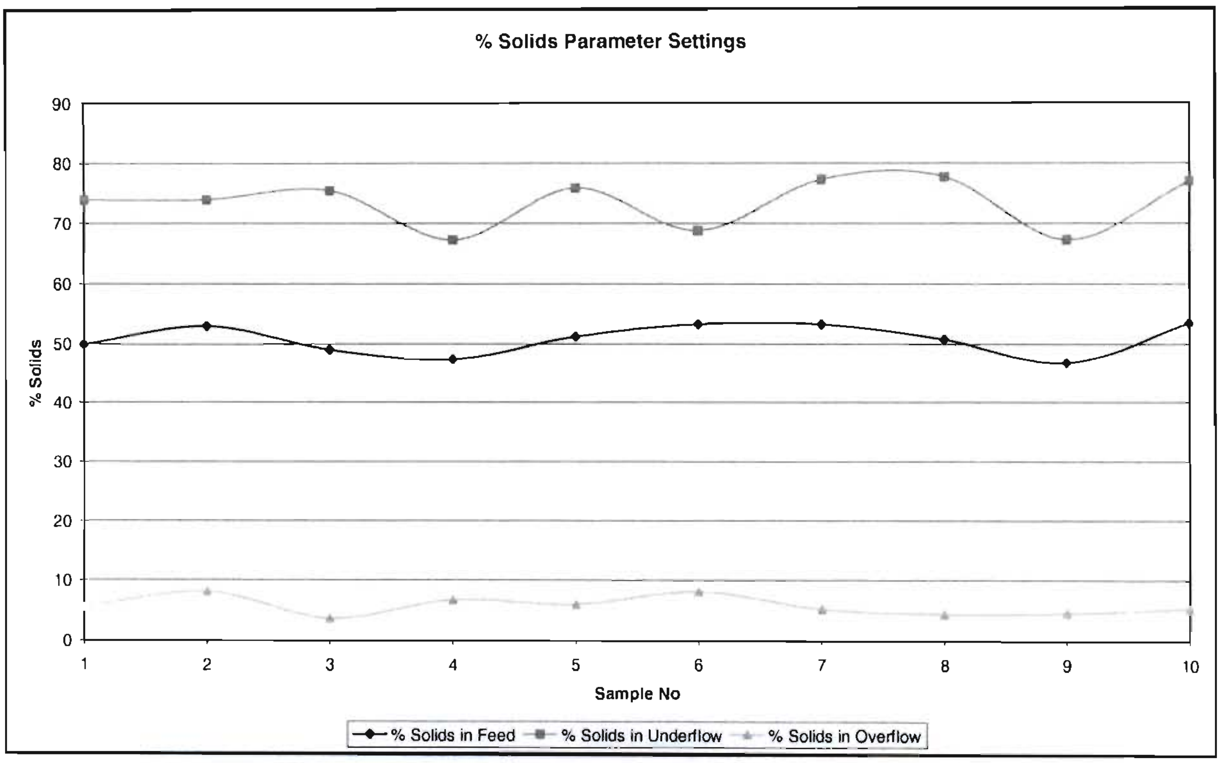

Figure 34: Percentage Solids Monitored

From the graphs (Figure 33 and Figure 34), it can be noted that the operating parameters remained fairly stable over the 24 hour run. On average, the feedrate of solids, feedwater and teeter water remained constant. The percentage solids of the feed remained on average at approximately 50% with the percentage solids in the overflow at 5% and the percentage solids in the underflow at 75%.

A sizing analysis was conducted on overflow and underflow product streams for each of the 10 samples chosen. Detailed results for each of the samples are presented in Appendix G.1 – G.10. The separation efficiencies of all test runs are presented in Figure 35.

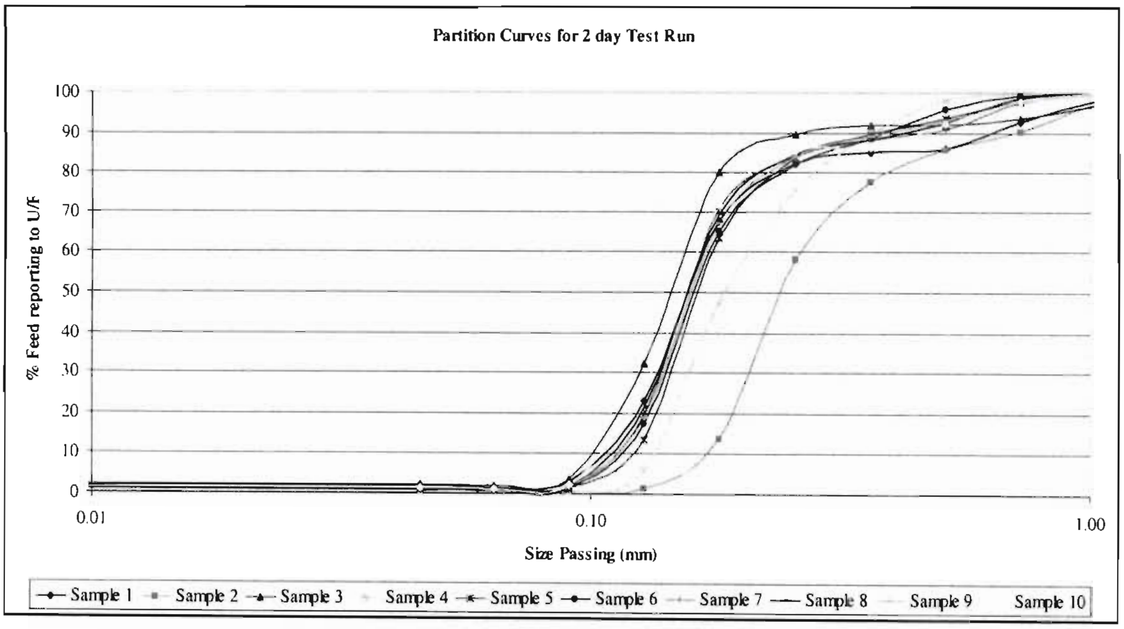

Figure 35: Partition Curves for 2 day run

It can be seen that results are fairly consistent throughout, with a few exceptions, for example, Sample 2. This however was due to change of shifts and possibly samples taken at unsteady conditions.

9.2 Bed Sizing

The elutriator bed was separated into three regions, top, middle and bottom. Sub-samples from each region were taken during operation. This was done five times throughout the entire two day run for repeatability purposes. A $\sqrt{2}$ sizing analysis was conducted for all regions, in order to evaluate the size distribution within the column. Detailed results for each of the five tests are presented in Appendix G.11 – G.15. Figure 36 is a graphical representation of the combined 5 test results.

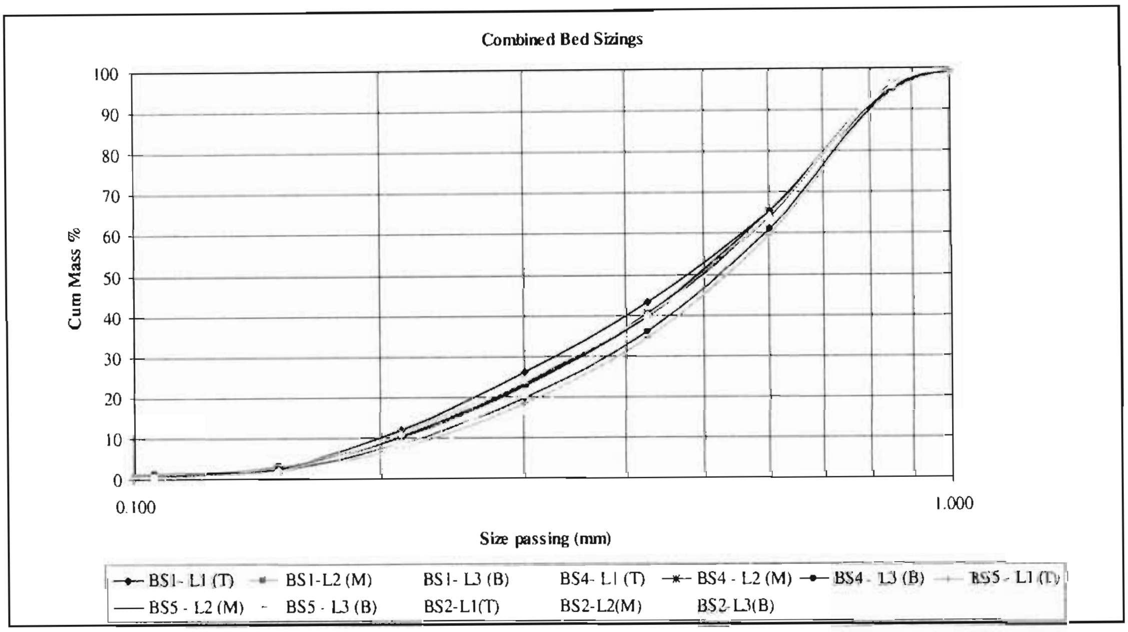

Figure 36: Graphical representation of combined bed-sizing results

Analysis of the elutriator bed at various levels (top, middle and bottom) revealed that separation by particle size was not the dominant criterion; rather density of particles was more prominent. The operating conditions were maintained extremely well during the two day period.

9.3 Grade Analysis

In order to evaluate the variability of grade throughout the continuous test run, sub-samples of the underflow and overflow was taken for four test runs along with a composite feed and submitted for chemical analysis of Fe_2O_3 and SiO_2. Figures 37-40 represents the partition curves obtained whereas Tables 18-21 is a summary of the results obtained. Also, Figure 41 represents a bar graph showing the consistency of grades and recoveries obtainable over time. The detailed data is contained in Appendix G.16 – G.19.

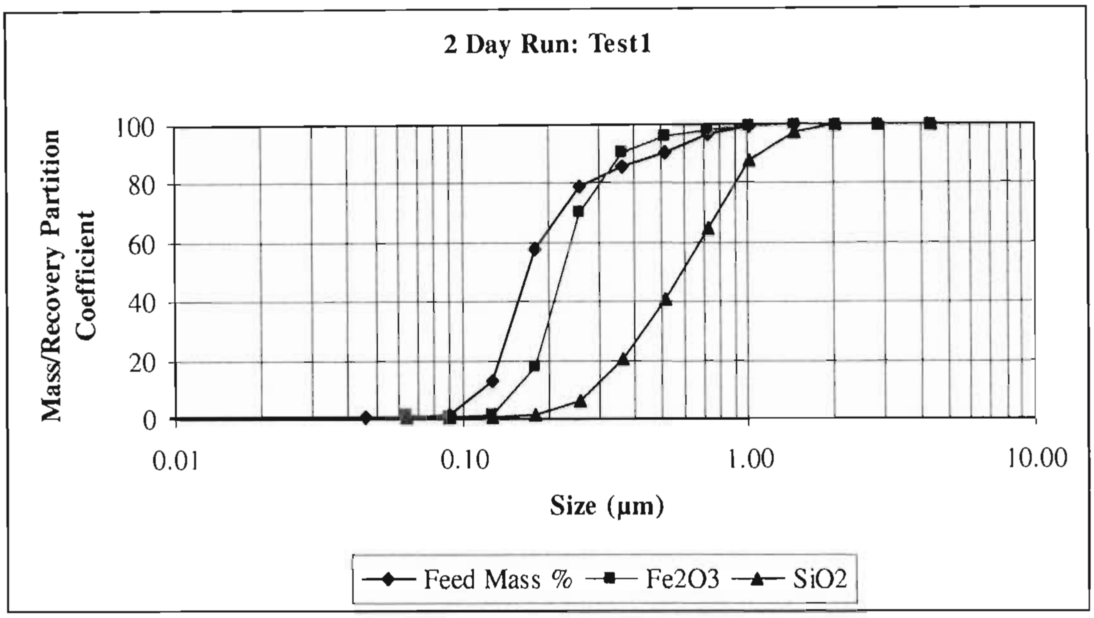

Figure 37: Graphical representation of grade analysis – Test 1

Table 18: Summary of grade analysis – Test 1

Test 1		Grade			Recovery	
	Mass [%]	Fe %	Fe2O3 %	SiO2 %	Fe2O3 %	SiO2 %
Feed	100.00	54.22	74.88	20.23	100.00	100.00
Overflow	40.00	46.84	64.70	31.59	34.56	62.47
Underflow	60.00	59.13	81.68	12.65	65.44	37.53

