# OPTIMIZATION OF PRODUCTION FROM AGGREGATE PROCESSING PLANT

## A DISSERTATION

*Submitted in partial fulfillment of the*
*requirements for the award of the degree*
**of**
**MASTER OF TECHNOLOGY**
**in**
**WATER RESOURCES DEVELOPMENT**
**(MECHANICAL)**

**By**

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JUNE, 2005

# CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in this thesis entitled " **Optimization of Production from Aggregate Processing Plant** " in partial fulfillment of the requirements for the award of the Degree of Master of Technology in Water Resources Development submitted in the Department of Water Resources Development and Management, Indian Institute of Technology Roorkee, Roorkee is an authentic record of my own work carried out during the period July 2004 till the date of submission under the supervision of Prof. Gopal Chauhan, Professor WRD&M and Dr. M. L. Kansal, Associate Professor WRD&M, Indian Institute of Technology Roorkee, India.

I have not submitted the matter embodied in this thesis for the award of any other degree.

Dated : June , 2005

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This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

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# ACKNOWLEDGEMENTS

It is my privilege and pleasure to express my profound sense of deep respect and gratitude to Prof. Gopal Chauhan, Professor WRD&M, and Dr. M.L. Kansal, Associate Professor WRD&M, Indian Institute of Technology Roorkee, for their valuable guidance throughout this dissertation work. In spite of their busy schedule, they have been ever ready to help me to solve any difficulty until the completion of this dissertation.

I wish to express my sincere gratitude to Prof. S.K. Tripathi, Professor and Head, Department of Water Resources Development and Management, for extending various facilities during the course of this work.

Special thanks to all of faculty members of Department of WRD&M for providing me sufficient knowledge. To all staff of Department of WRD&M and all colleagues for their sharing of valuable information.

Also my thanks to the Department of Public Work of Indonesia - Directorate General Water Resources Development which gave me a much appreciated opportunity of attending the Department of WRD&M course at IIT Roorkee.

Finally, I have no words to adequately express my most sincere and heartfelt gratitude to my parents, my wife Reny Mardiany, and my dear son Rama Yapin Koresy Lay, for their praying, love and never ending support and encouragement, for me to complete my study in this institute.

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# ABSTRACT

In every construction project, aggregate are required. Generally, the requirement of aggregate changes from one project to another in quantity and size. In order to fulfill the project requirement, an aggregate processing plant has to be installed. An aggregate processing plant is an integrated equipment system which usually consists of crushers, screens, and conveyors with the main purpose to produce graded aggregate.

For fulfillment of project's requirement of graded aggregate, which is usually specified in the form of size range and its quantity, the setting of crushers and opening size of screens has to be fixed before an amount of raw material is fed. Any size range of material required is obtained through size separation process which is handled by screen, while its obtained quantity is dependent on crusher's setting and amount of fed material. In fact, there is a possibility where an amount of fed material given may be less or more than maximum that can be handled by a plant. Since, the amount of input and output material of a plant is same then, the consequence is the output production will be less when the input is less. More input will choke and ultimately stall the plant operation. Many trials may have to be done at site by which different amount of raw material is fed to the plant in order that the production rate become optimum (i.e. maximum) but it consumes time and is costly. Therefore, another approach should be tried. In this study, the problem is solved by using mathematical approach.

The basic principal of the mathematical approach is to determine optimum production rate of an aggregate processing plant. An arrangement of aggregate processing plant is presented in this dissertation - as a case study. The plant consists of one unit each of jaw crusher for primary crushing; roll crusher for secondary crushing; single deck screen located before jaw crusher; and double deck screen to separate product of jaw crusher into three types of size ranges of material.

The aggregate stream diagram of the plant is drawn which indicates relationship between the equipments in processing of material.

For solving the optimization problem, the mathematical model of each equipment is needed. In this study, the optimization problem is solved by fixing an output stream of plant as the objective function to be maximized and to be subjected to various constraints. Using the computer software call as Mathcad 2001i Professional, the value of the objective function is obtained as the maximum production rate.

This study shows that the setting of crushers and different opening size of screens cause the change of output production rate of the plant. The result that has been obtained by using the computer software also indicates total amount of material that should be fed to the plant in order that the output is in the maximum condition.

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# CHAPTER - I

# INTRODUCTION

## I.1. GENERAL

Crushed stone aggregate is of the vital importance in most of the fields of construction. Large quantities of crushed stone aggregate have been used in water resources development projects. On large construction projects, crushed stone aggregate preparation is the first stage of concrete production. Crushed stone aggregate is produced through very complex procedure which is begun with drilling and blasting or excavation of rock until processing and storage of the finished product.

The purpose of aggregate processing is to produce clean and properly sized materials from raw material which is obtained through drilling and blasting or rock excavation processes.

In order to get different sizes of aggregates, stones have to be crushed and undergo size separation. To carry out these processes, it is required to have an interconnected system of several equipments which are installed to be a system of production of aggregate. The system is known as aggregate processing plant. This combined plant operation, however, is normally not just a joining of several processes. It will include several other components that assist in the feeding, gradation and discharge. The main equipments are crushers for doing crushing or size reduction process, screens for doing size separation process and conveyor for doing transportation process within the plant. These equipments available in many types, sizes and capacities that should be taken into consideration for installing a plant. Type of the equipment refers to its function, while, size of equipment refers to the dimension of the equipment and the capacity is the capability of equipment to produce an amount of material in a unit of time.

An important thing that usually needs to be considered for installing an aggregate processing plant is the capability of a plant to produce maximum quantity of material in an hour (i.e. rate of production). The capability of a plant could be a reference to decide total operation time required for fulfillment a demand of a certain quantities of material in specified size ranges which may be required by a construction project. For example if a project requires 10,000 tons of crushed stone from a particular plant which have maximum capability 20 ton per hour, then the operation time of plant is 500 hour. The operation time that has been known may help in determination cost of production.

In fact, although, the maximum rate of production or capacity from every single equipment within the plant can be determined analytically by formulas or taken directly from manufacturer's book provided by the manufacture for every type of equipment but the maximum capacity of that single equipment can not be used as the indicator to decide the capacity of the plant because the plant consists of many equipments.

Also, to fulfill the demand of the different sizes of aggregate, the setting of crushers and screens within a plant is often changed. When the setting of crushers and opening size of screens are changed, then the gradation of output material will be also changed, so that for a certain size range of material required, its production rate will be different for different setting of crushers and screen sizes, although its input or fed material to the plant may remain same.

Another important thing that should be considered in operating an aggregate processing plant is gradation control. Gradation control needs to be considered because the quantity of material at certain size range produced by a plant may in excess or short fall compared with its requirement.

## I.2. SCOPE OF DISSERTATION WORK

Scope of study in this dissertation has been restricted to determine optimum production rate of crushed stone aggregate at a certain screen size and crusher setting. It also includes studying of gradation control. The aggregate recoveries from quarry requiring drilling and blasting have been excluded.

