PRACTICAL WORKBOOK
MY-208 MINERAL PROCESSING

Name: ________________________________

Roll No: ________________________________

Batch: ________________________________

Year: ________________________________

DEPARTMENT OF METALLURGICAL ENGINEERING
NED UNIVERSITY OF ENGINEERING AND TECHNOLOGY,

PRACTICAL WORKBOOK

MY-208 MINERAL PROCESSING

PREPARED BY:

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(Course Teacher)

This is to certify that this practical book contains eight practical and 66 pages. All practical are prepared as per contents of course.

Approved By:

Chairman

DEPARTMENT OF METALLURGICAL ENGINEERING
NED UNIVERSITY OF ENGINEERING AND TECHNOLOGY

<u>CERTIFICATE</u>

It is certified that Mr. / Miss ____

Student of class **<u> SE </u>** Batch __________________ Bearing Roll No. MY-__________ has completed his/her course work in the subject of **<u>Mineral Processing (MY-208)</u>** as prescribed and approved by Board of Review of Metallurgical Engineering Department.

His/Her performance is reflected by index/contents of his/her practical workbook. This overall performance of the student is Excellent/Very Good/Good (satisfactory)/Not Satisfactory

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Course Teacher

MY-208 MINERAL PROCESSING

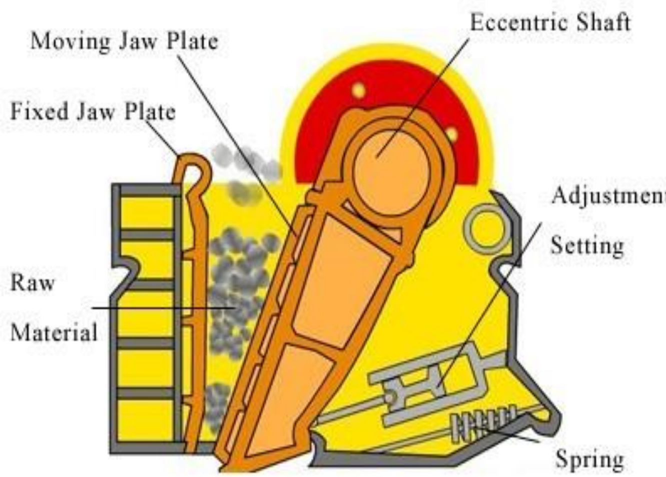
List of Practicals

Practical No: 01

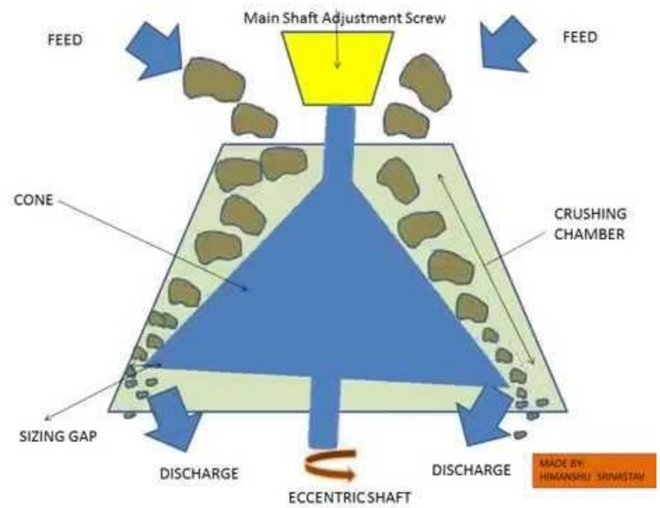
OBJECT:
Introduction to comminution devices (i.e. Crushers, grinders etc.)

TYPES OF CRUSHERS:
The two best known types of coarse crusher are the jaw crusher and gyratory crusher.

Jaw crusher:
A Jaw Crusher is one of the main types of primary crushers in a mine or ore processing plant. The size of a jaw crusher is designated by the rectangular or square opening at the top of the jaws (feed opening).
A Jaw Crusher reduces large size rocks or ore by placing the rock into compression. A fixed jaw, mounted in a "V" alignment is the stationary breaking surface, while the movable jaw exerts force on the rock by forcing it against the stationary plate. The space at the bottom of the "V" aligned jaw plates is the crusher product size gap, or the size of the crushed product from the jaw crusher. The rock remains in the jaws until it is small enough to pass through the gap at the bottom of the jaws.



Cone crusher (Gyratory crusher):
A gyratory crusher (or cone crusher) is similar in basic concept to a jaw crusher, consisting of inner and outer vertical crushing cones; the outer cone is oriented with its wide end upward, and the inner cone is inverted relative to the outer with its apex upward. The inner cone has a slight circular movement, but does not rotate; the movement is generated by an eccentric arrangement. material travels downward between the two cones being progressively crushed until it is small enough to fall out through the gap between the two cones at the bottom.



TYPES OFGRINDERS:
Hammer Mill:
A hammer mill is a machine whose purpose is to shred material into fine particles. They have many sorts of applications in many i A hammer mill is a machine whose purpose is to shred material into fine particles.

Ball Mill:

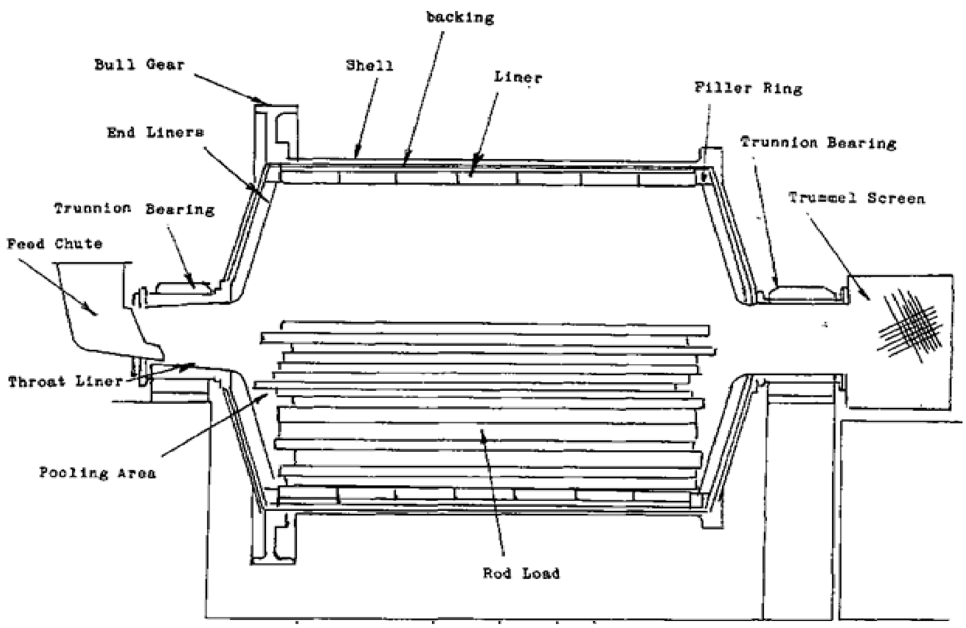
A ball mill is device that can be used to grind chemicals much more easily and to a finer consistency than can possibly be done by hand with a mortar and pestle. It is often useful to grind chemicals in order to increase their surface area. This will generally increase the rate at which they react in a pyrotechnic composition and make mixtures more homogenous which results in a steady burn rate. For making good quality black powder at home a ball mill is essential, and black powder is needed in very many pyrotechnic devices. In other words we can say that a ball mill is a type of grinder used to grind materials into extremely fine powder for use in paints, pyrotechnics, and ceramics

Rod mill:

The preparation of ball or pebble mill feed is an important application for Metso Minerals rod mills

The preparation of ball or pebble mill feed is an important application for Metso Minerals rod mills. These mills produce a uniform-sized product while minimizing the production of tramp oversize and unwanted fines.

The rod mills accept a feed size up to 2" and produce a typical product size of 5 to 10 mesh when operating in open circuit and as fine as 35 mesh in closed circuit with a screen or other sizing device.

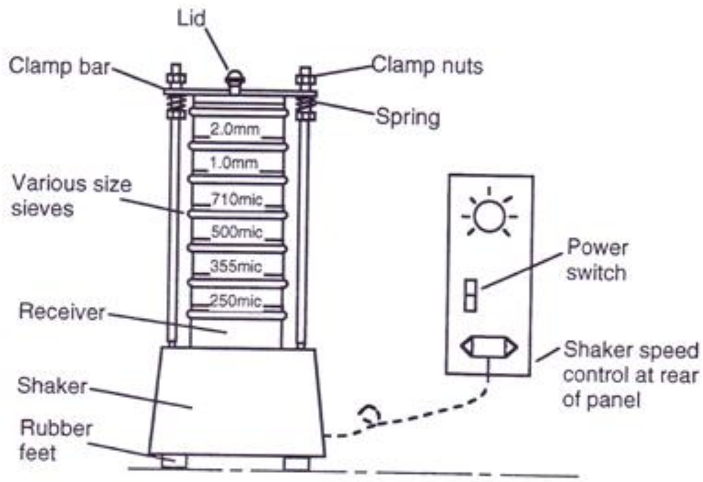


Practical No: 02

OBJECTIVE:

To determine and analyze the size distribution of a granular solid by using sieve analysis.

EQUIPMENT SET-UP:



SUMMARY OF THEORY:

Each test sieve consists of a woven wire screen with square apertures of known size and is used for the measurement of particle size. The necessary vibrating motion is imparted by a mechanical shaker to ensure reproducible results in a relatively short time.

Particle size may be specified by quoting the size of two screens, one through which the particles have passed and the other on which they are retained. However, sieving is usually used to measure size spread or particle size distribution. The results of sieve tests may be presented in a variety of ways either in tabular or graphical form. The graphical form is generally most useful and many different methods are available but semi-logarithmic presentation is found to be particularly informative.

ACTIVITIES:

We will complete these activities during lab:

- Listen to a brief lecture about grain size and sieves.
- Look at your unknown sample using a binocular microscope. Describe the roundness and the sorting of the sample using this visual method.
- Sieve your sample with the test sieves, and enter the weights for each fraction in the worksheet attached to this lab handout
- Assemble the nest of sieves on the vibratory shaker table with the coarsest mesh at the top and the finest mesh at the bottom, and a receiver pan below the bottom

sieve. Transfer an accurately weighed sample of mixed size granular solids to the top sieve and after covering with a lid, clamp the whole assembly to the shaker.

• Switch on the power using the shaker switch on the front panel and the power switch on the shaker speed controller mounted behind the panel. Select a mid-range speed and shake the sieve stack for two minutes.

• Carefully remove each sieve and the receiver pan in turn and tip out the contents into the digital balance pan in order to weigh the amount of material trapped by each sieve. (Accurate weighing is essential and the sum of the component weights must equal the weight of the initial sample).

• The amount of material retained by each sieve should be calculated as a percentage of the total sample weight and the results tabulated along with the cumulative oversize and undersize percentages.

OBSERVATIONS:

Sample material:________________________________ g

Initial sample weight:____________________________ g

Sieve (μm)	Weight Retained in sieve "W" (g) [W= "W" sample – "W" of Pan]	%Retained" "%R" [%R= W/T.W*100]	% Cumulative	
			Oversize "%O" [%O=cumulative of %R]	%undersize "%U" [%U=100-%O]
	Σ Weight (T.W)=			

RESULTS:

See Questionnaire on Page no 66

Practical No: 03

OBJECTIVE:

To reduce the particle size of a given material by ball milling operation.

SUMMARY OF THEORY:

The particle size of a particulate material may be reduced by tumbling the sample with grinding balls. The local high pressures at the points of contact of the balls break down the particles into smaller sizes.

ACTIVITIES:

- The particle size distribution of the chosen granular solid is determined using the sieve shaker.
- The ball mill is charged with the granular solid already measured and the grinding balls added.
- Switch on the ball mill drive at the lowest speed and increase to the highest speed. Reduce the speed until the balls tumble freely and run for 10 minutes.
- Remove the sample from the ball mill and analyze again with the sieve shaker.

OBSERVATIONS:

Amount of solid: __________kg.

Quantity of Ball:___________ % (w.r.t feed)

Milling Time: _____________sec

Before Milling operation				After Milling operation			
Sieve Size	Weight Retained in sieve “W” (g)	%Retained” ”%R”	Oversize “%O”	Sieve Size	Weight Retained in sieve “W” (g)	%Retained” ”%R”	Oversize “%O”

RESULTS:

See Questionnaire on Page no 66

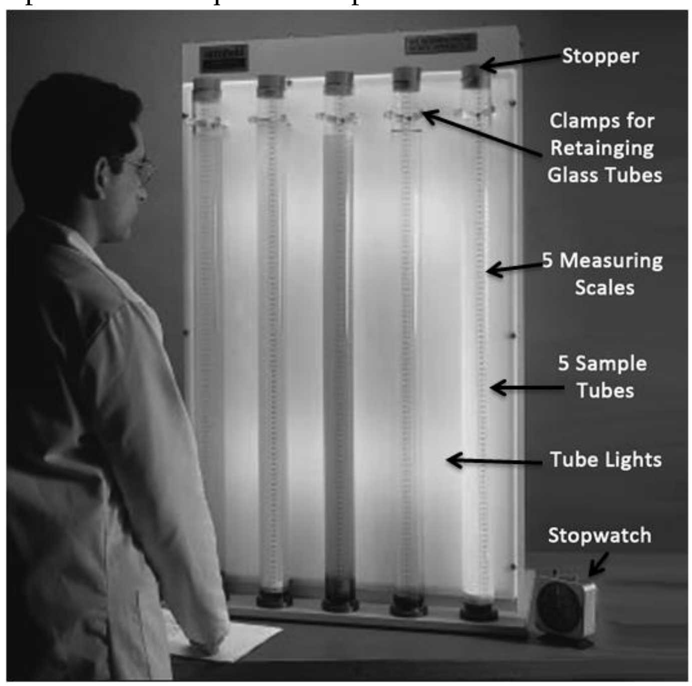
Practical No: 04

OBJECTIVE:

To Demonstrate the Sedimentation process for particle size analysis

SUMMARY OF THEORY:

Sedimentation is the tendency for particles in suspension to settle out of the fluid in which they are entrained, and come to rest against a barrier.
Settling is the process by which particles settle to the bottom of a liquid and form sediment. Sedimentation is one of the methods used in industry to separate liquid-liquid or solid-liquid mixtures. By definition, sedimentation is the separation of a dilute slurry or suspension by gravity settling into a clear fluid and slurry of higher solids content. The resulting liquid is essentially particle free. In industry, either the particle free liquid or the particles itself is the desired product.



Sedimentation is applied to accomplish the following process:

Separation

For the separation of liquid, solid mixtures, when the solid is in form of colloid or suspended. For example separation of solid particles from inorganic compound likes oil, ester, carbon tetra chloride etc.

Purification

On industrial scale, most important application of sedimentation is the purification of water. Removal of physical impurities like stones, straws, leafs etc. Separation of impurities is done on the basis of density of the particle.

ACTIVITIES:

1. Select a suitable, well mixed powder such as chalk. Weigh out five separate quantities to make up five equal volume of chalk in water called slurry of some concentration by weight,
2. Slurry should make up in a separate beaker and volume in each should be identical.
3. Stir slurry well in the preparation vessels and then fill each sedimentation tube in turn, starting with the most concentrated.
4. Tube should be well shaken to give consistent suspension.
5. The tubes should be replaced in the clips on the supporting frame, at the same interval of time between mixing and testing. Reading of the interface should be noted.
6. In addition to noting the fall of the interface in each sedimentation tube at convenient time intervals, the rise of the sludge interface at the bottom of the tube should be recorded.

OBSERVATIONS:

concentration of material by weight for Tube-1__________wt%

concentration of material by weight for Tube-2__________wt%

concentration of material by weight for Tube-3__________wt%

concentration of material by weight for Tube-4__________wt%

concentration of material by weight for Tube-5__________wt%

S#	Settling Time,T	Height of interface, H (cm)				
		Tube 1	Tube 2	Tube 3	Tube 4	Tube 5
1.						
2.						
3.						
4.						
5.						
6.						
7.						
8.						
9.						
10.						

RESULTS:

See Questionnaire on Page no 66

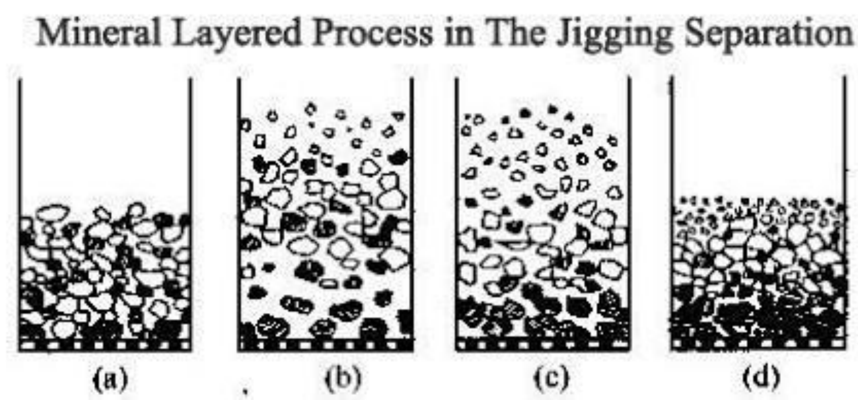
Practical No: 05

OBJECTIVE:

To demonstrate the operation of jigging process for size separation.

SUMMARY OF THEORY:

A Jig is described as ‘gravitational particle separator’ or ‘hindered settling device used to concentrate heavy and light material from feed’. Hindered settling ratio is defined as, ‘The ratio of the apparent specific gravities of the mineral against the suspension (not against the liquid) raised to a power between one-half and unity’.
In this process, the lighter and denser particles are separated by pulsating water in a container. These pulses are generated through pneumatic piston (Other methods for plunging action can also be used). The pulsating force of water counteract the gravity of lighter minerals, this cause them to remain at the top, while heavy minerals migrate downwards. Then these heavy particles are drawn from the perforated base controlled through valve system and light particles are drawn from the top as tailing.
The pulsating process is controlled by varying the rpm of motor, which is connected to piston.



(a) Particles mixed pile before laying;
(b) Rising water lift the bed layer;
(c) Particle sedimentation stratification in the water;
(d) Water drops, bed layer is dense, heavy mineral into the bottom.

Particle size is important in jigging if the feed is closely sized; it is easy to get good separation with narrow specific gravity range. It is suitable for the sizes between 25 mm and 75 microns for minerals and suitable for 20 cm and 0.5 cm for coal.
Jig is an open tank filled with water that has screen at the top and spigot or hutch compartment at the bottom. Jig bed may have heavy coarse material (ragging material).
Jigs have screen, stroke length hutch compartment under the screen and ragging, a layer of heavy material.
After repeated pulses, particles become stratified. Heavy materials settles at the bottom and light particles settle at the top. The other action is the effect of the water. Upward flow of water separates particles by their specific gravity.

Some conditions present in jigging action are;

1. Terminal Velocity: Initially particles have acceleration and increasing velocity. When equilibrium is achieved, particles reach their terminal velocity and they settle down at constant rate.
2. Free Settling: The sinking of particles in fluid.
3. Hindered Settling: The hindered settling conditions prevail when the proportion of solids in the pulp increases. The effect of particle crowding becomes more apparent and falling rate of particles begins to decrease. The system begins to behave as a heavy liquid whose density is that of the pulp rather than that of the carrier liquid.
4. Differential Initial Acceleration: The initial acceleration is dependent only on the densities of the solid and the fluid. It is necessary to use short jigging cycle to separate small heavy particles to light particles.
5. Consolidation Trickling: In consolidation stage, where the large particles in the bed come close to each other leaving relatively large interstices filled with draining water running down as a result of the suction part of the strike.

Separation may be achieved over the screen or through the screen in jigging.

The operation parameters of jigs are;

Dilution: It is the amount of water. High dilution is necessary to remove large quantity of materials.

Screen Aperture: It must be as large as possible, consistent with feed size to minimize resistance to flow.

Stroke and Frequency: Stroke is moving distance of the piston and it depends on particle size. Frequency is the number of stroke per time.

Feed Rate and Particle Size Range: Jigs have high unit capacity and can achieve good recovery in particle size under 150 um.

ACTIVITIES:

1. Prepare a mixture of heavy and light minerals
    a. Crushed heavy & light mineral with the size Range -A of -5mm +0.5mm.
    b. Crushed heavy & light mineral with the size Range -B of -10mm +3mm.
2. use steel balls as ragging material
3. Place both the collecting tubes near the outlet of tailing and heavy material.
4. Pour the weighted sample into the container.
5. Fill the container with water and place the screen into the container.
6. use steel balls as ragging material
7. Run the cycle until all the feed settles down observe the stratification, then switch off the motor.
8. Slowly move the knob of circuit and adjust the rpm as per requirement.
9. Collect heavy particles from the bottom through valves, and light particles from the top
10. Operating parameters of jig: They are design parameters such as stroke and frequency and operating parameters such as pulsation Rate and particle size range. Furthermore, if we supply a narrow size range of the minerals to be separated, we can increase the effect of specific gravity and have a good separation.

OBSERVATIONS:

1. Jigging time: _________sec.
2. Weight of Feed: __________gm.
3. Size range-A: ____________
4. Size range-B: ____________

- Effect of Feed size in stratification process.

S#	Feed Size (microns)	Amount of Heavy Mineral & 80% passing size		Amount of Light Mineral & 80% passing size	
		mass	D_{80}	mass	D_{80}
1.	Size Range-A				
2.	Size Range-B				

- Effect of Pulsation Rate in stratification process.

S#	Pulsation Rate (frequency) Motor RPM	Amount of Heavy Mineral & 80% passing size		Amount of Light Mineral & 80% passing size	
		Mass	D_{80}	mass	D_{80}
1.					
2.					
3.					

RESULTS:

See Questionnaire on Page no 66

Practical No: 06

OBJECTIVE:

To demonstrate the operation of Shaking Table for Concentration Operation.

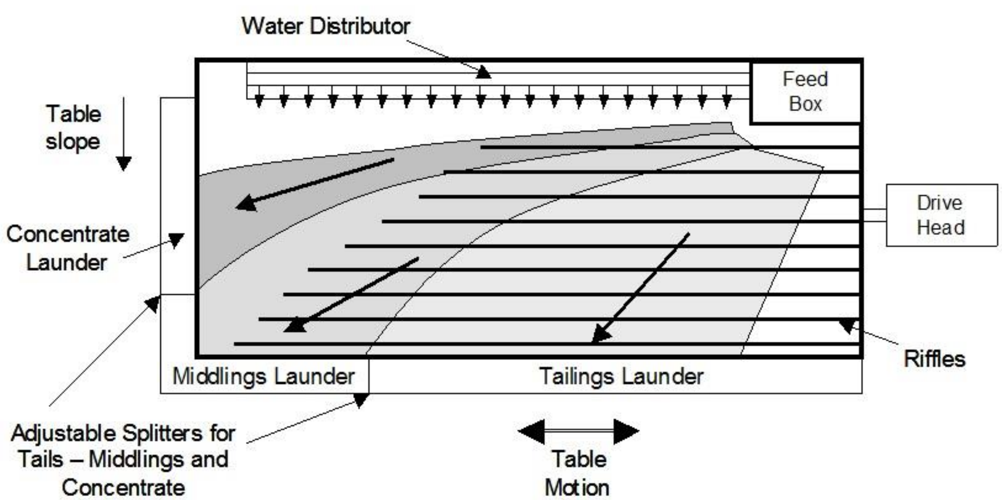
SUMMARY OF THEORY:

Shaking table, also known as wet table, consist of a sloping desk with a riffled surface. A motor drives the small arm that shakes the table along its length parallel to the riffle and riffle pattern. This longitudinal shaking pattern consists of a slow forward stroke by a rapid return strike. The riffles are arranged in such a manner that heavy material is trapped and conveyed parallel to the direction of motion. The heaviest particles and coarsest particles move to one end of the table while the lightest end finest particles tend to wash over the riffle and to the bottom edge. Intermediate points between there extreme provides recovery of the middling (intermediate size and density) particles.

This is a gravity separation method and is often used downstream of their gravity concentration equipments such as spirals, reicherts, jigs & centrifugal gravity concentrators for final extensive used in concentrating gold.

Working of Shaking Table:

- The table moves forward and backward, this motion is called stroke.
- The table is made with shallow longitudinal ridges running from one side to other called, riffles
- The movement of the stroke is in the direction of the riffles.
- As the table moves backwards the desire particles settle back down and the motion gradually causes the particles to move along the riffles in the direction of the table's forward stroke. The light material stays in the upper layer and flows down.
- The stroke length is the distance the table moves forwards and backwards.
- The feed rate should be kept constant and the solid feed density should be around 25%.



ACTIVITIES:

1. The machine is provided with a controlled switch button on the cast iron bar for processing at while the main switch would be connected.
2. The to and fro motion of the table pushes the suspended particles through the riffles at the other and of the table.
3. Use water and sample material (i.e. mixture of different ground ores) of various sizes.
4. Use water for the smooth flow since it helps the under size particles to flow through the path of the riffles to the discharge compartment size while the havier big ones stuck in the riffles.
5. After the process observe that all particles are separated out in three ways.
6. The havier large particle that couldn't be moved by the flow of water were pushed in the same direction as the to and fro movement in to the first compartment.
7. Next the havier but smaller particles separated out and stashed in the next compartment while the lightest particles flow at the edge of the table in to the compartment while the water is stored in to the containers.

OBSERVATION:

- The given design of the table will produce three concentrate fractions in each slot of the table.
- You will collect Fraction 1 from the top corner of table.
- You will collect Fraction 2 from upper part of the table.
- You will collect Fraction 3 from the lower middle part of the table.

Show your calculations here

RESULTS:

	Fraction-1	**Fraction-2**	**Fraction-3**	**Weight of sample (gm)**	**Losses %**
Nature of Fraction					
Mass Fraction (gm)					
%Recovery					

Practical No: 07

OBJECT:

Study of laboratory based froth floatation cell.

SUMMARY OF THEORY:

Froth flotation is a highly versatile method for physically separating particles based on differences in the ability of air bubbles to selectively adhere to specific mineral surfaces in mineral-water slurry. The particles with attached air bubbles are then carried to the surface and removed, while the particles that remain completely wetted stay in the liquid phase. Froth flotation can be adapted to a broad range of mineral separations, as it is possible to use chemical treatments to selectively alter mineral surfaces so that they have the necessary properties for the separation. It is currently in use for many diverse applications, with a few examples being: separating sulfide minerals from silica gangue (and from other sulfide minerals); separating potassium chloride (sylvite) from sodium chloride (halite); separating coal from ash-forming minerals; removing silicate minerals from iron ores; separating phosphate minerals from silicates; and even non-mineral applications such as de-inking recycled newsprint. It is particularly useful for processing fine-grained ores that are not amenable to conventional gravity concentration.

ACTIVITIES:

1. A sample of ore to be separated can be made by mixing very fine iron filings with sand. A ratio of 1 part iron filings: 3 parts sand should be satisfactory.
2. Students add _____ grams of the ore sample to floatation tank and then add _____ltr. Water.
3. Students should observe no bubbles or separation of the sand and iron filings. As the mixture sinks in, the iron filings may settle to the bottom.
4. Add _____ ltr. of kerosene and ______ amount of a good quality detergent should now be added, and agitate the tank for _____ seconds.

OBSERVATION:

- Observation should now show white bubbles rising up, carrying the iron filings with them. While the sand remains at the bottom.
- Now observe the effect of floatation time at given floatation reagents.
- Different detergents and shampoos may also be tested to select the most effective frother.
- In place of the kerosene students could investigate the effectiveness of other molecules such as olive oil, canola oil, cooking sprays or hair conditioners as collectors.

