Practical Workbook

MY-208 Mineral Processing

Name ____________________
Roll No ____________________
Batch ____________________
Year ____________________
Department ____________________

Department of Metallurgical Engineering
NED University of Engineering and Technology
Karachi-75270, Pakistan

Practical Workbook

MY-208 Mineral Processing

PREPARED BY

Dr. Zubia Anwer
(Assistant Professor, MYD)

This is to certify that this practical book contains __________ pages.

APPROVED BY

Prof. Dr. Ali Dad Chandio
Chairman, MYD

Department of Metallurgical Engineering
NED University of Engineering and Technology
Karachi-75270, Pakistan

CERTIFICATE

It is certified that Mr. / Ms. ____

student of class __SE__ Batch, bearing Roll No. MY __________ has completed his / her course work in the subject of **Mineral Processing (MY-208)** as prescribed and approved by Board of Review of Metallurgical Engineering Department.

His/her performance is reflected by the performance rubrics of his/her practical workbook. This overall performance of the student is going to address the assigned learning attribute.

____

Course Teacher

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MY-208 MINERAL PROCESSING

Safety Precautions

1. Keep the work area clean. Wipe up oil and grease spills immediately to prevent injuries caused by slipping and falling. Keep paths to exits clear.
2. Wear a lab coat at all times while in the sample preparation lab.
3. Use proper tools. Always use the proper-sized tools and equipment for the job.
4. Obtain the instructor's permission. Use equipment only with the instructor's permission.
5. The instructor must be aware of all laboratory activities and will know if the equipment is in safe working order.
6. Wear proper clothing. Wear clothing that is not loose or bulky and wear hard-toed shoes with non-skid soles.
7. Restrain long hair. Restrain excessively long hair with a band or cap to keep hair from getting entangled in machines.
8. Know emergency procedures. In the event of an emergency, all students involved in or observing the emergency should call for help immediately as well as assist in correcting the situation. You should know the location of fire extinguishers and fire blankets and how to use them. You should also know the approved procedure for exiting the laboratory.
9. Report all injuries or accidents to the instructor immediately, no matter how slight. The instructor will secure medical help.
10. Avoid horseplay and loud talk. Loud talking as well as pushing, running, and scuffling can cause serious accidents. Keep your mind on your work.
11. Turn off all equipment before leaving work area. Before leaving the laboratory or work station, make certain the equipment is properly shut off.

Experiment No. 1

Aim of the Experiment

To **manipulate** and observe the size distribution of a fixed granular solid by using a test sieve stack and a vibratory shaker.

Material/Equipment

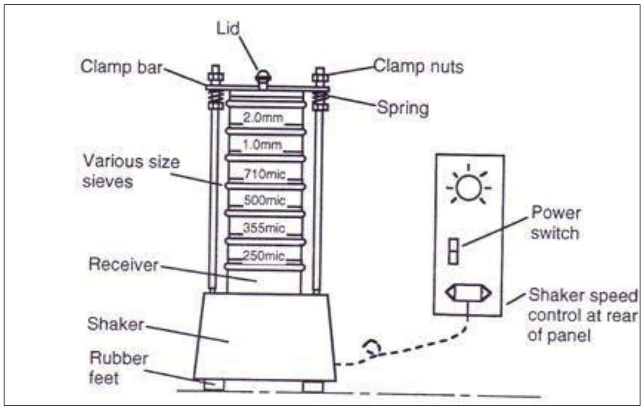

Fig. 1: Sieves of different mesh numbers

Theory

Sieve analysis is a technique, which is used for particle distribution based on their size and shape. There are two types of sieves used in general

- US STANDARD
- BSS / TAYLOR (ASTM) STANDARD

<u>Mesh Number</u>: It is defined as the number of square openings present per linear inch

Mesh number **α** (1/size of screen) **α** Thickness of wire **α** Fineness

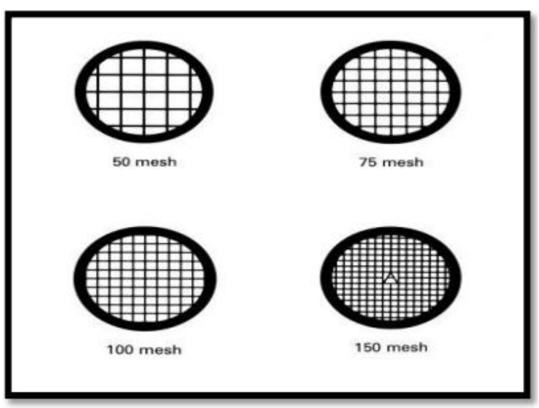

Fig. 2: Sieves of different mesh numbers

Size of the Screen: It is the distance between two consecutive wires.