For determining of optimum production rate of an aggregate processing plant, the mathematical approach is used. The basic principal of the mathematical approach to determine the optimum production rate of an aggregate processing plant is to define the objective function and constraints of the plant in which the objective function is subjected to the constraints to obtain the optimum value.

In order to apply the mathematical approach, an arrangement of aggregate processing plant is presented in this dissertation - as a case study. The plant consists of one unit each of jaw crusher for primary crushing; roll crusher for secondary crushing; single deck screen located before jaw crusher; and double deck screen to separate product of jaw crusher into three type of sizes range of material.

Also, in view of fact that the data for production from crushers and screens as available from various manufacturers is in FPS units, the work has been presented in FPS units because the units will not have any impact on mathematical model for maximizing the output.

## I.3. OBJECTIVES OF STUDY

1. to determine maximum production rate of material of a certain size range which can be produced by the aggregate processing plant in an hour at a possible combination of settings of crushers and opening size of screens.
2. to determine the combination of setting of crusher and opening size of screen that can give the highest output production rate of the material at a desired size range.

3. to determine the quantity of material that should be fed to an aggregate processing plant in order that the quantity of any size ranges produced by the plant is obtained as per requirement.

## I.4. ORGANIZATION OF DISSERTATION

This study report is presented in following chapters:

**CHAPTER I : INTRODUCTION**

Describes aggregate processing in general. Also includes scope of study and organization of dissertation.

**CHAPTER II : EQUIPMENT FOR AGGEGATE PRODUCTION PLANT,**

Describes the general equipment in aggregate processing plant including crushing equipment (jaw crusher and roll crusher) and screening equipment.

**CHAPTER III : OUTPUT PRODUCTION OF EQUIPMENT**

Covers various methods for estimating the capacity of jaw crusher, roll crusher and screening equipment.

**CHAPTER IV : MATHEMATICAL MODEL FOR OPTIMIZATION AGGEGATE PRODUCTION PLANT**

Basic theory for determining gradation of streams and the constraints of an aggregate processing plant are presented in this chapter.

**CHAPTER V : METHODOLOGY**

Illustrates method used for achieving the objectives of this study, description of computer program used for solving the model, and illustrative example for gradation control.

**CHAPTER VI : RESULT AND DISCUSSION**

Presents the calculations, results and discussion of maximizing aggregate production rate of an aggregate processing plant. Also includes the calculation for determining a possible setting of crushers and opening size of screens that can give the highest production of the plant for a certain size range required.

**CHAPTER VII : CONCLUSIONS**

Main conclusions of the study are included in this chapter

**REFERENCES**

# CHAPTER-II

# EQUIPMENTS FOR AGGREGATE PROCESSING PLANT

## II.1. INTRODUCTION

The production of aggregate calls for a variety of equipment, ranging in size from the very small to the very large. The individual pieces of equipment can be arranged, into an equipment system which meets the aggregate processing needs.

Generally, the aggregate processing system in the area of water resources development project calls for equipments such as feeders, crushers, screens, and belt conveyor for in-plant handling. However, in this chapter only jaw and roll crusher and vibrating screen are covered because they are most commonly used, and govern the output of aggregate processing plant.

## II.2. CRUSHING EQUIPMENTS

The term crushing in aggregate production refers to comminuition process, in which large sized aggregates are reduced in size to meet specified size requirement. Crusher is the typical equipment used for the purpose of reduction process.

As stone pass through a crusher, it undergoes a reduction in size, which may be expressed as a ratio of reduction. The broadly means of reduction ratio is;

$$\frac{\text{Sieve size before comminuition}}{\text{Sieve size after comminuition}}$$

Sometimes, the term is applied to the equipment, so that the equipment reduction ratio is stated. This usually refers to the nominal settings of the machine:

$$\frac{\text{upper size limit for receiving feed}}{\text{maximum size of product setting}}$$

or if the term of average reduction ratio which called as 80% passing ratio is used then the ratio become :

$$\frac{\text{Sieve size through which 80\% passes before comminuition}}{\text{Sieve size through which 80\% passes after comminuition}}$$

Ratio of reduction for some type of crusher which is usually used for crushing stone may be defined as follow:

Jaw crusher,

Ratio of reduction is the ratio of distance between the fixed and the moving faces at the top divided by the distance at the bottom of a crusher.

Impact crusher,

Ratio of reduction is the ratio between width of feed opening and the width of grate bar opening. Reduction ratio as high as 40 to 1 are achievable with this machine and ratio of from 10 – 20 are common.

Roll crusher,

Ratio of reduction is the ratio of the dimension of the largest stone that can be nipped by the rolls divided by the setting of the rolls, which is the smallest distance between the faces of the rolls. If a roll crusher is producing a finished aggregate, the reduction ratio should not be greater than 4 : 1. However, if a roll crusher is used to prepare feed for a fine grinder, the reduction may be as high as 7:1.

There are four basic ways to reduce a material. Most crushers employ a combination of all these crushing methods.

**Impact:**

In crushing terminology, impact refers to the sharp, instantaneous collision of one moving object against another. Both objects may be moving or one object may be motionless. There are two variations of impact: i.e. gravity impact and dynamic impact. Gravity impact is most often used when it is necessary to separate two materials which have relatively different friability. The more friable material is broken, while the less friable material remains unbroken. Separation can then be done by screening. Dynamic impact is the crushing method used by impactors. Material dropping in front of a moving hammer (both objects in motion), illustrates dynamic impact.

**Attrition:**

Attrition is a term applied to the reduction of materials by scrubbing it between two hard surfaces. It is practical for crushing less abrasive materials such as pure limestone and coal.

**Shear:**

Shear consists of a trimming or cleaving action rather than the rubbing action associated with attrition. Shear is usually combined with other methods. For example, single-roll crushers employ shear together with impact and compression.

**Compression:**

As the name implies, crushing by compression is done between two surfaces, with the work being done by one or both surfaces. Jaw crushers using this method of compression are suitable for reducing extremely hard and abrasive rock. The Jaw crushes by compression without rubbing.

Reduction process is carried out by various type of crusher. Crusher may be classified according to the stage of crushing which they accomplish, such as primary, secondary, tertiary, etc. While there is no rigid classification of crushers, the following is representative of common crusher uses.

a. Primary crushers are jaw, gyratory, hammer mill (impact crusher)
b. Secondary crushers are cone, roll, hammer mill
c. Tertiary crushers are roll, rod mill, ball mill

A primary crusher receives the stones from a quarry and produces the first reduction in sizes. The output of primary crusher is fed to a secondary crusher, which further reduces the size.

Generally, types of crusher used in aggregate production plant for water resources development project are jaw crusher, gyratory crusher, and roll crusher. Crusher such as cone, rod mill and ball mill are widely used in the area of mining.

### II.2.1. Jaw Crusher

Jaw crusher is used for crushing all type of ore, quarry rock or the oversize in gravel pits. It is designed to crush the toughest or hardest rock or ore. The distinctive feature of the jaw crusher is two plates which open and shut like animal jaws. The two plates are at an acute angle to each other and at least one of them is pivoted so that it swings relative to the other. Material is fed between the jaws and alternately nipped and released to fall farther into the mouth. Depending upon the size of the bottom opening, the comminuted material eventually falls from the crusher.