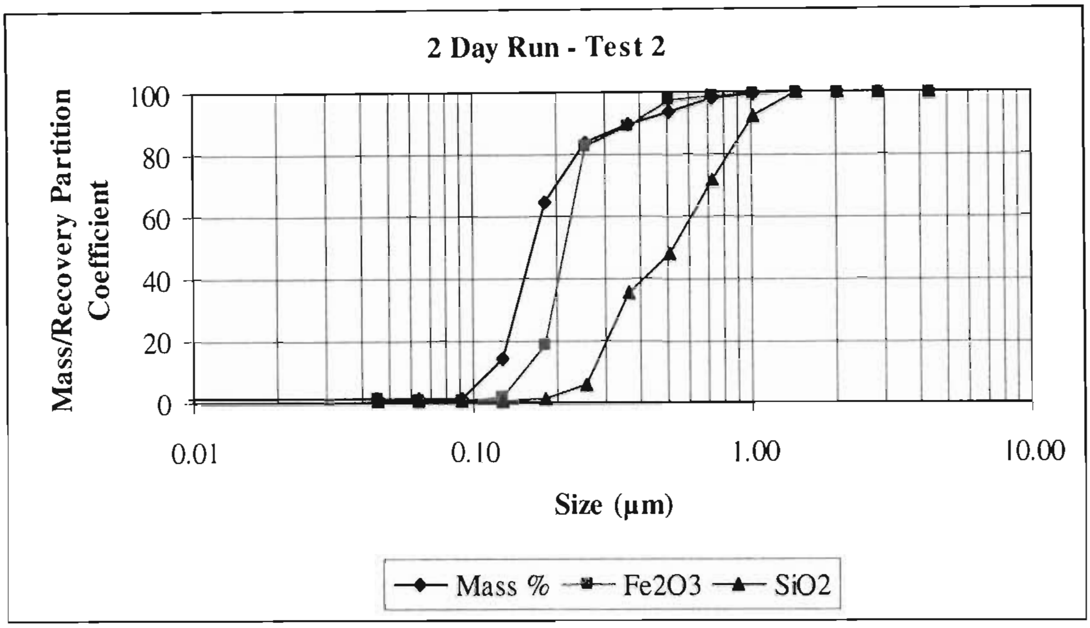

Figure 38: Graphical representation of grade analysis – Test 2

Table 19: Summary of grade analysis – Test 2

Test 2		Grade			Recovery	
	Mass [%]	Fe %	Fe2O3 %	SiO2 %	Fe2O3 %	SiO2 %
Feed	100.00	55.36	79.19	19.62	100.00	100.00
Overflow	30.78	44.93	64.28	34.21	24.98	53.65
Underflow	69.22	59.99	85.83	13.14	75.02	46.35

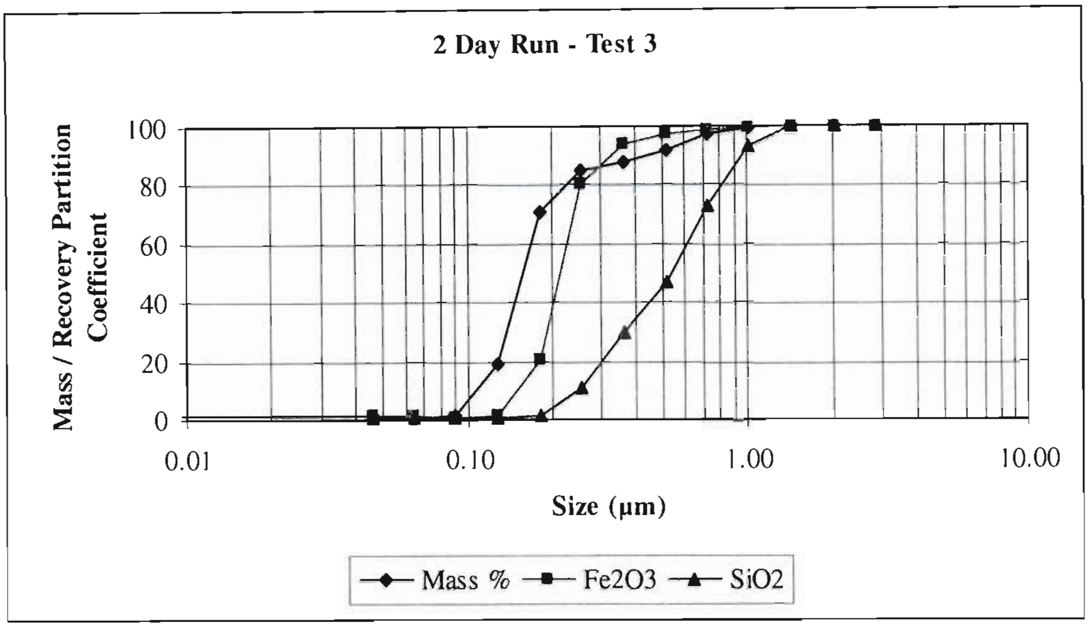

Figure 39: Graphical representation of grade analysis – Test 3

Table 20: Summary of grade analysis – Test 3

Test 3	Mass [%]	Grade			Recovery	
		Fe %	Fe2O3 %	SiO2 %	Fe2O3 %	SiO2 %
Feed	100.00	53.81	76.98	20.57	100.00	100.00
Overflow	26.16	40.80	58.36	35.56	19.83	45.23
Underflow	73.84	58.42	83.58	15.26	80.17	54.77

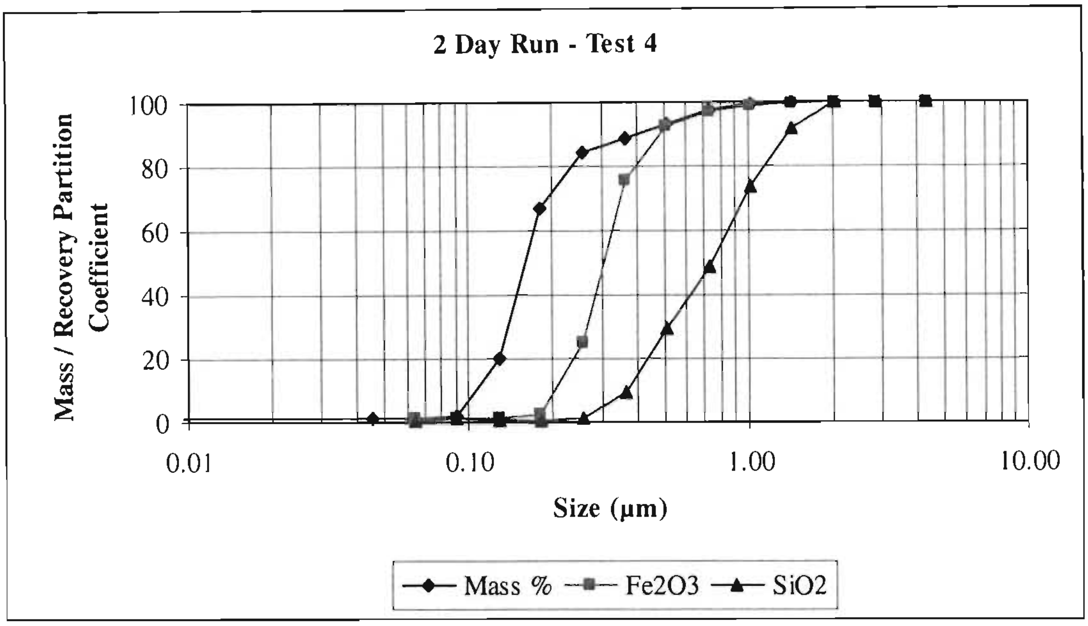

Figure 40: Graphical representation of grade analysis – Test 4

Table 21: Summary of grade analysis – Test 4

Test 4	Mass [%]	Grade			Recovery	
		Fe %	Fe2O3 %	SiO2 %	Fe2O3 %	SiO2 %
Feed	100.00	53.40	76.40	20.17	100.00	100.00
Overflow	27.61	44.03	62.99	35.43	22.76	48.50
Underflow	72.39	56.98	81.51	14.35	77.24	51.50

It can be noted that the grade analysis of all tests runs correspond. Figure 41 represents the consistency of data over the 24hr test run.

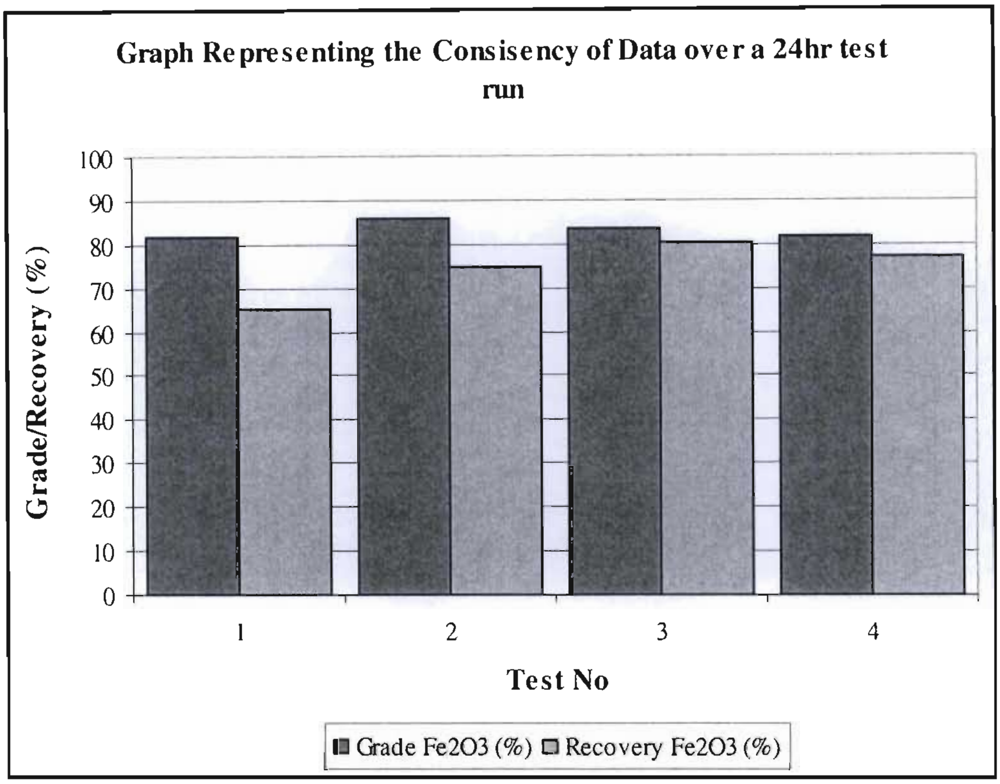

Figure 41: Graph representing the consistency of data over a 24hr period

The graph above represents the consistency of data with regards to grades and recovery obtainable over time. Thus mechanical defaults as well as operational failures were negligible throughout the two day run. The pilot elutriator can thus be deduced as being a stable equipment with regards to fine particle (<3mm) particle beneficiation.

CHAPTER 7: FINAL DISCUSSION AND CONCLUSION

10 Discussion of Test Procedures

The TBS test work focussed primarily on coal beneficiation. In order to test the efficiency of the unit and its applicability, alternative ore types for example ferrochrome and hematite were examined. The effectiveness of an elutriator with regards to fines beneficiation was investigated as well as determination of the optimum operating conditions for different applications. Test work on the elutriator has shown that it treats various material in the –2+0.5mm size fraction more efficiently than the spirals and shaking table.

A continuous 2-day test run of the elutriator was conducted to determine the units' ease of operation industrially. It was noted that the elutriator could operate under stable conditions for a long period of time.

For the separation of coal, the percentage of ash which reports to the product is the main criterion. It was noted that the elutriation process is more sensitive to teeter water flowrate than bed-height setpoint with coal. Operating at a teeter water flowrate of 3l/min resulted in an E.p. value of 0.095 for the -2+1mm fraction and E.p. of 0.06 for the -1+0.5mm fraction. Thus with regards to coal beneficiation, it is advisable to conduct test work at the lowest operable teeter water flowrate so as to minimize the percentage ash reporting to the product fraction.