Floatation Time (sec)							
Collector used							
Frother used							
Recovery of concentrate (%)							

RESULTS:

See Questionnaire on Page no 66

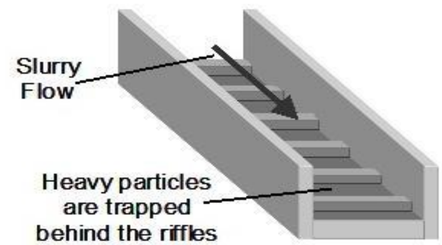
Practical No: 08

OBJECT:

To demonstrate the operation and fabrication of sluice box for Alluvial Mining.

Sluices:

Sluices or sluice boxes are commonly found at alluvial operations for the recovery of liberated placer gold. Sluice boxes with riffles are one of the oldest forms of gravity separation devices used today. The size of sluices range from small, portable aluminum models used for prospecting to large units hundreds of feet long. Sluice boxes can be made out of wood, aluminum, plastic or steel. The riffles in a sluice slow and retard heavy material flowing in the slurry, which forms a material bed that traps heavy particles and creates turbulence. This turbulence causes heavy particles to tumble, and repeatedly exposes them to the trapping medium. An overhanging lip, known as a Hungarian riffle, increases the turbulence behind the riffle, is commonly used in these units. Other configurations of sluices may use astro-turf, screens or rubber material with ridges.



Pinched type sluices: Pinched sluices have also been used for heavy-mineral separations for centuries. In its most basic form, the pinched sluice is an inclined trough 60 to 90 cm long, narrowing from about 24 cm in width at the feed end to 3 cm at the discharge end. Feed consisting of 50-65% solids enters the sluice and stratifies as the particles flow through the sluice and crowds into the narrow discharge area. The crowding causes the bed to dilate allowing heavy minerals to migrate and move along the bottom, while lighter particles are forced to the top. The resulting mineral bands are separated by a splitter at the discharge end. Pinched sluices are simple devices and are inexpensive to build and run. Pinched sluices are mainly used for separation of heavy mineral sands. A large number of pinched sluices are required for a high capacity operation, and a large amount of recirculation pumping is required for proper feed delivery. These drawbacks led to the development and adoption of the Reichert cone in many plants.

Reichert Cone sluice: The Reichert Cone concentrator is based on the pinched sluice concept but employs an inverted cone instead of a rectangular channel .The crowding and dilating effect of the bed is produced by a reduction in perimeter as the material approaches the center discharge point. Reicherts are more efficient than pinched sluices because there are no sidewalls to interfere in the separation process.

Reicherts cones are usually stacked to achieve high throughput for a given footprint.

Practical No: 09

OBJECT:
To provide the basic understanding of the Modeling & simulation technique in Mineral Processing Plant.

UNDERLYING THEORY:

What is simulation?
Simulation is any procedure that can be used to model a process without actually running it. There are several ways in which a simulation can be achieved but, by far the most effective, is by digital computer. The digital computer is programmed to mimic the behavior of the actual plant and can provide a description of what the plant will do and how it will perform under a variety of circumstances.
Simulation of a complex engineering system is only possible once a detailed understanding of each component of the system has been achieved and simulation provides the engineer with a tool for the prediction of system behavior even if the system does not exist in reality. However the simulator predictions can only be as good as the basic understanding of the component parts.
A computer simulation is an abstract representation of reality constructed in computer code. To be useful it must represent the appropriate aspects of the real situation in such a way that useful information can be gained. Models for the unit operations are synthesized from mathematical models of the component parts.

What is an ore dressing plant simulator?
An ore dressing plant simulator is a set of computer programs that will give a detailed numerical description of the operation of an ore dressing plant. The simulator must be provided with an accurate description of the ore that is to be processed, a description of the flowsheet that defines the process and an accurate description of the operating behavior of each unit operation that is included in the flowsheet. The simulator uses these ingredients to provide a description of the operating plant.
The detailed description of the ore will include information on its physical and mineralogical characteristics. The flowsheet is the familiar graphical representation of the location of the unit operations in the plant together with the network of pipes and conveyors that transmit material between the units. The description of the operating behavior of the unit operations is what is known as modeling and it is necessary to accurately model the behavior of each unit operation before the entire plant can be simulated. In a sense the simulator links together the modeled behavior of each of the unit operations and synthesizes the overall performance.

Four fundamental concepts underlie the construction of an ore dressing plant simulator.

1. Ore dressing plants are collections of unit operations connected by process flow streams that transmit material from one unit to the next. The flow of materials is directed by the flowsheet structure.
2. Each unit operation processes its own feed materials and will separate it or transform it in accordance with the specific objective of the unit.
3. The behavior of the plant as a whole depends on the operating characteristics of each of the unit operations as well as on the nature of the material that is processed in the plant.
4. A simulator reduces the actual plant operations, as defined by the flowsheet structure and the behavior of the units, to a sequence of logical mathematical functions. The simulator can then mimic the real plant performance.

Computerization of any complex engineering systems is a highly specialized business and this is true also in mineral processing and such activities should be attempted only by specialists. Several general-purpose simulators for ore dressing plants are now available and of these MODSIM offer the greatest versatility to the user to modify and adapt the models of the unit operations that are used by the simulator.

The standard models that are provided in the package are based on the latest concepts from the modern mineral processing literature. MODSIM is particularly strong in the modeling of mineral liberation phenomena.

In order for a general-purpose simulator to yield useful information on the actual process to be simulated, it must have access to 3 important classes of information. These are defined in general terms as follows:

- **The structure of the flowsheet:** what unit operations are included and how they are connected.
- **The nature of the material to be processed:** its mineralogical composition and structure, the size distribution and the amount that must be processed.
- **The operating characteristics of each unit in the flowsheet**: This requires the full description of the unit operations (the unit models) and a specification of the unit parameters that define the operating characteristics of the individual units.

What can a simulator be used for?

A good simulator is a useful tool to the process plant engineer. Essentially the simulator can demonstrate what a plant will do under any particular operating conditions. It can do so cheaply and without any real risk to the production rate of an operating plant or it can do so before a plant has been built and it does so in the engineer's office.

A. Design studies:

At the design stage a good simulator can be used to

1. Help the design engineer to find the best flowsheet
2. Ensure that design specifications will be met under all required operating conditions
3. Choose the most suitable units
4. Size the units correctly and so eliminate wasteful over-design and avoid the catastrophe of under design
5. Optimize the plant operation by achieving best economic combinations of grade and recovery
6. Identify potential production bottle necks
7. Provide comparative assessment of competing manufacturers' equipment
8. Define the performance guarantees that should be met by suppliers
9. Find out what will happen if performance guarantees are not met.

B. Operating plant performance:

A good simulator can help the plant manager to

1. Get the optimum performance from his/her plant
2. Tune his plant to suit variations in feed quality
3. Find plant bottlenecks
4. Identify unit operations that are not properly understood

C. Pilot plant and laboratory investigations

1. Test theoretical models for unit operations.
2. Plan experimental programs to get maximum information from well-designed experiments.

But remember that a simulator can be effective only if it gives a reliable and valid description of plant operations.

The ore model

Ore dressing is the process engineering technology that must necessarily come between the mining of mineralogical raw materials and the subsequent extraction processes that recover the useful metals. Ore dressing is directed primarily at the separation of individual minerals or groups of minerals from among the whole range of minerals that make up an ore body.

The physical separation of one mineral species from another can be achieved by the reduction of the solid material to the particulate state followed by the separation of particles by one or other physical means. The reduction to the particulate state is essential and the technology of any concentration processes is intimately linked to the nature of the particulate material that is produced by comminution of the parent ore. Indeed the transformation of the size of the material by comminution processes is the dominating transformation process that will be of concern to us. ***MODSIM*** is designed to exploit the modeling techniques that are based on the particle mechanics of the ore dressing unit operations. The models used in ***MODSIM*** are based on the particulate nature of the solid material that is processes and, as a result, models of considerable complexity can be devised and used for the description of the unit operations. This ability to accommodation models of considerable complexity gives ***MODSIM*** their versatility and power and a thorough understanding of the particulate description of the solid material is required to take advantage of the very many advances that have been made in ore dressing modeling techniques during the past three decades.

The particulate state

The particulate state is usually defined as describing solid material that is reduced in size to particles that range from a few hundredths of a micron to a few centimeters. For solid material of mineralogical origin this size range implies that 1 kg of material will consist of a very large number of particles. Commercial ore dressing plants process many thousands of tons of raw material per day so that the number of particles involved is exceedingly large.

Fortunately a powerful mathematical structure, which borrows heavily from the mathematical theory of probability is readily available and is forming the basis for all of the modern developments in the modelling of ore dressing operations.

The particle size distribution

The most obvious characteristic of a particle that is significant from the point of view of its behavior in an ore dressing operation is its size. The most common measure of particle size is the smallest square wire mesh that will permit the passage of the particle under gravity with prolonged shaking. Such a size is readily measured in the laboratory to sufficient precision for practical purposes by the familiar sieve analysis procedure.

The essential feature of the mathematical description is the particle size distribution function (d_p) defined as follows:

$F(d_p)$ = mass fraction of particles in the population that will pass through a square mesh sieve having an opening with side = d_p

$P(d_p)$ is an ordinary function of d_p but it does have some important properties that should always be borne in mind. These properties are:

$$P(0) = 0$$

$$P(\infty) = 1$$

$$P(x) \geq P(y) \text{ whenever } x \geq y$$

The value of *P* is measured experimentally at a number of fixed sizes that correspond to the mesh sizes of the set of sieving screens that are available in the laboratory. This data is usually presented in tabular form showing mesh size against fraction smaller than that mesh. Graphical presentations are very useful and are often preferred because it is generally easier to assess and compare particle size distributions when the entire function is immediately visible. Varieties of different graphical coordinate systems have become popular with the view to making the distribution function plot as or close to a straight line. The particle size axis, usually the abscissa is plotted on a logarithmic coordinate scale. The ordinate scale works according to whether the distribution function $P(d_p)$ is close to log-log, log-normal or Rosin-Rammler. The mesh sizes in the standard sieve sizes vary in geometric progression with each mesh size a constant factor larger than the previous one. The constant factor is usually a fractional power of 2 (very often root 2). Such a geometric series will plot as a series of equidistant points on a logarithmic scale.
Although the distribution function $P(d_p)$ is perfectly well defined and is amenable to direct measurement in the laboratory, it is not directly useful in most cases for modelling of ore dressing unit operations. For this purpose a derived density function is used. The discrete particle size density function $P_i(d_p)$ is defined as follows:

$$f(d_p)\,\Delta d_p = F(d_p + \Delta d_p) - F(d_p)$$

= *Mass fraction of the particle population that has size between* d_p *and* $(d_p + \Delta d_p)$.

Δd_p is the so-called size class width and is usually not constant but successive values form a geometric series. This leads to the idea of a particle class which includes all particles in the population which have properties falling in a narrow size interval or class. If the interval is sufficiently small it is possible to assign a single value to the property that defines the class so that each particle in the class may be assumed to behave as a particle having the class average property.
In the case of particle size this representative size is generally taken as the geometric mean except for the two extreme classes which have no geometric mean. It is usual to extend the average sizes as geometric series to the two extreme classes and this is generally satisfactory in practice. MODSIM operates with the individual particle classes and consequently the particle size distributions must be specified in the differential form.
A typical specification of the size distribution for the feed to a ball mill circuits is shown in Table. This is based on a standard 2 series and covers the range from 2,78mm to approximately 30 microns in 15 classes. MODSIM will normally use more size classes for its internal calculations than are used to specify the size distribution of the plant feed streams.

Size class	Size interval microns	Representative size microns	Particle size distribution density %
1	+2360	2780	2.4
2	-2360 +1700	2000	3.1
3	-1700 +1180	1416	4.0
4	-1180 +850	1000	5.0
5	-850 +600	714	6.6
6	-600 +425	505	9.1
7	-425 +300	357	13.1
8	-300 +212	252	16.4
9	-212 +150	178	12.7
10	-150 +106	126	7.6
11	-106 +75	89	4.9
12	-75 +53	63	3.7
13	-53 +38	45	2.8
14	-38 +27	32	1.8
15	-27	22	6.8

Mineral liberation and the grade distribution

The mineralogical composition of the particles that are processed in ore dressing operations varies from particle to particle and this is of paramount importance in the operation of ore dressing equipment. Considerable research has been devoted to the liberation phenomenon in recent years and several good models are available to describe the liberation characteristics of an ore. In order to properly allow for incomplete liberation of the mineral species an additional distribution function is defined but before this is done it is necessary to devise a method for representing the mineralogical composition of a particle.

When only two mineral species are involved, say a valuable mineral and a gangue, this is not difficult. It is necessary only to specify the mass or volume fraction of the particle that is composed of mineral. We normally use the symbol g to represent this fraction (the grade of the particle). When more than two mineral species are relevant the situation is somewhat more complicated and g will be a vector having more than one component, each component representing the mass fraction of a single mineral species. The fractions must accordingly sum to unity. To handle this complexity the concept of the distinct particle type is defined. Just as in the case of the particle size, finite classes are defined each of which is characterized by particles of an average mineralogical composition. The number of classes that should be used will depend on the mineralogical complexity and the liberation characteristics of the ore that is to be processed in the simulated process. One class is usually allocated to each of the pure minerals that are present because it is assumed that some of each mineral is perfectly liberated. MODSIM will automatically allocate such perfectly liberated classes but will only allocate particle classes to accommodate incompletely liberated minerals if specifically requested by the user. If such a request is made, the user must define the particle composition that is required to define each particle type.

The liberation spectrum is of course a strong function of the size of the particle. In general the finer the particles the more likely to find particles that are completely liberated. It is necessary therefore to specify the distribution of material among the particle types for each size class. However, if the plant that is to be simulated includes comminution units, it is often sufficiently accurate to assume that all the feed material is concentrated in the particle type class that includes the average mineral composition. The liberation of the minerals will be generated by MODSIM's liberation model. MODSIM cannot accommodate variations in the mineral distribution for the grade classes for the various particle sizes. In general that would not be necessary even for the most detailed of unit models.

Physical properties of the particles

All ore dressing operations rely on one or another physical property to effect the desired concentrating action in the unit. Since the objective of ore dressing is the separation of the valuable minerals from the others, it is necessary that the physical properties vary from particle to particle. The variation of physical properties can very conveniently be accounted for by specifying the value of the physical property for each particle type. Each particle in the type class may then be considered to have the value of the physical property assigned to that type class.

The most important of the physical properties that is used in ore dressing is the particle specific gravity. This property forms the basis of all the gravity, dense medium and centrifugal separation processes and, after flotation, these processes account for the largest tonnage of material processed.

The specific gravity of a particle is determined by its mineralogical composition. Thus the specific gravity of a composite particle is a weighted sum of the specific gravities of the constituent minerals with the weighting coefficients being the volumetric fractions of the mineral components. MODSIM therefore will compute the specific gravities of each particle type once the distribution of minerals has been defined for each particle type and the specific gravities of the individual minerals have been specified. This is the natural method of specification and relieves the user of the burden of calculating a specific gravity for each particle type. However in some situations it is not possible to specify the specific gravity of the pure mineral species. MODSIM will request the user to specify whether specific gravities of individual minerals will be specified or whether the specific gravities of the particle types will be specified.

Plant feeds and water addition

MODSIM can accommodate multiple feeds to the plant that is being simulated. The characterization of the feed material for each feed must be done according to the methods described in the previous sections. Material in all of the feeds must have identical class structures but the distribution of particles over the classes can vary from feed stream to feed stream. For example if the plant takes a feed of coarse material and a feed of fine material, the particle size distribution will be very different for the two feeds. However both feeds must have their size distributions specified against the same size class intervals. Obviously the coarse feed will have none or very little material in the fine size classes and the fine feed will have nothing in the coarse size classes.

The tonnage and water content of each feed must be specified. Dry feed is permissible. Water feeds may be added although these should be added to mixers or sumps only, never directly to a unit. This is not an important restriction since it is always possible to precede any unit with a mixer if water is to be added to the unit. Two options are provided for the specification of water addition rates: the absolute addition rate may be specified or alternatively the user can specify the percentage solid that is required in the stream that leaves the mixer or sump to which the water is added. In the latter case, MODSIM will continuously adjust the water addition rate to match the calculated total solid rate in the sump discharge to maintain the requested percentage solids. This device is very useful for the simulation of control actions that are incorporated to maintain a specified solid content in the slurry at any point in the flowsheet.

Models for ore dressing operations

The modular design of MODSIM has been developed specifically to give the user complete freedom in the choice of models for the unit operations. The only restriction on the models is the basic structure that requires that a unit model should be capable of receiving the details of the unit feed from the simulator and producing the appropriate product streams. This, of course, is the natural function of a unit model since it mirrors the actual behavior of the unit which transforms a feed material into the appropriate product streams. The details of the feed material provided by the simulator to the model subroutine are in accordance with the particulate model of the solid phase that has been described above. The subroutine is supplied with the mass flowrate to the unit in every particle class that has been defined. The parameters for the appropriate unit model as well as the vector of physical properties are also available to the model subroutine. The water rate in the feed is also supplied. This information gives the user almost unlimited scope to include models as simple or as complex as is desired to model the unit operations.

"Now, as I have covered a lot of theory associated with the subject matter, so it is a good time to move on our Simulation Software MODSIM. I have divided this practical into 8 different modules; each module has given sufficient exercise-problems to become master in using this Software".

Module-1:

Introduction to MODSIM and its Basic Operation.

This module is designed to introduce you to the graphics editor and Data specification in MODSIM. The editor is used to draw and edit flowsheets and it is necessary to become fluent with the editor in order to use MODSIM effectively. MODSIM makes a clear distinction between data that is needed to describe the ore and the data that is necessary to define the behavior of the unit models. The objectives of this module are:

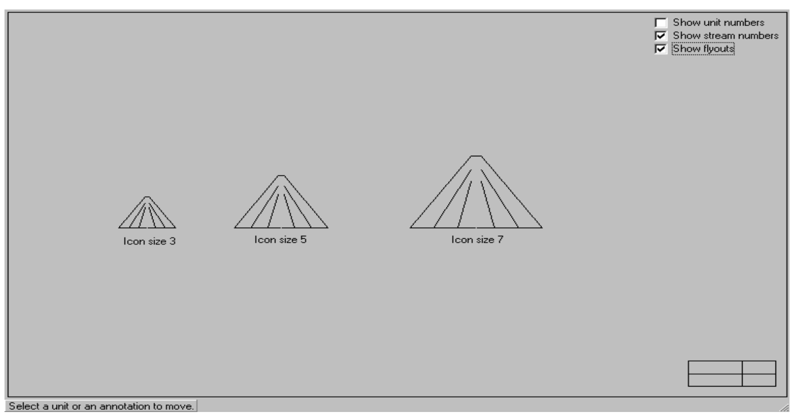
1. Learn to draw and edit a Flow sheet
2. Learn to specify the properties of the ore - ***The system data***.
3. Learn to specify parameters for the unit models - ***The unit models Data.***
4. Learn to find and analyze the data produced by the simulator.

These exercises will give you some practice with the drawing operations that are used in the graphics editor.

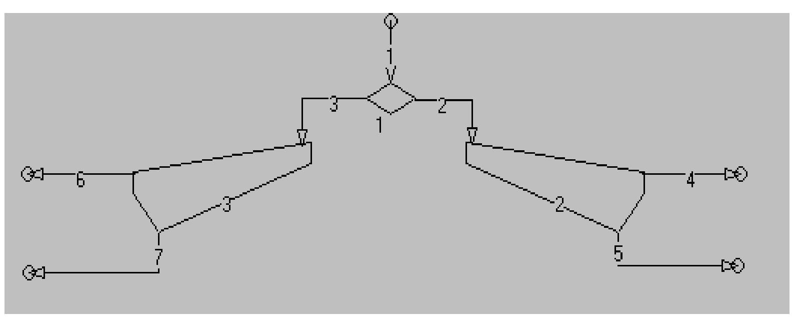
Exercise 1-1 Drawing the unit icons (consult fig-1 and fig-2 at the end of this Module-1).
Exercise 1-2 Changing icon size.
Exercise 1-3 Reflecting icons.
Exercise 1-4 Drawing conveyor belts.
Exercise 1-5 Editing functions in the graphics editor.
Exercise 1-6 Basic system data and the particle size distribution of the feed.
Exercise 1-7 Specification of unit model parameters.
Exercise 1-8 Data for multi-component ore.

EXERCISE 1-1: *Open a new job in MODSIM and draw one copy of each of the unit icons*. You will not be able to fit them all on to a single sheet. When you have filled a sheet, close the job without saving it and start a new job. Before closing the flowsheet, add an annotation to each icon and finally use Move on the Edit menu to rearrange icons and annotations to make a neat drawing.

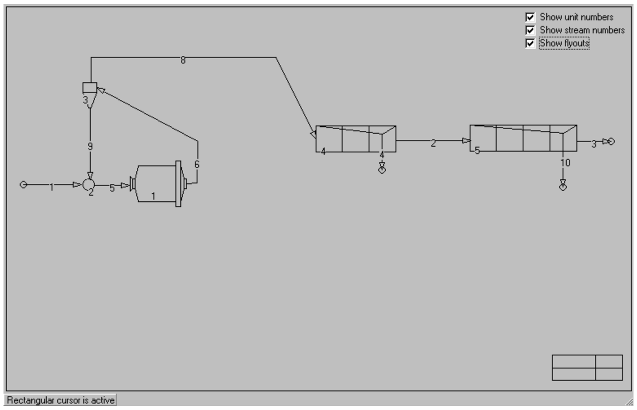
EXERCISE 1-2: Start a new flowsheet and draw *three stockpiles of different size*.

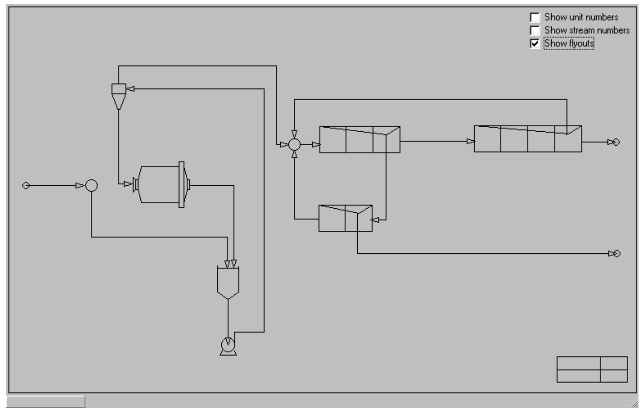


EXERCISE 1-3: Draw two vibrating screens on a new *flowsheet with one in the reflected orientation*.



EXERCISE 1-4: *Draw several conveyor belts of different lengths and in different orientations.*
EXERCISE 1-5: *Start MODSIM and retrieve the Exercise 1-5 job from the Packed Jobs folder*. Edit the flowsheet on left side and transform it as shown on right side.

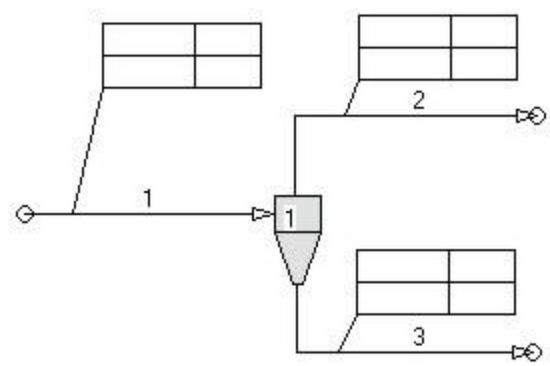




EXERCISE 1-6: *Basic system data and the particle size distribution of the feed.*
The specification of the data will be illustrated using a simple exercise based on simulating the performance of a single hydrocyclone.

The flowsheet

Start a new job in MODSIM and draw a flowsheet containing only a single hydrocyclone. Add a stream for the feed and one each for the overflow and the underflow. Add flyouts to each of the streams. The flowsheet should look something like this. You will probably need to move the flyouts to make the flowsheet look a bit neater.

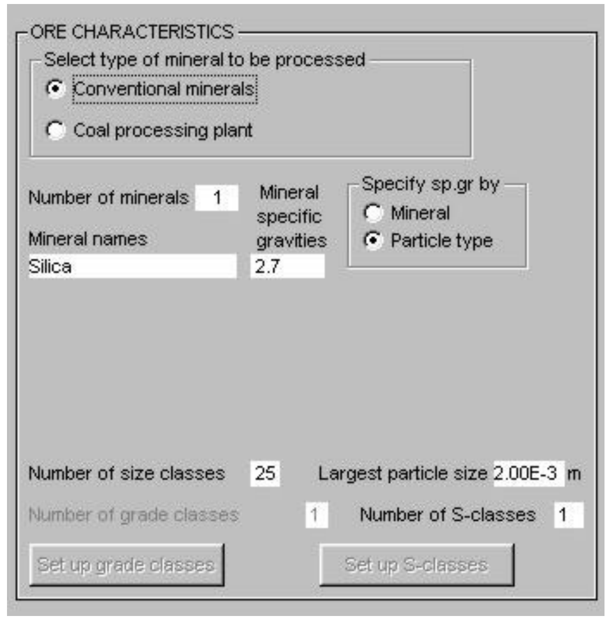


Accept the flowsheet, save the job and start to edit the system data.

The system data

The material to be processed will contain only 1 mineral - silica of specific gravity 2.7. The density of the solid material will influence behavior of the particles in most units and this must be specified before any simulation is attempted. Enter this information on the form. Choose to specify specific gravity by mineral.

The basis of the population balance method is the calculation of the behavior of each type of particle in the equipment that is being simulated. To do this, the particle population is conceptually divided into many classes in such a way that the particles in a single class are all similar to each other. The behavior of each class of material is then calculated and the overall behavior is calculated by accumulating the results from each particle class. In general the calculations produce more accurate results the more classes that are used and the narrower the class intervals. But of-course the amount of calculational effort will increase as the number of classes increases. MODSIM allows particle populations to be distributed in up to 3 dimensions. The first dimension describes the particle size. The second dimension describes the mineral composition or grade of the particles and the third dimension is available to describe any other particle property that might be useful in any particular simulation. It is necessary therefore to consider carefully what level of detail should be used to describe the solid material so that the results of the simulation are useful and meaningful. In this exercise we will simulate the classification of a homogeneous solid so that only the particle size is relevant. The solid phase should be described by as many size classes as possible to enable MODSIM to model the hydrocyclone in sufficient detail. The student version of MODSIM allows a maximum of 25 size classes so choose this value for this exercise. Because no other properties of the solid are relevant in this exercise, no further distribution of the particle population need be considered. Thus the number of grade classes will be 1 and the number of S-classes will also be 1. MODSIM also requires a specification of the largest particle size that will be relevant in the problem. MODSIM uses this size to set up the size classes that it will use internally to do the modeling and simulation calculations. The classes are constructed using a square root of 2 geometrical sequence starting at the largest size and working downward for the specified number of size classes. In this exercise a largest size of 2mm will be satisfactory. Please note that this size must be specified in m (i.e. 0.002 in this case). As a general rule MODSIM allows you to specify data in a variety of units but in some cases this would clutter the forms too much and when no alternatives for units are specified you should use the SI system. Internally MODSIM uses only SI units.



This is sufficient data to specify the ore characteristics for this exercise and you should complete the ore characteristics section of the system data form. The system data form looks like this (Shown on right side).