Jaw crusher operates by allowing stone to flow in to the space between two jaws, one of which is stationary, while the other is movable. The distance between the jaws diminishes as the stone travels downward under the effect of gravity and the movable jaw, until it ultimately passes through the lower opening. The movable jaw is capable of exerting a pressure sufficiently high to crush the hardest rock.

Jaw crushers are classified by the method of pivoting the mobile jaw. If the jaw is pivoted at the top, i.e. in the feed area, it has a fixed receiving area and is known as a Blake crusher. If the jaw is pivoted at the bottom, i.e. in the discharge area, it has affixed delivery area and is known as Dodge crusher. If the jaw is pivoted in an intermediate position, it is known as a Universal crusher. Essentially the mechanism required is some means of transforming circular motion into a to and fro one and the basis of that mechanism is an eccentric shaft to which toggle are connected.

The Blake form of crusher tends to produce pieces of less regular shape than Dodge type. The Blake can be in the forms of the single toggle plate and double toggle types. The single toggle machine is driven either through a pitman or directly by flywheel shaft by using the shaft both as a pivot for feed end of the mobile jaw and as an eccentric for the source of the opening and closing movement. The modification with direct drive from the flywheel shaft is known as the overhead eccentric or Telsmith-Wheeling form. The outlet end of the jaw has a grooved seating for one end of the toggle plate, the other end of which sits in a block mounted in the frame which can be adjusted so that, when it is lifted, the movement of the lower end of the jaw is increased. On some machine shims are used for this adjustment instead of the wedge. Some machines provide hydraulic equipment, so that this adjustment can be effected by the turn of a valve. Thus the whole jaw has two movements. This movement is adjustable between one approximately parallel to the fixed jaw, when the toggle is set at a large angle to the horizontal, and a movement diverse from the direction of the fixed jaw when the toggle is made nearly horizontal and the crushing stroke is a minimum at the outlet point. The action is of the jaws wagging about a neutral point between the inlet and the outlet. If the size of feed is close to the distance between the jaws at this neutral point, the jaws can be jammed.

The double toggle machine has a much simpler movement. The inlet end of the jaw is pivoted in the main frame of the crusher. A flywheel eccentric shaft has set upon it a connection rod or plate, usually called pitman, into the end of which are set, on opposite sides, the two toggle plate. The toggle plate on the site of the pitman away from the jaws is set in an adjustable block similar to that used in the single toggle machine. The other toggle plate is set on the jaw near the outlet end. The movement is a simple to and fro one, the pitman pushing down the toggle against the frame and the pivoted jaw and lifting up to release the jaw away from the fixed one. The extent of the movement of the outlet end of the jaw is adjusted by the toggle block or in some cases by shims or by hydraulic devices. The double toggle machine is suitable for tough, hard, abrasive materials.

The Dodge machine rarely has a receiving area greater than 30 -40 cm, but its products are of a more uniform size than are those from the Blake, because of fixed exit size. The movement of the jaw is usually effected by means of a pitman set on a flywheel shaft, the top and the bottom of the jaw being linked by arms to a spring loaded slide on the pitman. The disadvantage of the Dodge is that the leverage is weakest at the entrance to the jaws, where the largest pieces are required to be broken. It is now rarely used.

The universal crusher, as would be expected from its design, is intermediate in performance between the Blake and the Dodge. It can be operate on larger pieces than Dodge and its products are of more uniform size than those from the Blake.

Jaw crusher are usually rated according to their receiving area, i.e. in the form of width of plates x gape. The performance of the different types of jaw crushers are compared in Table II.2.1.

Jaw crusher can also be classified based on size of the jaw;

1. Jaw crusher with normal width, where the ratio between width of the jaw and minimum feed gap is in range 1.4 to 1.6
2. jaw with extended width, where the ratio between width of the jaw and minimum feed gap is in range 2.2 to 5.7

Method for feeding jaw crusher

Jaw crusher can be fed directly from dumper or by way of a feed hopper. For best capacities the chute from the feed hopper should diverge in to the mouth of the crusher. The feed should be even and continuous and the jaws kept not more than three quarters full. The size of all feed should be less than about 0.9 times the gape and undersize should be removed by screening prior to entry into the machine.

*Table II.2.1. Performance of the different types of jaw crushers* [4]

| Type | Receiving area, $cm^2$ | Power, kW | Ton/hr | Reduction ratio |
|---|---|---|---|---|
| Dodge | 350 | 3 | 4 | 4 |
| | 500 | 5 | 7 | 5 |
| | 1000 | 6.5 | 15 | 7 |
| Universal | 500 | 9 | 2.5 | 5 |
| | 1200 | 35 | 12.5 | 5 |
| | 1500 | 30 | 12.5 | 8 |
| | 2000 | 30 | 8 | 15 |
| | 3500 | 45 | 24 | 10 |
| Blake | 3000 | 35 | 41 | 10 |
| | 6500 | 60 | 70 | 10 |
| | 13000 | 100 | 150 | 10 |
| | 20000 | 140 | 205 | 10 |
| | 25000 | 170 | | |
| | 30000 | 220 | 430 | 10 |
| | 40000 | 230 | | |

## II.2.2. Roll Crusher

Roll crushers is another compression type, simply break the material by pinching. Roll crushers reduce size by compressing particles between two rolls or between a single roll and a stationary surface. Product size can be controlled by adjusting the gap clearance.

Depending upon their form, roll crushers are also known as crushing rolls, roller crushers, Cornish rolls, giant rolls and Slugges rolls. In the single-roll form the roll crusher is known as a roller and breast mill, a kibbler or a sledging roll, depending upon details or the roll design.

The action of the roll crusher is very similar to that of the jaw crusher. Instead of the jaws moving in a horizontal direction relative to each other, the surfaces of the cylinders (or, in the case of single roll, the surfaces of the cylinder and the breaker plate) move in combined horizontal and vertical movements relative to each other, so that the material being crushed is continuously and steadily induced into the smaller part of the mouth by the circular movement of the cylinders and the friction between the material and the cylinder surfaces. The roll crusher does not have the periodicity of the jaw crusher and its parts do not have to suffer the oscillating stresses or power demands. The roll crusher's power demands are much lower than those of both the jaw and gyratory crushers.

Advantages of the roll crusher are:

(1) It will handle wet, sticky or frozen feeds, or material which easily packs.

(2) The product can be controlled so that there is a high yield within a narrow size range: within a top-to-bottom size ratio of 4, 85% yields are possible.

(3) The power consumption of the machine is low compared with that of many other machines.

(4) Rolls can produce a product in an intermediate range of about minus 1 cm to about 3 mm more economically than most other machines.

(5) The surface of the rolls can be heated or cooled by the circulation of fluid within the interior of the rolls.

Disadvantages

(1) Only a relatively small size reduction is achievable by practical roll sizes, a ratio of 4 being usually accepted.

(2) Materials having a foliated structure will break into leaves unless rolls with lugs or intermeshing teeth are used.