For the separation of ferrochrome (-2+1mm fraction), the Eriez Crossflow elutriator exhibited no separation. With regards to the -1+0.5mm fraction, very minimal separation occurred. This degree of separation was identified by comparing the head grade of the sample to the product grade obtainable; virtually no upgrading was apparent. It was thus decided to process the ferrochrome material (-1+0.5mm fraction) through the Linatex separator. The feed entry point penetrating the bed allowed for a longer residence time of the feed material within the column allowing for good separation (E.p. of 0.06).

With regards to the separation of the hematite material, it was noted that the near density of the material (2.8-4.5kg/m^3) played a critical role in the separation. The most important criterion of hematite processing resides in the grade of the product. The building up of a steady bed prior to separation was necessary. Test work on the hematite ore (-2+1mm fraction) with the Linatex elutriator, served to upgrade the material as well as produce a high product recovery of 84.3%. The efficiency of the separation however was poor at an E.p. of 0.15 due to the near density of the material tested. Regarding the processing of the finer fraction (-1+0.5mm), it was noted that the efficiency of separation dropped significantly from 0.15 to 0.45, due the near density of the ore.

11 Conclusions

The basis of the investigation involved testing the effectiveness of the elutriator with regards to fines beneficiation (-2+0.5mm material) as well as the development of a prototype unit in which to evaluate improved performances of this unit. The study also involved examining the operability of the unit over a continuous 48 hour test run.

Various ore types namely coal, ferrochrome and hematite with a particular focus on coal was investigated. The size fractions under examination were -2+1mm and -1.0+ 0.5mm.

Regarding the coal separation, it was noted that the teeter bed separator is more sensitive to teeter water flowrate than bed-height setpoint. Operating at low teeter water flowrates (~30l/min), resulted in optimum conditions. It was noted that the Eriez Crossflow Elutriator resulted in best separation with an 8.3% ash content to product (-2+1mm fraction) at a mass yield of 72.8%. Also for the -1.0+0.5mm fraction the Eriez Crossflow Elutriator obtained a product containing 9.1% ash at a mass yield of 75.3%. The efficiency of separation (E.p.) was good at 0.06.

The elutriation process was noted to be operator dependent, requiring a clear understanding of the operating parameters that govern efficient separation. Coal beneficiation was attempted on site and off site with the on site operation achieving maximum efficiency with a product ash % of 16.8% as opposed to a product ash % of 19.2% off site.

With regards to the beneficiation of ferrochrome, it was noted that the Eriez Crossflow Elutriator exhibited minimum separation for the -2+1mm size fraction with virtually no upgrading of the product fraction in relation to the feed. Noticeable upgrading occurred with the -1.0+0.5mm fraction from 28.1% FeCr to 39.6% FeCr. Separation of the -1.0+0.5mm fraction on an alternative elutriator type, namely the Linatex Elutriator resulted in considerable upgrading from 28.1% FeCr to 85.1% FeCr at a product recovery of 83.8% and a separation efficiency of 0.085. The difference between the two units lies in the feed entry point, where it was observed that for denser material a feed penetration directly into the bed was more preferential.

Therefore with separation of the hematite material (S.G 2.8 – 4.5), the Linatex unit was used. Both the -2+1mm and -1.0+0.5mm fractions were processed through the Linatex. No significant upgrading was noted for the -2+1mm fraction from 32.4% Fe to 46.75 Fe at a separation efficiency of 0.15. Processing of the -1.0+0.5mm fraction resulted in a significant decrease in separation efficiency to 0.45 at an upgrading from 32.8% Fe to 57.9% Fe. The general market for iron ore beneficiation resides in a product grade of approximately 65% Fe. The fines material processed (-2mm) does not contribute towards a substantial marketable product.

By critical examination of the various TBS units utilized, a prototype unit was constructed focussing on improvements in design parameters such as adding a jigging dimension to the bed by vibrating or pulsing it. It was noted that pulsing of the column could aid in gangue reduction by rejecting trapped material within the concentrated bed. Also the wall effects which adversely contribute toward inefficient scale up for laboratory operations to pilot plant were investigated. Test work revealed that the density profile is considerably higher at the centre of the column walls. Thus the larger the column diameter, the less efficient the separation efficiency is.

The -1.0+ 0.5mm FeCr material was processed through the prototype unit. It was noted that the prototype unit performed significantly better than tests conducted on the Eriez unit. Despite the slight drop in recovery from 80.5% to 70.9%, the material was upgraded fro 28.1% FeCr to 76.4% FeCr with the prototype as opposed to 39.6% FeCr with the Eriez unit.

Although laboratory scale investigations and batch pilot plant operations indicated that the TBS unit is effective with in the beneficiation of fines, the final investigation conducted was to ascertain the feasibility of TBS operations for continuous pilot plant operations. A continuous 48 hour test run was conducted to evaluate the sustainable efficiency of the unit over time. A 35 ton hematite fines sample was delivered to Mintek for execution of this work. The head grade of the material delivered was 54% Fe. The test work program entailed a sampling campaign on an hourly basis of which ten product samples were randomly selected for further investigations into sizing effects of product streams over time and changes in grade. Sizing analysis as well as chemical analysis of sub-samples over time showed that over a two day trial, the unit's performance was consistent.

The TBS unit proved as effective for the beneficiation of fine material (less than -3mm). It is easily controllable and able to handle variations in feed material which is ideal for tailings dump material. The TBS is effective for the separation of material by size and can be used in desliming applications prior to downstream processing. The unit is also effective as a density classifier, separating gauge from product material. The optimal benefit for inclusion into a process flowsheet is the smaller footprint occupied by the unit.

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13 Appendix

A. Middelburg Coal Data

A 1 Eriez Crossflow Elutriator (-2+1mm): Run1

Bed-height setpoint = 2.3

Teeter water flowrate = 30l/min

S.G	Feed Mass %	U Mass %	O Mass %	Rfeed Mass %	Mass Split
2.3	7.0	4.0	0.0	4.0	0.0
2.1	2.6	1.5	0.0	1.5	0.0
1.9	3.2	1.7	0.0	1.7	0.0
1.7	9.5	3.1	0.0	3.1	0.0
1.5	36.5	8.5	33.0	41.6	79.5
1.35	31.7	2.8	34.2	37.0	92.4
1.2	9.5	0.7	10.4	11.1	93.3
Total	100.0	22.3	77.7		

A 2 Eriez Crossflow Elutriator (-2+1mm): Run2

Bed-height setpoint = 2.1

Teeter water flowrate = 30l/min

S.G	Feed Mass %	U Mass %	O Mass %	Rfeed Mass %	Mass Split
2.3	7.0	2.3	0.0	2.3	0.0
2.1	2.6	0.9	0.0	0.9	0.0
1.9	3.2	1.3	0.0	1.3	0.0
1.7	9.5	3.9	0.0	3.9	0.0
1.5	36.5	14.7	26.9	41.6	64.6
1.35	31.7	3.2	35.3	38.5	91.8
1.2	9.5	0.5	11.1	11.6	95.5
Total	100.0	26.7	73.3		

A 3 Eriez Crossflow Elutriator (-2+1mm): Run3

Bed-height setpoint = 1.8

Teeter water flowrate = 30l/min

S.G	Feed Mass %	U Mass %	O Mass %	Rfeed Mass %	Mass Split
2.3	7.0	2.0	0.0	2.0	0.0
2.1	2.6	0.6	0.0	0.6	0.0
1.9	3.2	1.0	0.0	1.0	0.0
1.7	9.5	2.9	0.0	2.9	0.0
1.5	36.5	16.9	25.0	41.9	59.6
1.35	31.7	3.2	36.5	39.7	92.0
1.2	9.5	0.6	11.3	12.0	94.6
Total	100.0	27.2	72.8		

A 4 Eriez Crossflow Elutriator (-2+1mm): Run4

Bed-height setpoint = 1.8

Teeter water flowrate = 40l/min

S.G	Feed Mass %	U Mass %	O Mass %	Rfeed Mass %	Mass Split
2.3	7.0	0.7	0.0	0.7	0.0
2.1	2.6	0.3	0.0	0.3	0.0
1.9	3.2	0.3	0.0	0.3	0.0
1.7	9.5	1.9	5.5	7.4	74.3
1.5	36.5	4.5	31.8	36.3	87.6
1.35	31.7	0.9	41.8	42.7	97.9
1.2	9.5	0.2	12.1	12.3	98.4
Total	100.0	8.8	91.2		

A 5 Eriez Crossflow Elutriator (-2+1mm): Run5

Bed-height setpoint = 1.8

Teeter water flowrate = 50l/min

S.G	Feed Mass %	U Mass %	O Mass %	Rfeed Mass %	Mass Split
2.3	7.0	14.3	0.0	14.3	0.0
2.1	2.6	4.8	0.0	4.8	0.0
1.9	3.2	6.5	0.0	6.5	0.0
1.7	9.5	16.5	23.3	39.8	58.6
1.5	36.5	4.5	20.8	25.3	82.1
1.35	31.7	1.1	11.7	12.8	91.6
1.2	9.5	0.5	9.0	9.5	94.5
Total	100.0	48.1	51.9		

A 6 Eriez Crossflow Elutriator (-2+1mm): Run6

Bed-height setpoint = 1.3

Teeter water flowrate = 30l/min

S.G	Feed Mass %	U Mass %	O Mass %	Rfeed Mass %	Mass Split Mass %
2.3	7.0	1.8	0.0	1.8	0.0
2.1	2.6	0.6	0.0	0.6	0.0
1.9	3.2	0.9	0.0	0.9	0.0
1.7	9.5	2.2	8.2	10.4	79.1
1.5	36.5	2.8	37.7	40.5	93.1
1.35	31.7	2.2	33.1	35.3	93.6
1.2	9.5	0.6	10.0	10.6	94.6
Total	100.0	11.0	89.0		

Middelburg Coal (-1+0.5mm) Data

A 7 Eriez Crossflow Elutriator (-1+0.5mm): Run1

Bed-height setpoint = 2.3

Teeter water flowrate = 30l/min

S.G	Feed Mass %	U Mass %	O Mass %	Rfeed Mass %	Mass Split
2.3	8.1	8.4	0.0	8.4	0.0
2.1	2.0	3.2	0.0	3.2	0.0
1.9	3.0	3.3	0.0	3.3	0.0
1.7	7.3	11.4	0.0	11.4	0.0
1.5	40.2	24.8	13.7	38.5	35.6
1.35	34.1	0.9	29.6	30.5	97.0
1.2	5.2	0.1	4.6	4.7	98.3
Total	100.0	52.1	47.9		

A 8 Eriez Crossflow Elutriator (-1+0.5mm): Run2

Bed-height setpoint = 2.1

Teeter water flowrate = 30l/min

S.G	Feed Mass %	U Mass %	O Mass %	Rfeed Mass %	Mass Split
2.3	8.1	7.7	0.0	7.7	0.0
2.1	2.0	2.5	0.0	2.5	0.0
1.9	3.0	3.6	0.0	3.6	0.0
1.7	7.3	7.9	0.0	7.9	0.0
1.5	40.2	8.3	31.4	39.6	79.2
1.35	34.1	0.3	33.3	33.5	99.2
1.2	5.2	0.0	5.1	5.1	99.6
Total	100.0	30.3	69.7		

A 9 Eriez Crossflow Elutriator (-1+0.5mm): Run3

Bed-height setpoint = 1.8

Teeter water flowrate = 30l/min

S.G	Feed Mass %	U Mass %	O Mass %	Rfeed Mass %	Mass Split
2.3	8.1	9.4	0.0	9.4	0.0
2.1	2.0	3.3	0.0	3.3	0.0
1.9	3.0	4.4	0.0	4.4	0.0
1.7	7.3	8.9	0.0	8.9	0.0
1.5	40.2	16.2	21.9	38.1	57.5
1.35	34.1	0.8	30.4	31.2	97.5
1.2	5.2	0.1	4.7	4.8	97.9
Total	100.0	43.0	57.0		