The feed stream data

The hydrocyclone is primarily a size classification device and obviously the size distribution in the feed material will be of particular importance and must be specified before the operation of the hydrocyclone can be simulated. Other important properties of the feed will be the solids content and the feed rate.

The feed material for this exercise is silica having a size distribution given in the table below.

Mesh size microns	850	600	425	300	212	150	106	75	53	38
% passing	95.7	88.3	77.0	63.3	49.6	37.4	27.3	19.6	13.8	10.2

The feed rate will be set at 50 tonnes/hr of solid and the feed slurry will contain 40% solids by mass.

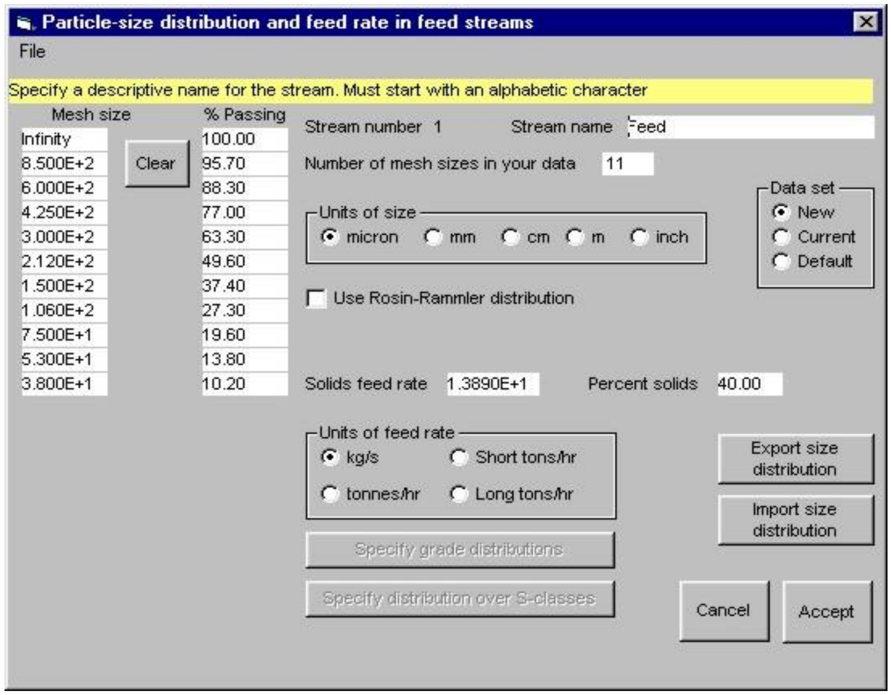
Since these data items are specific to the material in the feed stream, they must be attached to the appropriate stream in the flowsheet. All the streams are shown in one or other box on the right hand side of the system data form. You should now double click on the feed stream number in the feed stream box in order to specify the properties of the feed.

The first thing to do is give the stream a name so that it can be identified easily later.

The next thing to do is to specify the size distribution. Note that the experimental data for the size distribution that is usually determined by screening will include less mesh sizes than the number that you previously specified for internal computations. You can specify just as many mesh sizes as are available and MODSIM will interpolate your data to match the internal size distributions. In the table above there are 11 size intervals (note not 10 as you might think if you count the columns in the table because the oversize on the top screen is not shown explicitly). So specify 11 mesh sizes in the form. Clear the default data and type in the data from the table. Remember to choose the units of size that you are using.

When this is complete, specify the feed rate and the percent solids in the feed in the appropriate boxes on the form.

Note that all other selections on the form are greyed out in this case because they are not required and MODSIM always tries to help the user to specify only the data that is necessary for the problem on hand. The feed data input screen should look like this (on right side).



Accept the data when you are satisfied that it is what you want.

Naming internal and product streams

Finally you should name the overflow and underflow streams for future reference. To do this, double click on the stream number in the "Internal and product streams" box. This will open the "Particle size distribution" form for the chosen stream. Specify the name for the stream and click Accept to return to the previous form.

Save the job. This completes this exercise.

EXERCISE 1-7: *In this exercise you will use the job that you started in exercise 1-6. Open the job you previously saved in exercise 1-6. Edit the unit model parameters. (This can be accessed from the main Edit menu). For this exercise you should use the Plitt hydrocyclone model. The model is identified as model CYCL in MODSIM.*

Parameters for the unit models.

Each unit model will require some parameters that define the operating conditions for the unit. These need to be specified before the plant is simulated. The models that are available in MODSIM are very varied so that the data required for each unit model is unique. Furthermore the parameters required for the different units that use the same model may very well be different. It is therefore necessary to specify model parameters for every unit in the flowsheet.

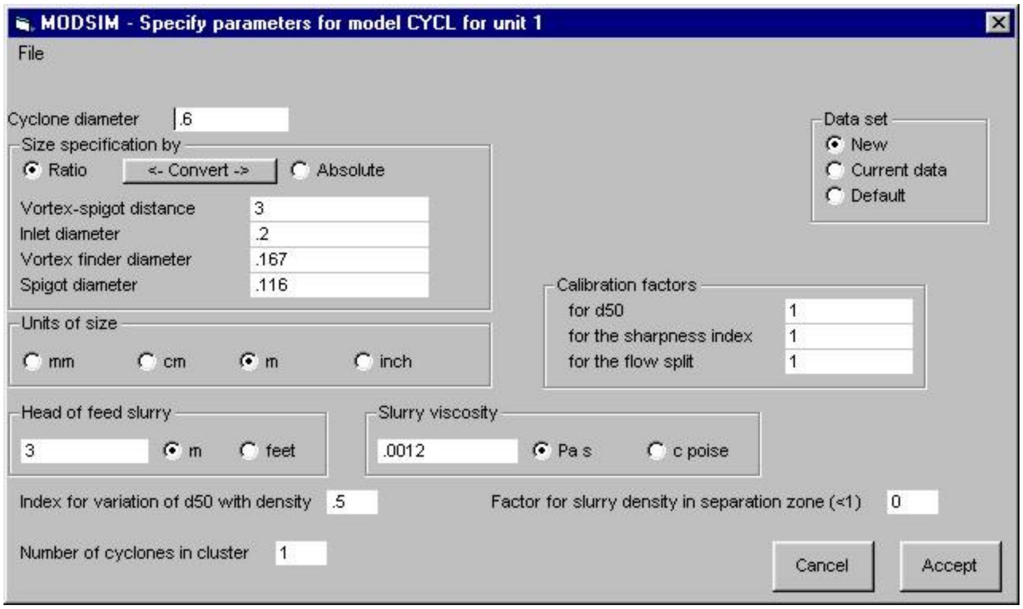
Selecting models for units

The flowsheet for this exercise includes only a single hydrocyclone so there is only one entry in the "Units" block of the "Select models and parameters for units" form. Click on "hydrocyclone" and the models that are available for a hydrocyclone will be listed in the "Models" list. Note MODSIM uses 4-character mnemonics to identify unit models. Check the "Help" box if you wish to see a brief description of the model before you specify the parameters. Double click on the model that you wish to use. If "Help" is checked you will see a description of the model including a description of the parameters that are required for the model. At this stage you can accept the model or cancel your selection and try another model.

Specifying model parameters

The forms that are provided to specify parameters for the unit models are unique and each model has its own form. Some are very simple and some are quite lengthy including more than 20 parameters for complex models such as those for autogenous mills. The form for specifying parameters for the Plitt hydrocyclone model looks like this.

For this exercise use the default values for all parameters except the cyclone diameter. Choose a cyclone of 60 cm diameter with standard geometry. Accept this data and click Accept and you are back on the "Select models and parameters for unit" form. Click accept to accept all parameter model parameter data for this flowsheet. Save the job.



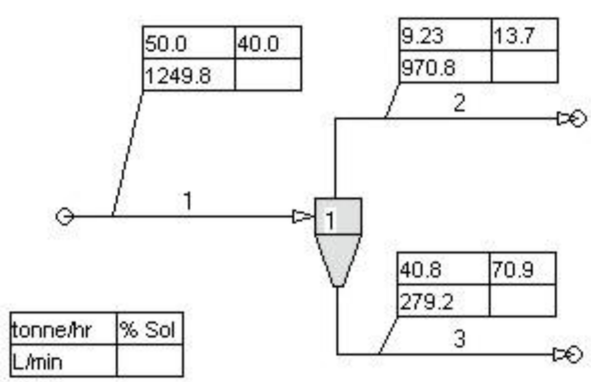
Running the simulation

Open the main Run menu and click "Run simulation". If you do not get the "Simulation was completed successfully" and the "Data output completed successfully" messages you have specified some data badly. Review your system data and model parameters carefully.

It is unlikely that anything will go seriously wrong in this simple exercise so you should be able to see the results of the simulation now. This is a good time to save the job.

Getting results from the simulator

Open the main View menu and view the flowsheet. The flowsheet appears and you can get an immediate summary of the plant behavior from the data in the stream flyouts.

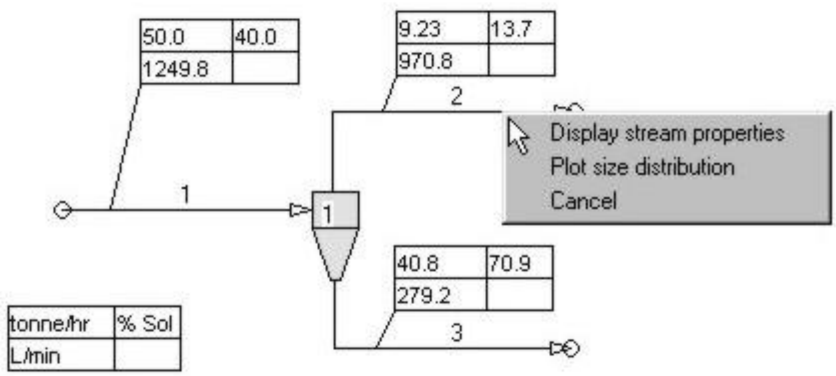


Note in particular that the overflow has 13.7% solids and the underflow 70.9% solids. (If you do not see these values you have not specified some of the data as required and you ought to check all your data before proceeding. The 70.9% solids in the underflow should catch your attention because a hydrocyclone will probably rope when discharging such dense slurry. This will be discussed further later in this exercise.

The first thing to note is the units that are used to display the flowrates in the flyouts. The defaults (kg/s) should be showing in this exercise. In most problems you will want to choose more appropriate units. To do this you must leave the flowsheet (Select Accept flowsheet or Cancel from the File menu) and edit the output format. (Open the main Edit menu and choose "Edit output format"). Select tonnes/hr in the "Units for solid flowrate" block and L/min in the "Units for water flowrate" block. Uncheck the "Display latest output data" box and click "Accept". View the flowsheet again. Note that the flyouts now display quantities using the units that you have selected. The lower right space in the flyouts is reserved for the display of metal content. This will be covered in a later exercise.

Calculated properties of the streams

You can obtain more information about the properties and composition of any stream by right clicking on the stream while viewing the flowsheet. This will pop up a menu from which you can select the "Stream properties".



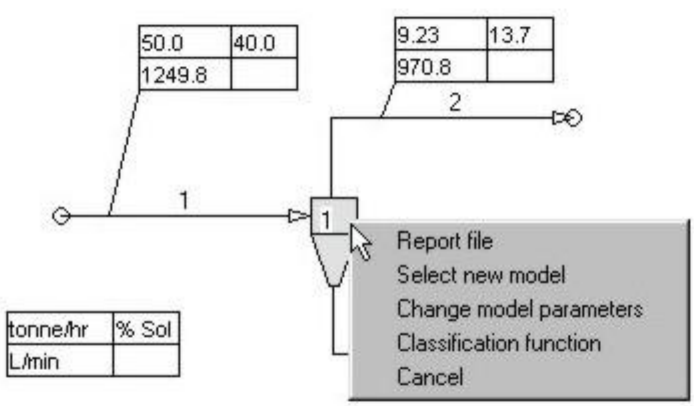
Right click on a stream to see its properties

This will display most if not all of the information that you may wish to obtain about the stream including flowrates, solid yield and the particle size distribution in the stream. The d80, d50 and d20 sizes of the solids are also given. Right click on the overflow stream and note that the d80 size for the cyclone overflow is 81.6 microns. Right click on the underflow stream and note that the d80 size for the underflow is 516 microns.

You can also display a plot of the particle size distribution in the stream.

Calculated performance of the units

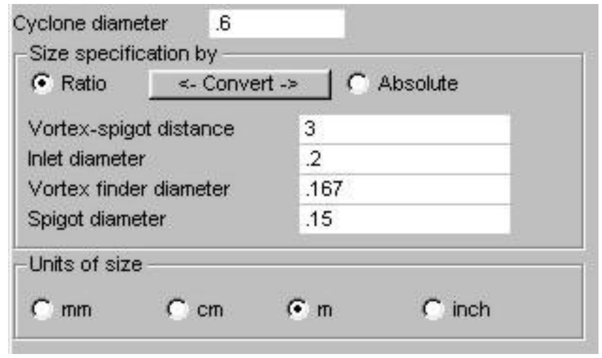
The next type of data to look at is the report on the operation of the hydrocyclone. This is contained in the report file for the unit which is produced whenever the simulation is run. The easiest way to access the report file for the unit is to right click on the unit icon for the hydrocyclone and select "Report file" from the pop-up menu.



Right click on the unit to see its performance.

A formatted file is displayed that is specific to the simulated performance of the unit. Scroll through this file and note the kind of information that is displayed. In particular note the following items: the parameters used are shown for reference, the size distributions in the feed and product streams are tabulated and the calculated d50c size for the operating conditions

(90.9 mm) is shown. The actual d50 achieved can be read from the graph of the actual classification function which can be displayed by selecting the "Classification function" item from the pop-up menu Note that at the bottom of the file a warning is issued to the effect that the Mular-Judd criterion indicates that the cyclone will rope in operation. This correlation suggests that a spigot diameter of at least 7.4 cm is required to prevent roping. Furthermore the Concha analysis indicates that the air core diameter is 13% larger than the spigot diameter. This also indicates that roping can be expected. Before proceeding it is advisable to fix this potential problem. Recall that a 60 cm diameter cyclone was chosen with "standard" geometry. This requires the spigot diameter to be 11.6% the cyclone diameter which is equivalent to 6.9 cm. So now go back to edit the unit parameters and set the spigot diameter to 15% of the cyclone diameter. This can be done most conveniently by selecting "Change model parameters" from the pop-up menu. The new data looks like this.



Running modified simulations

RUN THE SIMULATION AGAIN and view the flowsheet. This is done most easily by right clicking anywhere on the flowsheet background and clicking on the "run simulation" pop-up. You could also use the main menu bar or go back to the main Run menu. Notice that the underflow is now 55.1% solids. Look at the report file for the hydrocyclone and note that d50c is now 75.8 mm. At the bottom of the file you will note that the Mular-Judd criterion is still issuing a warning but the Concha formula indicates that operation is fine with an air core 92% of the spigot diameter. In my experience the Mular-Judd criterion is too conservative and flags warning too easily. Although we always take note of a warning like this, it is always necessary to exercise some judgement about it. This is a good time to change the job name to Exercise 1-7 and save the job.

Plotting the calculated size distributions

The next type of output data that are of interest are the particle-size distribution graphs. These are accessed from the View menu by selecting "Size distribution graphs". This will display the "Plot size distributions" window. Double click each of the three streams and these will be placed in the graph list. Click View graph to see the graphs.

Comparing size distributions from different simulations

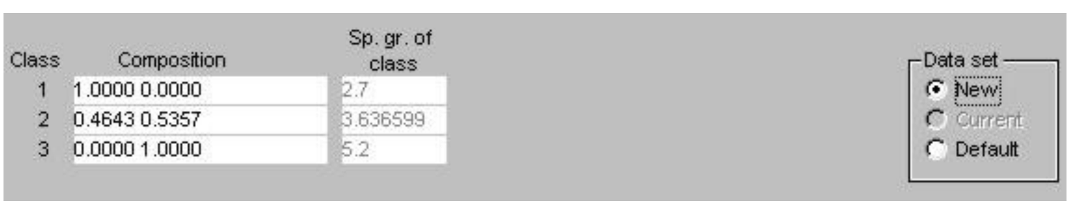
At this point you will probably want to see the difference in the overflow size distributions that resulted from the increase in spigot diameter. In order to do this, it is necessary to accumulate the size distributions from the separate simulations outside of MODSIM. (Remember that MODSIM handles only one job at a time). The most convenient way to save a size distribution is to right click on the stream in the flowsheet and select "Plot size distribution' from the pop-up menu. This shows a small graph of the size distribution of the material in the stream. Right click anywhere on the face of this graph and you will be able to save the size distribution as a comma delimited file which will import nicely into many other applications including an Excel spreadsheet.

Run Exercise 1-6 again and save the size distribution of the overflow as described above. Import this into "Graphics for Mineral Processors" and select each distribution into the graph list by double clicking. Display the graph. (Log - log coordinate system is probably best but feel free to experiment). **Look carefully and you will see that in spite of the smaller d50 size with the larger spigot the overflow size distribution is slightly coarser. Why? (You will need a sharp understanding of the behavior of hydrocyclone to answer this. That completes exercise 1-7.** You may wish to vary some of the other parameters in the cyclone model now and check the results. In fact you could really spend some time and put the Plitt model through its paces. You can also experiment with the other models that are available for simulating hydrocyclone classifiers.

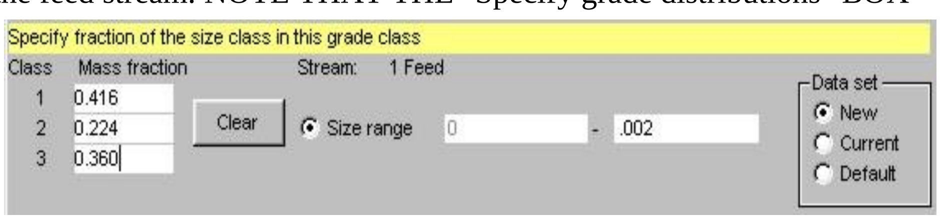
EXERCISE 1-8: *This exercise will demonstrate the specification of data when the ore contains more than one mineral component*. The problem studied in exercises 1-6 and 1-7 will be used but now the material to be processed is an iron ore consisting of 48% magnetite by mass in silica. To keep things simple assume that 80% of the silica is completely liberated and 75% of the magnetite is completely liberated. The remainders of the ore is unliberated and for simplicity assume that all incompletely liberated particles have the same composition or grade. (You will examine the correct way to get accurate representations of unliberated ore in Module 6).
Load the previous job from Exercise 1-7. Change the job name to Exercise 1-8 and save this job. Open the flowsheet editor to check that you have got the correct flowsheet and if so accept the flowsheet to register the new job name on the flowsheet. Edit the system data. Change the number of minerals to 2, select "Specific gravity by mineral " and add magnetite of specific gravity 5.2. Change the number of grade classes to 3, one for liberated silica, one for incompletely liberated particles and one for liberated magnetite. It is now necessary to specify the composition of the particles in each grade class. Click on "Set up grade classes". This brings up a form that enables the grade of each particle type to be specified. Note that the default composition of the unliberated particles is 50% silica and 50% gangue. This must be changed in this example according to the following calculation.
Calculate distribution over G-classes
Consider 100 mass units of ore:

Units of liberated silica = 52 x 0.8 = 41.60
Units of liberated magnetite = 48 x 0.75 = 36.00
Units of unliberated ore = 100 - 41.60 - 36.00 = 22.40
Units of silica in unliberated portion = 52 - 41.60 = 10.40
Units of magnetite in unliberated portion = 48 - 36.00 = 12.00
Average silica grade in unliberated particles = 10.40/22.40 = 0.4643
Average magnetite in unliberated particles = 12.00/22.40 = 0.5357.

Change the composition of grade-class 2 to 0.4643 0.5357. Note that you cannot change the specific gravity of the unliberated particles. MODSIM will calculate this for you because you previously specified that specific gravities are to be specified by mineral. The easiest way to get the calculation done is to select "Default" in the "Data set" box and then immediately reselect "New" which will show the new data with the specific gravity calculated.



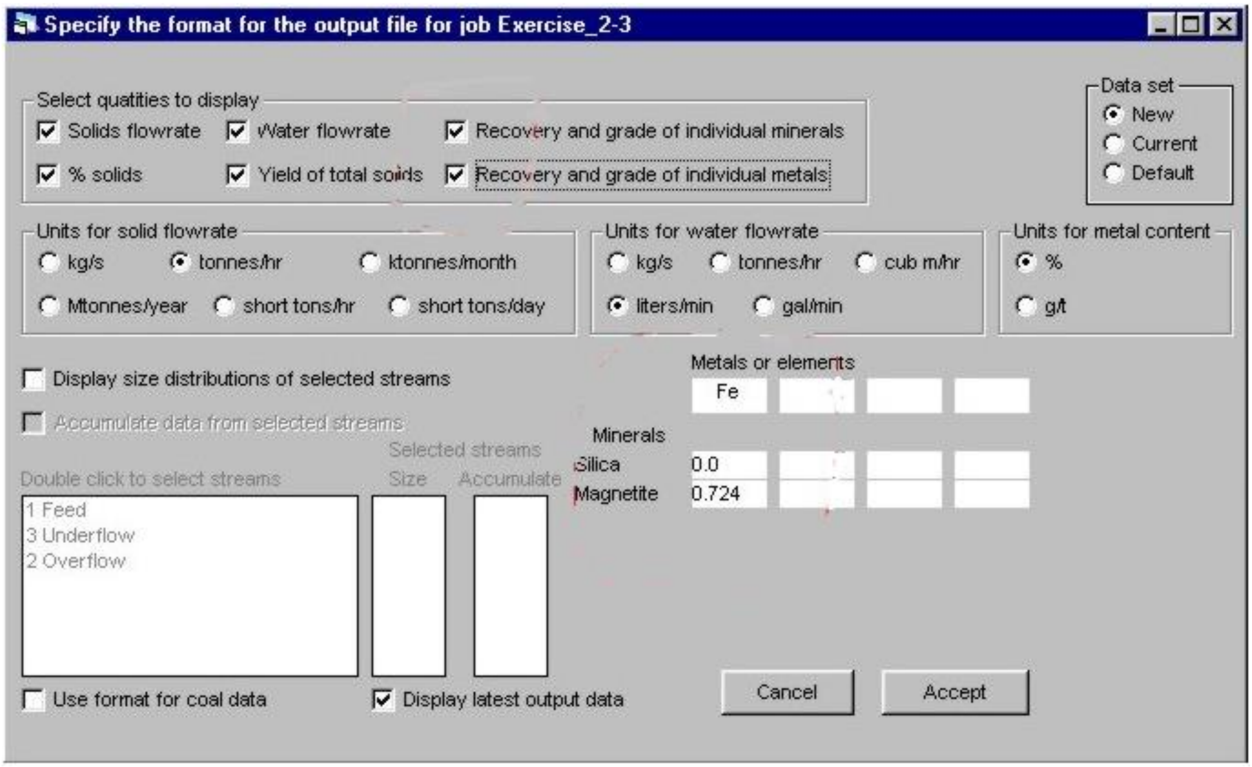
You can now accept this data. It is now necessary to specify how the particles in the feed population are distributed over these three grade classes. To do this double click on the feed stream in the "Feed streams" box on the system data editing form. This will bring up the particle-size distribution form for the feed stream. NOTE THAT THE "Specify grade distributions" BOX IS GREYED OUT in this example. This is because MODSIM remembers that the current data was inherited from the



previous exercise which did not require G-classes. To register the new data click "Accept" which takes you back one form and immediately double click on the feed stream. This time the particle size distribution form opens with the "Specify grade distributions" button enabled. You will keep the size distribution used in the previous exercise so click on the "Specify grade distribution" button.

This opens the form to specify the distribution of particles among the grade classes. From the calculation given above the mass fraction of the particles in G-class 1 is 0.4160, in G-class 2 (the unliberated particles) it is 0.2240 and in G-class 3 it is 0.3600. Clear the default data and enter these values.

Accept this data and the particle size data and the system data (Click three Accept buttons in succession). This will take you back to the main page. Take a quick look at the unit parameters to make sure everything is OK and you are ready to run the simulation. Run it and then view the flowsheet to see the results.

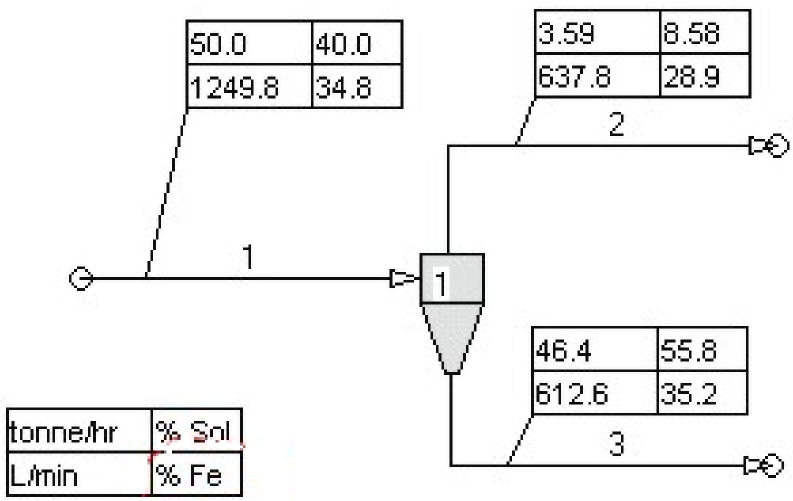


I expect that the hydrocyclone should show an upgrading of the heavier mineral in the underflow and it is interesting to check this. A convenient way to do this is to show the Fe content of each stream in the vacant quadrant of each flyout. This is done using the output format facility so cancel the flowsheet and edit the output format.

Select your preferred units for the solid and water flowrates. Enter Fe into the first field under "Metals or elements". This will tell MODSIM that you want to keep track of iron in the flowsheet streams. Because MODSIM does all calculations using the individual minerals you must specify how much Fe is in each mineral that is listed - 0% in silica and 72.4% in magnetite (enter 0.724).

To display the Fe content in each stream check the "Recovery and grade of individual metals" in the "Select quantities to display" frame. While your cursor is in the neighborhood, check the "Recovery and grade of individual minerals" because you will need this information shortly. Check the "Display latest output data" box and accept the form. The results from the simulation

are displayed in a formatted file which you can examine. This file is most often used to insert simulation data into a report. Close this form. View the flowsheet and notice that the iron content of each stream is displayed in the 4th quadrant of the flyouts. Note the upgrading of the heavy mineral in the underflow.
Right click on the overflow and underflow streams and note the d80 size for each stream.
Right click on the hydrocyclone icon and open its report file. Scroll down and check the d50c sizes for each (Grade-Class) G-class. **Note that these decrease from G-class 1 to G-class 3. Why? Note also that d50c for silica is smaller now than in exercise 1-7. Why?**
One final piece of information should be checked before you start investigating possible parameter changes. Recall that we never specified that the magnetite content of the feed should be 48%. MODSIM had to reconstruct this from the G-class information. To check this, View the simulation results from the main View menu. Because the grade and recovery of the minerals was selected in the output format these are displayed in the table. The grade of magnetite in the feed is correctly calculated as 48%.
This concludes the exercises.



CONCERNS TO BE ADDRESS:

1. Differentiate between d_{50} and d_{50c}
2. Differentiate between G-class and S-class
3. What is Mular-Judd criterion & Concha formula?
4. For Exercise1-8: d50c decreases from G-class 1 to G-class 3. Why? Also note that d50c for silica is smaller than in exercise 1-7. Why?
5. For exercise 1-7: in spite of the smaller d50 size with the larger spigot the overflow size distribution is slightly coarser. Why? (You will need a sharp understanding of the behavior of hydrocyclone to answer this.