The rolls can be smooth, or corrugated or toothed to reduce slippage. [9]

ROLL TOOTH PATTERNS

On some machines the distance between the rolls is adjusted by inserting shims between the fixed and sliding bearings of the rolls. On others it is adjusted by means of bearings for one roller being set upon an arm which is pivoted and controlled by a spring-tensioned square-threaded rod or by a similar device using hydraulic pressure in place of the springs. Many designs permit of adjustment during operation. The length of rolls has been found by experience to be best kept short. It is unusual for the length to be much more than the diameter of the roll, as experience has shown that short rolls offer best control of feed and cause least maintenance difficulty.

Method for feeding roll crusher

The rolls are usually fed from flat belts. Care is taken to spread the material evenly on these belts and make it fall uniformly into the hopper above the rolls. The hopper runs the length of the rolls and has a distributing plate at the bottom; cheek plates in the hopper form a seal on the rolls, so that all material is directed into the wedge space between the rolls. Rolls invariably wear more in the centre than at the edges and it is important that the distribution of feed across the rolls be as even as can be managed. Some machines incorporate a device by which one roll can be moved laterally parallel to the axis and relative to the other roll and thus be adjusted for preferential wear, particularly wear that leaves flanges at the ends of the rolls which prevent proper adjustment of the roll distance; corrugations in the main body of the roller can also be prevented by such a device. Such an arrangement means having rolls some what longer than the capacity demands.

Wear on the rolls can be quite considerable and they are designed thick enough to withstand this wear. For example, a roll 100 cm in diameter may have a tire 15 cm thick and will take 10cm of wear, i.e. the diameter of the roll can be worn down to 80 cm before it is discarded.

For best control of product size the rate of feed should correspond to about one-third of the rate at which the theoretical ribbon of product could pass between the rolls.

It has been suggested that if rollers are fed at speed to the clearance between the rolls, preferably so that the material reaches the rolls at the peripheral speed of the rolls, energy consumption by the roll crusher is decreased.

## II.3. SCREENING EQUIPMENT

Screening of crushed aggregate is necessary for elimination of oversize rocks or for grading the crushed aggregate to the specified sizes. Separation of larger aggregate particle sizes is accomplish by various types of screens having square, round, diamond, or rectangular slotted openings and most wire screens require back up stiffeners, to keep them from depressing from superimposed loads.

The material screened should be sufficiently moved or shaken for effective screening otherwise clogging of screen with inert material may take place. The movement of the material may be cause by gravity flow on an inclined screen or by mechanical movement of screens. Most screen are sloped a few degree to provide gravity flow. Mechanical movement of screens is popularly provided for in the form of vibrations to the screens. Different manufacturers impart vibratory motion to the screens by various eccentric or unbalanced weight drives. Some drives are so arranged as to induce a forward flow of material across the screen even when it is not sloped. Screens are steel spring or air cushion mounted to absorb vibrations.

Vibrating screen are the most common screen used in aggregate production, combination of the vibration and the slope from receiving to the discharge end of the vibrating screens causes the aggregate to flow off the screen at the discharge end, and the undersize will drop through the screen. Vibrating screens are commonly made in single and double deck construction and are set at an angle to develop gravity flow material. Triple deck constructions are also used with 3 screens mounted one above the other.

Horizontal vibrating screens have also been developed and quite effective in giving accurate gradation and high capacities. Frequency of vibrating ranges from 800 to 3600 vibrations per minute and throw is up to ½ in. (12 mm).

Screen equipment usually consists of single or several decks. The material retained on top deck screen would be probably got back to the jaw crusher for further reduction. Material retained on the middle deck would probably pass on to roll crusher for secondary reduction. Material retained on the bottom deck, and that passing the bottom deck would go to stock piles.

# CHAPTER - III

# OUTPUT PRODUCTION OF EQUIPMENTS

## III.1. OUTPUT PRODUCTION OF CRUSHING EQUIPMENTS

### III.1.1. Output Production of Jaw Crusher

Jaw type crusher is commonly used for primary crushing or initial reduction. The rock is passed downward by gravity, by the weight of the material itself, and by the kneading action of the working jaws, until it is finally reduced in size sufficiently to allow discharge through the bottom of the jaws.

Jaw openings must be adequate to accept the feed and produce the desired aggregate size. As a size limitation, a jaw crusher should have a top opening at least 2 in. wider than the largest stones that that will be fed to it. It is for this reason that the size of jaw crushers is specified by two sets of numbers, the first set of numbers indicate the width of the feed opening known as gape while the second number indicate the width of jaw plates, so that a suitable size of jaw crusher could be conveniently chosen to match the feed.

The size of lumps, $D_{max}$ fed into the crusher must be less than 0.9 times gape. The reduction ratio that can be ensured in jaw crushers and also their capacity depend on the size of the discharge opening which is assumed equal to the distance between the corrugations at the instant when the swing jaw is in its most distance position in respect to the fix jaw. The stroke is adjusted as required by means of special devices. Proper performance of a crusher requires that the angle, $\theta$ between the jaws should not be over a definitive value, since otherwise the material will be pushed out of the crusher.

It has been suggested that capacity of jaw crushers, for straight and either smooth or corrugated jaws, is measured by following formula after Gies King as quoted by Lowrison. [4]

$$C = f\ \rho\ w\ q\ l\ N\ a\ r \quad \text{..............................} \mathbf{(III\text{-}1)}$$

Where,

C = capacity in tons per hour

f = factor dependent upon grading of feed and surface of jaw, as follow :

| | Smooth plates | Corrugated plates |
|---|---|---|
| Normal fines | $4.14 \times 10^{-5}$ | $3.05 \times 10^{-5}$ |
| Fines scalped out | $3.64 \times 10^{-5}$ | $2.54 \times 10^{-5}$ |
| Large piece only | $3.12 \times 10^{-5}$ | $2.07 \times 10^{-5}$ |

$\rho$ = bulk density of the product in $lb/ft^3$

w = width of crushing chamber in inches

q = open side setting of the crusher in inches (for corrugated sides, measurement is from tip of corrugation)

l = q – t = length of stroke at the lower tip of swing jaw plate in inches (t = closed side opening)

N = number of stroke per minute

a = nip angle factor is as follows

| Nip angle in degree | **25** | **24** | **23** | **22** | **21** | **20** |
|---|---|---|---|---|---|---|
| Capacity factor 'Giesking" | 1.03 | 1.06 | 1.09 | 1.12 | 1.15 | 1.18 |
| Capacity factor 'Gauldie' | 1.03 | 1.10 | 1.15 | 1.21 | 1.27 | 1.34 |

r = 'Giesking' factor having the form as follows

| Size passing all fed / Size of crusher receiving opening | | **0.4** | **0.5** | **0.6** | **0.7** | **0.8** | **0.9** |
|---|---|---|---|---|---|---|---|
| Truck dumping directly into converging hopper onto crusher | Single toggle | 0.95 | 0.92 | 0.87 | 0.73 | 0.52 | |
| | Double toggle | 0.93 | 0.90 | 0.80 | 0.61 | 0.35 | |
| Controlled feeding into straight side hopper onto crusher | Single toggle | 1.00 | 0.99 | 0.97 | 0.95 | 0.90 | 0.76 |
| | Double toggle | 1.00 | 0.98 | 0.96 | 0.92 | 0.82 | 0.60 |