A 10 Eriez Crossflow Elutriator (-1+0.5mm): Run4

Bed-height setpoint = 1.8

Teeter water flowrate = 40l/min

S.G	Feed Mass %	U Mass %	O Mass %	Rfeed Mass %	Mass Split
2.3	8.1	6.0	0.6	6.6	8.8
2.1	2.0	1.4	0.2	1.5	9.8
1.9	3.0	2.1	0.2	2.3	8.4
1.7	7.3	7.4	2.5	9.8	24.9
1.5	40.2	6.0	35.2	41.2	85.4
1.35	34.1	0.7	32.7	33.5	97.8
1.2	5.2	0.04	5.1	5.1	99.2
Total	100.0	23.6	76.4		

A 11 Eriez Crossflow Elutriator (-1+0.5mm): Run5

Bed-height setpoint = 1.8

Teeter water flowrate = 50l/min

S.G	Feed Mass %	U Mass %	O Mass %	Rfeed Mass %	Mass Split
2.3	8.1	4.5	0.5	5.0	10.2
2.1	2.0	3.0	0.5	3.5	14.6
1.9	3.0	3.0	0.5	3.5	14.6
1.7	7.3	2.2	0.5	2.8	18.5
1.5	40.2	3.7	39.2	42.9	91.3
1.35	34.1	0.2	36.5	36.7	99.5
1.2	5.2	0.0	5.6	5.6	99.8
Total	100.0	16.7	83.4		

A 12 Eriez Crossflow Elutriator (-1+0.5mm): Run6

Bed-height setpoint = 1.3

Teeter water flowrate = 30l/min

S.G	Feed Mass %	U Mass %	O Mass %	Rfeed Mass %	Mass Split Mass %
2.3	8.1	2.2	0.5	2.7	19.8
2.1	2.0	3.3	1.1	4.3	24.3
1.9	3.0	2.2	0.8	3.0	27.2
1.7	7.3	0.6	0.5	1.1	49.5
1.5	40.2	5.5	39.1	44.6	87.6
1.35	34.1	0.2	38.2	38.4	99.4
1.2	5.2	0.0	5.9	5.9	99.7
Total	100.0	14.0	86.0		

B. Koornfontein Coal (-3mm) Data

B 1 Eriez Crossflow Elutriator (-3mm): Run1

Bed-height setpoint = 1.14

Teeter water flowrate = 40l/min

S.G	Feed	O Mass %	U Mass %	Rfeed	Split
2.3	2.2	0.0	1.5	1.5	0.0
2.1	1.2	0.0	1.2	1.2	0.0
1.9	2.0	0.0	0.6	0.6	0.0
1.7	3.1	0.3	1.3	1.6	17.9
1.5	20.2	14.6	3.5	18.1	80.8
1.35	47.5	50.1	2.2	52.3	95.8
1.2	19.8	15.7	0.2	15.9	98.8
-1.2	4.0	8.9	0.0	8.9	100.0
Total	100.0	89.6	10.4		

B 2 Eriez Crossflow Elutriator (-3mm): Run2

Bed-height setpoint = 1.14

Teeter water flowrate = 45l/min

S.G	Feed	O Mass %	U Mass %	Rfeed	Split
2.3	2.2	0.0	0.9	0.9	0.0
2.1	1.2	0.0	0.4	0.4	0.0
1.9	2.0	0.0	0.7	0.7	0.0
1.7	3.1	0.2	1.2	1.3	12.7
1.5	20.2	13.8	2.6	16.4	84.1
1.35	47.5	46.6	3.1	49.7	93.8
1.2	19.8	27.0	0.3	27.2	99.0
-1.2	4.0	3.4	0.0	3.4	99.9
Total	100.0	90.9	9.1		

B 3 Eriez Crossflow Elutriator (-3mm): Run3

Bed-height setpoint = 1.14

Teeter water flowrate = 60l/min

S.G	Feed	O Mass %	U Mass %	Rfeed	Split
2.3	2.2	0.0	0.8	0.8	0.0
2.1	1.2	0.0	0.6	0.6	0.0
1.9	2.0	0.0	0.7	0.7	0.0
1.7	3.1	0.8	1.3	2.1	38.6
1.5	20.2	12.9	3.3	16.2	79.8
1.35	47.5	49.6	8.9	58.6	84.8
1.2	19.8	20.2	0.3	20.5	98.7
-1.2	4.0	0.5	0.0	0.5	99.5
Total	100.0	84.1	15.9		

C. Middelburg Ferrochrome Data

C 1 Linatex Elutriator (-1+0.5mm): Run1

Bed-height setpoint = 1.2

Teeter water flowrate = 60l/min

SG	Feed Mass %	U/F Mass %	O/F Mass %	Rfeed Mass %	Split
4	8.1	20.3	0.1	20.5	99.4
3.9	2.0	13.5	0.1	13.7	99.1
3.7	3.0	13.5	0.1	13.6	99.1
3.5	7.3	10.2	0.1	10.3	98.8
3.3	40.2	16.9	9.1	26.0	65.0
3.1	34.1	0.8	13.0	13.9	6.0
2.7	5.2	0.0	2.0	2.1	2.3
Total	100.0	75.3	24.7		

C 2 Linatex Elutriator (-1+0.5mm): Run2

Bed-height setpoint = 1.3

Teeter water flowrate = 60l/min

SG	Feed Mass %	U/F Mass %	O/F Mass %	Rfeed Mass %	Split
4	8.1	18.7	0.0	18.7	100.0
3.9	2.0	5.9	0.0	5.9	100.0
3.7	3.0	8.8	0.0	8.8	100.0
3.5	7.3	19.2	0.0	19.2	100.0
3.3	40.2	20.0	9.2	29.1	68.5
3.1	34.1	0.6	15.2	15.8	4.1
2.7	5.2	0.1	2.3	2.4	2.5
Total	100.0	73.3	26.7		

C 3 Linatex Elutriator (-1+0.5mm): Run3

Bed-height setpoint = 1.4

Teeter water flowrate = 60l/min

SG	Feed Mass %	U/F Mass %	O/F Mass %	Rfeed Mass %	Split
4	8.1	15.6	0.0	15.6	100.0
3.9	2.0	5.6	0.0	5.6	100.0
3.7	3.0	7.3	0.0	7.3	100.0
3.5	7.3	14.9	0.0	14.9	100.0
3.3	40.2	27.0	7.3	34.3	78.7
3.1	34.1	1.3	18.1	19.4	6.7
2.7	5.2	0.2	2.8	2.9	5.5
Total	100.0	71.8	28.2		

D. Northern Cape Hematite Data

D 1 Linatex Elutriator (-2+1mm): Run1

Bed-height setpoint = 1.66

Teeter water flowrate = 80l/min

S.G	Feed Mass%	U/F Mass%	O/F Mass%	Rfeed Mass%	Mass Split
4.2	20.5	21.9	0.9	22.9	95.9
4	18.1	17.6	0.9	18.5	95.1
3.75	20.5	17.1	4.1	21.1	80.7
3.6	22.5	20.2	9.9	30.1	67.3
3.2	11.1	1.6	4.9	6.5	24.3
2.9	7.3	0.9	3.7	4.6	19.6
	100.0	79.3	20.7		

D 2 Linatex Elutriator (-1+0.5mm): Run1

Bed-height setpoint = 1.75

Teeter water flowrate = 60l/min

S.G	Feed Mass%	U/F Mass%	O/F Mass%	Rfeed Mass%	Mass Split
4.2	12.2	15.6	0.4	16.0	97.2
4.0	12.1	13.8	0.5	14.2	96.8
3.8	28.2	12.6	10.5	23.0	54.6
3.6	23.7	11.9	18.7	30.6	38.9
3.2	19.8	2.1	8.8	10.9	19.3
2.9	4.0	0.8	4.4	5.2	15.4
	100.0	56.7	43.3		

D 3 Linatex Elutriator (-1+0.5mm): Run2

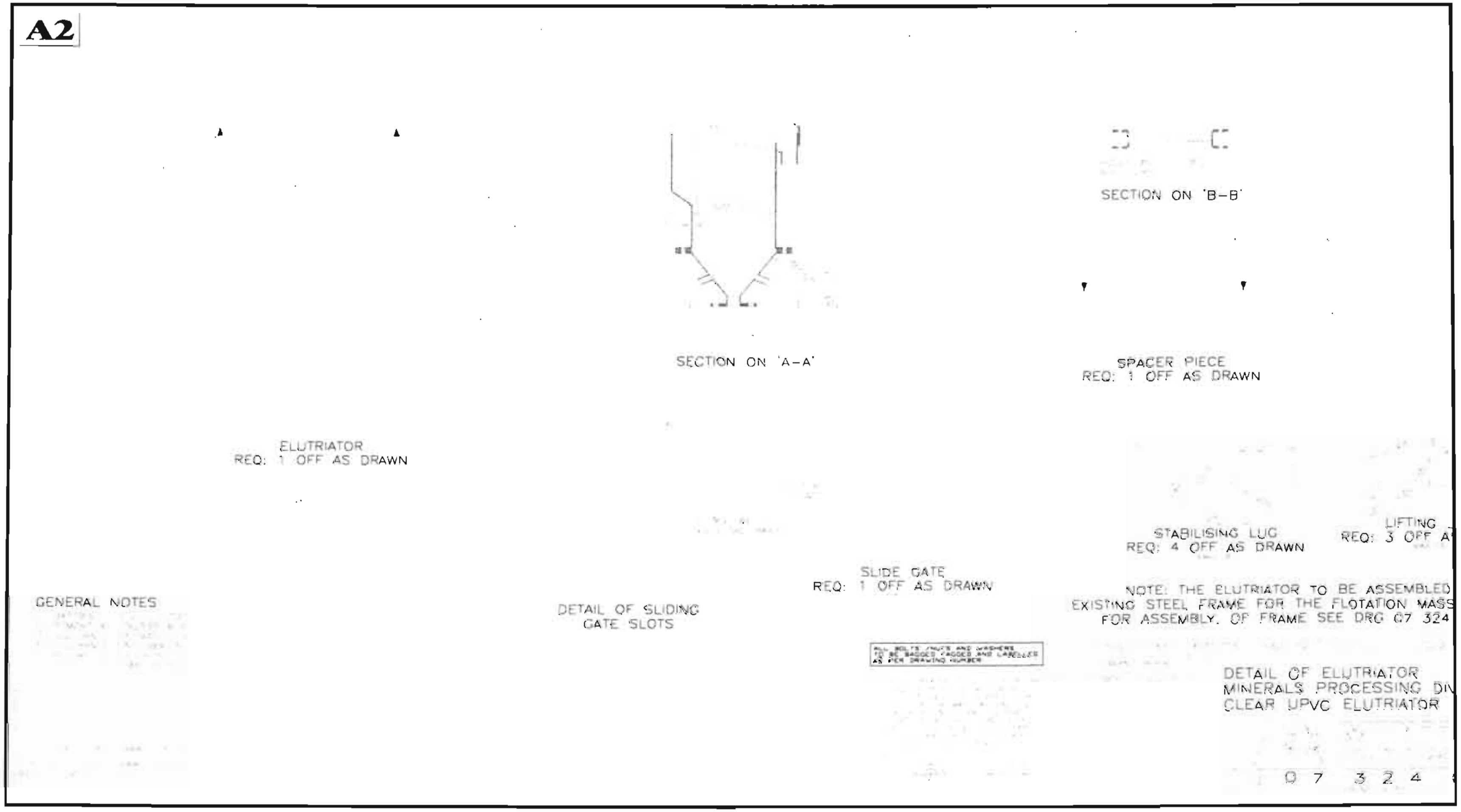
Bed-height setpoint = 1.75

Teeter water flowrate = 80l/min

S.G	Feed Mass%	U/F Mass%	O/F Mass%	Rfeed Mass%	Mass Split
4.2	12.2	25.7	1.2	26.9	95.4
4.0	12.1	20.7	1.2	21.9	94.5
3.8	28.2	16.3	8.5	24.8	65.7
3.6	23.7	6.9	6.6	13.5	51.3
3.2	19.8	1.7	5.1	6.8	24.6
2.9	4.0	1.5	4.6	6.1	23.9
	100.0	72.7	27.3		