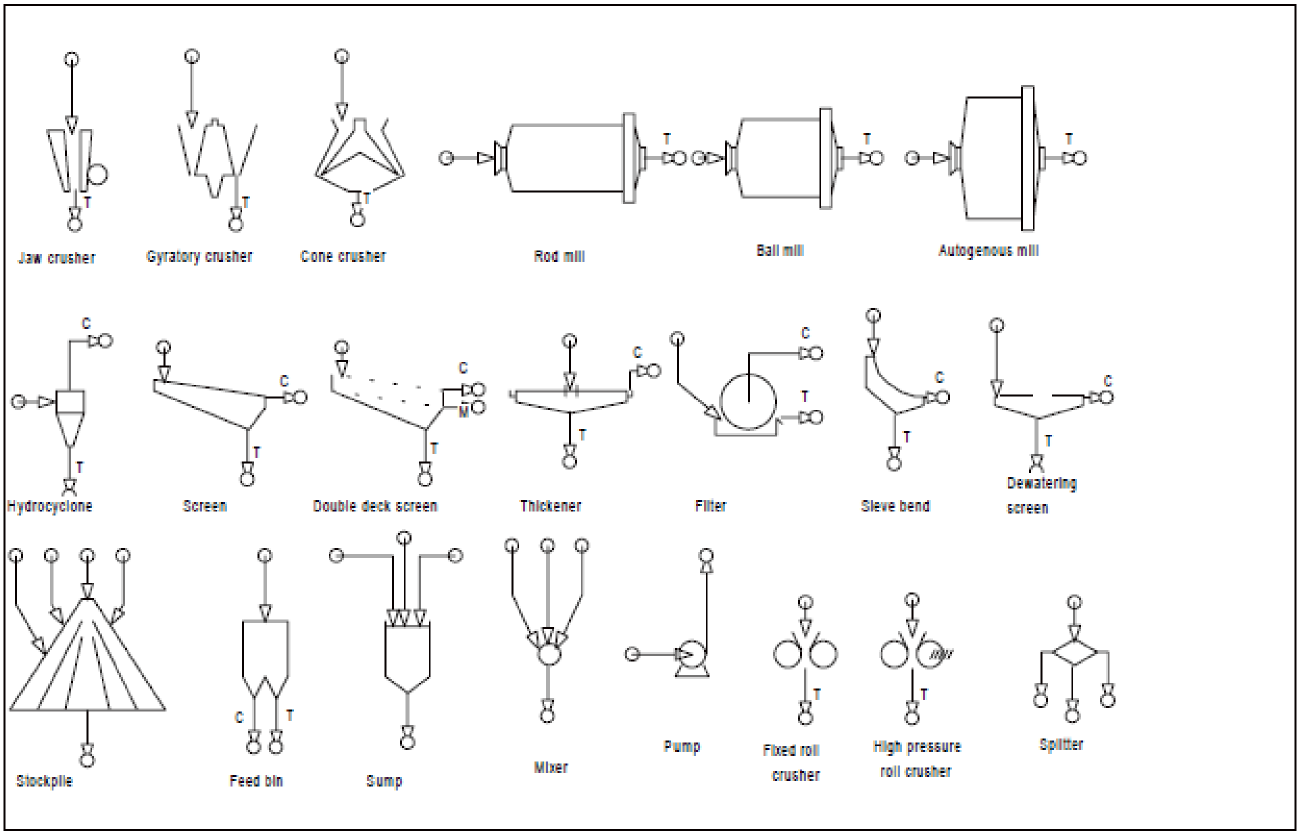


Figure 1: The unit icons. Concentrate streams are identified by C, tailings streams by T and middling streams by M.

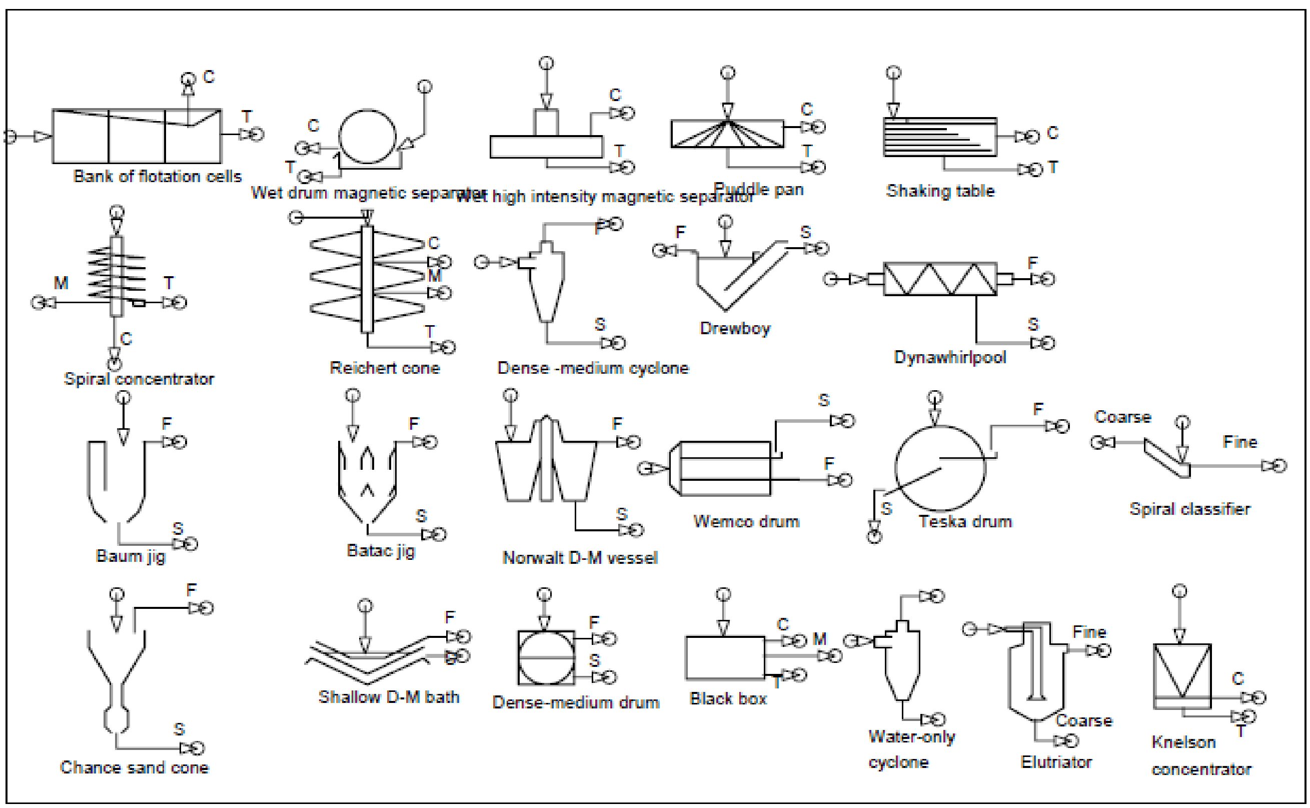


Figure 2: The unit icons. Concentrate streams are identified by C, tailing streams by T and middling streams by M. Dense medium and gravity units have float and sink streams which are identified by F and S in the figure.

Module-2:

Simulation of Crushing and Screening Circuits with MODSIM.

Objectives:

1. Review the basic principles that are used to model the operation of crushers and screens.
2. Learn how to specify parameters for screen and crusher models.
3. Learn to understand the relationship between model parameters and the size distribution in the product streams.
4. Learn how to set up and simulate complete crushing plants.
5. Learn how to set up crushers and screens for best operation.

We will examine two screen models that are based on the traditional method that is used to size screens for industrial applications. These models are based on a series of capacity factors that can be used to determine the tonnage of a particular material that can be handled by a screen of specified mesh size. The traditional method does not attempt to make a realistic calculation of the size distribution in the oversize and undersize products from the screen. However this traditional model is convenient for preliminary simulations particularly in the early stages of a project when not much data is available and the precise details of the screens that are to be used are not known.

A useful modification to the traditional model was made by Dr. V.K. Karra who used an extensive collection of industrial data to model the actual screening process in terms of the physical parameters that define the screen operation. This model is to be preferred when simulating a screening operation for which the physical properties of the screen are known such as the simulation of a screening operation in an existing plant. The Karra model has proved to be reliable when compared against industrial operating data and is the recommended screen model for real plant simulation.

The traditional model is demonstrated in exercise 2-1 and the Karra model is demonstrated in exercise 2-2.

EXERCISE 2-1: *Investigate the information generated by the traditional screen model in a typical operating environment.*

Start a new job in MODSIM and draw a flowsheet containing only a single-deck screen.

Add a feed stream and product streams for oversize and undersize. Add flyouts to each stream.

Accept the flowsheet and edit system data.

Use the following settings: 1 mineral sp. gr. 2.7, 25 size classes, and maximum particle size 15 cms. Specify the feed: 300 tonne/hr. at 95% solids with Rosin-Rammler distribution having D63.2 = 4 cm and = 1.2 Use 20 mesh sizes in the feed size distribution data.

Don't forget to name the two product streams for convenient reference later.

Edit unit parameters. Use model SCRN for the vibrating screen. Check the help box the first time you select the model to see a brief description of the model. Choose the following parameters: mesh size 3 cm, transmission efficiency 90%, surface water on oversize 2%. Do not specify screen dimensions on the first run.

Accept the parameters and run the simulation. View the flowsheet. Check the data in the stream flyouts which show the total tonnages in each stream.

Right click on the screen icon to see the report file for that unit. Examine the report file carefully to become familiar with the information that it provides. Note in particular that the basic capacity factor for this screen is 60.5 tonnes/hr. Note the calculated values of the six correction factors and that 5.76 sq.meters of screen area would be required for this duty.

View the size distribution graphs (View menu). Size distribution graphs and the report file for the screen are shown below for reference. **Modify some of the unit parameters and note how the performance data changes after each simulation run.** Save the job as Exercise 2-1.

EXERCISE 2-2: *Karra model for vibrating screens*

Load the job from exercise 2-1. From the edit menu change the job name to exercise 2-2 Keep the same flowsheet consisting of a single screen and edit the system data to register the change in job name. Edit the unit parameters. Note that the current model for the screen, SCRN, is shown at the top of the models list for the screen. Change the model to SCR2, set the screen mesh size to 3 cm and the screen length to 3.0 m and the screen width to 1.92 m. This gives a screen of area equal to that found necessary in exercise 2-1. Choose woven wire mesh with wire diameter 7.94 mm. All other parameters can be left at default values. Run the simulation and view the flowsheet. Right click the screen icon to get the report file for the unit. Scroll through the report file to check the performance of the screen. Note the capacity factors and note that the area utilization factor is 1.11. This parameter has been found to be useful in assessing the results of a simulation of screening behavior using the Karra model. It is calculated as the ratio between the actual amount of undersize that is transmitted by the screen to the amount of undersize that the screen is capable of transmitting as calculated using the Karra model. Thus it gives a measure of the loading on the screen relative to its theoretical capacity. An area utilization factor less than unity indicates that the screen is under loaded while a value greater than unity indicates that the screen is over loaded. Since the screen chosen had the area suggested by the traditional model in Exercise 2-1, the Karra model indicates that the traditional model underestimates the required area by about 11% with the medium heavy woven wire mesh that we have chosen. Look at the size distribution in the three streams from the view menu. **You can now investigate a number of what-if scenarios. For example check how the area utilization factor varies as the wire diameter changes. Standard wire diameters for this mesh size are: heavy duty 9.53 mm, medium heavy 7.94 mm, medium 6.35 mm and medium light 5.72 mm.**

You could also investigate how the area utilization factor varies as the feed rate changes.

You could also substitute a double check screen and simulate its performance.

EXERCISE 2-3. *Gyratory crusher*

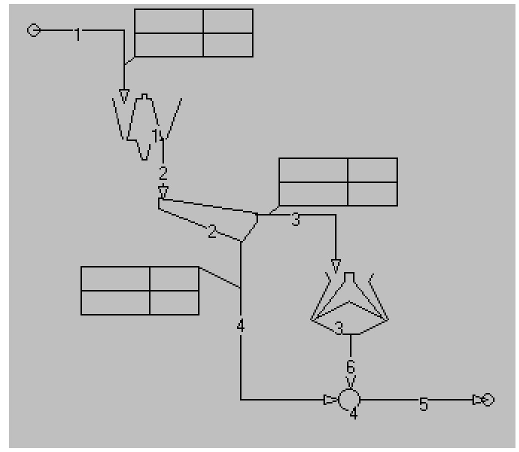
The next three exercises step you through the method to develop a crusher circuit to produce 1200 tonnes/hr of 80% passing 10 mm aggregate.

Start a new MODSIM job. Select a single gyratory crusher for the flowsheet and add a feed stream and a product stream.

Edit the system data and select one mineral of specific gravity 2.7. Set the largest size to 1.2 m with 25 size classes. Double click on the number of the feed stream to specify feed stream data. Name the feed stream, show 20 size classes, and use Rosin-Rammler distribution with D63.2 = 40 cm, lambda = 1.4. Remember to click the clear button to generate the R-R distribution. Name the product stream before accepting the system data. Edit the unit parameter and select model GYRA for the gyratory crusher. Select the following parameters: OSS = 15 cm, W_I = 12 kWh/tonne. Average ore type. Edit the output format and select tonne/hr for solid flowrate. Run the simulation. View the particle size distributions in the feed and product streams. View the flowsheet. Right click on the crusher icon to view its report file. Note that the output includes a table of size distributions for the crusher feed and the crusher product. An estimate of the power required is also calculated using the crushing work index and the d80 sizes of feed and product. **You should investigate how the size distribution of the crusher product varies as the open side setting is varied.**

EXERCISE 2-4: *Two-stage crushing*

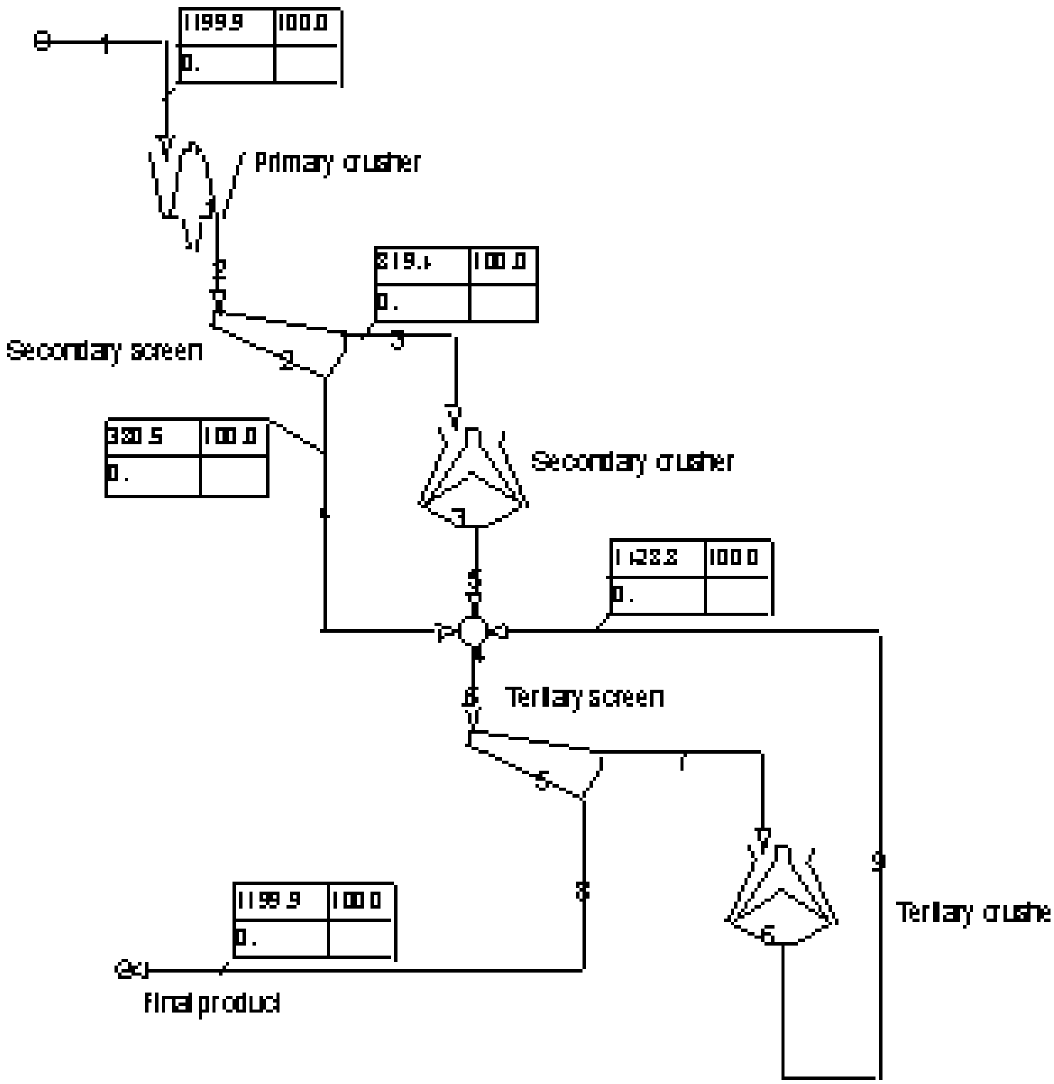
Add a second-stage cone crusher to handle the product from the gyratory crusher that was used in example 2-3. Since cone crusher capacity is less than the gyratory you must either use more than one secondary crusher in parallel or, preferably, screen the primary crusher product and send only the oversize to the second-stage crusher (see flow sheet below).



Change the jobname to exercise 2-4 and edit the system data to name the additional product stream.
Edit the unit parameters for the additional crusher, use the model CRSH, and set the CSS to 35 mm. Leave other parameters at their default values.
Edit the parameters for the screen. Use model SCRN with 45 mm mesh.
Run the simulation and view the flowsheet. Right click on the cone crusher icon to view the report file for this unit. One 7-ft standard crusher would be required to handle the tonnage.
Save this job as exercise 2-4.

EXERCISE 2-5: *Three-stage crusher circuit*
The following elements are included in this exercise:
1. Instructions
2. Flowsheet
3. Size distribution graphs
4. Report file for tertiary crushers.
In this exercise you will add a third stage of crushing to the flowsheet to reduce the size to meet the requirement that the product should have a d80 size of 10 mm. The third stage will be operated in closed circuit, and this will introduce you to the simulation of plants with recycle.
Open the job that you saved as exercise 2-4. Change the job name to Exercise 2-5. Add a screen and a cone crusher and connect the final product as the feed to the screen. (You can draw the screen icon then move it so that it just touches the arrowhead of the product stream. MODSIM will recognize the connection when you refresh the flowsheet.) Direct the screen oversize to the crusher. At this stage it is not advisable to close the circuit, and you should run the simulator in open circuit at least once to make sure that all parameters are properly set up.
Use model SCRN for the screen with a mesh size of 13 mm. choose the short head model SHHD for the crusher and set the CSS to 13 mm.
Run the simulation and check the report files for the two units that have been added. You should also check the size distributions in the products from the screen and the mill. When you are satisfied that the units are functioning properly, direct the crusher product back to the screen. Remember that the screen icon can accept only one feed stream so that a mixer or sump must be inserted in the flowsheet ahead of the screen to receive the secondary screen undersize, the secondary crusher product, and the tertiary crusher product.
Run the closed-circuit simulation and MODSIM should converge easily. If you are using a slow computer (<66 MHz), you should notice that the calculation does take a little longer because the recirculating load is calculated by iteration. In the unlikely event of some difficult with the iterative calculation, MODSIM will give you some diagnostic information to pinpoint the trouble. By far the most common cause of difficulty with iterative calculations is caused by inappropriate choice of model parameters. Check these thoroughly and you should find your error.
When you are comfortable with the simulation, you could try any number of what-if scenarios. Try all or some of the following:
1. **Vary the mesh size of the tertiary screen over the range 8 mm to 15 mm and observe how the recirculating load and the size distribution of the final product change.**
2. Vary the mesh size and the CSS in the tertiary circuit and seek out an optimal combination that will minimize the size and number of crushers required. Also keep track of the area requirements for the screen.

3. **Reverse the order of the tertiary screen and the tertiary crusher so that the entire product from the secondary circuit passes through the crusher which is then screened to close the circuit.**



CONCERNS TO BE ADDRESS:

- **For Exercise 2-1** Modify some of the unit parameters and note how the performance data changes after each simulation run.
- **For Exercise 2-2** Check how the area utilization factor varies as the wire diameter changes. Standard wire diameters for this mesh size are: heavy duty 9.53 mm, medium heavy 7.94 mm, medium 6.35 mm and medium light 5.72 mm. Also investigate how the area utilization factor varies as the feed rate changes.
- **For Exercise 2-3** Investigate how the size distribution of the crusher product varies as the open side setting is varied.
- **For Exercise 2-5**
  - ✓ Vary the mesh size of the tertiary screen over the range 8 mm to 15 mm and observe how the recirculating load and the size distribution of the final product change.
  - ✓ Vary the mesh size and the CSS in the tertiary circuit and seek out an optimal combination that will minimize the size and number of crushers required. Also keep track of the area requirements for the screen.

Module-3:

Simulation of Gravity Separation Operations with MODSIM.

Gravity separation operations can be classified into two broad categories: manufactured media separators and autogenous media separators. In the former, separation takes place in an artificial medium which is manufactured to have a density intermediate between that of the particles to be separated. In the latter, the particles make up their own media in which they separate. This distinction is important in practice because autogenous media separators behave in a nonlinear manner in the sense that the separation that is achieved is a strong function of the composition of the feed to the unit. Models for manufactured media separators are generally based on the partition curve but this method is not suitable for autogenous media separators and, for these, radically different models are required for satisfactory simulation.

Manufactured media gravity separators are easiest to model. It is only necessary to establish the cut point and the shape of the partition curve. We will demonstrate the principle involved using a simple dense medium cyclone circuit. Exercise 3-1 uses a simple single stage dense medium cyclone circuit. Exercise 3-2 extends this to a two-stage circuit.

EXERCISE 3-1: *Dense-medium cyclone - Single stage*

One of the first investigations on the use of the dense-medium cyclone was reported by the Dutch State Mines in the 1960s. They were interested in separating magnesite from calcite and producing a low-silica magnesite concentrate using the dense-medium cyclone. In these two exercises we will investigate the possibility of using a two-stage dense-medium cyclone circuit to achieve the desired concentrate. Data for these examples is taken from the reference that is cited above. The target concentrate was specified as containing no more than 2% CaO and no more than 3.5% SiO2. Start a new job in MODSIM.

Draw a flowsheet containing a single dense-medium cyclone and add a feed stream, an overflow stream and an underflow stream and add stream flyouts. Accept the flowsheet, specify a job name and edit the system data. Although we are interested ultimately in a two-stage circuit it is always a good idea to build up your flowsheet unit by unit so that you can test each individual model as you go. This exercise will enable you to extend your experience of specifying data for a multi-component ore. Specify 3 minerals, calcite, silica and magnesite with specific gravities 2.70, 2.67 and 3.00 respectively. Specify sp. gr. by mineral.

Select 25 size classes with a largest size of 0.01 m.

Select 6 grade classes and 1 S-class.

Click "Set up grade classes" and specify the composition of each class according to the data in Table I. Compositions are specified by mass but please note that the laboratory data is given in terms of %CaO which must be converted to %CaCO3 to specify the mineral grade in the G-classes. (Calcite, CaCO3, contains 56% CaO). The class specific gravities need not be specified because these will be computed by MODSIM.

Table 1 Washability data for the magnesite ore

Density g/cc	Yield	%CaO	%SiO2
Float at 2.85	21.6	19.3	18.2
2.85 - 2.88	5.70	21.76	2.49
2.88 - 2.91	3.20	10.15	1.52
2.91 - 2.94	0.90	9.67	2.92
2.94 - 2.96	7.60	2.95	3.89
2.96 - 3.03	61.00	0.96	2.55
Sink at 3.03	0.00	-	-

Mesh size mm	6.00	4.21	3.00	2.11	1.48	1.05	0.74	0.53	0.37	0.26	0.19
% passing	95.0	82.0	62.7	43.2	27.6	17.0	10.2	6.0	3.5	2.0	1.2

Table II Particle size distribution

It is not necessary to specify a liberation model since no grinding mills will be used in the flowsheet.
Double click on the plant feed stream and specify the particle size distribution from Table II.
Set the feed rate at 100 tonnes/hr at 30% solids. Click "specify grade distributions" and specify the distribution among the grade classes from Table I. Note that the grade distribution does not vary with particle size so only one size range is required. This completes the specifications of the system data.
Edit the unit parameters and check the help file for the dense-medium cyclone model DMCY. Select target specific gravity of 2.80. This will invoke the Gottfried-Jacobsen model to calculate the variation of both cut point and imperfection with the particle size.
Run the simulation. View the flowsheet. In this plant we want to keep track of the CaO content of each stream and this can be displayed in the fourth quadrant of the flyouts. To set this up, edit the output format. In the "metals or elements" section, specify CaO in the first block. Specify 0.56 for the CaO content of calcite, 0 for the CaO content of silica and 0 for the CaO content of magnesite.
You should now investigate how the grades of CaO and SiO2 in the underflow vary as the target specific gravity in the dense-medium cyclone is changed systematically over the range 2.80 to 3.1. This can be reported most effectively on a graph of grade vs target specific gravity. This will give you the opportunity to try out the the method for transfering output data from MODSIM directly to a spreadsheet or to your favorite graph plotting program. In this exercise this can be done mostly conveniently by running the simulation and choosing "Display simulation results" from the main View menu. Locate the underflow stream by its stream number, select that row in the table and copy (Use copy from the Edit menu or Ctrl-C) it to the clipboard. Open your spreadsheet and paste the row to a convenient location in the spread sheet. Go back to MODSIM, edit the unit parameter data and change the target specific gravity to the next value. Accept the new parameter data and run the simulation again and copy and paste the results. Do this until you have built up enough data to plot a graph of grade vs. target specific gravity for CaO and SiO2. You should also plot the recovery of magnesite vs CaO grade on a separate graph. From these graphs you can easily find the target specific gravity that is required to meet the product specification and also the yield of magnesite that can be achieved.
You could also repeat the whole exercise using the alternative method of setting the cutpoint by specifying the medium specific gravity. If you decide to do this, you will gain some insight into these different modeling techniques for dense-medium cyclones.
When you are comfortable with the simulation of a single stage dense-medium cyclone you are ready to add a second stage to the flowsheet. Save this job for future reference.

EXERCISE 3-2: *Dense-medium cyclone - two stage*
Open the job saved in exercise 3-1. Change the job name to Exercise 3-2.
Edit the flowsheet and add a second dense-medium cyclone to receive the underflow (sink fraction) from the first stage. Note that it is necessary to process the underflow in order to make a heavy concentrate with minimum silica content.
At this stage do not attempt to simulate closed-circuit operation. Your flowsheet should look similar to Figure 1
Because the flowsheet has changed, the system data must be edited to register the changes. You can take this opportunity to name any of the intermediate streams. Check that MODSIM has recognized all the new streams that were added.
Edit the unit parameters and set the second stage medium density at 2.8.
Run the simulation and view the flowsheet note the silica content of the second-stage underflow.
You can now run several simulations with varying medium density in the second-stage cyclone. You should easily find the medium density that minimizes the silica content of the

second stage underflow. You should also look at the data output file to check the recovery of the valuable mineral magnesite.