It may be noted that the angle of jaws is primarily a question of nip. Refer to Fig.III.1.1.a, will show that if 'b' is the diameter of the particle which will just enter the jaw, and 't' is the setting of the discharge of the jaw, the minimum size reduction equal to b/t, equal to say 'R'. if the gape is 'G', and 'b' equal to 0.9G, and if the length of the plate is 2G, then it can be easily shown that, if θ is the angle between the jaw, then,

$$\text{Tan } \theta = \frac{G - t}{2.G} = \frac{b - 0.9t}{2.b} = \frac{R - 0.9}{2.R} \quad \text{........................(III-2)}$$

The action of the jaws is to produce a succession of wedges as indicated in Fig.III.1.1.a which are each reduced progressively to smaller sizes by compression and compaction until the first in the series is small enough to fall out of the crusher, after which the second takes its place, with the third coming on in a procession.

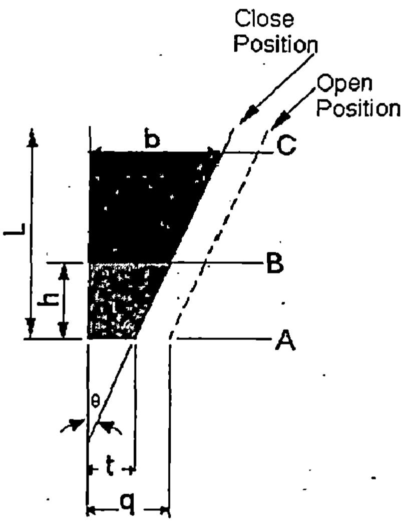

*Figure.III.1.1.a. Cross-sectional area of jaw crusher* [4]

Thus, in Fig.III.1.1.a, the wedge bounded by the levels 'A' and 'B' will leave the crusher at the next backward movement of the jaw and the wedge bounded by the levels 'B' and 'C' will take its place to be compressed and crushed by the forward movement of the jaw and to be released and discharged, in turn, by the backward movement of the jaw. The dimensions of the fragment leaving the crusher are limited in three ways; (1) by the width of the plates, i.e. the width of the crusher feed opening (w); (2) by the maximum opening of the jaws at the discharge or product end (q); (3) by the time permitted by the frequency of opening and shutting for the material to fall freely before it is nipped again. Thus, the dimension of the largest fragment would be multiplication of width of feed opening, 'w' (i.e. of crusher plates), maximum of opening of jaws at the discharge end, 'q' and function of frequency of jaw movement cycle.

In Fig.III.1.1.a, the movement of the jaws is first considered to be such as to maintain them in parallel. The extreme portions of the jaw are represented by a continuous line at minimum and by broken line at maximum. The portion in the throat of the jaws at which material has the same dimension as the maximum discharge opening, i.e. 'q' is seen to be 'B'. if the vertical distance of 'B' above 'A' were 'h', the frequency of backward movement of the jaws would have to allow the material to fall a distance 'h' between being at minimum distance apart and being at maximum distance, i.e. during half the cycle time. If the frequency of the jaw movement is 'N' cycles/min. then the time for one whole cycle is 60/N second and the greatest distance the fragment can fall freely in half a cycle is

$$h = \left(\frac{30}{N}\right)^2 \left(\frac{g}{2}\right) \quad \text{or} \quad \frac{442000}{N^2}\ \text{cm} \quad \text{..........................}\mathbf{(III\text{-}3)}$$

Thus, for fragment to have a length h centimeters the frequency must be less than $\frac{664}{\sqrt{h}}$ value of h can also equal to (q – t) cot θ.

*The dimensions of the largest fragments leaving the crusher would* be products of width of feed opening, w; maximum opening of jaw at the discharge end, q ; and function of frequency of jaw movement cycle.

The quantity issuing from the crusher in conditions such that the frequency is about the optimum is obtained from the product of:

- Area of parallelepiped bounded by parallel sides of length q and t, respectively, and a side at right angle to these of length h, so that area =1/2. h. (q + t);
- Width of plate = w;
- Density of compacted mass, which can be taken to be about 0.8ρ times the true density of the material; and
- Frequency of jaw movement.

$$\text{Quantity per minute} = \frac{1}{2}\ h\ (q + t)\ .\ w.\ \frac{664}{\sqrt{h}}\ .\ 0.8\rho \quad \text{.........}\mathbf{(III\text{-}4)}$$

The effect of the movement of the jaws is both; (a) to rush and break and thereby to increase the voids between pieces and to decrease the bulk density and (b) to compress and compact and thereby fill the interstices between pieces and to increase the bulk density. The effect of this conflict on the bulk density of the material as it pass down between the jaws is therefore not easy to be predict, but the broadly tendency must be to increased the bulk density of material. The effect of absolute density of the material on jaw crusher capacity is as follows

| Specific gravity (A) | 1.1 | 1.9 | 2.7 | 3.0 | 4.4 | 6.2 |
|---|---|---|---|---|---|---|
| Capacity, tph (B) | 100 | 170 | 380 | 435 | 640 | 950 |
| B/A | 91 | 90 | 140 | 145 | 145 | 153 |

The settings also affect the capacities of jaw crushers. Figure III.1.1.b. indicates the effect of altering the setting on the capacities of some jaw crushers.

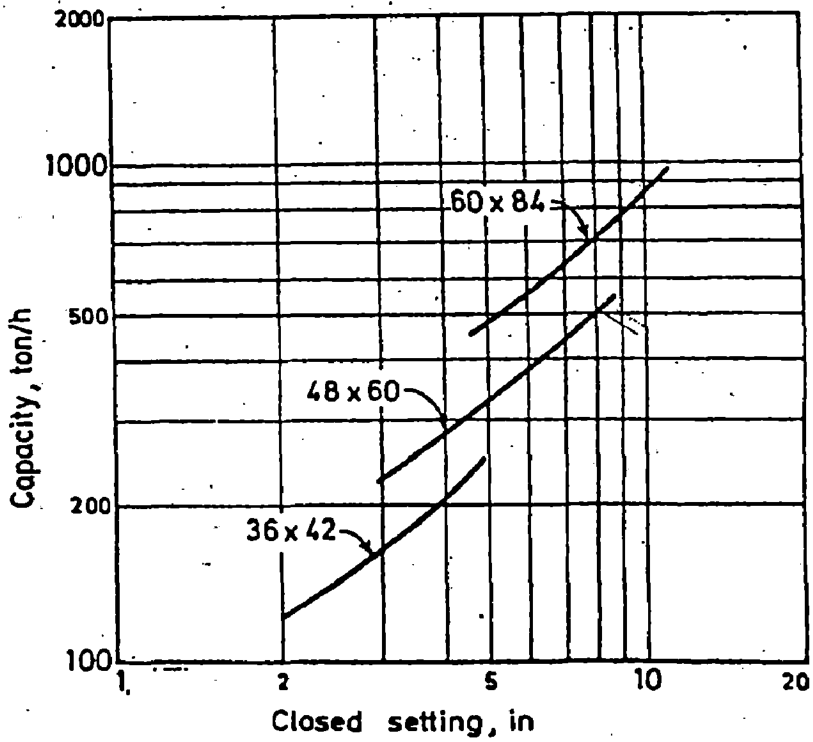

*Figure III.1.1.b. Capacity of Blake jaw crusher at various setting for three different feed openings* [4]