Fig. 3: Sample sieves

Sieve Shaker: Many natural and manufactured products or materials occur in a dispersed form, it may consist of different sizes and shapes of particles. The particle size distribution is responsible for physical, chemical, and mechanical properties.

Sieve Analysis: It is carried out to determine the particle size by using different methods. Manual sieving: The sieve analysis is done manually. Mechanical sieving: The sieve analysis is done automatically with the help of a Ro-Tap sieve shaker.

Mass Fraction: It is defined as the ratio of mass retained to that of the total mass taken. The cumulative mass fraction is the sum of all the previous mass fraction values.

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 the most useful and many different methods are available but semi-logarithmic presentation is 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 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 it 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

Table 1: Particle size distribution

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]**
	∑ Weight (T.W)=			

Results

……………………………………………………………………………………………..

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Department of________________________Engineering
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Remarks	
Instructor's Signature with Date:	

Experiment No. 2

Aim of the Experiment

To **operate** the ball mill operation to reduce the particle size of a given material.

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 it 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 it again with the sieve shaker.

Observations

Amount of solid: __________kg.

Quantity of Ball: __________ %

(w.r.t feed) Milling

Time…………….sec

Table 1: Particle size analysis before and after milling.

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:

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Weighted CLO (Psychomotor Score)	
Remarks	
Instructor's Signature with Date:	

Experiment No. 3

Aim of the Experiment

To **practice** the sedimentation process for particle size analysis.

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.

Sedimentation is applied to accomplish the following process:

Separation

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

Purification

On an industrial scale, the most important application of sedimentation is the purification of water. Removal of physical impurities like stones, straws, leaves, etc. The separation of impurities is done based on the density of the particle.

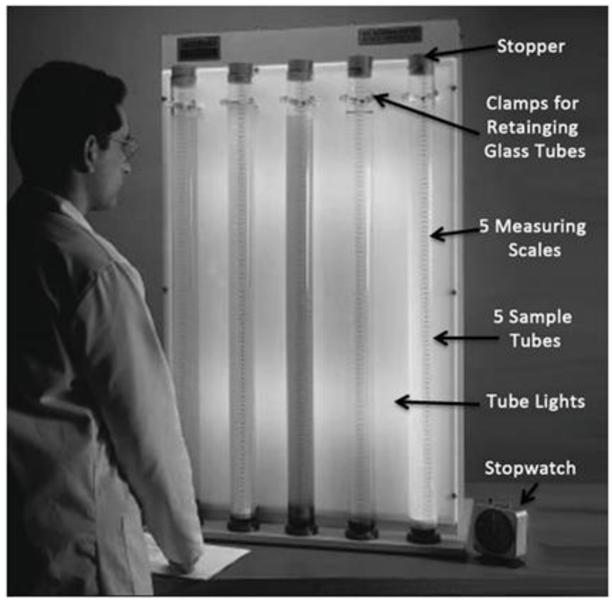

Fig 4: Sedimentation setup.

Activities

1. Select a suitable, well-mixed powder such as chalk. Weigh out five separate quantities to make up five equal volumes of chalk in water called slurry of some concentration by weight,
2. Slurry should be made up in a separate beaker and the 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. The tube should be well shaken to give a 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%

Table 1: Sedimentation behavior concerning settling time.

S.No.	**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

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NED University of Engineering & Technology

Department of_______________________Engineering

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Weighted CLO (Psychomotor Score)	
Remarks	
Instructor's Signature with Date:	

Experiment No. 4

Aim of the Experiment

To **practice** the operation of the shaking Table for concentration Operation.