You are now in a position to simulate closed-circuit operation. Edit the flowsheet. Delete the second stage overflow stream and add a new stream from the second stage overflow and mix it with the fresh feed to the first stage. Remember to use a mixer or sump to mix the recycle with the feed. Your flowsheet should look similar to Figure 2.

Run the simulation and note that the silica content of the second stage underflow inevitably increases but the recovery of the magnesite increases significantly.

To complete this exercise you should plot a series of grade recovery curves using the two medium densities as the control variables. To accumulate the grade-recovery data you should copy and paste the appropriate data from the simulation results screen into a spreadsheet program from which you can plot the grade recovery curves.

This simple exercise has introduced you to dense-medium circuits and has shown you how to generate grade-recovery curves quickly and easily for a concentration plant with recycle.

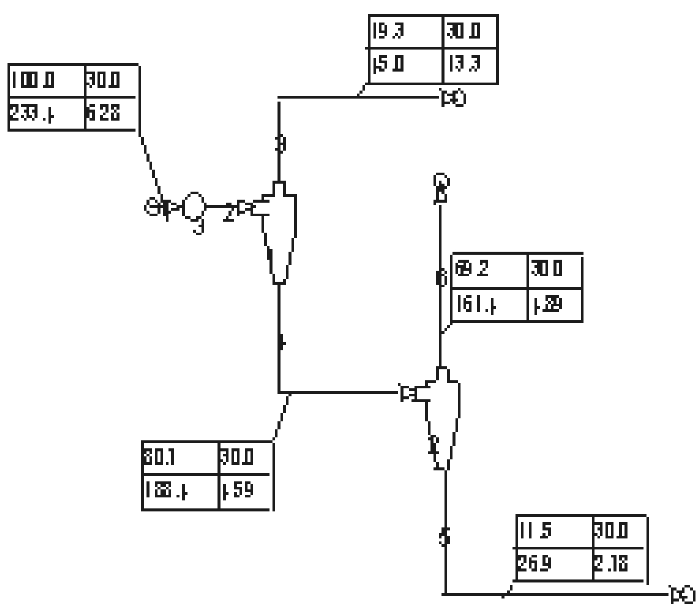


Figure 1: Two-stage open circuit configuration.

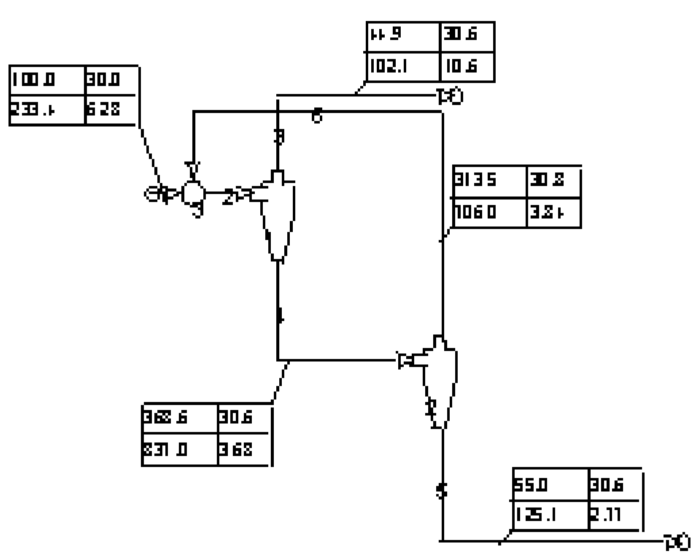


Figure 2: Two-stage closed circuit configuration

Autogenous media separators require somewhat more complex models. We will illustrate the possibilities that are offered by these models using two typical systems: a single-stage coal jig and a Reichert cone. The assignment for this module will deal with a multistage Reichert cone circuit.

The model for the Reichert cone is particularly complex because each unit is itself a multistage separator with a fairly complex internal arrangement of flow streams. The model used in MODSIM allows each of the important configurations to be faithfully simulated and, in spite of the complexity of the stratification model, good results can be obtained.

EXERCISE 3-3 (Optional): *Coal washing jig*

In this exercise you will learn how to enter coal washability data into MODSIM and investigate the modeling of coal washing jigs. You will use the equilibrium stratification model for the jig. The washability data for the coal is given in Table I.

Start a new job in MODSIM. Place a single Batac jig on the flowsheet. Draw a feed stream and clean coal and discard streams. Accept the flowsheet.

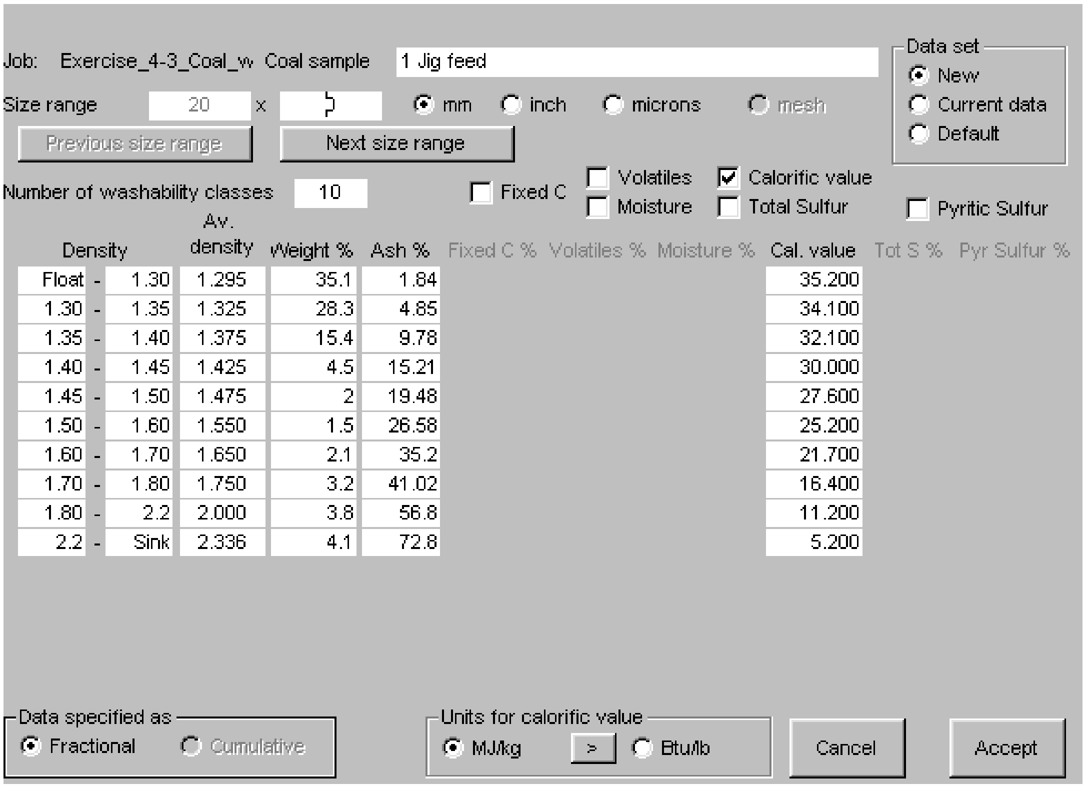
Edit the system data. Select coal processing plant but do not check proximate analysis because this is not available in this case. Specify specific gravity by particle type because washability data is available and the density of each washability fraction will be known. Set the number of size classes to 1 since washability is not available at different sizes in this example. Set largest particle size to 0.02 m. Specify 10 washability classes.

Double click on the feed stream, name the feed stream, and clear the default size distribution data. Now specify the washability data. The data from Table I can be transcribed into the washability form. This is straightforward. Check all boxes that apply to the data. Only calorific value in the present case. It is necessary to specify the average density of each washability fraction. This is usually specified as the average density in washability classes 2 to 9. In the two extreme classes the average density is obtained by extrapolation assuming a linear relationship between the ash content and the reciprocal of the average density. Thus washability class I is assigned an average density of 1.295 and washability class 10 an average density of 2.336.

Finally make sure that the correct units for calorific value are specified.

Accept this data, edit the unit parameters and run the simulation. To see the stratification profiles in the jig, right click on the jig icon.

Density	Class density	Weight %	Ash %	Calorific value MJ/kg
Float -1.30	1.295	35.1	1.84	35.2
1.30 - 1.35	1.325	28.3	4.85	34.1
1.35 - 1.40	1.375	15.4	9.78	32.1
1.40 - 1.45	1.425	4.5	15.21	30.0
1.45 - 1.50	1.475	2.0	19.48	27.6
1.50 - 1.60	1.550	1.5	26.58	25.2
1.60 - 1.70	1.650	2.1	35.20	21.7
1.70 - 1.80	1.750	3.2	41.02	16.4
1.80 - 2.20	2.000	3.8	56.8	11.2
2.20 Sink	2.336	4.1	72.8	5.2



Job: Exercise_4-3_Coal_w Coal sample 1 Jig feed

Data set: New / Current data / Default

Size range 20 x mm / inch / microns / mesh

Previous size range | Next size range

Number of washability classes 10

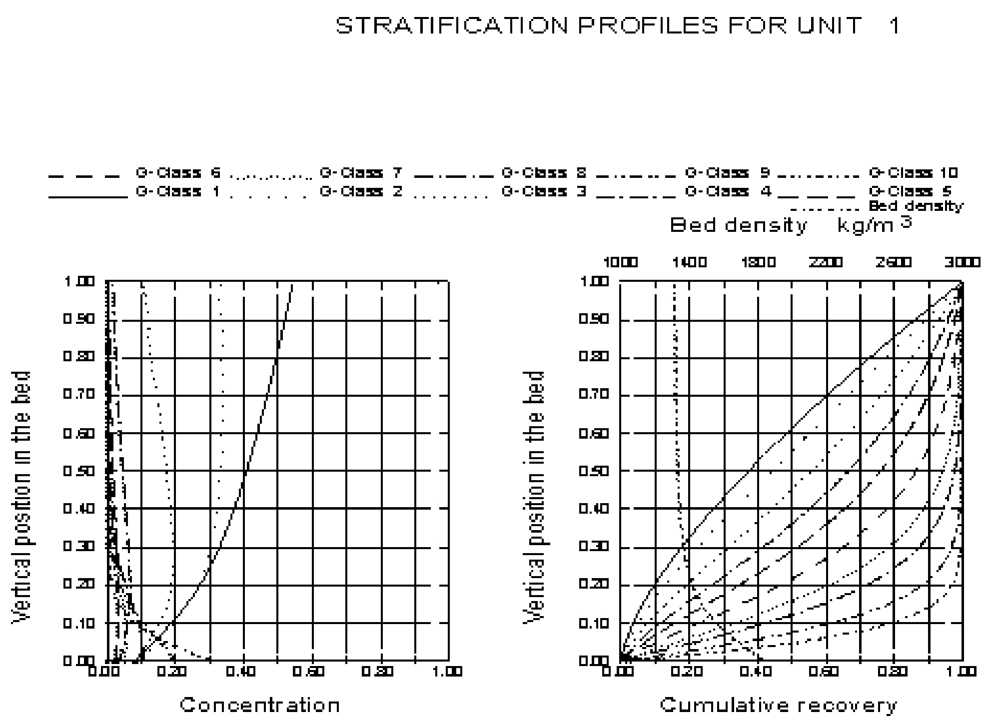
Fixed C / Volatiles / Moisture / Calorific value / Total Sulfur / Pyritic Sulfur

Density			Av. density	Weight %	Ash %	Fixed C %	Volatiles %	Moisture %	Cal. value	Tot S %	Pyr Sulfur %
Float	-	1.30	1.295	35.1	1.84				35.200		
1.30	-	1.35	1.325	28.3	4.85				34.100		
1.35	-	1.40	1.375	15.4	9.78				32.100		
1.40	-	1.45	1.425	4.5	15.21				30.000		
1.45	-	1.50	1.475	2	19.48				27.600		
1.50	-	1.60	1.550	1.5	26.58				25.200		
1.60	-	1.70	1.650	2.1	35.2				21.700		
1.70	-	1.80	1.750	3.2	41.02				16.400		
1.80	-	2.2	2.000	3.8	56.8				11.200		
2.2	-	Sink	2.336	4.1	72.8				5.200		

Data specified as: Fractional / Cumulative

Units for calorific value: MJ/kg > Btu/lb

Cancel | Accept



These stratification profiles are accessible from the View Flowsheet menu and right clicking on the jig icon.

EXERCISE 3-4 *The Model for the Reichert Cone*

This exercise will allow you to investigate the model for the Reichert cone. These interesting devices can be installed in any one of many different configurations. Start a new MODSIM job.

Select a Reichert cone from the gravity separation group in the select menu. Add a feed stream, a concentrate stream, a tailing stream and a middling stream.

The cone will treat 60 tonnes/hr of iron ore at 60% solids. The feed material has the following specifications: Minerals: Magnetite specific gravity 5.2 and silica specific gravity 2.7.

Mesh size mm	% passing
4.29	99.0
3.04	90.0
2.15	68.4
1.52	43.8
1.07	25.0
0.76	13.4
0.54	6.9
0.38	3.5
0.27	1.8

G-class	Fraction	% magnetite	0x1.07 mm	1.07x2.15 mm	>2.15 mm
1	Float 2.7	0.0	0.6	0.5	0.4
2	2.7x3.17	16.3	0.2	0.25	0.25
3	3.17x3.94	49.8	0.0	0.05	0.10
4	3.94x5.2	85.1	0.1	0.1	0.2
5	Sink 5.2	100	0.1	0.1	0.05

Edit the system data to specify the feed material. Specify 2 minerals: Silica and magnetite. Specify the specific gravity by mineral.

Specify 10 size classes, 5 grade classes and largest particle size = 0.005 m.

Click "Set up grade classes" to specify the composition of the 5 types of particles. The default compositions must be changed to reflect the magnetite compositions of the 5 particles types as shown in Table 2. The specific gravities of the particle types will be calculated automatically.

Double click the feed stream in the system data form. Specify a name for the stream and enter the particle size distribution from Table 1. Specify a feed rate of 60 tonnes/hr at 60% solids.

Click on "Specify the grade distribution" to specify the distributions over the grade classes. Note that the distribution varies with particle size and data for 3 size ranges is given in Table 2. Change the upper size of the size range to 0.00107 (1.07mm) and press enter. A second size range is automatically created. Create the third size range by changing the upper size of the second size range to 0.00215. A new size range is automatically created. Select the size ranges in turn and enter the distributions over the grade-classes as specified in Table II.

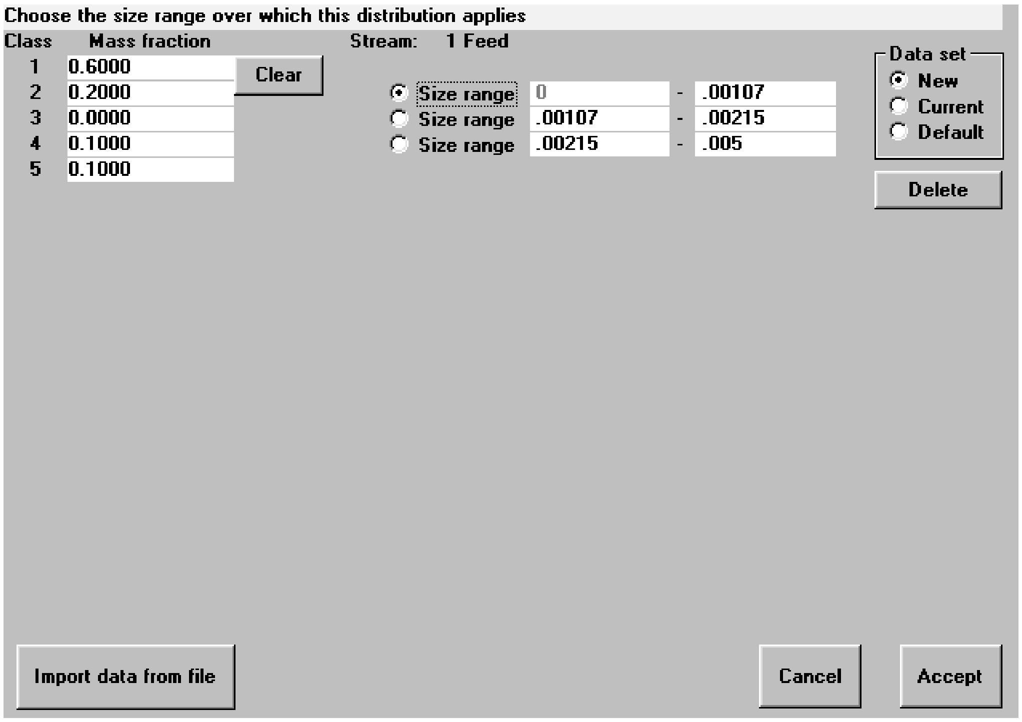
Edit the model parameter data for the Reichert cone. The model is quite versatile and any of the standard cone configurations can be simulated. For this exercise the 4DSV configuration is suggested. Note that because a middling stream has been drawn on the flow sheet, the cone configurations that do not permit the withdrawal of a middling stream cannot be selected.

For the first run of this model set the slots at value 5 for each stage. This means that each stage slot is set at the mid point of the available range. Choose the number of stage concentrates that make up the middling stream. Select the coordinates of the point of convergence as (-31.0. 2.5). The specific stratification constant = 0.002 which is a typical value for the Reichert cone. This completes the data specification for this exercise. Accept the data and run the simulation.

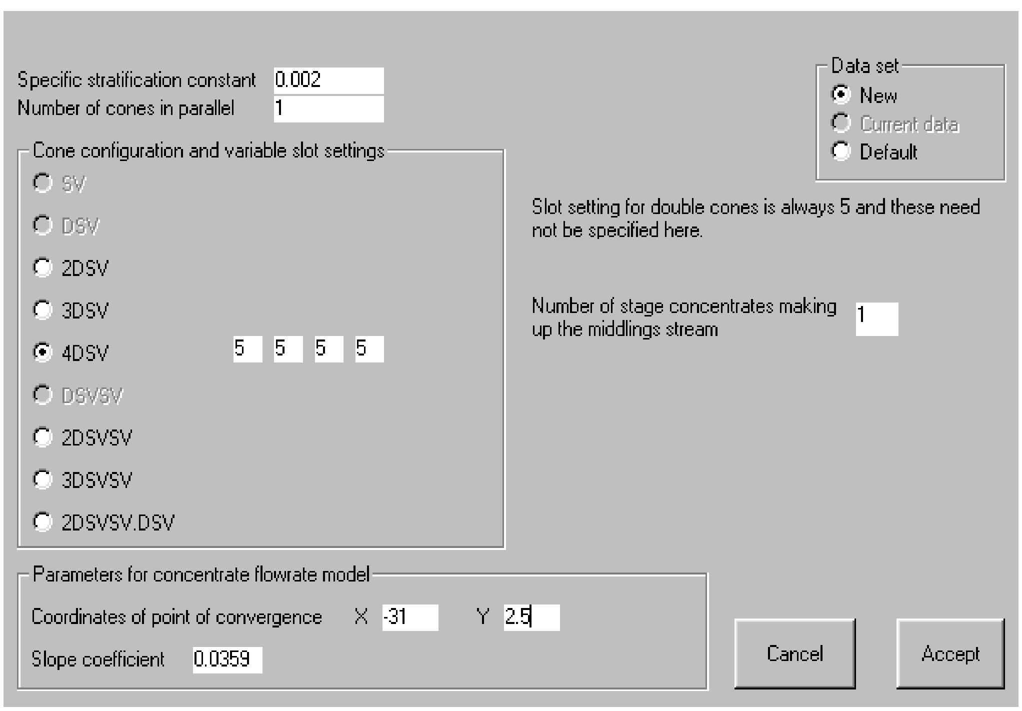
The iron content of each of the process streams would normally be of interest in an operation such as this. The iron content can be displayed in the stream flyouts on the flow sheet and this need to be set up in the output format. Edit the output format. Choose Fe as the metal and specify the Fe content of the two minerals that are present (0% in silica and 72.4% in magnetite).

You can immediately assess the effectiveness of the Reichert cone for this type of application.

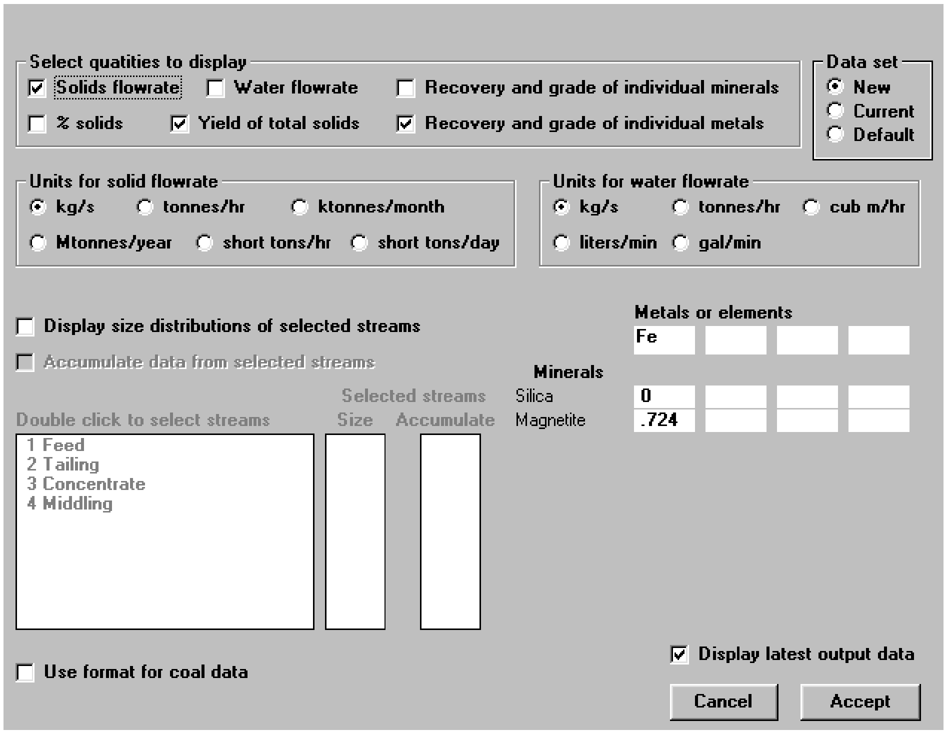
You should now investigate the many possible variations that are available for this versatile piece of equipment. You should investigate the effect of using the different slot settings and also the effect of allocating concentrate streams between the concentrate and middlings. An interesting exercise is the investigation of the change in performance as the middling stream is recycled to the head of the unit.



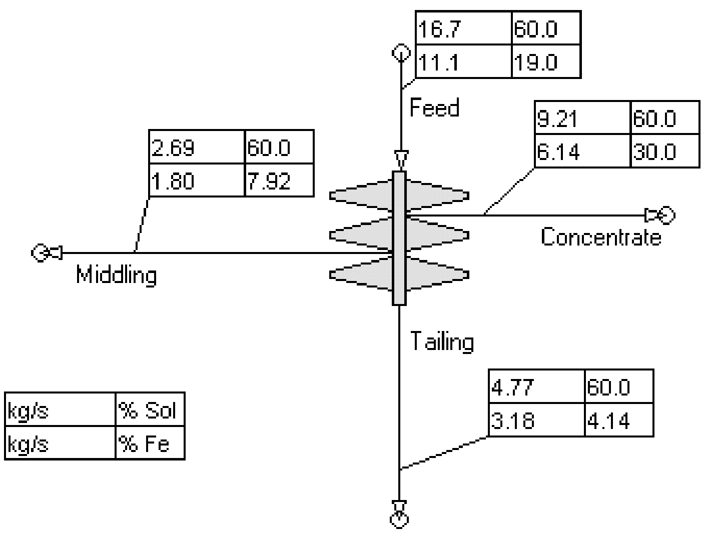
Form to specify the distribution of particles over the G-classes in the 0x1.07 mm size range.



Form to specify the operating parameters for the Reichert cone. A 4DSV configuration has been chosen here.



Set up the output format using this form. Note that "Recovery and grade of separate metals" is checked which generates the data for the fourth quadrant in the stream flyouts.



CONCERNS TO BE ADDRESS:

- In Exercise 3-1 Investigate how the grades of CaO and SiO2 in the underflow vary as the target specific gravity in the dense-medium cyclone is changed systematically over the range 2.80 to 3.1. This can be reported most effectively on a graph of grade vs target specific gravity.
- In Exercise 3-2 Run several simulations with varying medium density in the second-stage cyclone and find out the medium density that minimizes the silica content of the second stage underflow.
- In Exercise 3-4 investigate the effect of using the different slot settings and also the effect of allocating concentrate streams between the concentrate and middlings. Also investigate the change in performance as the middling stream is recycled to the head of the unit.

Module-4:

Simulation of Froth Flotation with MODSIM.

Froth flotation is the most difficult of the mineral processing unit operations to model and simulate. Although the basic processes that govern the flotation process have been identified and researched for many years, the complex interactions between the many chemical and physical micro-processes require careful analysis in order to build models that are reliable and can be used for effective and accurate simulation. In this module we will look at two of the most successful flotation models - the Klimpel model and the distributed rate constant model. The Klimpel model has been used widely to evaluate flotation systems but it is not really effective for plant simulation work. The distributed rate constant model was developed specifically for flotation plant simulation.

In this model you will learn to specify kinetic parameters for a flotation system and how to fix the water balance in a flotation cell. The water balance fixes the residence time in the cell which ultimately determines the recovery of each component. You will also observe the benefits of multistage and recycle configurations.

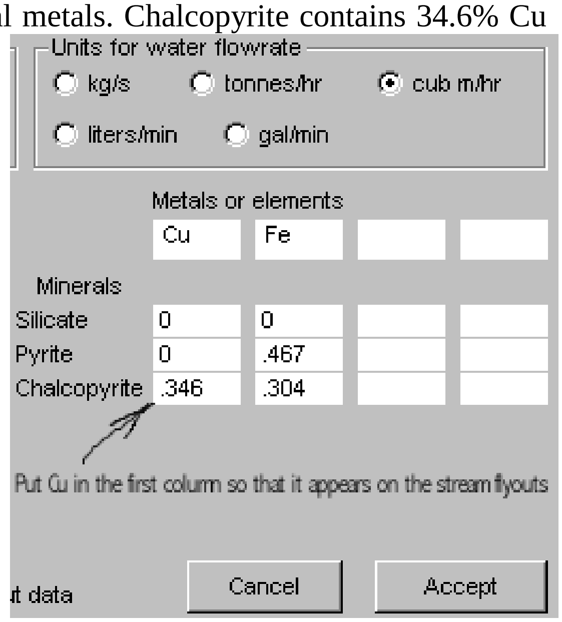
EXERCISE 4-1: *shows how to simulate a single flotation cell using the Klimpel model.*

Draw a flowsheet with a single flotation cell (A bank of flotation cells with one cell). The ore to be treated is from a porphyry copper sulfide deposit with chalcopyrite and pyrite as the main sulfide minerals in a silicate gangue. To keep a focus on the flotation model we will assume that the minerals are perfectly liberated. Therefore there are three minerals, silicates with specific gravity 2.71, pyrite with specific gravity 5.0 and chalcopyrite with specific gravity 4.1 in 3 grade classes. Since the Klimpel model does not allow the kinetic constant to vary with particle size, only one size class is required. Set largest particle size to 5.0E-4 m. Each grade class consists of one pure mineral so check the grade-class set up. Specify a feed rate of 75 tonnes/hr at 28% solids. The composition of the feed is 80% silica, 8.5% pyrite and 11.5% chalcopyrite. Specify 1 mesh size on the feed stream form and clear the default size distribution.