Jaw crushers are usually rated according to their receiving areas, i.e. in term of width of plates x gape. The performance of the different types of jaw crushers are compared in Table II.3.1. Capacities of jaw crushers for different sizes are shown in Tables III.1.1.a & b. As, the setting may be based on the opening or closed position of the bottom of the swing jaw, a capacity table should specify which setting applies. The closed position is most commonly used and is the basis for the values given in table. The capacity is given in tons per hour for stone weighing 100 lbs/ft$^3$ (1602 kg/m$^3$) when crushed.

### III.1.2. Output Production of Roll Crusher

Roll crushers are used for production additional reduction in the size of stone after the output of a quarry has been subjected to one or more stages of prior crushing. Commonly they are used as secondary units.

The reduction ratio of a finished aggregate should be not greater than 4 : 1. The feed size to the secondary unit is in reality the output size of the jaw or other primary crusher. Based on this sequence, the product desired will govern the roll setting. This setting governs the feed size to the secondary unit. As the feed size to the secondary is the output of the primary crusher, the jaw settings are therefore prescribed for this production.

The maximum size of material that may be fed to a crusher is directly proportional to the diameter of the roll. If the feed contains stones that are too large, the roll will not grip them and pull them through the crusher. Hence, the roll crusher size is specified in terms of diameter of the rolls. Another parameter which is of relevance in this regard is the length of the roller. Thus, the roll crushers are specified by two sets of numbers. The first set indicated the diameter of rollers while the second set refers to length of rollers.

Maximum rock size that can be fed into roll crusher can be analyzed by considering the fact that the comminuting effect is achieved by two roll surfaces gripping. The material between them and submitting the material to a force imposed by one or both surfaces. The material may be fed between the surfaces under the influence of gravity or assisted by centrifugal force.

A circular particle held between two circular surfaces is shown in Figure III.1.2., the angle between the tangents at the two points of contact between the particle and the surfaces is called the angle of nip.

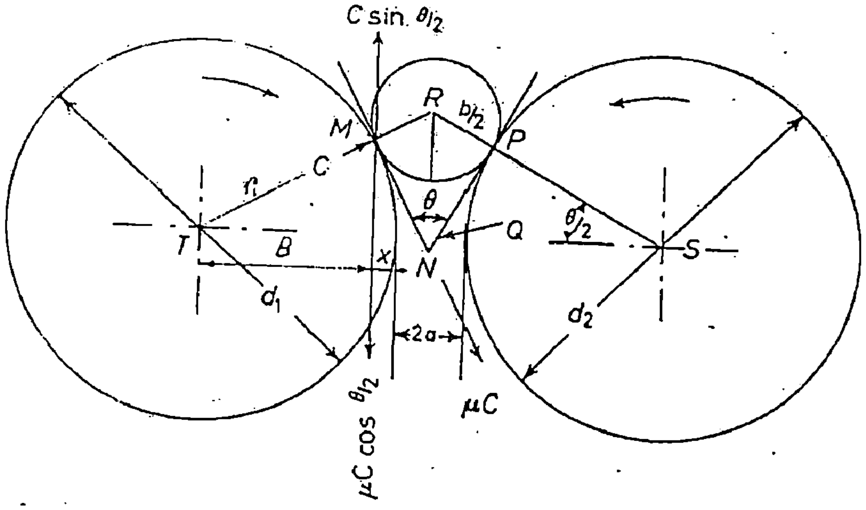

***Figure III.1.2. Cross-section of double roll crusher*** [4]

There is an angle beyond which the surfaces fail to nip the particle, which would slip when pressure was applied to it by the surfaces and would thus not be broken. The maximum angle of nip at which a particle can be gripped between two given surfaces is therefore a determinant of the maximum particle diameter which can be comminuted by nipping between curved surfaces. Figure III.1.2 represents a general condition for nipping with the simplifying assumption that the particle is spherical or, more accurately, makes point contact with the other two surfaces and in one place on each. The circular form of the particle is idealistic: real particles will sometimes have more contact and will hardly ever be spherical, but the circular form offers the most resistance to breaking for this particular consideration.

The determination of the value of this maximum angle of nip may be approached as follows. Let the particle in Figure III.1.2 receives a compressive force C normal to the tangent at the point of contact and let the angle of nip be $\theta$. The particle will be gripped by the surfaces if the vertical component of the compressive force C, i.e C sin $\theta/2$, is not greater than the vertical component of the frictional force opposing it (ignoring the contribution from the weight of the particle, which is small but would assist friction). Now the frictional force is $\mu C$, where $\mu$ is the coefficient of friction between the surfaces in the direction of the tangent to the point of contact, and the vertical component of this is $\mu C \cos \theta/2$, where $\theta/2$ is half the angle of nip. Thus, for gripping

$$\mu C \cos \theta/2 > C \sin \theta/2 \quad \underline{\text{or}} \quad \mu > \tan \theta/2 \quad \ldots\ldots\ldots\ldots\ldots \textbf{(III-5)}$$

Now the static coefficient of friction has values of which the following are typical:

| | |
|---|---|
| Between steel and limestone | 0.24 |
| Between steel and marble | 0.17 |

These values would correspond with angles of nip of $27^0$ and $20^0$, respectively. But this is the desired situation before the particle has moved. Once the particle begins to move, the friction is reduced.

The method for determining the maximum angle of nip having been established, a relationship will now be developed between the curvature of the gripping surfaces and the maximum diameter of particle which can be gripped by them for a given maximum angle of nip $\theta$.

The first circumstance to be considered is that of a particle of diameter b gripped between the curved surfaces of two dissimilar cylinders of diameter $d_1$ and $d_2$, with the smallest distance separating them equal to 2a (Figure III.1.2.). Then the angle MNP is the angle of nip ($\theta$).