E. Prototype Design

E 1 Test Unit – Elutriator Design



Test Unit Data

E2 Middelburg Ferrochrome (-1+0.5mm): Run1

Bed-height setpoint = 1.4

Teeter water flowrate = 60l/min

SG	Feed Mass%	U/F Mass%	O/F Mass%	Rfeed Mass%	Mass Split
4.0	8.5	19.3	0.2	19.5	99.2
3.9	2.3	17.0	0.2	17.2	99.1
3.7	3.1	15.2	0.2	15.4	99.0
3.5	7.1	5.0	0.2	5.2	97.0
3.3	38.2	16.7	9.2	25.9	64.4
3.1	33.8	0.6	13.6	14.2	4.0
2.7	7.0	0.1	2.6	2.7	2.5
Total	100.0	73.9	26.1		

E3 Middelburg Ferrochrome (-1+0.5mm): Run2

Bed-height setpoint = 1.6

Teeter water flowrate = 80l/min

SG	Feed Mass%	U/F Mass%	O/F Mass%	Rfeed Mass%	Mass Split
4.0	8.5	15.7	0.3	16.0	98.3
3.9	2.3	14.8	0.3	15.1	98.2
3.7	3.1	14.5	0.3	14.8	98.2
3.5	7.1	10.9	0.3	11.2	97.6
3.3	38.2	15.2	8.6	23.8	63.9
3.1	33.8	2.3	10.9	13.2	17.6
2.7	7.0	0.8	5.2	5.9	12.7
Total	100.0	74.3	25.7		

F. Examination of Operability Factors Associated with Pilot Scale Operations

Sizing Analysis

F.1 Sample 1

Size Passing (mm)	Mass (%)		Mass (%)		Reconst Feed	Nominal Size (mm)	Part Coeff
	u/f	o/f	u/f	o/f			
+3.35	0.00	0.00	0.00	0.00	0.00	4.34	100.00
-3.35+2.36	0.06	0.00	0.04	0.00	0.04	2.86	100.00
-2.36+1.7	0.64	0.00	0.45	0.00	0.45	2.03	100.00
-1.7+1.18	0.64	0.00	0.45	0.00	0.45	1.44	99.73
-1.18+0.85	3.36	0.19	2.35	0.06	2.41	1.02	97.68
-0.85+0.6	29.40	5.43	20.58	1.63	22.21	0.73	92.67
-0.6+0.425	25.37	9.58	17.76	2.87	20.63	0.51	86.08
-0.425+0.3	18.25	7.42	12.77	2.23	15.00	0.36	85.16
-0.3+0.212	13.43	6.76	9.40	2.03	11.43	0.26	82.26
-0.212+0.15	7.41	8.23	5.19	2.47	7.65	0.18	67.75
-0.15+0.106	1.09	8.58	0.77	2.57	3.34	0.13	22.93
-0.106+0.075	0.09	6.81	0.07	2.04	2.11	0.09	3.12
-0.075+0.053	0.04	6.80	0.03	2.04	2.07	0.06	1.29
-0.053+0.038	0.04	4.77	0.03	1.43	1.46	0.05	1.98
-0.038	0.18	35.43	0.12	10.63	10.75	0.00	1.14
Total	100.00	100.00	70.00	30.00	100.00		

F.2 Sample 2

Size Passing (mm)	Mass (%)		Mass (%)		Reconst Feed	Nominal Size (mm)	Part Coeff
	u/f	o/f	u/f	o/f			
+3.35	0.00	0.00	0.00	0.00	0.00	4.34	100.00
-3.35+2.36	0.05	0.00	0.03	0.00	0.03	2.86	100.00
-2.36+1.7	0.42	0.00	0.25	0.00	0.25	2.03	100.00
-1.7+1.18	0.49	0.00	0.29	0.00	0.29	1.44	100.00
-1.18+0.85	2.68	0.03	1.61	0.01	1.62	1.02	99.36
-0.85+0.6	25.71	1.28	15.43	0.51	15.94	0.73	96.78
-0.6+0.425	23.77	3.93	14.26	1.57	15.84	0.51	90.06
-0.425+0.3	20.55	5.15	12.33	2.06	14.39	0.36	85.68
-0.3+0.212	16.13	6.98	9.68	2.79	12.47	0.26	77.61
-0.212+0.15	8.69	9.37	5.22	3.75	8.96	0.18	58.20
-0.15+0.106	1.16	10.98	0.70	4.39	5.09	0.13	13.70
-0.106+0.075	0.09	8.78	0.05	3.51	3.57	0.09	1.53
-0.075+0.053	0.04	8.51	0.02	3.40	3.43	0.06	0.70
-0.053+0.038	0.04	6.85	0.03	2.74	2.77	0.05	0.91
-0.038	0.16	38.14	0.10	15.26	15.35	0.00	0.64
Total			60.00	40.00	100.00		

F.3 Sample 3

Size Passing (mm)	Mass (%)		Mass (%)		Reconst Feed	Nominal Size (mm)	Part Coeff
	u/f	o/f	u/f	o/f			
+3.35	0.00	0.00	0.00	0.00	0.00	4.34	100.00
-3.35+2.36	0.10	0.00	0.08	0.00	0.08	2.86	100.00
-2.36+1.7	0.56	0.00	0.45	0.00	0.45	2.03	100.00
-1.7+1.18	0.57	0.00	0.46	0.00	0.46	1.44	99.83
-1.18+0.85	3.15	0.43	2.52	0.09	2.60	1.02	96.72
-0.85+0.6	27.61	7.62	22.09	1.52	23.62	0.73	93.54
-0.6+0.425	24.22	8.58	19.38	1.72	21.09	0.51	91.87
-0.425+0.3	20.01	7.04	16.01	1.41	17.42	0.36	91.92
-0.3+0.212	14.71	6.77	11.77	1.35	13.12	0.26	89.68
-0.212+0.15	7.73	7.69	6.18	1.54	7.72	0.18	80.08
-0.15+0.106	1.01	8.46	0.81	1.69	2.50	0.13	32.32
-0.106+0.075	0.07	7.07	0.05	1.41	1.47	0.09	3.65
-0.075+0.053	0.03	6.64	0.03	1.33	1.36	0.06	2.01
-0.053+0.038	0.03	5.19	0.02	1.04	1.06	0.05	2.19
-0.038	0.20	34.50	0.16	6.90	7.06	0.00	2.31
Total			80.00	20.00	100.00		

F.4 Sample 4

Size Passing (mm)	Mass (%)		Mass (%)		Reconst Feed	Nominal Size (mm)	Part Coeff
	u/f	o/f	u/f	o/f			
+3.35	0.00	0.00	0.00	0.00	0.00	4.34	100.00
-3.35+2.36	0.04	0.00	0.02	0.00	0.02	2.86	100.00
-2.36+1.7	0.74	0.00	0.45	0.00	0.45	2.03	100.00
-1.7+1.18	0.77	0.00	0.46	0.00	0.46	1.44	100.00
-1.18+0.85	2.95	0.01	1.77	0.00	1.77	1.02	99.80
-0.85+0.6	30.87	0.14	18.52	0.06	18.58	0.73	99.70
-0.6+0.425	27.60	0.85	16.56	0.34	16.90	0.51	98.00
-0.425+0.3	18.61	3.26	11.16	1.30	12.46	0.36	89.55
-0.3+0.212	12.62	6.14	7.57	2.45	10.03	0.26	75.52
-0.212+0.15	5.23	8.65	3.14	3.46	6.60	0.18	47.55
-0.15+0.106	0.54	12.78	0.32	5.11	5.44	0.13	5.95
-0.106+0.075	0.02	9.71	0.01	3.88	3.89	0.09	0.25
-0.075+0.053	0.01	8.93	0.01	3.57	3.58	0.06	0.15
-0.053+0.038	0.01	7.16	0.01	2.86	2.87	0.05	0.21
-0.038	0.01	42.39	0.00	16.96	16.96	0.00	0.02
Total	100.00	100.00	60.00	40.00	100.00		

F.5 Sample 5

Size Passing (mm)	Mass (%)		Mass (%)		Reconst Feed	Nominal Size (mm)	Part Coeff
	u/f	o/f	u/f	o/f			
+3.35	0.00	0.00	0.00	0.00	0.00	4.34	100.00
-3.35+2.36	0.06	0.00	0.04	0.00	0.04	2.86	100.00
-2.36+1.7	0.49	0.00	0.34	0.00	0.34	2.03	100.00
-1.7+1.18	0.61	0.00	0.42	0.00	0.42	1.44	100.00
-1.18+0.85	2.12	0.02	1.47	0.01	1.47	1.02	99.50
-0.85+0.6	26.26	1.29	18.18	0.40	18.58	0.73	97.86
-0.6+0.425	25.77	4.06	17.84	1.25	19.09	0.51	93.46
-0.425+0.3	19.89	5.25	13.77	1.62	15.38	0.36	89.50
-0.3+0.212	16.51	7.17	11.43	2.21	13.64	0.26	83.82
-0.212+0.15	7.23	9.32	5.00	2.87	7.87	0.18	63.56
-0.15+0.106	0.76	10.97	0.52	3.38	3.90	0.13	13.42
-0.106+0.075	0.06	9.16	0.04	2.82	2.86	0.09	1.38
-0.075+0.053	0.03	8.32	0.02	2.56	2.58	0.06	0.91
-0.053+0.038	0.03	6.05	0.02	1.86	1.88	0.05	1.25
-0.038	0.18	38.40	0.13	11.82	11.94	0.00	1.05
Total			69.22	30.78	100.00		

F.6 Sample 6

Size Passing (mm)	Mass (%)		Mass (%)		Reconst Feed	Nominal Size (mm)	Part Coeff
	u/f	o/f	u/f	o/f			
+3.35	0.00	0.00	0.00	0.00	0.00	4.34	100.00
-3.35+2.36	0.03	0.00	0.02	0.00	0.02	2.86	100.00
-2.36+1.7	0.34	0.00	0.20	0.00	0.20	2.03	100.00
-1.7+1.18	0.41	0.00	0.25	0.00	0.25	1.44	100.00
-1.18+0.85	1.61	0.01	0.96	0.00	0.97	1.02	99.63
-0.85+0.6	22.07	0.30	13.24	0.12	13.36	0.73	99.11
-0.6+0.425	23.85	1.52	14.31	0.61	14.92	0.51	95.91
-0.425+0.3	19.97	3.92	11.98	1.57	13.55	0.36	88.42
-0.3+0.212	18.85	6.22	11.31	2.49	13.80	0.26	81.97
-0.212+0.15	10.84	8.73	6.50	3.49	9.99	0.18	65.07
-0.15+0.106	1.58	11.32	0.95	4.53	5.48	0.13	17.35
-0.106+0.075	0.09	9.79	0.05	3.92	3.97	0.09	1.32
-0.075+0.053	0.04	8.39	0.02	3.36	3.38	0.06	0.73
-0.053+0.038	0.04	5.79	0.02	2.31	2.34	0.05	1.00
-0.038	0.31	44.02	0.18	17.61	17.79	0.00	1.03
Total			60.00	40.00	100.00		

F.7 Sample 7

Size Passing (mm)	Mass (%)		Mass (%)		Reconst Feed	Nominal Size (mm)	Part Coeff
	u/f	o/f	u/f	o/f			
+3.35	0.00	0.00	0.00	0.00	0.00	4.34	100.00
-3.35+2.36	0.01	0.00	0.01	0.00	0.01	2.86	100.00
-2.36+1.7	0.22	0.00	0.17	0.00	0.17	2.03	100.00
-1.7+1.18	0.37	0.00	0.28	0.00	0.28	1.44	99.91
-1.18+0.85	2.94	0.04	2.17	0.01	2.18	1.02	99.56
-0.85+0.6	28.10	2.01	20.75	0.53	21.27	0.73	97.53
-0.6+0.425	24.46	7.03	18.06	1.84	19.90	0.51	90.76
-0.425+0.3	20.24	7.69	14.95	2.01	16.96	0.36	88.14
-0.3+0.212	14.91	8.03	11.01	2.10	13.11	0.26	83.97
-0.212+0.15	7.65	8.91	5.65	2.33	7.98	0.18	70.80
-0.15+0.106	0.88	10.21	0.65	2.67	3.32	0.13	19.56
-0.106+0.075	0.04	8.89	0.03	2.33	2.35	0.09	1.19
-0.075+0.053	0.02	7.73	0.01	2.02	2.04	0.06	0.65
-0.053+0.038	0.02	5.17	0.01	1.35	1.37	0.05	0.92
-0.038	0.14	34.29	0.10	8.97	9.07	0.00	1.14
Total			73.84	26.16	100.00		