Theory

A shaking table, also known as a wet table, consists 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 their extreme provide recovery of the middling (intermediate size and density) particles.

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

Working of Shaking Table

- The table moves forward and backwards, this motion is called a stroke.
- The table is made with shallow longitudinal ridges running from one side to the 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%.

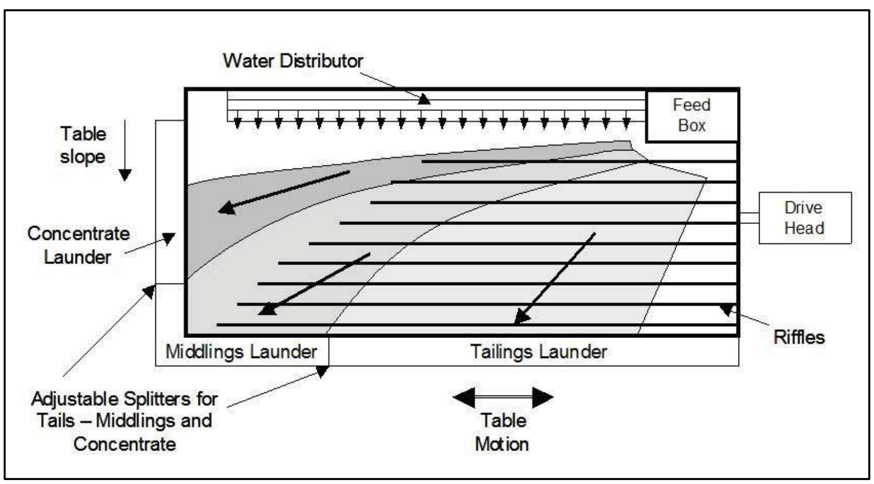

Fig 5: Shaking table operation.

Activities

1. The machine is provided with a controlled switch button on the cast iron bar for processing at while the main switch is connected.
2. The to-and-fro motion of the table pushes the suspended particles through the riffles at

the other end 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 heavier big ones are stuck in the riffles.
5. After the process observe that all particles are separated in three ways.
6. The heavier large particle that couldn't be moved by the flow of water was pushed in the same direction as the to and fro movement into the first compartment.
7. Next the heavier but smaller particles are separated and stashed in the next compartment while the lightest particles flow at the edge of the table into the compartment while the water is stored in to the containers.

Observations

- 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 the table.
- You will collect Fraction 2 from the upper part of the table.
- You will collect Fraction 3 from the lower middle part of the table

Table 1: Percent recovery in terms of different particle fractions.

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

Results

____

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Experiment No.5

Aim of the Experiment

To **operate** the laboratory-based magnetic separator **under supervision.**

Material/Equipment

1. Ore
2. Sieve screen of ASTM size.
3. Magnetic separator
4. Weight balance

Theory

It is a technique used to separate mineral particles from gangue particles based on their magnetic properties. There are three types of magnetic materials.

1. Ferro magnetic – strong magnetic field
2. Para magnetic – weak magnetic field
3. Dia magnetic – no magnetic field

Type

Based on magnetic intensity:

o Low-intensity magnetic separator
o High-intensity magnetic separator

Again, based on medium:
o Dry magnetic separator
o Wet magnetic separator

Basic Principle of Magnetic Separation Process
It works on the principle of mutual attraction of unlike charges, and mutual repulsion of like charges (Coulomb's law). Based on electrostatic charge, a body is said to be positively charged if it is deficient in electrons and is said to be negatively charged if it has excess electrons.

Fundamental concept of magnetic separation:
1. Low-intensity magnetic separators are used to separate highly magnetic materials.
2. High-intensity magnetic separators are used to separate weak magnetic materials.

Activities

i. Weight feeding ore of a particular size by a digital weight balance.

ii. Switch on the impeller motor, and also the motor of the rake.
iii. Allow the addition of the feed sample through the feed at a steady rate.
iv. Collect the ore under the flow of the magnetic field thrown away from the separator.
v. Also, collect the free flow placed nearer to the separator, and switch off the machine.
vi. Calculate the efficiency.
vii. Repeat the procedure while changing amperes.