The first circumstance to be considered is that of a particle of diameter 'b' gripped between the curved surfaces of two dissimilar cylinders of diameter $d_1$ and $d_2$, with the smallest distance separating them equal to 2a (Figure III.1.2.) then, the angle MNP is the angle of nip ($\theta$). As MR and PR are radii of the particle, each of size b/2, and the angles NMR and NPR are right angles, because MN and PN are tangents, while RN is common, the triangles MNR and NPR are congruent. In particular, angles MNR and PNR are equal and therefore equal to θ/2. The angle BRS in therefore $180^0$ - θ and, by the cosine rule,

$$\left(\frac{d_1}{2}+\frac{d_2}{2}+2a\right)^2=\left(\frac{d_1}{2}+\frac{b}{2}\right)^2+=\left(\frac{d_1}{2}+\frac{b}{2}\right)^2-2=\left(\frac{d_1}{2}+\frac{b}{2}\right)\left(\frac{d_1}{2}+\frac{b}{2}\right)^2\cos\angle BR$$

But cos ∠BRS = - cos θ. Completing the square, the right hand side of the equation becomes:

$$\left(\frac{d_1}{2}+\frac{d_2}{2}+b\right)^2-2(1-\cos\theta)\left(\frac{d_1}{2}+\frac{b}{2}\right)\left(\frac{d_2}{2}+\frac{b}{2}\right)$$

or

$$(b-2a)(d1+d2+2a+b)=2(1-\cos\theta)\left(\frac{d_1}{2}+\frac{b}{2}\right)\left(\frac{d_2}{2}+\frac{b}{2}\right)$$

$$=\frac{1-\cos\theta}{2}(d_1+b)\,(d_2+b)$$

and

$$\frac{(d_1+b)\,(d_2+b)-(b-2a)\,(d_1+d_2+2a+b)}{(d_1+b)\,(d_2+b)}=\frac{1+\cos\theta}{2}$$

or

$$\frac{(d_1+2a)\,(d_2+2a)}{(d_1+b)\,(d_2+b)}=\frac{1+\cos\theta}{2}\qquad\text{(Case1)}\ \ldots\ldots\ldots\ldots\ldots\ldots\ \textbf{(III-6)}$$

In the special case or $d_1 = d_2 = d$, e.g. two equal rolls or balls.

$$\frac{d+2a}{d+b}=\sqrt{\frac{1+\cos\theta}{2}}=\cos\theta/2\qquad\text{(Case2)}\ \ldots\ldots\ldots\ldots\ldots\ldots\ \textbf{(III-7)}$$

In the special case of one surface being plane or $d_1 = \infty$, $d_2 = d$, e.g. a rod or ball on a drum with a large enough diameter for its surface to be considered flat:

$$\frac{d + 2a}{d + b} = \frac{1 + \cos\theta}{2} \quad \text{(Case 3)}\ldots\ldots\ldots\ldots\ldots \textbf{(III-8)}$$

If the gripping surfaces are in contact, i.e. 2a = 0, e.g. when two rods or balls touch,

$$\frac{d_1 d_2}{(d_1 + b)(d_2 + b)} = \frac{1 + \cos\theta}{2} \quad \text{(case 4)} \ldots\ldots\ldots\ldots\ldots \textbf{(III-9)}$$

and when the diameters of the gripping surfaces are equal, e.g. when two rods or balls of equal diameter touch,

$$\frac{d_2}{(d + b)^2} = \frac{1 + \cos\theta}{2}$$

or

$$\frac{d}{d + b} = \cos(\theta / 2)$$

and

$$1 + \frac{b}{d} = \sec(\theta / 2) \quad \text{or} \quad \frac{b}{d} = \sec(\theta / 2) \qquad \text{(Case 5)}\ldots\ldots\ldots\ldots \textbf{(III-10)}$$

Thus, knowing the parameter like angle of nip and physical characteristic of roll crusher, the feed size can be computed. However, in view of the fact that the feed is not spherical, the approximate method which follows is more popular for determination of maximum feed size.

Figure III.1.2 also reflect how the maximum rock size may be determined. According to the typical coefficient of friction for stones, the angle could be about $30^0$ for smooth shell. This angle applies to the static condition and could apply when the rolls are moving slowly. However, as will be discussed later, practice is to use high peripheral speeds and angles in the range $11\text{-}25^0$ are used by manufacturers. For rolls of unequal diameter the relationship is (case -1)

$$\frac{(d_1 + 2a)(d_2 + 2a)}{(d_1 + b)(d_2 + b)} = \frac{1 + \cos\theta}{2}$$

In which $d_1$ and $d_2$ are diameters of the rolls, 2a is the distance between them and b is the diameter of the feed particle. For the more usual case of equal roll diameters (case 2), the relationship simplifies to

$$\frac{d + 2a}{d + b} = \cos(\theta / 2) \quad \dots\dots\dots\dots \quad \textbf{(III-11)}$$

To take the range of angle used by manufacturers, this means that (d+2a)/(d+b) can vary from 0.976 to 0.995. Now 2a is nominally the maximum product size, so that reduction ration R is b/2a. Taking the mean of the values in the above equation, say 0.985 (corresponding to $\theta = 20^0$), and solving for b,

$$B = 0.015d + 2.031a \quad \text{or} \quad \frac{b}{2a} = R = \frac{0.015d}{2a} + 1.016$$

$$R - 1 = \frac{0.015d}{2a} = \frac{d}{67x2a} \quad \dots\dots\dots\dots \quad \textbf{(III-12)}$$

Another formula for determining the maximum rock size is by assuming the angle of nip for smooth shell to be $33^0$ 30'. By geometry then, the angle between the horizontal and the line to point of tangent become equal to $16^0$ 45'. On the basis of that, the maximum feed size for equal roll diameter is determined as follows

If, $r = \frac{d}{2}$ = radius of rolls

$\theta$ = angle of nip = $33^0$ 30'

2a = distance between roll face = roll setting.

Then, referring to Figure III.1.2., $\frac{\theta}{2} = 16^0\ 45'$

$$B = r \cos \theta/2 = r \cos 16^0\ 45' = 0.9575\ r$$

$$x = r - B = r - 0.9575\ r = 0.0425\ r$$

Capacity of roll crusher will vary with the kind of stone, size of feed, size of finish product desired, width of rolls, speed at which rolls rotates, uniformity of flow, and extent to the type of roll shell being used. Smooth shell must be used when producing materials of ½ in and under. From ½ in. to 1 in. a smooth shell and a fine corrugated will be found to give best results. Corrugated shells are recommended for the production of material over 1 in. The combination of one smooth and one corrugated shell will increased the stage of reduction over that of two smooth shells. Likewise, a greater stage of reduction over that of one smooth and one corrugated shell is obtained when both shell are corrugated.