F.8 Sample 8

Size Passing (mm)	Mass (%)		Mass (%)		Reconst Feed	Nominal Size (mm)	Part Coeff
	u/f	o/f	u/f	o/f			
+3.35	0.00	0.00	0.00	0.00	0.00	4.34	100.00
-3.35+2.36	0.03	0.00	0.02	0.00	0.02	2.86	100.00
-2.36+1.7	0.58	0.00	0.45	0.00	0.45	2.03	100.00
-1.7+1.18	0.74	0.00	0.57	0.00	0.57	1.44	100.00
-1.18+0.85	3.72	0.02	2.87	0.00	2.88	1.02	99.86
-0.85+0.6	32.04	1.64	24.77	0.37	25.14	0.73	98.52
-0.6+0.425	24.93	7.04	19.28	1.60	20.87	0.51	92.34
-0.425+0.3	18.25	8.33	14.11	1.89	16.00	0.36	88.19
-0.3+0.212	12.46	7.77	9.63	1.76	11.39	0.26	84.53
-0.212+0.15	6.26	9.41	4.84	2.13	6.98	0.18	69.40
-0.15+0.106	0.75	9.36	0.58	2.12	2.70	0.13	21.45
-0.106+0.075	0.04	7.98	0.03	1.81	1.84	0.09	1.60
-0.075+0.053	0.02	7.29	0.01	1.65	1.67	0.06	0.83
-0.053+0.038	0.02	5.50	0.01	1.25	1.26	0.05	1.04
-0.038	0.17	35.66	0.13	8.09	8.22	0.00	1.64
Total			77.31	22.69	100.00		

F.9 Sample 9

Size Passing (mm)	Mass (%)		Mass (%)		Reconst Feed	Nominal Size (mm)	Part Coeff
	u/f	o/f	u/f	o/f			
+3.35	0.00	0.00	0.00	0.00	0.00	4.34	100.00
-3.35+2.36	0.04	0.00	0.03	0.00	0.03	2.86	100.00
-2.36+1.7	0.49	0.00	0.35	0.00	0.35	2.03	99.77
-1.7+1.18	0.62	0.00	0.45	0.00	0.45	1.44	99.75
-1.18+0.85	2.25	0.03	1.63	0.01	1.63	1.02	99.48
-0.85+0.6	27.89	1.72	20.19	0.47	20.67	0.73	97.71
-0.6+0.425	26.03	5.13	18.84	1.41	20.26	0.51	93.02
-0.425+0.3	19.12	6.25	13.84	1.72	15.57	0.36	88.92
-0.3+0.212	15.07	7.47	10.91	2.06	12.97	0.26	84.11
-0.212+0.15	7.24	9.27	5.24	2.56	7.80	0.18	67.19
-0.15+0.106	0.94	10.54	0.68	2.91	3.59	0.13	18.90
-0.106+0.075	0.06	9.16	0.04	2.53	2.57	0.09	1.74
-0.075+0.053	0.03	8.21	0.02	2.27	2.29	0.06	0.98
-0.053+0.038	0.03	5.98	0.02	1.65	1.67	0.05	1.34
-0.038	0.20	36.24	0.14	10.00	10.15	0.00	1.40
Total			72.39	27.61	100.00		

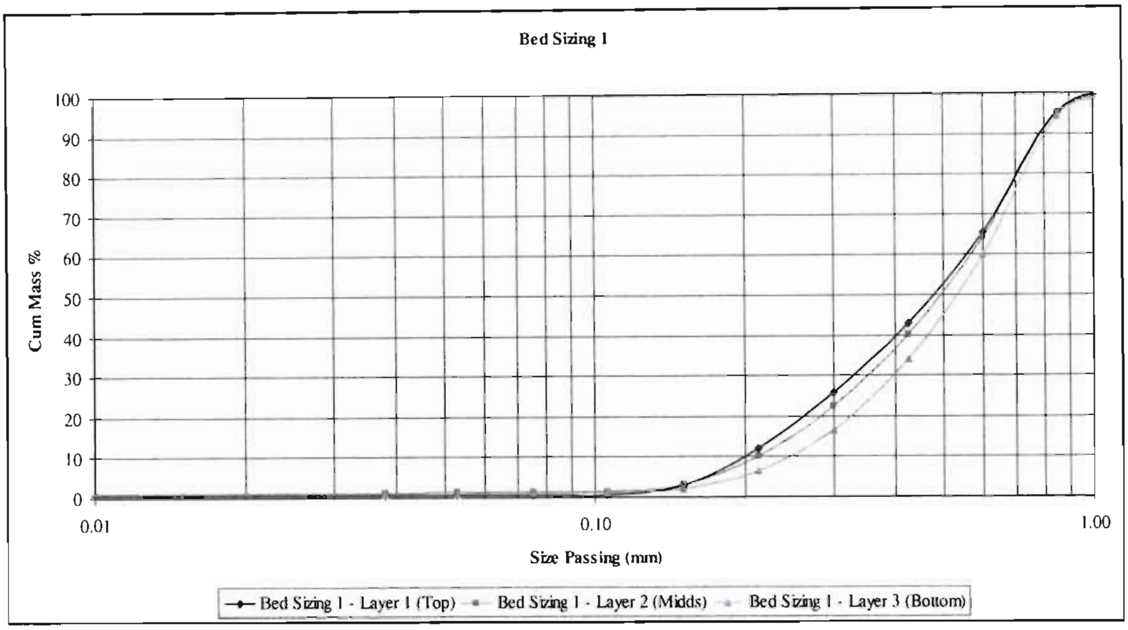
F.10 Sample 10

Size Passing (mm)	Mass (%)		Mass (%)		Reconst Feed	Nominal Size (mm)	Part Coeff
	u/f	o/f	u/f	o/f			
+3.35	0.00	0.00	0.00	0.00	0.00	4.34	100.00
-3.35+2.36	0.00	0.00	0.00	0.00	0.00	2.86	100.00
-2.36+1.7	0.30	0.00	0.22	0.00	0.22	2.03	100.00
-1.7+1.18	0.39	0.01	0.29	0.00	0.29	1.44	99.45
-1.18+0.85	2.39	0.02	1.76	0.01	1.77	1.02	99.69
-0.85+0.6	24.98	1.56	18.41	0.41	18.82	0.73	97.82
-0.6+0.425	26.22	6.31	19.32	1.66	20.98	0.51	92.08
-0.425+0.3	19.71	8.80	14.52	2.32	16.84	0.36	86.24
-0.3+0.212	15.87	7.52	11.70	1.98	13.68	0.26	85.53
-0.212+0.15	8.51	9.40	6.27	2.47	8.74	0.18	71.71
-0.15+0.106	1.31	10.26	0.97	2.70	3.67	0.13	26.33
-0.106+0.075	0.07	7.71	0.05	2.03	2.08	0.09	2.30
-0.075+0.053	0.03	6.99	0.02	1.84	1.86	0.06	1.19
-0.053+0.038	0.03	5.57	0.02	1.47	1.49	0.05	1.39
-0.038	0.20	35.84	0.14	9.43	9.58	0.00	1.51
Total			73.68	26.32	100.00		

Bed Sizing Analysis

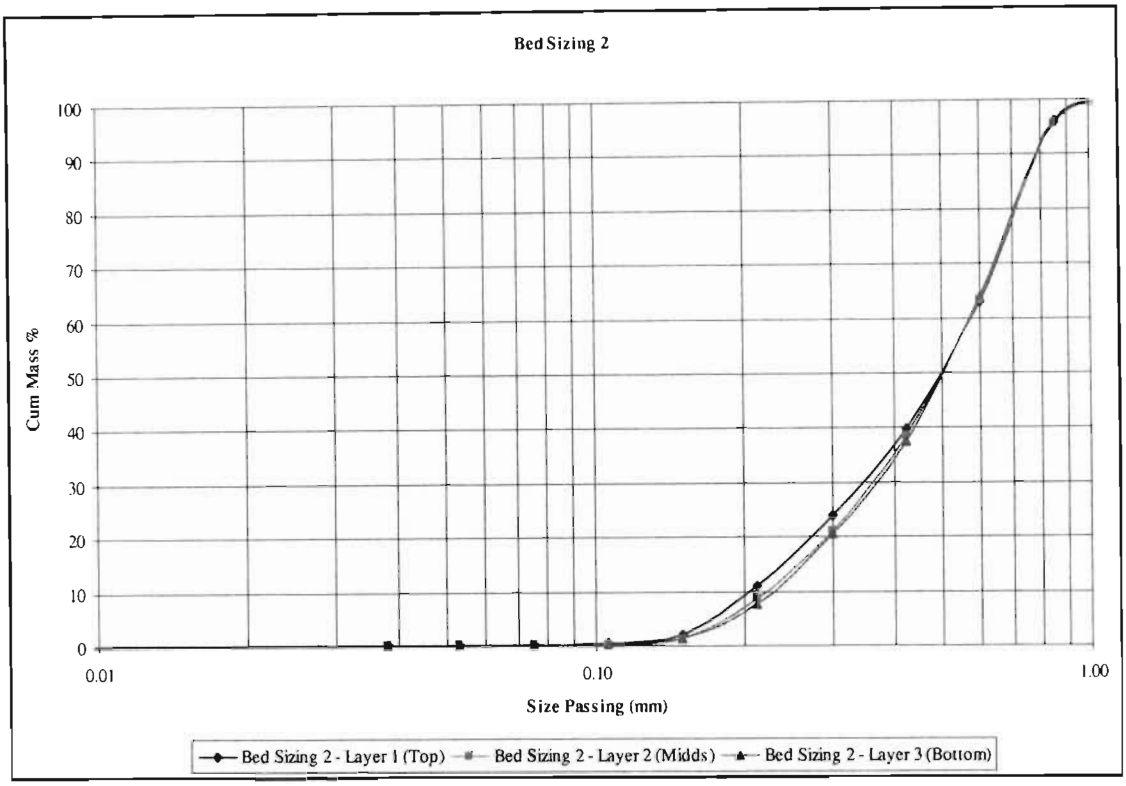
F.11. Test 1

Size Passing (mm)	Layer 1		Layer 2		Layer 3	
	Mass (%)	Cum Mass (%)	Mass (%)	Cum Mass (%)	Mass (%)	Cum Mass (%)
2.360	0.00	100.00	0.00	100.00	0.00	100.00
1.700	0.21	99.79	0.35	99.65	0.60	99.40
1.180	0.31	99.48	0.46	99.19	0.69	98.71
0.850	3.98	95.50	4.26	94.93	4.70	94.01
0.600	30.11	65.39	30.74	64.19	34.28	59.73
0.425	22.30	43.09	24.13	40.06	25.72	34.01
0.300	17.16	25.93	17.50	22.56	17.33	16.68
0.212	13.89	12.04	12.47	10.09	10.29	6.39
0.150	9.31	2.73	7.08	3.01	4.54	1.85
0.106	2.04	0.69	1.51	1.50	0.74	1.11
0.075	0.18	0.51	0.15	1.35	0.12	0.99
0.053	0.05	0.46	0.06	1.29	0.07	0.92
0.038	0.03	0.43	0.05	1.24	0.06	0.86
0.000	0.43	0.00	1.24	0.00	0.86	0.00
Total	100.0		100.0		100.0	