It will be useful to track the grades and recoveries of Cu and Fe in this exercise so edit the output format and request grades and recoveries of individual metals. Chalcopyrite contains 34.6% Cu and 30.4% Fe. Pyrite contains no Cu and 46.7% Fe.

Choose model KLIM for the flotation cell. Choose a single cell of 10 m^3 with 15% air holdup. Set the concentrate percent solids to 55%. This value will fix the water balance around the cell. The kinetic parameters for the minerals (feed) are:

Mineral	Ultimate recovery %	Kinetic constant 1/min
Silicates	12	0.12 (0.0020 1/sec)
Pyrite	53	0.8 (0.0133 1/sec)
Chalcopyrite	83	2.5 (0.0417 1/sec)



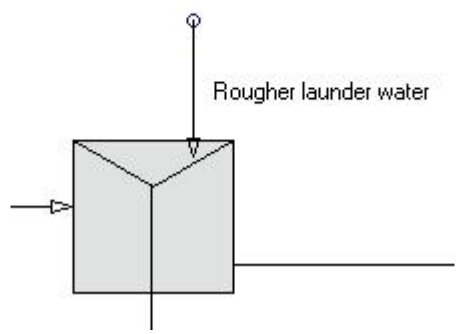
Run the simulation and you should find that the cell will recover 71% of the copper at a grade of 21% Cu. The concentrate will also contain 29% Fe.

Save this job when you are satisfied with the result.

EXERCISE 4-2: *Multi-stage flotation plant*

This exercise will use the same feed material as was used in exercise 4-1 and also the same rougher stage. Therefore open the existing saved job from exercise 4-1. Edit the flowsheet and add a scavenger cell to take the tailings from the rougher and a cleaner cell to take the concentrate from the rougher. Add concentrate and tailings streams from these cells but at this stage DO NOT CONNECT THE RECYCLES. Flotation plants can be tricky to calculate when they have recycles and you should run a few simulations with the open-circuit configuration until you are satisfied that the various units in the flowsheet are behaving as expected.

You should also add water to the concentrate launder of the rougher cell. Recall that you specified a rougher concentrate at 55% solids in exercise 4-1. This would be too dense to serve as the feed to the cleaner cell so it must be diluted. You can add a water stream directly to the concentrate launder of the rougher cell as shown here.



Accept the flowsheet and this is a good time to change the job name.

Edit the system data to register the new flowsheet structure and to specify the water flowrate in the rougher launder. Specify that this should dilute the concentrate to 25% solids which will make a satisfactory feed to the cleaner.

Edit the unit model parameters and choose model KLIM for each stage in the circuit. Specify one cell of 10 m^3 for the scavenger and one cell of 2 m^3 for the cleaner. The kinetic constant should be set to the values shown in Table.

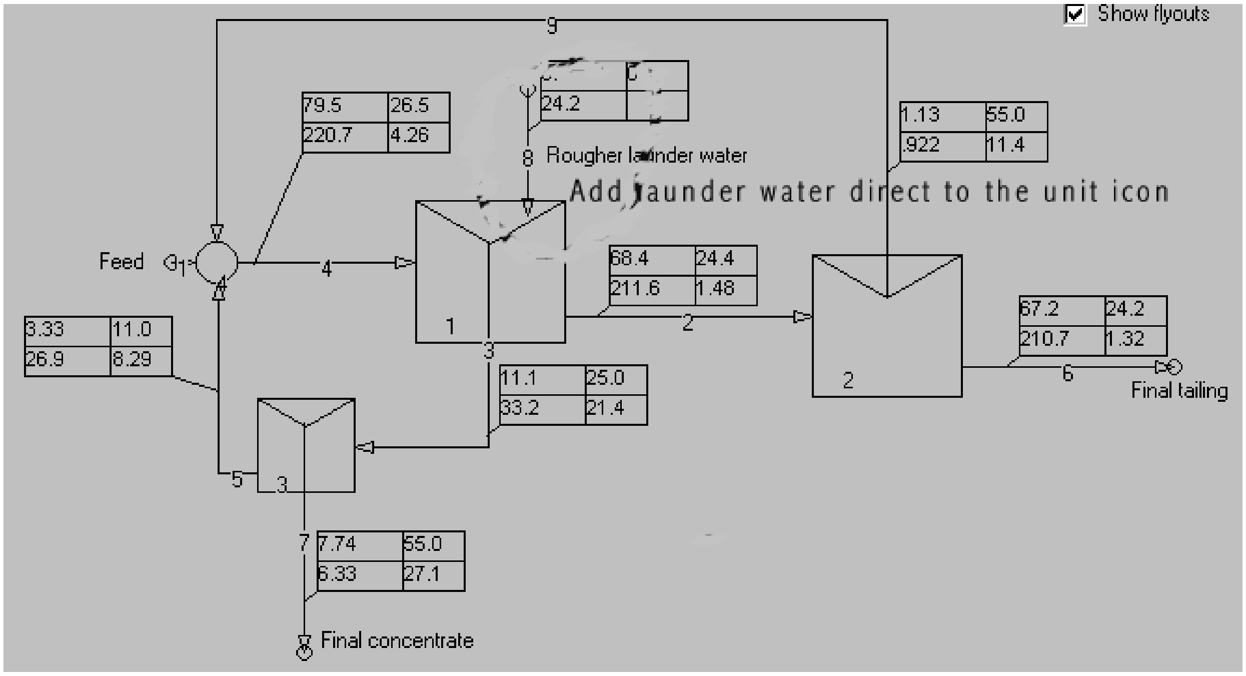
Mineral	Scavenger	Cleaner
Silicates	2%	15%
Pyrite	15%	80%
Chalcopyrite	15%	98%

It is not possible to specify accurately the ultimate recoveries in the scavenger and cleaner cells. Most of the sulfide minerals that gets to the scavenger are non-floating since it consists of all of the non-floatable fraction in the rougher as well as the unrecovered portion of the floatable fraction. Almost the entire sulfide mineral in the cleaner is floatable since the only non-floatable material that gets to the cleaner is by entrainment into the rougher froth. It is impossible to know these amounts before the simulation is done so the ultimate recoveries must be estimated for the scavenger and cleaner cells. Use the values given in Table.

This difficulty in specifying the ultimate recoveries is made even worse when the plant includes recycle streams and makes the Klimpel model unsuitable for any but the most approximate simulations. MODSIM has a better method that is based on the distributed rate constant model and you will investigate this in exercise 4-3.

Run the simulation to check that all parameters have been set up correctly.

When you are satisfied that all three cells are operating properly you are ready to close the recycle loops. To do this you need to insert a mixer in the feed stream ahead of the rougher cell. Close the recycle from the scavenger concentrate and run the simulation. If this is satisfactory, close the recycle from the cleaner tailing. This should produce a final concentrate containing 27% Cu at 69% recovery. The advantage of multistage operation is immediately apparent by comparison with the results from a single rougher stage in exercise 4-1.



EXERCISE 4-3: *Flotation plant using distributed rate constants.*

Use the flowsheet and system data that were set up for exercise 4-2.

Edit the system data and specify 25 size classes, 3 grade classes and 4 S classes. 4 S classes will allow each of the 3 grade classes to be divided into a floatable and a non-floatable class. (Note that 4 not 6 S classes are required to do this). Click the "set up S classes" button on the system data form. Specify the values of the kinetic constants (K values) in the four S classes as follows.

S class	K value
1	0.0
2	0.12
3	0.8
4	2.5

Note in particular that S class 1 has a kinetic constant of zero and therefore is associated with non-floatable particles.

Make sure that the largest particle size is set to 500 microns (5.0E-4 m) and edit the data for the feed stream. Specify 20 mesh sizes and generate a Rosin-Rammler distribution with D63.2 = 100 microns and lambda = 1.2.

Feed rate should be 20.83 kg/s at 28% solids. Check that grade distribution is 80% silicates, 8.5% pyrite and 11.5% chalcopyrite.

Specify the distribution over S classes to reflect the kinetic behavior of each mineral type according to the data in Table.

Mineral	Ultimate recovery	Kinetic constant 1/min
Silcates	12	0.12
Pyrite	53	0.8
Chalcopyrite	83	2.5

Thus for the grade class that is associated with silicates, the particles are distributed as 0.88 in S class 1 and 0.12 in S class 2. For the grade class that is associated with pyrite, the particles are distributed as 0.47 in S class 1 and 0.53 in S class 3. For the grade class associated with chalcopyrite, the particles are distributed as 0.17 in S class 1 and 0.83 in S class 4.

This completes the specification of the system data. Accept the system data and edit the unit model parameters.

Choose model FLTN for the three flotation stages. Since MODSIM will now keep track of each S class as the particles move from cell to cell in a bank of flotation cells, it is possible to specify that each stage is actually a bank of cells as would normally be found in practice. Specify the rougher and scavenger as 5 cells each of 2 cubic meters and the cleaner as 4 cells of 0.5 cubic meters. Notice that the data input form automatically defaults the kinetic constants to those defined for the S classes in the system data. You can change these values for this particular unit if you wish. This is done, for example, when additional collector is added in the circuit ahead of a particular bank to boost the flotation kinetics. It is also necessary when the chemical environment is changed for a particular flotation stage to change the flotation behavior radically. The chemical environment is changed by changing the type of collector, the pH, the frother or by the addition of depressants. In the present example this would occur if we wanted to make a differential separation of chalcopyrite from pyrite by floating the mixed chalcopyrite-pyrite concentrate.

We do not want to investigate these aspects of flotation technology in this exercise so do not change any of the flotation kinetic constants in any of the three stages.

The trickiest parameter to set when using the FLTN model for flotation is the solids hold-up in the cells. This is the parameter that defines the water balance. The behavior of the individual cells and the plant as a whole is very sensitive to the value of this parameter and it must be chosen with care. The following values are recommended for this exercise: rougher 300 kg/m^3, scavenger 300 kg/m^3 and cleaner 250 kg/m^3. It is common to run cleaner cells at lower pulp densities than roughers and scavengers. This parameter defines the solid content in the floatation cell in terms of the solid hold up per unit cell volume.

All other unit parameters should be left at their default values. If you started from a successful simulation in exercise 4-2, the current data should lead to a successful simulation. Run the simulation and you should make a concentrate that assays 23% Cu and 31% Fe at a copper recovery of 79%. This represents a more realistic simulation than exercise 4-2.

CONCERNS TO BE ADDRESS:

- In exercise 4-3 you should note the large increase in residence time as the pulp progresses from cell to cell down the cleaner bank. Why does this happen and does it suggest a possible design modification to you? (You can see the residence times for the individual cells in the report file for the unit.) Try a few alternatives and see what the simulator tells you.

Module-5:

Simulation of Comminution with MODSIM.

Models for comminution operations are comparatively well developed and comminution circuits are comparatively easy to model and simulate. Comminution processes are quite complex and it is necessary to understand what kind of information and data is required to model and simulate comminution circuits successfully. It is also necessary to have an appreciation of the different model types that are available. In this module we will restrict attention to an analysis of a conventional closed ball mill circuit. We will use the classic time-based approach that is usually associated with the name of Len Austin and then look at the modeling of the same circuit using the specific grinding energy method. Both methods use the breakage and selection function approach. Three different ores will be investigated in the exercises: limestone, taconite and a tough porphyry ore.

EXERCISE 5-1: *Ball milling circuit using Austin's model - Limestone*

Simulate a ball milling circuit that must handle 100 tonnes/hr of ore. The largest particle size in the feed is 10 mm. The feed has a Rosin-Rammler size distribution with D63.2 = 2.5 mm and lambda = 1.2. The specifications of the equipment are

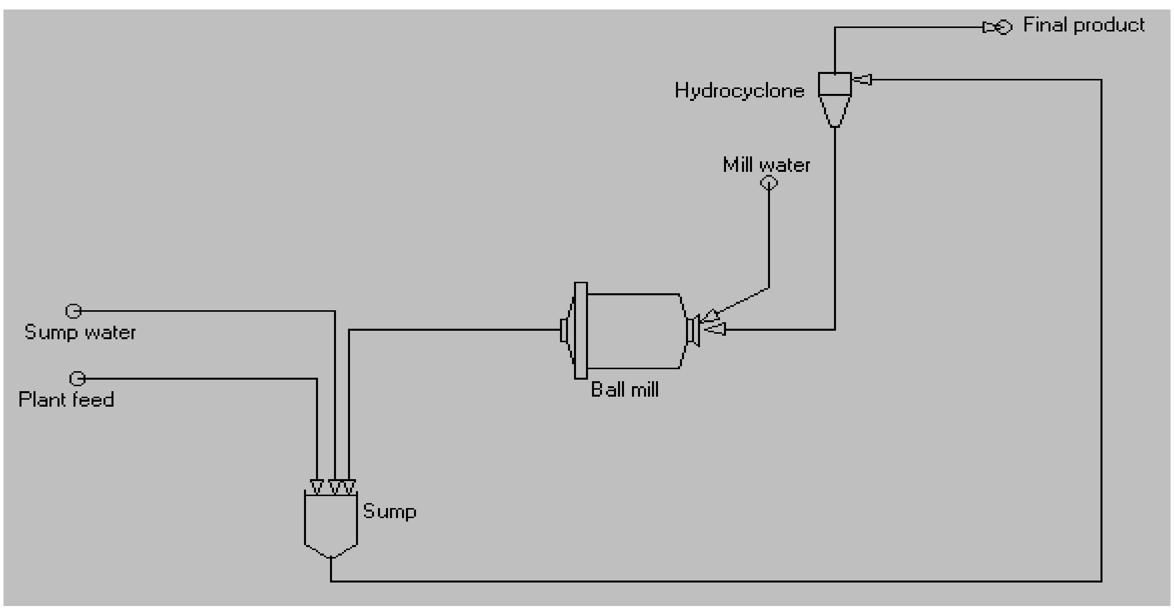
Ball mill

Mean residence time 7 minutes

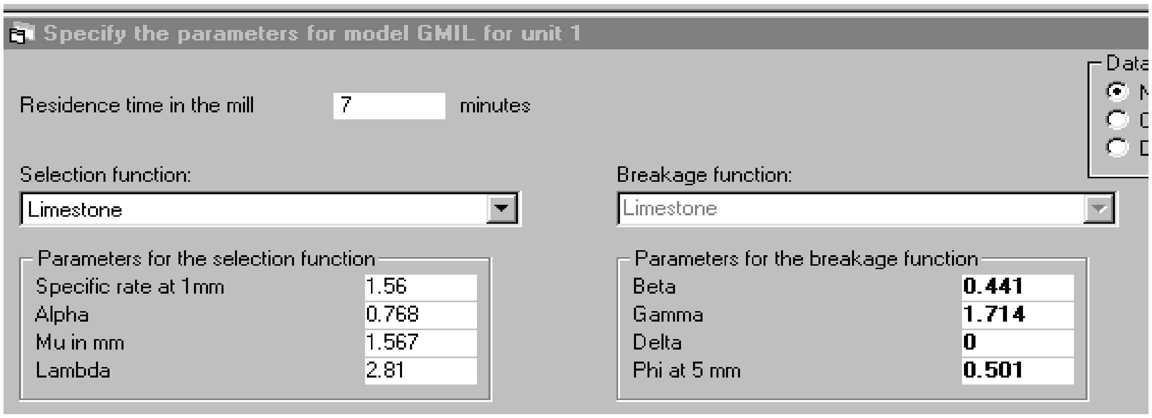
Overflow discharge with no overfilling and no post classification. 70% solids in the mill.

Cyclones

38 cm diameter "standard" geometry with 10 cyclones in the cluster. Sufficient water should be added to the sump to make the cyclone feed 45% solids by weight.



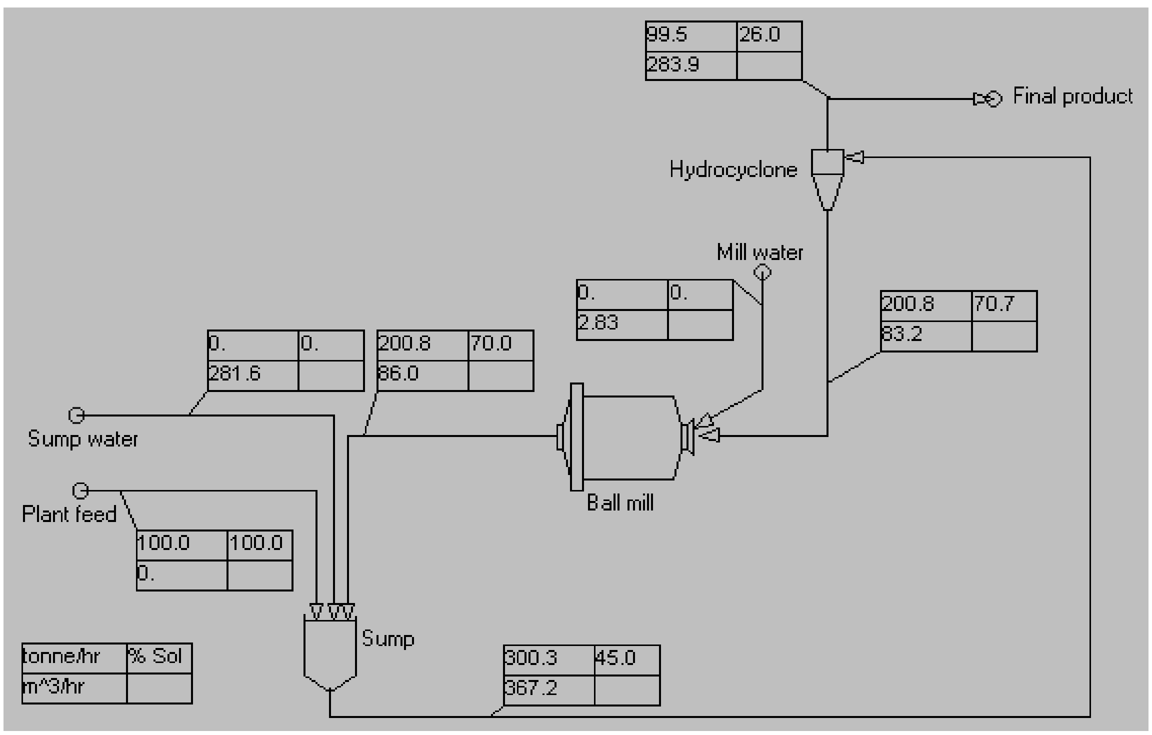
The circuit is standard with pre classification of feed. A suitable flowsheet is illustrated in Figure. Name the plant feed stream, the ball mill feed stream, the ball mill product stream and the cyclone overflow stream for future reference. Simulate the operation of this circuit when it processes limestone. Parameters that define the selection function for limestone have been determined and are preloaded for selection using the model GMIL in MODSIM. Limestone has a specific gravity of 2.7 and Bond Work index of 11.1 kWhr/tonne.



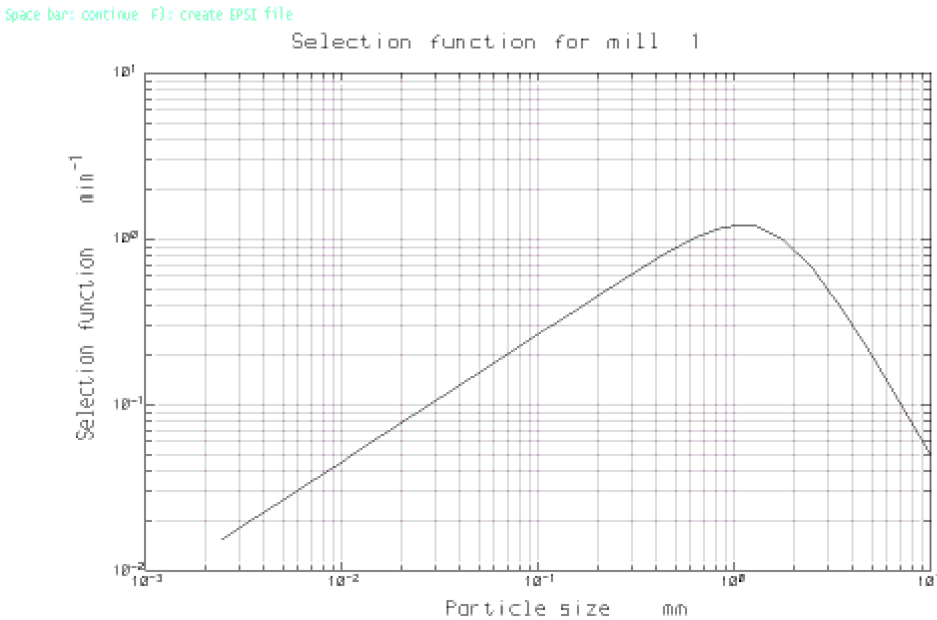
Use the preset parameters for the selection function and the breakage function. These parameters can be changed by the user to suit any particular material but for the purposes of this exercise the default values should be used.

Edit the parameters for the hydrocyclone. Choose the Plitt model CYCL. Set the cyclone diameter to 38 cm and specify 10 cyclones in the cluster. Leave all other parameters at their default settings.

Run the simulation and make a note of the following information.



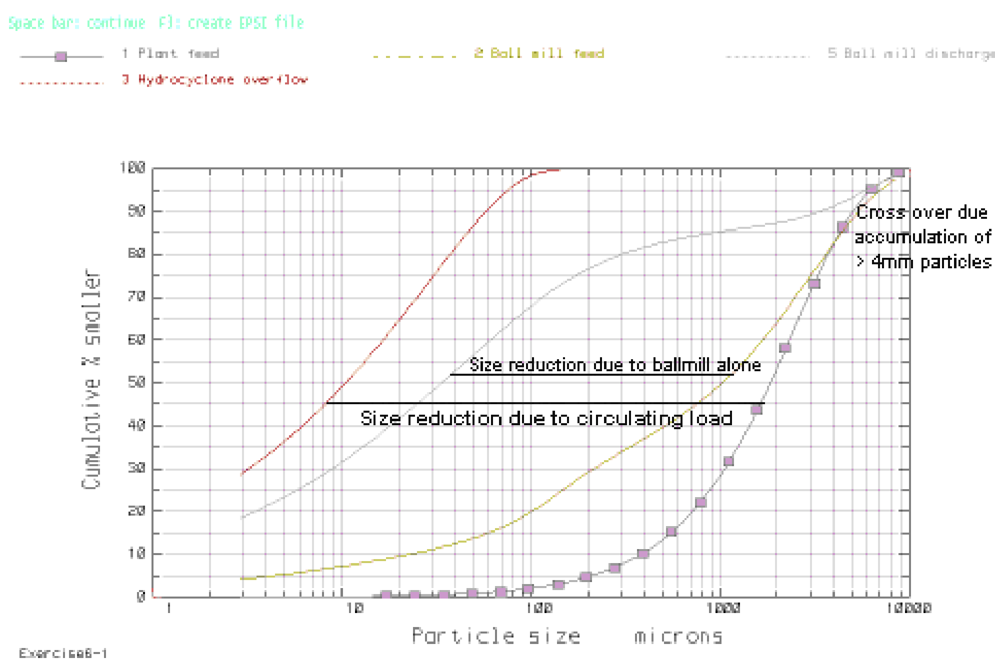
1. Recirculating load = 100xball mill feed/plant feed
2. Cyclone underflow % solids
3. D80 in the mill feed and product. Calculate the power required using Rowland's factor for Bond work index in open circuit.
4. D50 in the cyclone
5. Pressure drop across the cyclone
6. Right click on the mill icon to generate a plot of the selection function that was generated by the mill model. Save a copy of this graph for future reference.
7. Plot the size distributions in the plant feed, the ball mill feed and the cyclone overflow.



View the size distribution graphs for the plant feed, the ball mill feed; the ball mill product and the cyclone overflow make a pattern that gives an immediate diagnosis of the health of the milling circuit.

The graphs for this case are shown below. Note the spread between the plant feed and plant product graphs and the much narrower spread between the ball mill feed and the ball mill product. This shows the additional size reduction that is achieved by the circulating load over and above that generated by the ball mill itself. In a well-designed and operated ball mill circuit the inner mills envelop should be entirely within the outer circuit envelope. In this example the plant and mill feed lines cross at about 4 mm indicating that >4 mm material is accumulating in the circuit which is symptomatic of a media ball size that is too small for the material that is processed.

The graphs for this case are shown below: Save the job.



EXERCISE 5-2 *Ball milling circuit using time-based model - Taconite*
Repeat exercise 5-1 using the Austin model for the rate of breakage and the default values for taconite. The specific gravity of taconite is 3.4 and Bond work index is 14.9 kWhr/tonne.
Run the simulation and record the data as specified in exercise 5-1.

EXERCISE 5-3: *Ball milling circuit using time-based model - Porphyry*
Repeat exercise 5-1 using the Austin model for the rate of breakage and the default values for porphyry ore. The specific gravity is 2.7 and the bond work index is 28.5 kWhr/tonne. Because this ore is so tough a larger ball mill will be required so increase the residence time to 15 minutes. A much larger circulating load will be required so increase the cyclone diameter to 76 cm and put 20 cyclones in the cluster.
Run the simulation and record the results as before.

EXERCISE 5-4 *Ball mill circuit - Energy-based model for Limestone*
This exercise uses the flowsheet that was constructed in exercise 5-1. Open the job that was saved in exercise 5-1. All data remains the same except that the ball mill will be modeled using the Herbst-Fuerstenau energy-specific model for the rate of breakage. Use MODSIM model HFMI.
Selection function parameters for this ore are:
S1E = 1.15 tonnes/kWhr, zeta1 = 0.185 zeta 2 = -0.100 (Note the negative value which is essential).
Breakage function parameters are:
Beta = 3.723, gamma = 0.748, delta = 0.0 Phi 5 = 0.720.
Note that the Herbst-Fuerstenau model requires the power input to the mill and not the average residence time. Set the power to the estimate power obtained in exercise 5-1 (1.07 MW)
Run the simulation and record the data as in exercise 5-1 and compare the data from the two exercises.

EXERCISE 5-5 *Ball mill circuit - Energy-based model for Taconite*
Repeat exercise 5-4 using the Herbst-fuerstenau model. Use the power that was calculated in exercise 5-2 (2.34 MW).
Selection function parameters for this ore are:
S1E = 0.75 tonnes/kWhr zeta1 = 0.23 zeta2 = -0.2
Breakage function parameters are:
Beta = 3.723 gamma = 0.624 delta = 0 Phi5 = 0.65

EXERCISE 5-6 *Ball mill circuit - Energy-based model for porphyry*
Repeat exercise 5-3 using the Herbst-fuerstenau model. Use the power that was calculated in exercise 5-3 (1.48 MW).
Selection function parameters for this ore are:
S1E = 0.3 tonnes/kWhr zeta1 = 0.3 zeta2 = -0.25
Breakage function parameters are:
Beta = 3.723 gamma = 0.748 delta = 0 Phi5 = 0.72
This exercise provides a good opportunity to observe the behavior of the circuit processing this ore as the power input to the mill varies.

CONCERNS TO BE ADDRESS:

- Run the simulation several times varying the power input in steps from 3000 kW down to 1300 kW. Plot the circulating load as a function of the power and observe the size distribution graphs at each power level. This will give you a good idea how to interpret the four size distribution graphs as the mill handles less and less of the comminution load.

Module-6:

Simulation of Liberation with MODSIM.