Observations

Table 1: Separation Efficiency in terms of magnetic response.

Applied current **(Amperes)**	**Weight of collected magnetic materials** **(Kg)**	**Separator Efficiency** **(%)**

Calculations

The efficiency of the magnetic separation is calculated by using the formula given below

$$\text{Efficiency (in\%)} = \frac{\text{Weight of the collected magnetic materials}}{\text{Weight of the total feed materials}} \times 100$$

Results

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Experiment No. 6

Aim of the Experiment

To **operate** laboratory-based froth floatation cell **under supervision.**

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___liters. of kerosene and________amount of a good quality detergent should now be added, and agitate the tank for_____seconds.

Observations

Observation should now show white bubbles rising, 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.

Table 1: Percent recovery in terms of different particle fractions.

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

Measure the following parameter:

- Weight of initial coal taken (W1)
- Weight of sand taken (W2)
- Weight of sand dried froth taken (W3)
- Weight of filter paper
- Total weight of filter, and coal
- Weight of the dried coal (W4)

So, using the above data, we can calculate the separation efficiency using the following formula

$$\text{Separation efficiency (in \%)} = [\, W4/\, W2 \times 100]$$

Results

See the Questionnaire on Page no 33

NED University of Engineering & Technology
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Course Code & Title ____________________

F/OBEM01/05/00

Psychomotor Domain Assessment Rubric-Level P3					
Skill Sets	Extent of Achievement				
	0	1	2	3	4
Equipment Identification Sensory skill to ***identify*** equipment and/or its component for a lab work.	Not able to identify the equipment.	--	--	--	Able to identify equipment as wellas its components.
Equipment Use Sensory skills to ***demonstrate*** the use of the equipment for the lab work.	Doesn't demonstrate the use of equipment.	Slightly demonstrates the use of equipment.	Somewhat demonstrates the use of equipment.	Moderately demonstrates the use of equipment.	Fully demonstrates the use of equipment.
Procedural Skills ***Displays*** skills to act uponsequence of steps in lab work.	Not able to either learn or perform lab work procedure.	Able to slightly understand lab work procedure and perform lab work.	Able to somewhat understand lab work procedure and perform lab work.	Able to moderately understand lab work procedure and perform lab work.	Able to fully understand lab work procedureand perform lab work.
Response Ability to ***imitate*** the lab work on his/her own.	Not able to imitate the lab work.	Able to slightly imitate the lab work.	Able to somewhat imitate the lab work.	Able to moderately imitate the lab work.	Able to fully imitate the labwork.
Observation's Use ***Displays*** skills to use theobservations from lab work for experimental verifications and illustrations.	Not able to use the observations from lab work for experimental verifications and illustrations.	Slightly able to use the observations from lab work for experimental verifications & illustrations.	Somewhat able touse the observations fromlab work for experimental verifications & illustrations.	Moderately able touse observations from lab work for experimental verifications, illustrations.	Fully able to use the observations from lab work for experimental verifications & illustrations.
Safety Adherence Adherence to ***safety*** procedures.	Doesn't adhere to safety procedures.	Slightly adheres to safety procedures.	Somewhat adheres to safety procedures.	Moderately adheresto safety procedures.	Fully adheres to safety procedures.
Equipment Handling ***Equipment care*** during theuse.	Doesn't handle equipment with required care.	Rarely handles equipment with required care.	Occasionally handles equipment with the required care.	Often handles equipmet withrequired care.	Handles equipment withrequired care.
Group Work ***Contributes*** in a group-based lab work.	Doesn't participate and contribute.	Slightly participate &contribute.	Somewhat participates and contributes.	Moderately Participates & contributes.	Fully participatesand contributes.

Weighted CLO (Psychomotor Score)	
Remarks	
Instructor's Signature with Date:	

Experiment No. 7

Aim of the Experiment

To **practice** the basic understanding of the Modeling & simulation technique in the Mineral Processing Plant.

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 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 behaviour 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 modelling 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.

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 circuit 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.

Fig 6: MODSIM Input data

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 minerals. 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 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 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 the 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. The 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 of 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 unified 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 flow rate 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, it is a good time to move on to our Simulation Software MODSIM.