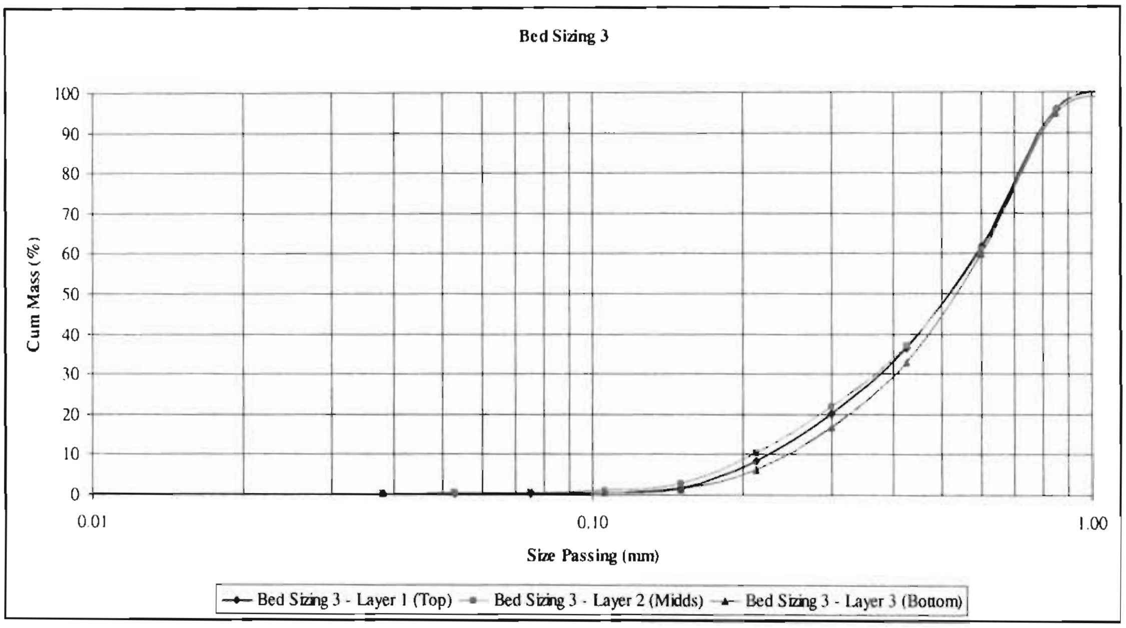
F.12. Test 2

Size Passing (mm)	Layer 1		Layer 2		Layer 3	
	Mass (%)	Cum Mass (%)	Mass (%)	Cum Mass (%)	Mass (%)	Cum Mass (%)
3.350	0.00	100.00	0.00	100.00	0.00	100.00
2.360	0.00	100.00	0.02	99.98	0.01	99.99
1.700	0.16	99.83	0.41	99.57	0.32	99.67
1.180	0.38	99.45	0.55	99.02	0.58	99.09
0.850	3.66	95.79	3.54	95.48	2.80	96.29
0.600	32.76	63.03	32.16	63.32	32.14	64.15
0.425	23.11	39.92	24.82	38.50	26.58	37.58
0.300	15.93	23.99	17.35	21.15	16.96	20.61
0.212	13.14	10.85	12.60	8.55	13.02	7.59
0.150	8.83	2.02	7.14	1.41	6.37	1.22
0.106	1.60	0.42	1.08	0.34	0.88	0.33
0.075	0.13	0.30	0.10	0.24	0.09	0.25
0.053	0.05	0.25	0.05	0.19	0.04	0.21
0.038	0.04	0.22	0.04	0.15	0.03	0.17
0.000	0.22	0.00	0.15	0.00	0.17	0.00
Total	100.0		100.0		100.0	



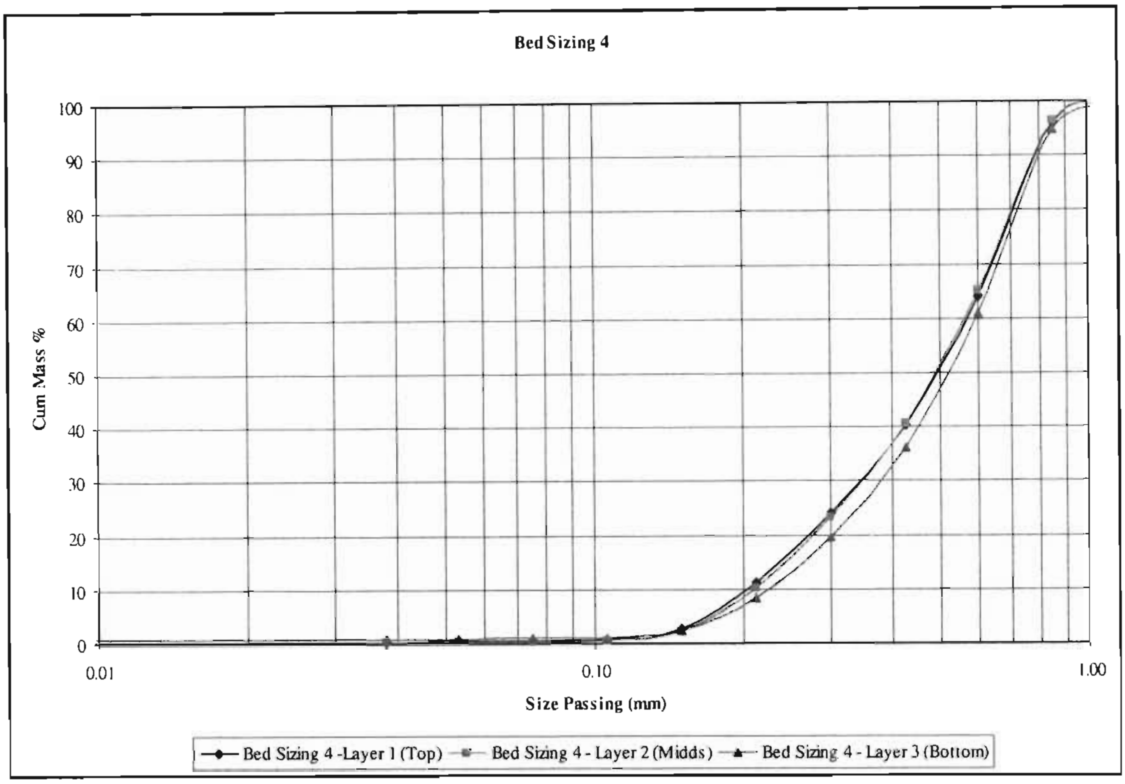
F.13. Test 3

Size Passing (mm)	Layer 1		Layer 2		Layer 3	
	Mass (%)	Cum Mass (%)	Mass (%)	Cum Mass (%)	Mass (%)	Cum Mass (%)
3.350					0.01	100.00
2.360	0.00	100.00	0.00	100.00	0.00	100.00
1.700	0.14	99.86	0.15	99.85	0.48	99.51
1.180	0.25	99.61	0.24	99.61	0.68	98.83
0.850	3.72	95.89	4.21	95.40	4.09	94.75
0.600	33.98	61.91	34.31	61.09	34.78	59.97
0.425	25.53	36.38	23.97	37.12	27.23	32.73
0.300	16.10	20.28	15.21	21.91	15.94	16.80
0.212	11.81	8.47	11.59	10.32	10.72	6.08
0.150	6.88	1.59	7.47	2.85	4.69	1.40
0.106	1.13	0.46	1.79	1.06	0.71	0.69
0.075	0.14	0.32	0.41	0.65	0.14	0.55
0.053	0.06	0.26	0.17	0.48	0.08	0.47
0.038	0.05	0.21	0.11	0.37	0.07	0.40
0.000	0.21	0.00	0.37	0.00	0.39	0.01
Total	100.0		100.0		100.00	



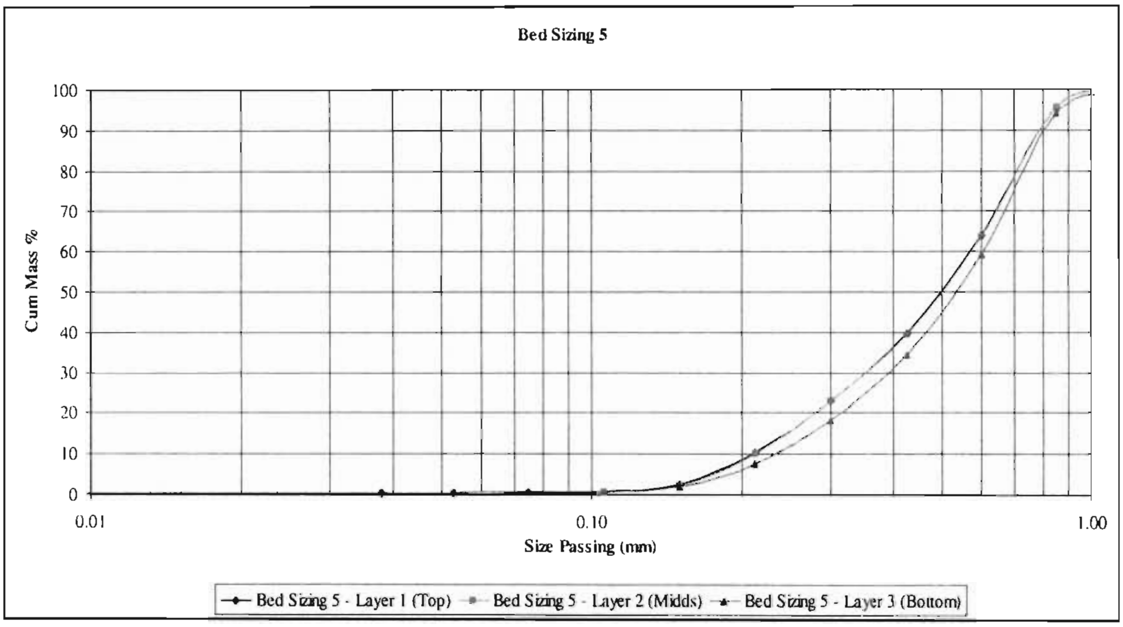
F.14. Test 4

Size Passing (mm)	Layer 1		Layer 2		Layer 3	
	Mass (%)	Cum Mass (%)	Mass (%)	Cum Mass (%)	Mass (%)	Cum Mass (%)
2.360	0.00	100.00	0.00	100.00	0.00	100.00
1.700	0.16	99.84	0.20	99.80	0.43	99.57
1.180	0.17	99.67	0.26	99.54	0.49	99.08
0.850	3.71	95.96	3.29	96.25	4.44	94.64
0.600	31.76	64.20	31.00	65.25	33.69	60.95
0.425	23.93	40.27	24.68	40.57	24.81	36.14
0.300	16.27	24.00	17.19	23.38	16.43	19.71
0.212	12.68	11.32	13.15	10.23	11.22	8.49
0.150	8.59	2.73	8.06	2.17	6.24	2.25
0.106	1.88	0.85	1.54	0.63	1.15	1.10
0.075	0.31	0.54	0.24	0.39	0.16	0.94
0.053	0.13	0.41	0.10	0.29	0.07	0.87
0.038	0.10	0.31	0.07	0.22	0.06	0.81
0.000	0.31	0.00	0.22	0.00	0.81	0.00
Total	100.0		100.0		100.0	



F.15. Test 5

Size Passing (mm)	Layer 1		Layer 2		Layer 3	
	Mass (%)	Cum Mass (%)	Mass (%)	Cum Mass (%)	Mass (%)	Cum Mass (%)
2.360	0.00	100.00	0.00	100.00	0.00	100.00
1.700	0.14	99.86	0.24	99.76	0.63	99.37
1.180	0.30	99.56	0.34	99.42	0.62	98.75
0.850	4.03	95.53	4.01	95.41	4.67	94.08
0.600	31.56	63.97	31.74	63.67	34.79	59.29
0.425	24.41	39.56	24.15	39.52	25.00	34.29
0.300	16.53	23.03	16.67	22.85	16.14	18.15
0.212	12.56	10.47	12.67	10.18	10.55	7.60
0.150	8.07	2.40	7.99	2.19	5.60	2.00
0.106	1.69	0.71	1.56	0.63	1.03	0.97
0.075	0.28	0.43	0.25	0.38	0.24	0.73
0.053	0.12	0.31	0.10	0.28	0.14	0.59
0.038	0.08	0.23	0.08	0.20	0.12	0.47
0.000	0.23	0.00	0.20	0.00	0.47	0.00
Total	100.0		100.0		100.0	


Bed Sizing 5
Cum Mass %
100
90
80
70
60
50
40
30
20
10
0
0.01
0.10
1.00
Size Passing (mm)
Bed Sizing 5 - Layer 1 (Top)
Bed Sizing 5 - Layer 2 (Midds)
Bed Sizing 5 - Layer 3 (Bottom)