A liberation model for comminution operations can be used effectively when the model is based on the Population Balance approach. Two such models have been implemented in MODSIM. The "ljubljana" model and the "beta function model". Both models describe the internal structure of the bivariate breakage function, also known as the Andrews-Mika diagram. The ljubljana model is a clever conceptual model of the A-M diagram. Its main advantage is that it contains a single parameter that can be changed to describe a wide range of textures, and therefore simulate the liberation process. The beta function model on the other hand is based on careful observation of the liberation process in real ores. It contains a number of parameters that can be adjusted to provide an as accurate as possible description of the liberation process under almost all circumstances, including differential and preferential breakage. Both models are currently two-phase models, and one phase is invariably the gangue phase while the other is the phase of interest, the valuable. Although this may be seen as a limitation, it represents a tremendous improvement over assuming that liberation remains constant in comminution circuits.

Simulation of liberation is quite a complex subject. However, and fortunately, the interface implemented in MODSIM greatly facilitates the effective use of this rather advanced technology.

Objectives

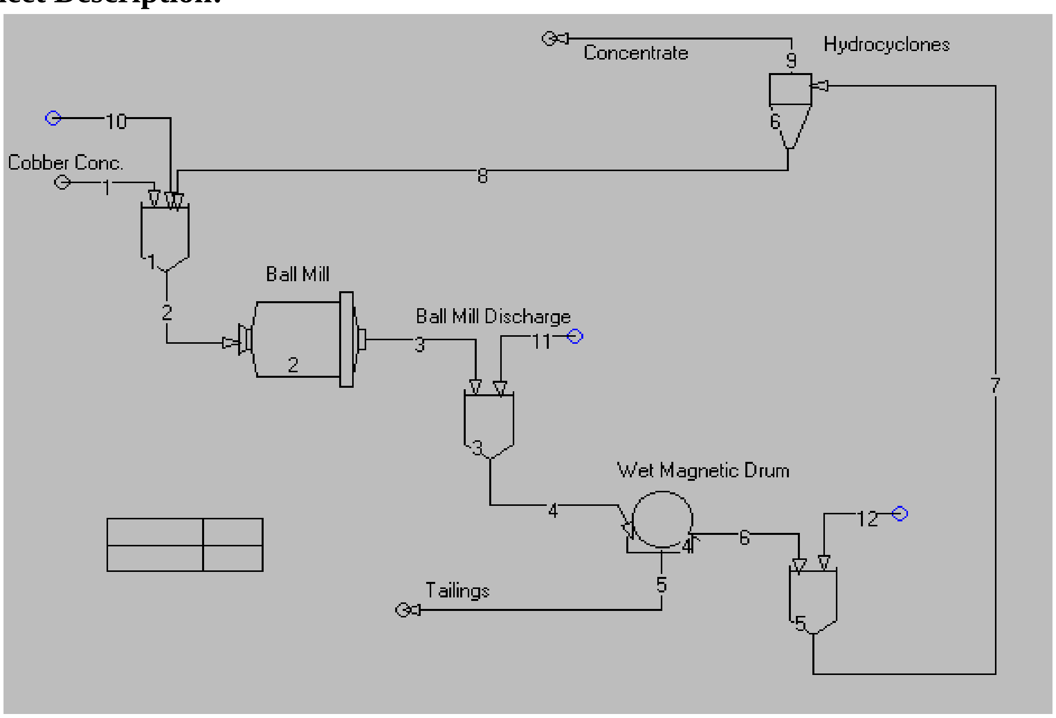
1. Learn how to specify liberation data for a binary ore feed stream in MODSIM.
2. Learn how to simulate the liberation process together with the size reduction process in a Ball Mill using a liberation model.
3. Learn to view and interpret liberation simulation results.

This module contains the following case study:

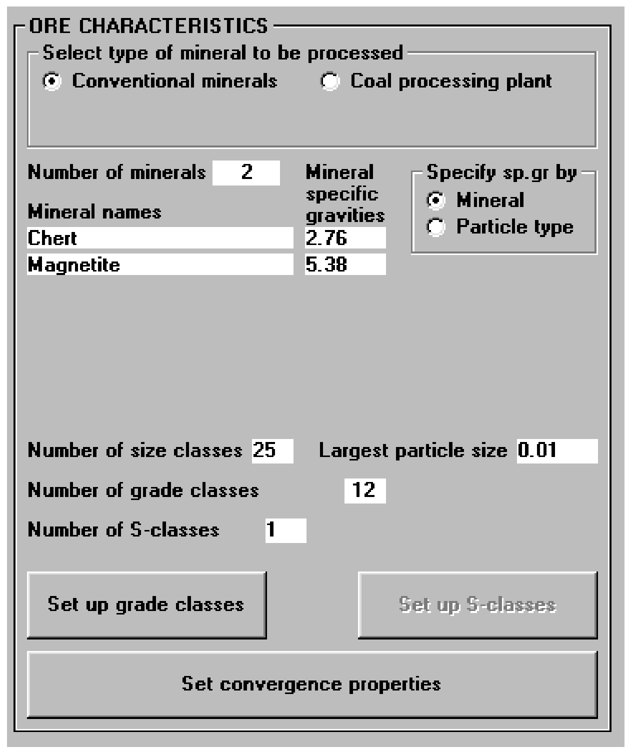
Simulation of a closed continuous grinding circuit with beneficiation of a Taconite ore.

- *Flowsheet Description*
- *System Data*
- *Unit Model Parameters*
- *Simulation Results*
- *Exercises*

Flowsheet Description:



The circuit grinds Taconite that has been pre-concentrated in a Cobber Magnetic Drum, thus the feed stream is labeled Cobber Conc. For those unfamiliar with this process, a Cobber is basically a high-intensity magnetic drum separator, designed to operate with relatively coarse ore particles. The Cobber Concentrate enters the circuit through a sump, which regulates the flow and solids content to the feed to a Ball Mill. Different than a standard closed grinding circuit with classification, this circuit contains a concentrating stage between the milling and classification stages. This concentration is accomplished by a bank of Wet Magnetic Drums, treating the Ball Mill Discharge. The solids content in the feed to the drum must also be regulated by a sump, since the Ball Mill discharge solids content is too high for this process. The tailings of the Magnetic Drum are discarded. This makes a lot of sense since regrinding particles that contain little or no Iron is definitely not cost effective. The magnetic drum concentrate is fed to a hydrocyclone classifier cluster, through a sump, again to regulate the solids content. The hydrocyclone underflow is recirculated, with the circuit feed, back to the mill. The overflow stream is the product of the grinding circuit, and this undergoes further concentration and screening.**Note:** when drawing the magnetic drum icon you will have to reflect the icon if you want your flowsheet to look similar to the one in the figure.



System Data: Ore Characteristics

The ore contains two phases, namely Chert and Magnetite. Phase densities are 2.76 and 5.38 g/cc respectively. The maximum particle size is about 10 mm in the Cobber Concentrate and 25 sizes are more than enough. Set the number of grade classes to 12 and make sure that you are specifying specific gravities by Mineral.

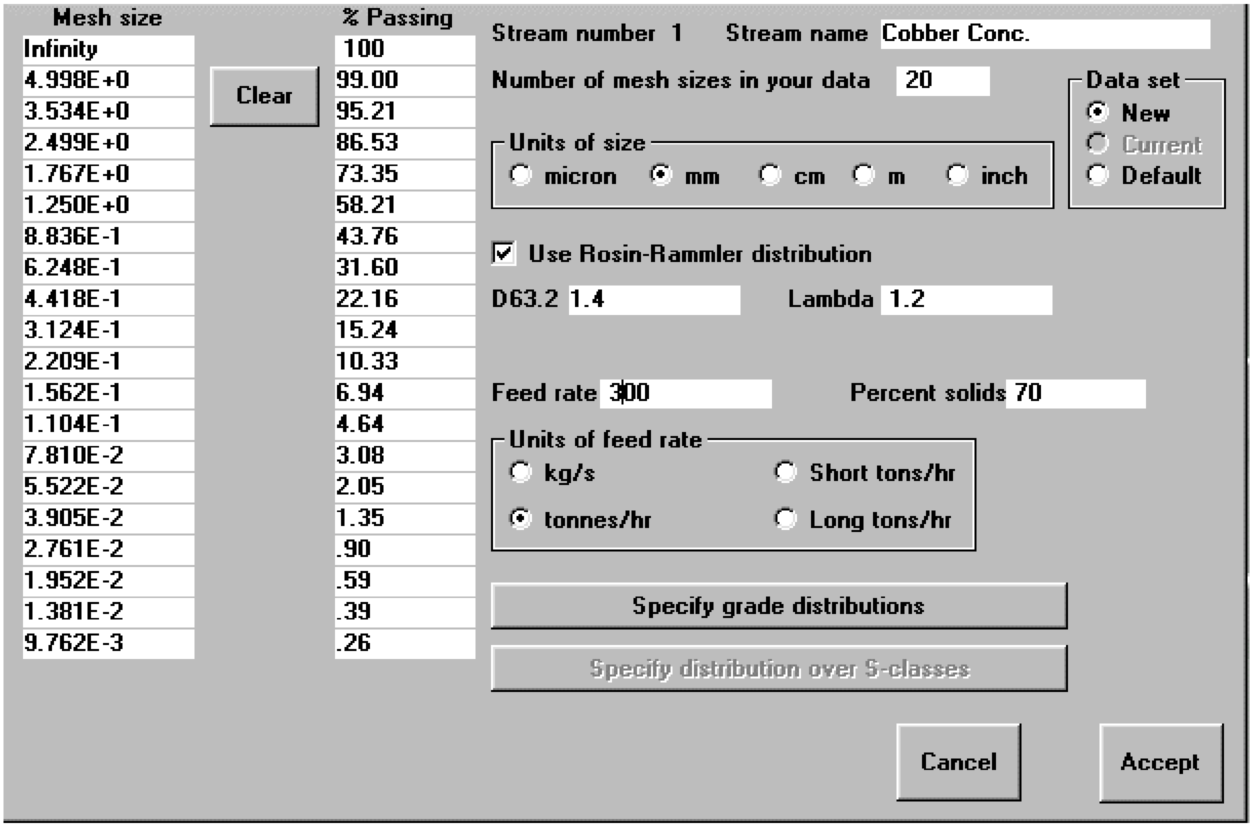
Click on *Set up grade classes*. Modsim automatically sets up 10 equally spaced grade classes and the two liberated ends. This is the standard setup for liberation data, and liberation is normally measured using these same grade classes when image analysis techniques are employed. Note that the densities of each of the 12 particle types are correctly calculated by Modsim.

At this stage, you should go ahead and set up the liberation model data, so click on the *Specify liberation model data* button. For this simulation we are going to use the Ljubljana model. Set the parameter to 50 and check the Calculate Andrews-Mika diagram check box. Accept these parameters and then accept the specified particle types.

Class	Composition	Sp. gr. of class
1	1.0000 0.0000	2.76
2	0.9500 0.0500	2.828882
3	0.8500 0.1500	2.977501
4	0.7500 0.2500	3.142603
5	0.6500 0.3500	3.327089
6	0.5500 0.4500	3.534587
7	0.4500 0.5500	3.769688
8	0.3500 0.6500	4.038292
9	0.2500 0.7500	4.348111
10	0.1500 0.8500	4.709419
11	0.0500 0.9500	5.136216
12	0.0000 1.0000	5.38

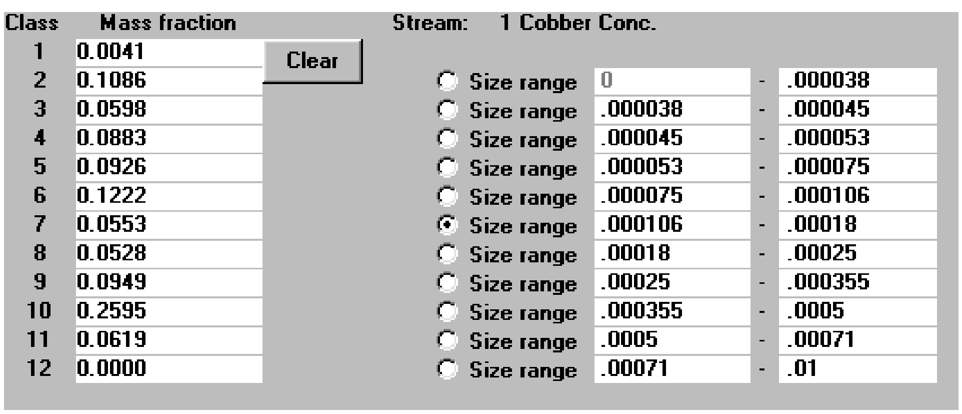
Feed stream data

We now need to specify the characteristics of the feed stream. Double-click on the feed stream number. For the size distribution you can use a Rosin-Rammler distribution with D63.2 = 1.4 mm and Lambda = 1.2, and 20 size classes. The feed rate is about 300 tonnes/hour and the solids content is about 70% in the Cobber Concentrate.



Normally, system data is complete at this stage when there is no liberation data available. In this case, the complete liberation spectrum has been measured for the Cobber Concentrate stream. Click on *Specify grade distributions.*

Specifying grade distributions by hand demands time and is error prone. Fortunately, the liberation spectra can be imported from a file. Click on *Import data from file*, and browse your way to the DemoJobs directory in your Modsim installation directory. Double click on the LiberationData folder and select the cobcon.dat file. Click on Open.



Click on the different *Size range* radio buttons to see the particle grade distributions that are associated with each size. This is the liberation spectra for a single stream and this data was measured by Image Analysis on a sample taken from the real plant. Accept this grade distribution and then accept the feed stream data.

Water addition streams data

Double-click on the water streams to specify water rates. All water streams in this job are specified by the percentage of solids in the Sump units. In this way, Modsim calculates how much water is needed so that the desired solids content is achieved. Specify 77% solids in the

Ball Mill Feed sump, 50% solids in the Magnetic Drum Feed sump and 57% solids in the Hydrocyclone Feed sump. It is also a goog idea to add names to the water addition streams.
No other system data is required but it would be nice to have all internal streams named as well.
Click on Accept. You will see the following Notice window:
This is because we checked the "Calculate Andrews-Mika diagram for Ljubljana model on exit" when specifying the Liberation model. Modsim calculates several Andrews-Mika diagrams, one for each particle type specified, using the single model parameter PhiA. You will be able to see one of these Andrews-Mika diagrams once you completed the simulation.

Unit model parameters

Ball Mill

Choose model GMIL.	Residence time = 4 min,
Selection function: Taconite,	Liberation model: Ljubljana model

Wet Drum Magnetic Separator

Choose model WDM2	Sharpness index = 0.9
Grade for 50% recovery = 0.1	Small size limit of short circuit = 0.466
Bypass coefficient = 56	Water Split to tail stream = 0.78

The magnetic separator is largely dependent on grade, and grade is indeed the operating variable in this separation model. Particles with as little as 10% Magnetite have a 50% probability of being recovered in the magnetics stream. Low grade particles cannot be economically ground and these are removed from the circuit.

Hydrocyclone

Choose model CYCA	Short circuit to underflow = 0.1	Sharpness index = 0.6
Cut size = 120 microns	Classification function = Logistic	

Allow D50 to vary with density and specify the parameter for D50 x density as 0.8
This is a simple model for the Hydrocyclone. In the plant, it was observed that particles with high Magnetite content tend to concentrate in the Underflow. This is because D50 is smaller for havier particles.

Simulation results

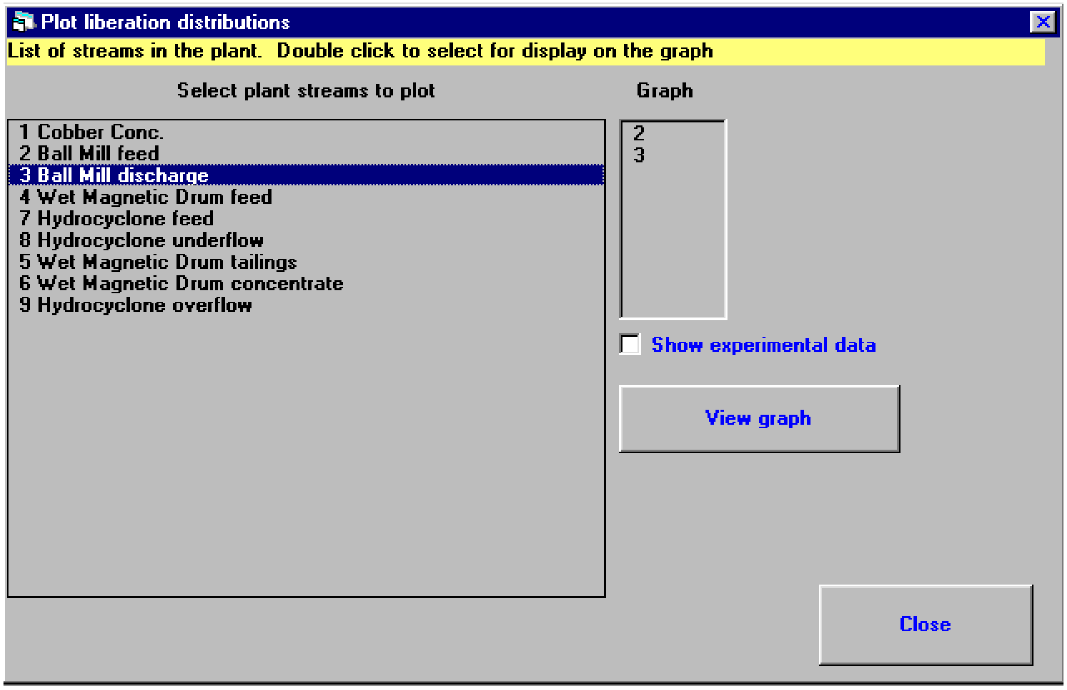
After running this simulation, it is possible to view one of the Andrews-Mika diagrams that were generated by the Ljubljana model. More importantly, you should be able to review the liberation distributions in the circuit streams, and understand what the grade distributions mean.

View the A-M diagram

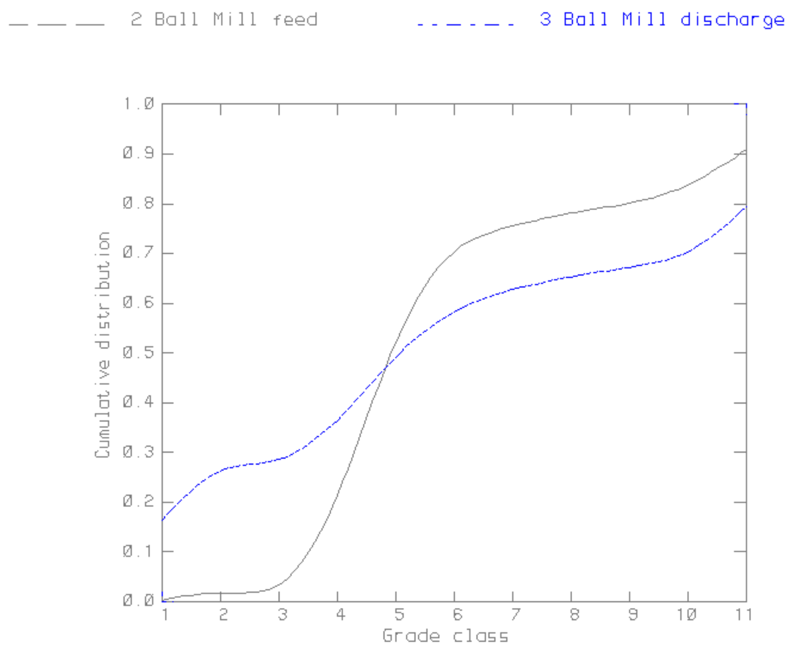
There are in fact 300 A-M diagrams that are generated by the Ljubljana model for this simulation, one for each particle type, 12 grade classes x 25 size classes. To see one of the A-M diagrams generated by the Ljubljana model, select View Flowsheet. Right-click on the ball mill icon and select Andrews-Mika diagram. Take some time analyzing the diagram. Make a note of the liberation size, i.e. the size at which liberated particles start appearing from breakage of a parent particle of about 45% Magnetite. Note the ratio between parent size and liberation size. You may want to run this simulation at several values of phiA and compare the diagrams that are generated. Remember that phiA is the parameter that is defined by the texture of the ore

Liberation spectra around the ball mill

To view the liberation spectra in the ball mill streams select View->Liberation distribution graphs. The Plot liberation distribution s form is opened. This works similarly to the size distribution interface.



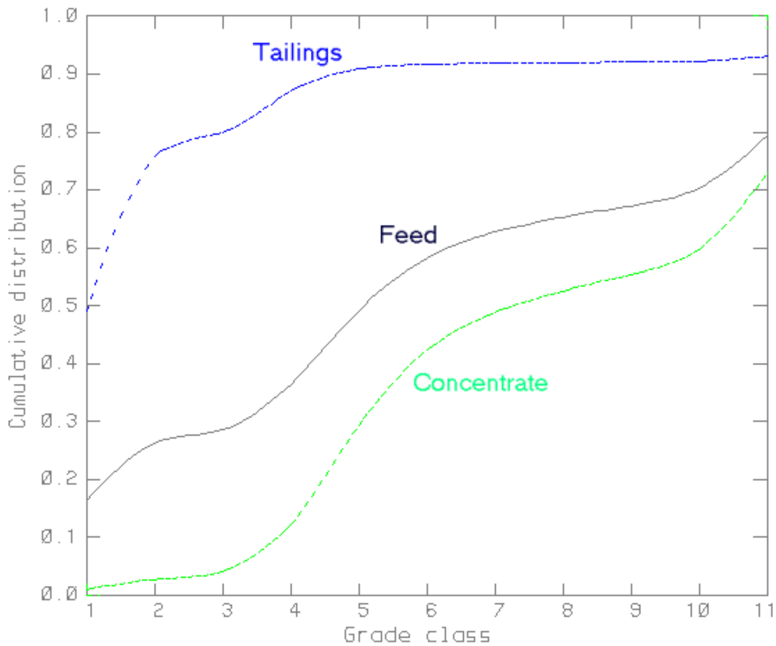
Double-click on the streams you want liberation spectrum to be displayed. The stream numbers are added to the Graph list. In this case we want to view the ball mill feed and discharge streams. Click on view graph.



For each stream, the line represents the distribution of particle grades overall size ranges. The ball mill feed stream has no liberated chert particles and small amounts of low grade particles. It also shows that most particles are accumulating in the 30 to 50% Magnetite grade range. Also, about 9% of liberated Magnetite particles are present in the mill feed. This leads to an important and fundamental question: Do we want to further grind liberated Magnetite? The ball mill discharge on the other hand contains about 17% liberated Chert particles and 21% liberated Magnetite particles, and the unliberated particles are spread more uniformly over the grade domain. The mill is indeed doing its job! Note: Why are there so few particles of low grade in the ball mill feed? See the liberation distributions around the Wet magnetic Drum.

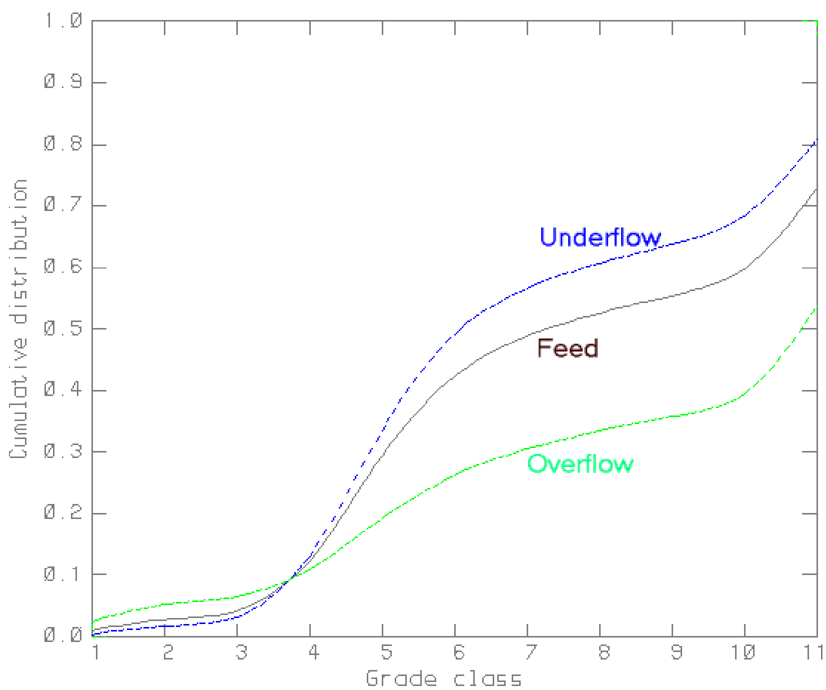
Liberation spectra around the Wet Magnetic Drum

Now select the Wet Magnetic Drum feed (ball mill discharge), concentrate and tailings streams. Clear the ball mill feed stream if this is still selected. Click on view graph.



The feed stream is the ball mill discharge. We have already discussed this in the previous section. The tailings stream is made up of almost 50% of liberated Chert particles, and an accumulation of low grade particles. It also contains about 7% of liberated magnetite particles. In the actual plant, this stream is treated in a scavenging unit, and the liberated Magnetite is recovered. Their presence in the tailings stream is due to the by-pass factor in the Drum. The concentrate stream contains no liberated Chert particles. That is the reason the ball mill feed does not contain this type of particles. From about 30% Magnetite content and up, the Drum recovers most particles, which is expected. The concentrate stream contains about 27% liberated Magnetite particles.

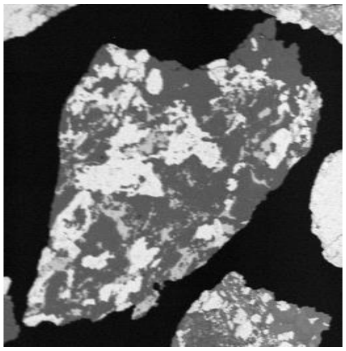
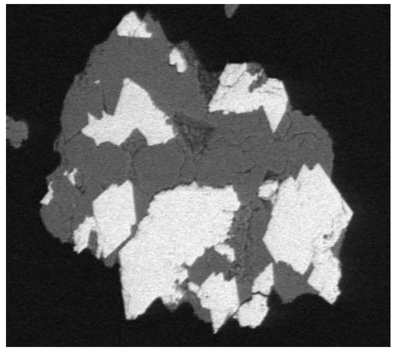
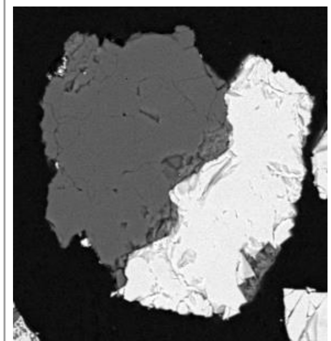
Liberation spectra around the Hydrocyclone



Now select the Hydrocyclone streams. Click on view graph.
The underflow contains mostly particles in the 30 to 50% Magnetite grade range. However, it also contains significant amounts of liberated and high grade Magnetite particles, even though most of these particles are in the smaller size ranges. This is a good indication of the concentrating action in the Hydrocyclone. These small high grade particles are redirected to the mill. Surely, we would rather regrind only the unliberated particles, but this inherent Hydrocyclone concentrating action is difficult to avoid.

EXERCISE 6-1: Complete the simulation described in the section above.

EXERCISE 6-2: Ore bodies are not homogeneous and variability in grade, texture and other properties is in fact the norm. The Taconite studied in this module has a texture characterized by the parameter phiA in the Ljubljana model. Taconite from different areas in the ore body may be different in texture. Consider the hypothetical cases below:

PhiA = 90	**PhiA = 50**	**PhiA =10**
		

In the images above (see Table), Chert is dull grey while Magnetite is bright. Note how the texture parameter is directly related to the complexity of texture, in the morphological sense. In the left particle, texture is so complex that grain size becomes a concept that is difficult to grasp. Interphase area per unit volume of phase is the quantitative property that applies in all cases, and this is how the parameter phiA is derived.