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Psychomotor Domain Assessment Rubric-Level P3					
Skill Sets	Extent of Achievement				
	0	1	2	3	4
Equipment Identification Sensory skill to ***identify*** equipment and/or its component for a lab work.	Not able to identify the equipment.	--	--	--	Able to identify equipment as wellas its components.
Equipment Use Sensory skills to ***demonstrate*** the use of the equipment for the lab work.	Doesn't demonstrate the use of equipment.	Slightly demonstrates the use of equipment.	Somewhat demonstrates the use of equipment.	Moderately demonstrates the use of equipment.	Fully demonstrates the use of equipment.
Procedural Skills ***Displays*** skills to act uponsequence of steps in lab work.	Not able to either learn or perform lab work procedure.	Able to slightly understand lab work procedure and perform lab work.	Able to somewhat understand lab work procedure and perform lab work.	Able to moderately understand lab work procedure and perform lab work.	Able to fully understand lab work procedureand perform lab work.
Response Ability to ***imitate*** the lab work on his/her own.	Not able to imitate the lab work.	Able to slightly imitate the lab work.	Able to somewhat imitate the lab work.	Able to moderately imitate the lab work.	Able to fully imitate the labwork.
Observation's Use ***Displays*** skills to use theobservations from lab work for experimental verifications and illustrations.	Not able to use the observations from lab work for experimental verifications and illustrations.	Slightly able to use the observations from lab work for experimental verifications & illustrations.	Somewhat able touse the observations fromlab work for experimental verifications & illustrations.	Moderately able touse observations from lab work for experimental verifications, illustrations.	Fully able to use the observations from lab work for experimental verifications & illustrations.
Safety Adherence Adherence to ***safety*** procedures.	Doesn't adhere to safety procedures.	Slightly adheres to safety procedures.	Somewhat adheres to safety procedures.	Moderately adheresto safety procedures.	Fully adheres to safety procedures.
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Group Work ***Contributes*** in a group-based lab work.	Doesn't participate and contribute.	Slightly participate &contribute.	Somewhat participates and contributes.	Moderately Participates & contributes.	Fully participatesand contributes.

Weighted CLO (Psychomotor Score)	
Remarks	
Instructor's Signature with Date:	

Experiment No. 8

Aim of the Experiment

To **try** to simulate the 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 8-1 and the Karra model is demonstrated in exercise 8-2.

EXERCISE 8-1: *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.

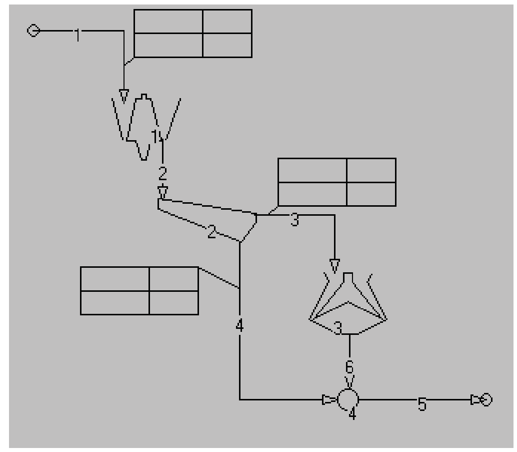
View the size distribution graphs (View menu). Size distribution graphs and the report file for the screen are shown below for reference. **Modify some of the unit parameters and note how the performance data changes after each simulation run.** Save the job as Exercise 2-1.

EXERCISE 8-2: *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 8-3. 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.