Grade Analysis

F.16. Test 1

Size fraction	Mass [%]					Grade O/F		Grade U/F		Recovery O/F		Recovery U/F		Reconst Feed		Part Coeff	
[um]	O/F	U/F	Recon Feed	Nom Size	Part coeff	Fe2O3 %	SiO2 %	Fe2O3 %	SiO2 %	Fe2O3 %	SiO2 %	Fe2O3 %	SiO2 %	Fe2O3 %	SiO2 %	Fe2O3 %	SiO2 %
+3.35		0.01	0.01	4.34	100.00												
-3.35+2.36		0.02	0.02	2.86	100.00			43.40	3.55			0.01	0.00	0.01	0.00	100.00	100.00
-2.36+1.7		0.26	0.26	2.03	100.00			78.60	20.40			0.27	0.26	0.27	0.26	100.00	100.00
-1.7+1.18	0.00	0.29	0.29	1.44	100.00			73.30	23.90			0.28	0.34	0.28	0.34	100.00	100.00
-1.18+0.85	0.01	1.08	1.09	1.02	99.04	12.00	72.60	73.50	25.10	0.00	0.04	1.06	1.34	1.06	1.38	99.84	97.27
-0.85+0.6	0.51	13.96	14.47	0.73	96.44	11.90	86.70	74.10	23.20	0.08	2.21	13.81	16.01	13.89	18.21	99.41	87.89
-0.6+0.425	1.58	15.38	16.96	0.51	90.67	15.00	82.50	69.40	15.70	0.32	6.45	14.25	11.94	14.57	18.39	97.82	64.91
-0.425+0.3	2.08	12.22	14.30	0.36	85.44	23.20	69.40	88.50	8.17	0.64	7.14	14.44	4.93	15.09	12.08	95.73	40.86
-0.3+0.212	2.86	10.64	13.50	0.26	78.85	36.80	57.80	93.50	3.95	1.40	8.16	13.29	2.08	14.69	10.24	90.45	20.30
-0.212+0.15	3.82	5.28	9.09	0.18	58.02	57.90	34.80	97.90	1.71	2.95	6.57	6.90	0.45	9.85	7.01	70.03	6.36
-0.15+0.106	4.38	0.67	5.04	0.13	13.20	71.30	24.60	99.40	1.76	4.17	5.32	0.88	0.06	5.05	5.38	17.49	1.08
-0.106+0.075	3.62	0.05	3.67	0.09	1.39	74.70	22.30	89.50	10.20	3.61	3.99	0.06	0.03	3.67	4.01	1.66	0.64
-0.075+0.053	3.29	0.03	3.31	0.06	0.81	74.90	21.40	85.77	11.50	3.29	3.48	0.03	0.02	3.32	3.49	0.93	0.44
-0.053+0.038	2.54	0.03	2.56	0.05	1.00	77.00	20.80	82.89	12.21	2.61	2.61	0.03	0.02	2.64	2.63	1.08	0.59
-0.038	15.31	0.10	15.41	0.00	0.64	75.70	21.80	83.60	14.00	15.48	16.50	0.11	0.07	15.59	16.57		
Total (calc)	40.00	60.00	100.00			64.70	31.59	81.68	12.65	34.56	62.47	65.44	37.53	100	100		

F.17. Test 2

Size fraction	Mass [%]					Grade O/F		Grade U/F		Recovery O/F		Recovery U/F		Reconst Feed		Part Coeff	
[um]	O/F	U/F	Recon Feed	Nom Size	Part coeff	Fe2O3 %	SiO2 %	Fe2O3 %	SiO2 %	Fe2O3 %	SiO2 %	Fe2O3 %	SiO2 %	Fe2O3 %	SiO2 %	Fe2O3 %	SiO2 %
+3.35		0.00	0.00	4.34	100.00												
-3.35+2.36		0.03	0.03	2.86	100.00			56.20	36.50			0.02	0.06	0.02	0.06	100.00	100.00
-2.36+1.7		0.36	0.36	2.03	100.00			63.20	30.60			0.29	0.56	0.29	0.56	100.00	100.00
-1.7+1.18	0.00	0.39	0.39	1.44	100.00			74.75	24.30			0.37	0.49	0.37	0.49	100.00	100.00
-1.18+0.85	0.01	1.45	1.46	1.02	99.43			74.40	24.10			1.36	1.78	1.36	1.78	100.00	100.00
-0.85+0.6	0.39	18.02	18.42	0.73	97.86	11.40	89.95	76.70	22.60	0.06	1.81	17.45	20.76	17.51	22.56	99.68	92.00
-0.6+0.425	1.24	17.94	19.18	0.51	93.52	14.20	86.70	84.50	15.20	0.22	5.49	19.14	13.89	19.36	19.38	98.85	71.69
-0.425+0.3	1.60	13.64	15.24	0.36	89.51	22.60	77.90	89.90	8.30	0.46	6.34	15.48	5.77	15.94	12.12	97.14	47.63
-0.3+0.212	2.16	11.39	13.55	0.26	84.07	60.30	38.50	94.90	4.03	1.64	4.24	13.65	2.34	15.30	6.58	89.26	35.59
-0.212+0.15	2.89	5.22	8.10	0.18	64.38	37.40	58.40	96.40	1.90	1.36	8.59	6.35	0.51	7.71	9.10	82.33	5.55
-0.15+0.106	3.33	0.56	3.89	0.13	14.42	71.60	25.70	97.20	1.80	3.01	4.36	0.69	0.05	3.70	4.41	18.62	1.17
-0.106+0.075	2.89	0.05	2.94	0.09	1.53	76.80	23.20	91.70	10.20	2.81	3.42	0.05	0.02	2.86	3.44	1.83	0.68
-0.075+0.053	2.44	0.03	2.47	0.06	1.07	76.70	22.70	46.90	11.35	2.37	2.83	0.02	0.02	2.38	2.84	0.65	0.54
-0.053+0.038	1.95	0.03	1.98	0.05	1.36	78.10	20.60	43.45	12.54	1.93	2.05	0.01	0.02	1.94	2.07	0.76	0.84
-0.038	11.87	0.13	11.99	0.00	1.05	74.20	24.00	82.70	13.90	11.12	14.51	0.13	0.09	11.25	14.60	1.16	0.61
Total (calc)	30.78	69.22	100.00			64.28	34.21	85.83	13.14	24.98	53.65	75.02	46.35	99.99	72.61		

F.18. Test 3

Size fraction	Mass [%]					Grade O/F		Grade U/F		Recovery O/F		Recovery U/F		Reconst Feed		Part Coeff	
[um]	O/F	U/F	Recon Feed	Nom Size	Part coeff	Fe2O3 %	SiO2 %	Fe2O3 %	SiO2 %	Fe2O3 %	SiO2 %	Fe2O3 %	SiO2 %	Fe2O3 %	SiO2 %	Fe2O3 %	SiO2 %
+2.36		0.00	0.00	2.86	100.00												
-2.36+1.7		0.17	0.17	2.03	100.00			66.80	26.80			0.15	0.22	0.15	0.22	100.00	100.00
-1.7+1.18	0.00	0.28	0.28	1.44	100.00			64.70	29.00			0.23	0.39	0.23	0.39	100.00	100.00
-1.18+0.85	0.01	1.48	1.48	1.02	99.52			67.50	27.90			1.29	2.00	1.29	2.00	100.00	100.00
-0.85+0.6	0.47	18.77	19.24	0.73	97.55	12.00	78.80	68.20	26.60	0.07	1.80	16.62	24.26	16.70	26.07	99.56	93.08
-0.6+0.425	1.81	19.93	21.74	0.51	91.69	13.00	78.80	81.20	18.90	0.31	6.92	21.03	18.31	21.33	25.24	98.57	72.57
-0.425+0.3	2.05	14.70	16.76	0.36	87.74	20.60	72.60	91.90	9.00	0.55	7.25	17.55	6.43	18.10	13.68	96.96	47.01
-0.3+0.212	2.12	12.10	14.22	0.26	85.11	34.70	58.00	96.90	4.28	0.95	5.97	15.23	2.52	16.18	8.49	94.10	29.66
-0.212+0.15	2.36	5.63	7.99	0.18	70.50	57.50	34.60	99.00	1.79	1.76	3.96	7.24	0.49	9.00	4.45	80.45	11.00
-0.15+0.106	2.68	0.62	3.30	0.13	18.75	73.60	23.20	82.00	1.43	2.56	3.02	0.66	0.04	3.22	3.07	20.46	1.40
-0.106+0.075	2.28	0.03	2.31	0.09	1.25	77.80	21.30	88.00	10.20	2.30	2.36	0.03	0.01	2.34	2.37	1.41	0.60
-0.075+0.053	1.87	0.02	1.89	0.06	0.82	78.40	20.40	87.80	9.71	1.91	1.86	0.02	0.01	1.93	1.87	0.92	0.39
-0.053+0.038	1.50	0.02	1.52	0.05	1.07	77.90	20.00	91.20	8.19	1.52	1.46	0.02	0.01	1.54	1.47	1.25	0.44
-0.038	9.01	0.10	9.11	0.00	1.13	67.40	24.20	66.70	14.60	7.89	10.60	0.09	0.07	7.98	10.67	1.12	0.69
Total (calc)	26.16	73.84	100.00			58.36	35.56	83.58	15.26	19.83	45.23	80.17	54.77	100	100		

F.19. Test 4

Size fraction	Mass [%]					Grade O/F		Grade U/F		Recovery O/F		Recovery U/F		Reconst Feed		Part Coeff	
[um]	O/F	U/F	Recon Feed	Nom Size	Part coeff	Fe2O3 %	SiO2 %	Fe2O3 %	SiO2 %	Fe2O3 %	SiO2 %	Fe2O3 %	SiO2 %	Fe2O3 %	SiO2 %	Fe2O3 %	SiO2 %
+3.35		0.00	0.00	4.34	100.00												
-3.35+2.36		0.04	0.04	2.86	100.00												
-2.36+1.7		0.37	0.37	2.03	100.00			73.80	25.00			0.35	0.46	0.35	0.46	100.00	100.00
-1.7+1.18	0.00	0.42	0.42	1.44	100.00			67.30	24.90			0.37	0.52	0.37	0.52	100.00	100.00
-1.18+0.85	0.01	1.53	1.54	1.02	99.44			68.30	25.40			1.37	1.92	1.37	1.92	100.00	100.00
-0.85+0.6	0.48	19.59	20.06	0.73	97.63	12.40	84.00	70.85	23.00	0.08	1.98	18.16	22.34	18.24	24.32	99.58	91.84
-0.6+0.425	1.41	19.41	20.82	0.51	93.23	12.20	84.50	79.10	17.50	0.23	5.91	20.10	16.85	20.33	22.76	98.89	74.03
-0.425+0.3	1.73	13.82	15.55	0.36	88.86	23.20	76.60	87.60	9.20	0.53	6.58	15.85	6.30	16.37	12.88	96.79	48.93
-0.3+0.212	2.05	10.96	13.01	0.26	84.21	39.70	56.30	92.90	4.39	1.07	5.73	13.32	2.38	14.39	8.12	92.58	29.38
-0.212+0.15	2.60	5.30	7.90	0.18	67.14	61.90	37.50	93.70	1.85	2.10	4.83	6.50	0.49	8.61	5.31	75.56	9.16
-0.15+0.106	2.89	0.73	3.62	0.13	20.09	72.90	27.10	96.30	1.49	2.76	3.88	0.92	0.05	3.67	3.94	24.93	1.36
-0.106+0.075	2.52	0.05	2.57	0.09	1.80	75.00	25.00	93.70	6.17	2.48	3.13	0.06	0.01	2.53	3.14	2.24	0.45
-0.075+0.053	2.15	0.02	2.17	0.06	1.10	75.60	23.80	82.60	10.90	2.13	2.54	0.03	0.01	2.15	2.55	1.20	0.51
-0.053+0.038	1.73	0.03	1.76	0.05	1.48	75.60	22.90	76.40	20.00	1.71	1.97	0.03	0.03	1.74	1.99	1.50	1.30
-0.038	10.04	0.14	10.18	0.00	1.39	73.70	24.00	80.70	15.40	9.68	11.94	0.15	0.11	9.83	12.05	1.52	0.90
Total (calc)	27.61	72.39	100.00			62.99	35.43	81.51	14.35	22.76	48.50	77.24	51.50	100	100		