CONCERNS TO BE ADDRESS:

- In Exercise 6-1 make a note of the recovery and grade of Magnetite in the cyclone overflow stream.
- In Exercise 6-2 Run simulations using the values of phiA in the Table above. Compare grade and recovery of Magnetite for each case in the Cyclone Overflow stream. (You already completed the simulation for PhiA = 50 in the previous exercise.)

Module-7:

Assessment of Plants and Model Calibration with MODSIM.

Once a simulator such as MODSIM has been mastered, the simulation of even complex plants becomes a straightforward task. It is a matter of specifying the flowsheet, choosing suitable models for the unit operations and characterizing the feed material. The real difficulty with the method lies in the choice of parameters and settings for the unit models. In most cases these values do not have absolute values and they must be chosen to suit the characteristics of the particular material that is to be processed in a particular plant or installation. Usually the parameters have values that are strongly influenced by the material that is to be processed, so parameter values must be obtained for every project. Parameters for the models can be obtained from data collected in the laboratory or from data that is collected on an operating plant. Clearly the second alternative is not available if the plant does not yet exist. A number of standard laboratory methods have been developed to measure the parameters for many of the models and one of these will be discussed later in the course. We will concentrate in this module on methods that can be used to obtain model parameter values from operating plant data and on the interpretation of these values in terms of plant performance.

Objectives of this module

1. Learn the features in MODSIM that can be used to compare simulation output with real data.
2. Learn to interpret parameter values in terms of the operating characteristics of the units and to diagnose operating problems.
3. Learn how to use simulation to achieve better plant operation.

Determining Parameters from Operating Data

When good data are available from a plant sampling campaign, the operating values of the parameters in the models for the unit operations can be estimated using conventional parameter estimation techniques. Typically plant streams are sampled and analysed and, if the feed and product streams from any particular unit are available, the parameters for that unit can be estimated using the MODSIM model directly. All MODSIM models accept the details of the unit feed as input and produce the simulated output of that unit. When experimental data are available for the feed and product streams, the least-squares best estimates of the unit parameters can be obtained by matching the simulated output to the measured output to minimize the sum of squared deviations. This is best done by embedding the code for the unit model as it is used in MODSIM into a least-squares minimization search program. This method is very effective and usually produces good estimates of the parameters for the unit in question. Sometimes data that are specific to the material inside the unit must also be used to estimate all the parameters for that unit. The size distribution in the load of a ball or SAG mill is an example when it is necessary to estimate the parameters that define the classification action of the grate discharge. Data of this sort are typically difficult to get and it is often necessary to use best guess values for these parameters.

When operating data are not available for all the process streams that are associated with a particular unit, data from a larger section of the plant must be used. This can be done by embedding the entire Modsim simulator inside a least squares minimization program. Typically, measured size distributions from several of the plant streams are matched against the simulator outputs for those streams. Modern optimization codes make this possible and the method is now used routinely.

EXERCISE 7-1: *Assessment of a rod and ball mill circuit.*

The data is given in the Appendix resulted from a careful sampling campaign on an operating plant.

In particular, both feed and product streams were sampled for the rod and ball mills. These data were used to estimate the breakage and selection function parameters for both of these mills. In each case the average residence time of the solids in the mill was estimated from the mill dimensions, the media load and the estimated flowrate through the mill. The values found for the residence times were 3.40 minutes in the rod mill and 2.19 minutes in the ball mill. The simple perfectly mixed mill model MILL in MODSIM was used for the ball mill and the model RODM was used for the rod mill. The least-squares best estimates of the parameters are given in Tables 1 and 2. Since the size distribution in the cyclone feed was not measured during the sampling campaign, the parameters for the cyclone could not be estimated directly.

Table 1 Estimated parameters for the rod mill.

Selection function	**Breakage function**
S1 = 1.658 1/min	beta = 3.696
alpha = 0.602	gamma = 1.481
mu = 1.4 mm	delta = 0.0
Lambda = 0.736	Phi = 0.242

Table 2 Estimated parameters for the ball mill.

Selection function	**Breakage function**
S1 = 1.508 1/min	beta = 7.699
alpha = 1.662	gamma = 0.683
mu 1.4	delta = 0.0
Lambda = 0.735	Phi = 0.683

These values can be tested in the simulation and the calculated size distributions can be compared to those measured during the plant sampling campaign. The comparison is facilitated in MODSIM since the measured data can be entered as part of the system data. The measured data are entered using the system data form. Double click on each stream for which measured size distribution data are available and enter the experimental data in the usual way. It is a good idea to specify a name for the stream at the same time. The information that is entered in this way is not used by MODSIM for simulation calculations in any way. It is merely displayed in the graphs for comparison.

The physical dimensions of the hydrocyclones were specified in the data set and under normal opertaing conditions no other infromation is required to specify the operation of the hydrocyclones if the Plitt model is used. The feed head was estimated to be 3.81 m. However in practice the cyclones should be calibrated to match the actual operation. Three calibration factors are provided in the model for this purpose. It is a simple matter to adjust these using least-squares stimation to find a good fit to the experimental size distributions. In this case the factors found were for D50c, 0.293, for the sharpness index 0.152 and fo rthe flow split 0.856.

The resulting simulated output for this plant is shown in Figure 1.

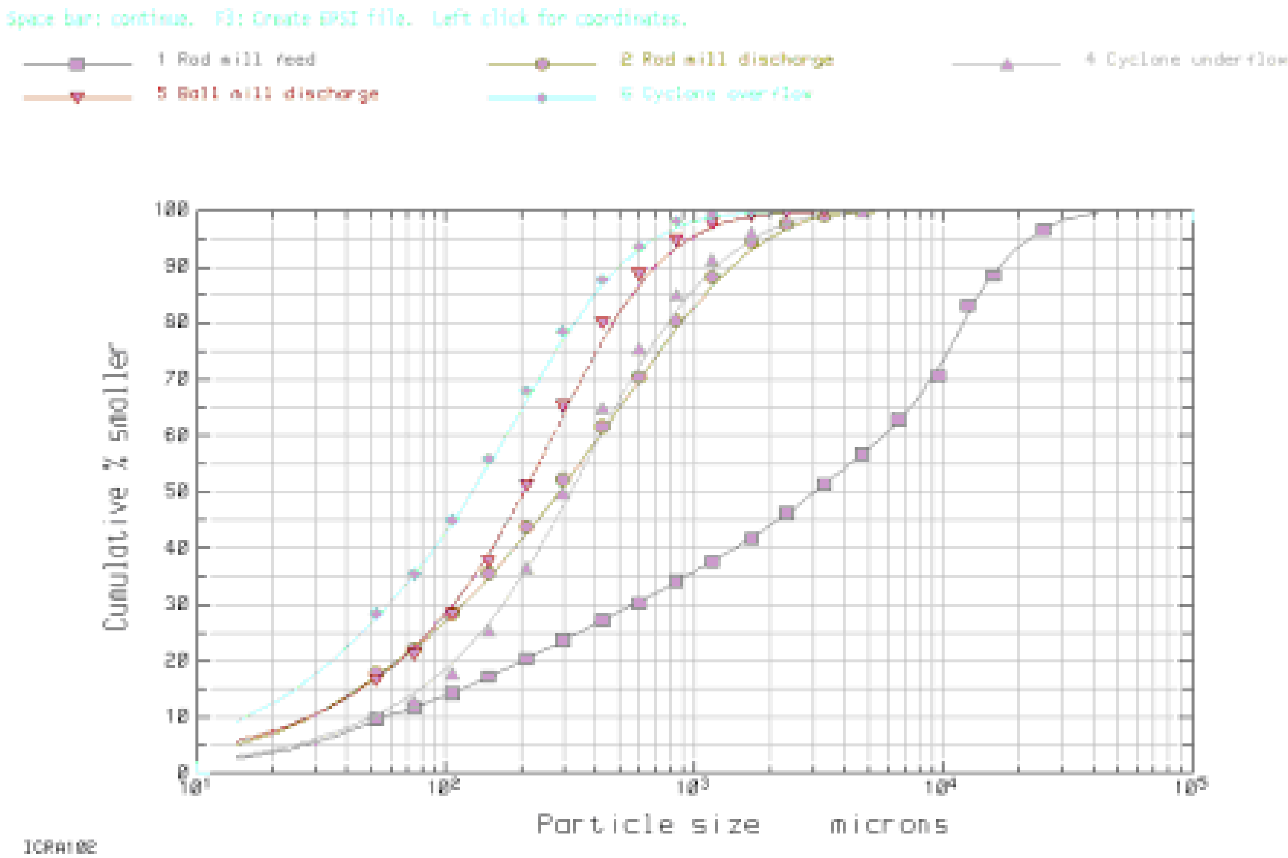


Figure 1 Simulator output for the plant as sampled. Points are experimental data and lines are the simulator output.

It should be immediately obvious that the simulation is a good representation of the actual plant operation since the size distributions match the experimental data well. However, this is an example of a poorly operating milling circuit. Note how the rod mill is accounting for the greatest portion of the size reduction. The ball mill is not producing as much size reduction as it could if the circuit were set up more appropriately.

Some unusual aspects of this data are apparent. The media for the ball mill are described as slugs rather than balls. This means that the media are not spherical but have flat surfaces which have the effect of cushioning the very fine particles. This shows up as an unusually high value for alpha (1.662) in the selection function for the ball mill. This makes the specific rate of breakage fall off rapidly as the size deceases. This can be seen by inspecting the selection function for the ball mill. (Right click the mill icon when viewing the flowsheet). In this case this leads to inefficient grinding in the ball mill.

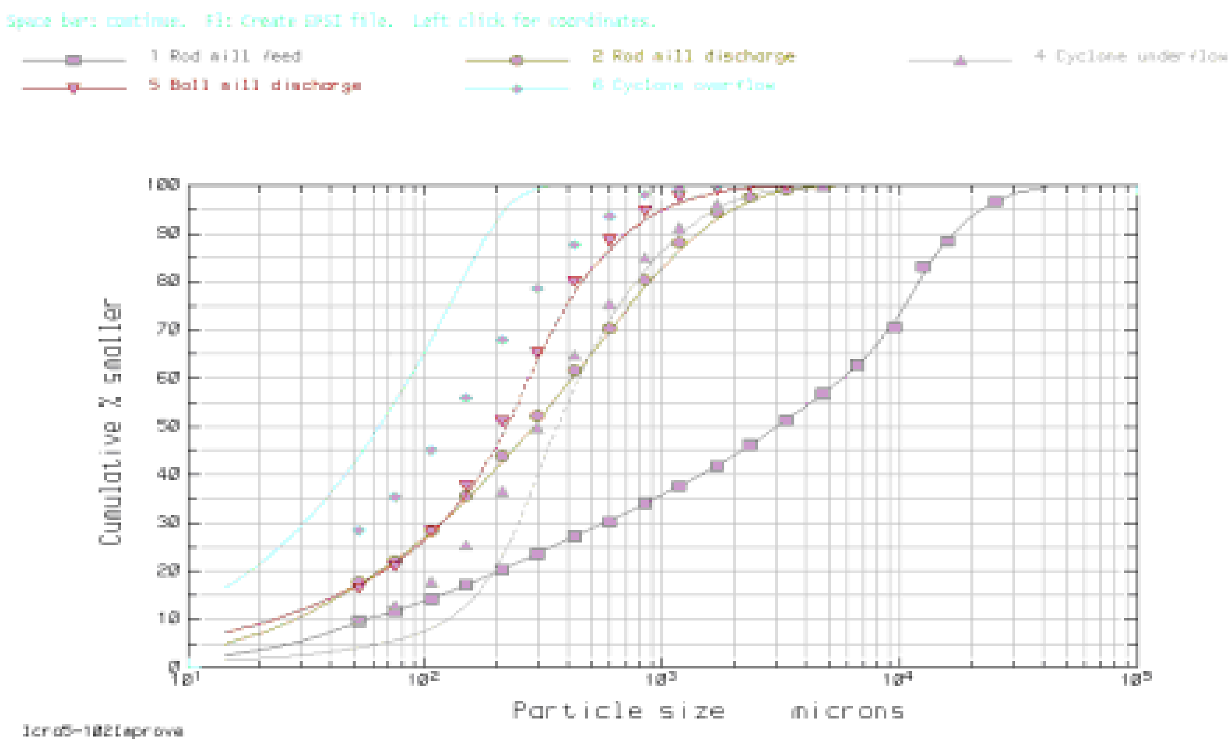


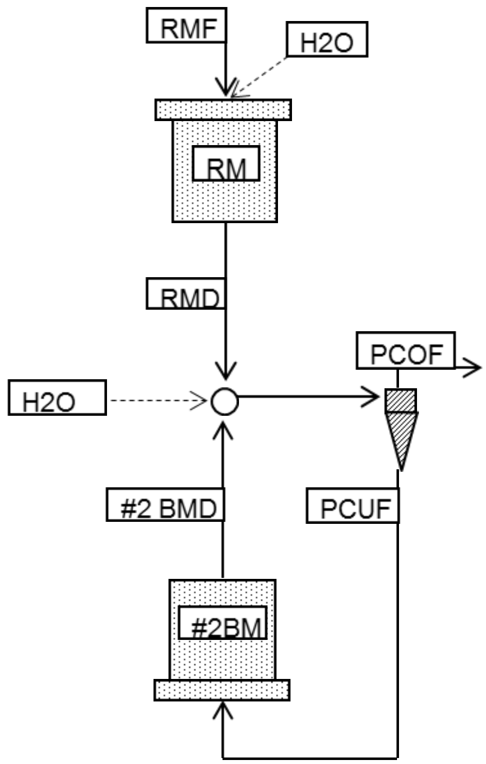
Figure 2. Size distributions *under improved plant conditions. The data points represent the original plant operation and they are shown for reference.*

Both the spigot and vortex finder diameters are unusually large in this plant. This gives rise to an unusually large cut point for the size of cyclone that is used.

CONCERNS TO BE ADDRESS:

- You should now try to suggest changes that will improve the performance of this plant. Things you should consider are replacing the slug media with balls and using cyclones with a more conventional geometry. To simulate the effect of using balls rather than slugs you can simply change the value of alpha from 1.662 to 1.0 in the ball mill. The cyclones could be changed to the "standard" geometry (use MODSIM default values) and the three calibration factors to 1.0. You should produce results that are similar to those shown in Figure 2 which represents a significantly better performance for this plant than the original data.

Appendix *(For Exercise 7-1)*



Flow Diagram Primary Rod/Ball Mill Circuit

CIRCUIT:	**Primary Rod/Ball Mill Circuit**
Unit name:	**Rod Mill**
Internal dia, m	3.51
Internal len, m	4.11
Critical speed, %	61
Media load, %	35
Media type	rods
Media size, mm	89
Power demand, kw	560
Unit name	**Primary Cyclones**
# of parallel cyclones	3
Cyclone dia, m	0.38
Inlet dia, m	0.10
Vortex finder dia, m	0.152
Apex dia, m	0.076
Cyclinder len, m	0.28
Cone angle, degrees	15
Pressure drop, kpa	70
Unit name:	**#2 Ball Mill**
# of parallel mills	1
Internal dia, m	3.51
Internal len, m	4.11
Critical speed, %	61
Media load, %	35
Media type	slug
Media size, mm	76.2
Power demand, kw	616

MATERIAL BALANCE								
	RMD		**PCUF**		**#2 BMD**		**PCOF**	
	Mean	**Estimate**	**Mean**	**Estimate**	**Mean**	**Estimate**	**Mean**	**Estimate**
Solids, sdtph		176.7		284.1		284.1		176.7
Solids, mdtph		160.3		257.7		257.7		160.3
Water, sdtph		55.5		82.7		82.7		145.1
Water, mdtph		50.3		75.0		75.0		131.7
% Solids	76.1		77.4		77.5		54.9	

% Heavies (Sink at 2.97)			
MESH	**MICRONS**	**PCUF Mean**	**PCOF Mean**
4 Mesh	4750	1%	1%
6 Mesh	3350	1%	1%
8 Mesh	2360	28%	1%
10 Mesh	1700	30%	1%
14 Mesh	1180	33%	1%
20 Mesh	850	38%	4%
28 Mesh	600	48%	8%
35 Mesh	425	59%	14%
48 Mesh	300	65%	21%
65 Mesh	212	67%	32%
100 Mesh	150	67%	39%
150 Mesh	106	64%	41%
200 Mesh	75	61%	43%
270 Mesh	53	58%	47%
Pan			

SIZE DISTRIBUTIONS, WEIGHT PERCENT ON SIZE										
MESH	**MICRONS**	**RMF**	**RMD**		**PCUF**		**#2 BMD**		**PCOF**	
		Mean	**Mean**	**Smoothed**	**Mean**	**Smoothed**	**Mean**	**Smoothed**	**Mean**	**Smoothed**
1.5"	38100	0.6								
1"	25400	2.7								
.75"	19050	2.7								
.625"	15875	5.4								
.5"	12700	5.3								
.375"	9525	12.6								
.25"	6700	7.8								
4 Mesh	4750	6.1	0.1	0.1	0.1	0.1				
6 Mesh	3350	5.3	0.7	0.7	0.4	0.4				
8 Mesh	2360	5.3	1.5	1.4	1.0	1.1	0.2	0.2	0.0	0.0
10 Mesh	1700	4.4	3.3	3.2	2.4	2.5	0.5	0.5	0.0	0.0
14 Mesh	1180	4.2	6.3	6.1	4.7	5.0	1.6	1.5	0.5	0.5
20 Mesh	850	3.5	7.8	7.7	6.4	6.6	2.9	2.8	1.5	1.6
28 Mesh	600	3.8	9.9	10.0	9.4	9.4	6.0	5.9	4.3	4.4
35 Mesh	425	3.1	8.7	8.8	10.7	10.5	8.8	8.7	5.8	5.9
48 Mesh	300	3.6	9.6	9.7	15.0	14.8	14.6	14.6	9.2	9.3
65 Mesh	212	3.2	8.3	8.4	13.2	13.0	14.1	14.3	10.5	10.5
100 Mesh	150	3.3	8.3	8.3	11.3	11.3	13.5	13.6	12.1	12.0
150 Mesh	106	3.0	7.1	7.2	7.6	7.5	9.5	9.7	11.0	10.7
200 Mesh	75	2.6	6.3	6.3	5.0	5.1	7.2	7.2	9.7	9.7
270 Mesh	53	2.0	4.4	4.4	3.0	3.0	4.5	4.5	6.9	6.8
Pan		9.7	17.8	17.8	9.8	9.8	16.6	16.6	28.5	28.7

SIZE DISTRIBUTIONS, CUMULATIVE % PASSING										
MESH	**MICRONS**	**RMF**	**RMD**		**PCUF**		**#2 BMD**		**PCOF**	
		Mean	**Mean**	**Smoothed**	**Mean**	**Smoothed**	**Mean**	**Smoothed**	**Mean**	**Smoothed**
1.5"	38100	99.4								
1"	25400	96.7								
.75"	19050	94.0								
.625"	15875	88.6								
.5"	12700	83.3								
.375"	9525	70.7								
.25"	6700	62.8								
4 Mesh	4750	56.8	99.9	99.9	99.9	99.9	100.0	100.0	100.0	100.0
6 Mesh	3350	51.5	99.2	99.2	99.5	99.5	100.0	100.0	100.0	100.0
8 Mesh	2360	46.3	97.7	97.8	98.5	98.5	99.8	99.8	100.0	100.0
10 Mesh	1700	41.9	94.5	94.6	96.1	96.0	99.3	99.3	100.0	100.0
14 Mesh	1180	37.7	88.2	88.5	91.4	91.0	97.7	97.8	99.5	99.5
20 Mesh	850	34.2	80.4	80.9	85.0	84.4	94.7	95.0	98.0	97.9
28 Mesh	600	30.4	70.5	70.9	75.6	75.0	88.7	89.1	93.7	93.6
35 Mesh	425	27.3	61.8	62.0	64.9	64.5	80.0	80.4	87.9	87.7
48 Mesh	300	23.7	52.2	52.4	49.9	49.6	65.3	65.8	78.7	78.4
65 Mesh	212	20.5	43.9	44.0	36.7	36.6	51.2	51.5	68.2	67.9
100 Mesh	150	17.2	35.6	35.7	25.4	25.4	37.8	37.9	56.1	55.9
150 Mesh	106	14.3	28.5	28.5	17.8	17.8	28.2	28.2	45.1	45.2
200 Mesh	75	11.7	22.2	22.1	12.8	12.8	21.1	21.1	35.4	35.4
270 Mesh	53	9.7	17.8	17.8	9.8	9.8	16.6	16.6	28.5	28.7

Note: Cyclones steady at 10 psi

Module-8:

To investigate any flowsheet/s that is/are of particular interest with MODSIM.

This module has been set aside for students to investigate any flowsheet/s that is/are of particular interest. I encourage you to look around for some interesting flowsheet and start to investigate what data would be required to achieve a successful simulation. It is usually possible to get started using defaults that are supplied by MODSIM but it is essential to learn to be sensitive to the effect of assumptions on a simulation output.

Examples of Some Simple Simulations

EXAMPLE 8-1 *Ball mill circuit*

A ball mill operates in closed circuit with a hydrocyclone classifier. It processes rod mill discharge at 800 tons solid per hour. The size distribution of the feed is the rod mill discharge given in the Table (page no 18) and the pulp is 76% solids. The hydrocyclone should be operated at 50% solids. The size of the mill will give a residence time of 7 mins. The ore can be taken as silica having a specific gravity of 2.67.

1. Draw the flowsheet using MODSIM and specify the necessary data.
2. Simulate the circuit and obtain the size distributions in the feed and the product.
3. Investigate the effect of hydrocyclone diameter on the D50 cutsize.
4. Investigate circuits with 1, 2 and 3 hydrocyclones in parallel.

EXAMPLE 8-2 *Flotation cell*

The flotation constants associated with the ore are

$$\mathbf{k_1 = 1.23 \times 10^{-2}\ s^{-1}}$$
$$\mathbf{k_2 = 5.12 \times 10^{-3}\ s^{-1}}$$
$$\mathbf{k_3 = 8.2 \times 10^{-4}\ s^{-1}}$$
$$\mathbf{k_4 = 0}$$

1. Simulate the operation of a single 4-cell rougher bank of cells. The feed pulp density is 34% solids and solid holdup in the cells is 450 kg solid/m^3 of cell volume.
2. Plot the grade-recovery relationship as cell volume varies from 1 m^3 to 10 m^3. The feed rate is 135 tons/hr. The effect of particle size on the flotation kinetics can be ignored and the unliberated particles may be assumed to contain 16.8% mineral on average. The feed contains 10% liberated mineral, 5% unliberated particles and 85% liberated gangue.
3. The simple kinetic model with distributed rate constants should be used for the flotation cells. This is identified as model FLTN in MODSIM.

QUESTIONNAIRE

The following outcomes have to be submitted along with the lab manual as an attachment.

PRACTICAL NO: 02

2.1- Make a graph between sieve size and %O, similarly for sieve size and %U. Use MS Excel or other software for generating graphs; take printout and staple with this workbook/handout. Highlight the important findings of your sieve analysis and give comments.

PRACTICAL NO: 03

3.1- Plot results on linear or log-linear graph paper to show the effect of ball milling. Use MS Excel or other software for generating graphs**,** Compare the size distributions and comment on the effect of ball milling operation.

PRACTICAL NO: 04

4.1- Plot results on linear or log-linear graph paper to show the height variation of interface in the sedimentation tube as the time passes ("H" on y-axis & "T" on x-axis). Use MS Excel or other software for generating graphs; take printout and compare the sedimentation curves and comment on the behavior of solid particles of different concentration.

PRACTICAL NO: 05

5.1- Use your own words to describe the effect of Feed size and Pulsation Rate in the stratification process.

5.2- Determine D_{80} via sieving Test.

PRACTICAL NO: 07

7.1- Make a graph between Floatation Time (sec) and Recovery at different collectors & frothers. And comment on the effect of reagents and residence time on floatation process.

PRACTICAL NO: 09

Module-1

- **i.** Give your thoughts on $\mathbf{d_{50}}$, $\mathbf{d_{50c}}$, **G-class** and **S-class**.
- **ii.** What is Mular-Judd criterion & Concha formula?
- **iii.** For Exercise1-8: d50c decreases from G-class 1 to G-class 3. Why? Also note that d50c for silica is smaller than in exercise 1-7. Why?
- **iv.** For exercise 1-7: in spite of the smaller d50 size with the larger spigot the overflow size distribution is slightly coarser. Why? (You will need a sharp understanding of the behavior of hydrocyclone to answer this.

Module-2

i. For Exercise 2-1: Modify some of the unit parameters and note how the performance data changes after each simulation run.

ii. For Exercise 2-2: Check how the area utilization factor varies as the wire diameter changes. Standard wire diameters for this mesh size are:

   a. Heavy duty 9.53 mm
   b. Medium heavy 7.94 mm
   c. Medium 6.35 mm
   d. Medium light 5.72 mm

   Also investigate how the area utilization factor varies as the feed rate changes.

iii. For Exercise 2-3: Investigate how the size distribution of the crusher product varies as the open side setting is varied.

iv. For Exercise 2-5: Vary the mesh size of the tertiary screen over the range 8 mm to 15 mm and observe how the recirculating load and the size distribution of the final product change. Vary the mesh size and the CSS in the tertiary circuit and seek out an optimal combination that will minimize the size and number of crushers required. Also keep track of the area requirements for the screen.

Module-3

i. For Exercise 3-1: Investigate how the grades of CaO and SiO_2 in the underflow vary as the target specific gravity in the dense-medium cyclone is changed systematically over the range 2.80 to 3.1. This can be reported most effectively on a graph of grade vs target specific gravity.

ii. For Exercise 3-2: Run several simulations with varying medium density in the second-stage cyclone and find out the medium density that minimizes the silica content of the second stage underflow.

iii. For Exercise 3-4: investigate the effect of using the different slot settings and also the effect of allocating concentrate streams between the concentrate and middlings. Also investigate the change in performance as the middling stream is recycled to the head of the unit.

Module-4

For exercise 4-3: you should note the large increase in residence time as the pulp progresses from cell to cell down the cleaner bank. Why does this happen and does it suggest a possible design modification to you? (You can see the residence times for the individual cells in the report file for the unit.) Try a few alternatives and see what the simulator tells you.

Module-5

Run the simulation several times varying the power input in steps from 3000 kW down to 1300 kW. Plot the circulating load as a function of the power and observe the size distribution graphs at each power level. This will give you a good idea how to interpret the four size distribution graphs as the mill handles less and less of the comminution load.

Module-6

For Exercise 6-2: Run simulations using the values of phiA in the given Table. Compare grade and recovery of Magnetite for each case in the Cyclone Overflow stream. (You already completed the simulation for PhiA = 50 in the exercises.)

Module-7

You should try to suggest changes that will improve the performance of the plant. Things you should consider are replacing the slug media with balls and using cyclones with a more conventional geometry. To simulate the effect of using balls rather than slugs you can simply change the value of alpha from 1.662 to 1.0 in the ball mill. The cyclones could be changed to the "standard" geometry (use MODSIM default values) and the three calibration factors to 1.0. You should produce results that are similar to those shown in Figure 2 which represents a significantly better performance for this plant than the original data.

<u>THE END</u>