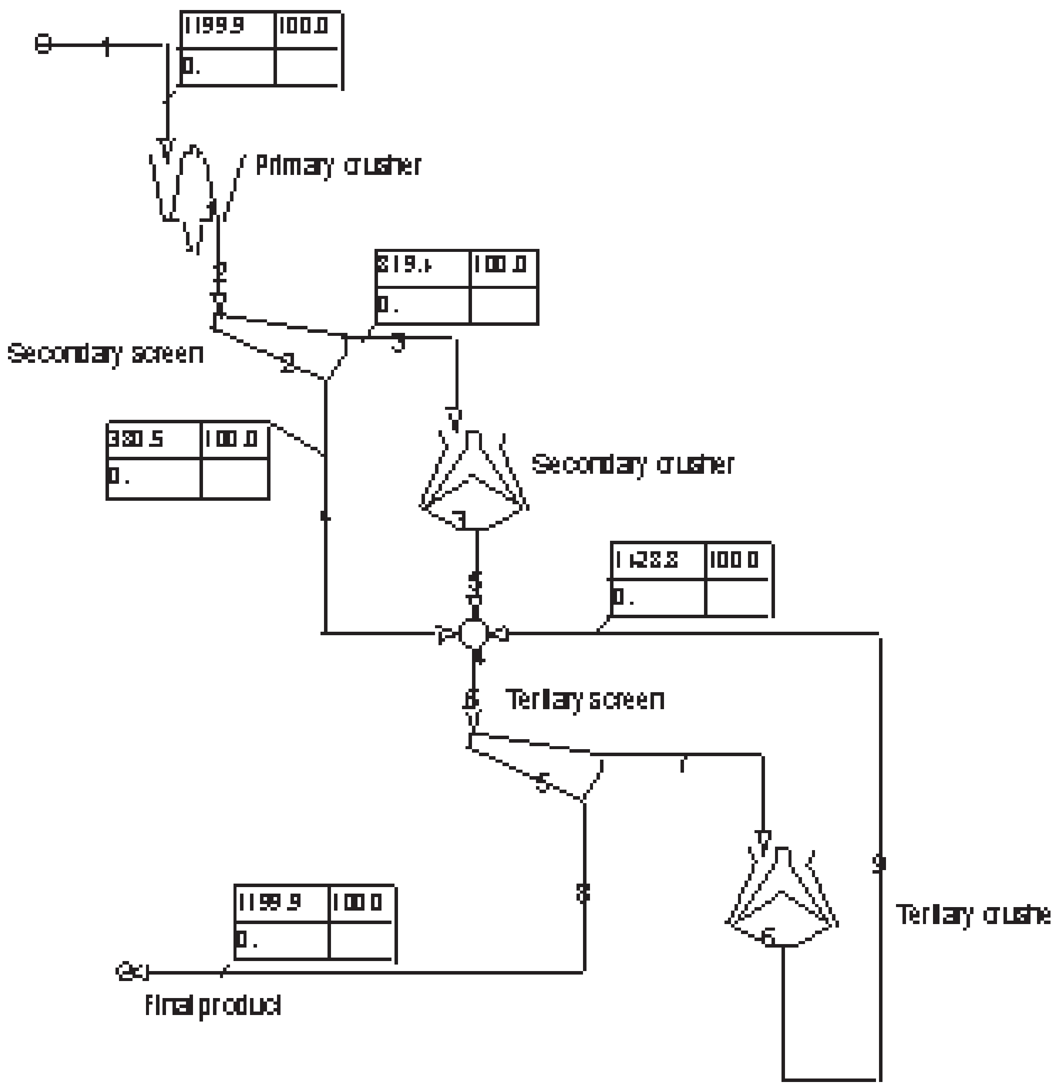
EXERCISE 8-4: Two-stage crushing
Add a second-stage cone crusher to handle the product from the gyratory crusher that was used in example 2-3. Since cone crusher capacity is less than the gyratory you must either use more than one secondary crusher in parallel or, preferably, screen the primary crusher 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 8-5: 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.**

Questionnaire

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

Experiment- 2

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.

Experiment- 3

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.

Experiment- 4

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.

Experiment- 5

5.1- Give your thoughts about separator efficiency with the amperes given.

Experiment- 6

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

Experiment- 7

- Give your thoughts on $\mathbf{d_{50}}$, $\mathbf{d_{50c}}$.
- What is Mular-Judd criterion & Concha formula.
- 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 hydro-cyclone to answer this

Experiment- 8

i. For Exercise 8-1: Modify some of the unit parameters and note how the performance data changes after each simulation run.

ii. For Exercise 8-2: 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 8-3: Investigate how the size distribution of the crusher product varies as the open side setting is varied.

iv. For Exercise 8-5: Vary the mesh size of the tertiary screen over the range of 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.