The theoretical volume of solid ribbon of material passing between the two rolls in 1 minute would be the product of the width of the opening times the width of the rolls times the speed of the surface of the rolls. The volume may be expressed in cubic centimeters (cu.in.) or cubic feet (cu.ft.). In actual practice the ribbon of crushed stone will never be solid. A more realistic volume should approximate one-fourth to one-third of the theoretical volume. A formula which may be used as a guide in estimating the capacity of roll crushers is derived as follows; if,

$C$ = distance between rolls = roll setting (= 2a in figure III.1.2)
$W$ = width of roll
$S$ = peripheral speed of rolls
$N$ = speed of roll
$r$ = radius of rolls
$V_1$ = theoretical volume
$V_2$ = actual volume
$Q$ = probable capacity

Then,

$$V_1 = C \,.\, W \,.\, S \quad \text{.............................................} \textbf{(III-13)}$$

Assuming $V_2 = V_1 / 3$

We get $V_2 = C\,W\,S / 3$

If, C and W are expressed in cms, then,

$$V_2 = C\,W\,S/3 \;\; cm^3/min, \text{ for } S \text{ in cms/min}$$

$$= C\,W\,S/3 \times 10^{-6} \text{ cum/min.}$$

Similarly, if C and W are expressed in inches, then

$$V_2 \quad = C\,W\,S/3 \text{ in}^3/\text{min, for S in inches/min}$$

$$= C\,W\,S/3 \times 1728 \text{ cu. ft./min. (1cu. ft. = 1728 cu. in.)}$$

Again if the crushed stone weigh 1600 kg/cum or 1.6 tonne/cum, then Q tones/hr. is given by

$$Q \quad = 1.6\,V_2\text{ . where } V_2 \text{ is in cum/hr.}$$

$$= 1.6 \times 60 \times \frac{CWS}{3} \times 10^{-6} = 48 \times 10^{-6}\,C\,W\,S \quad \text{tones/hr.}$$

Similarly, in FPS units, corresponding unit weigh of stone 100 lbs/cft.

$$Q \quad = \frac{100}{2000} \times V_2 \text{ , for } V_2 \text{ in cft/hr.}$$

$$= {}^{1}/_{20} \times 60 \times \frac{CWS}{3\text{x}1728}$$

$$= \frac{CWS}{1728} \text{ tons/hr.}$$

also, $S = 2\pi\,r\,N$, so that Q in MKS units is given by

$$Q \quad = 48 \times 10^{-6} \times C\,W\,2\pi\,r\,N$$

$$Q \quad = 96 \times 10^{-6} \times C\,W\,2\pi\,r\,N \text{ tones/hr.} \qquad \text{.............(III-14)}$$

and in FPS units, Q becomes

$$Q = \frac{C\ W\ 2\pi\ r\ N}{1728}$$

$$Q = \frac{C\ W\ \pi\ r\ N}{864} \text{ tons/hr.} \qquad \text{..........(III-15)}$$

Table III.1.2.a and Table III.1.2.b provide production capacity of smooth roll crusher for material weighing 100 lbs per cu. ft. Such tables can be used as guidance to determine capacity of roll crusher.

### *Table III.1.1.a* [1]

### CAPACITY – TELSMITH 10"×16" THRU 22"×50" OVERHEAD ECCENTRIC JAW CRUSHERS

| Size | 10"×16" | 10"×21" | 10"×30" | 12"×36" | 15"×24" | 15"×38" | 20"×36" | 20"×44" | 22"×50" |
|---|---|---|---|---|---|---|---|---|---|
| Capacity – Tons Per Hour at Discharge Setting of: | | | | | | | | | |
| 1/4" | 6–8 | 7–10 | 13–20 | – | – | – | – | – | – |
| 1/2" | 8–11 | 9–13 | 17–25 | 22–33 | 17–25 | – | – | – | – |
| 3/4" | 9–13 | 12–16 | 20–29 | 25–38 | 21–30 | 38–57 | 45–85 | 65–115 | – |
| 1" | 10–15 | 15–20 | 23–34 | 29–43 | 25–35 | 43–64 | 52–95 | 72–125 | 170–250 |
| 1 1/4" | 12–18 | 17–23 | 26–38 | 33–48 | 27–40 | 48–72 | 58–105 | 80–135 | 175–266 |
| 1 1/2" | 14–20 | 19–26 | 29–43 | 36–54 | 30–45 | 53–79 | 64–115 | 90–115 | 180–283 |
| 2" | 17–25 | 22–33 | 35–52 | 43–65 | 37–55 | 57–86 | 75–135 | 110–168 | 210–315 |
| 2 1/2" | – | – | – | 50–75 | 43–65 | 67–100 | 85–155 | 123–192 | 230–343 |
| 3" | – | – | – | – | – | 76–114 | 96–174 | 152–217 | 250–370 |
| 3 1/2" | – | – | – | – | – | 85–128 | 108–192 | 167–243 | 270–405 |
| 4" | – | – | – | – | – | – | 146–210* | 183–267 | 290–440 |
| 5" | – | – | – | – | – | – | 165–250* | 212–316 | 330–475 |

** Capacity with short toggle (Optional). Capacities shown are based on conditions listed in general notes on Pages 18-19. Capacities are listed for jaws in closed position and measured peak-to-peak.*

*Table III.1.1.b* [1]

## CAPACITY – TELSMITH 25"×40" THRU 55"×66" OVERHEAD ECCENTRIC JAW CRUSHERS

| Size | 25"×40" | 30"×42" | 30"×55" | 36"×48" | 38"×58" | 40"×50"† | 44"×48" | 50"×60" | 55"×66" |
|---|---|---|---|---|---|---|---|---|---|
| Capacity – Tons Per Hour at Discharge Setting of: | | | | | | | | | |
| 2" | – | – | – | – | – | – | – | – | – |
| 2 1/2" | 133–217 | 150–230 | – | – | – | – | – | – | – |
| 3" | 148–237 | 167–252 | – | – | – | – | – | – | – |
| 3 1/2" | 160–259 | 183–273 | 283–430 | – | – | – | – | – | – |
| 4" | 178–282 | 197–319 | 300–460 | 290–435 | 390–600 | – | – | – | – |
| 5" | 206–334 | 230–342 | 350–530 | 328–492 | 432–680 | – | 384–580 | – | – |
| 6" | 234–389* | 270–405* | 390–600 | 362–547 | 500–735 | – | 443–655 | 548–785 | – |
| 7" | 266–444* | 310–505* | 430–670 | 408–620 | 530–800 | – | 500–750 | 570–850 | 670–995 |
| 8" | – | – | – | 438–660 | 575–890 | – | 540–810 | 625–940 | 720–1,080 |
| 9" | – | – | – | – | 620–950 | – | 580–870 | 680–1,015 | 785–1,175 |
| 10" | – | – | – | – | – | – | 620–930 | 745–1,120 | 857–1,282 |
| 11" | – | – | – | – | – | – | 660–980 | 840–1,190 | 938–1,410 |
| 12" | – | – | – | – | – | – | 700–1,030 | 925–1,260 | 1,045–1,565 |
| 13" | – | – | – | – | – | – | – | 995–1,330 | 1,170–1,750 |
| 14" | – | – | – | – | – | – | – | 1,065–1,400 | 1,310–1,950 |
| 17" | – | – | – | – | – | 750–1,120 | – | – | – |
| 18" | – | – | – | – | – | 770–1,160 | – | – | – |
| 19" | – | – | – | – | – | 800–1,200 | – | – | – |
| 20" | – | – | – | – | – | 830–1,250 | – | – | – |
| 21" | – | – | – | – | – | 870–1,300 | – | – | – |
| 22" | – | – | – | – | – | 900–1,350 | – | – | – |

* Capacity with short toggle (Optional). † Option with 18" spacer for min. opening of 1" is available. Capacities shown are based on conditions listed in general notes on Pages 18-19. Capacities are listed for jaws in closed position and measured peak-to-peak The 40"×50" crusher is an extended frame version of the 22"×50" crusher.

*Table III.1.2.a. Representative capacity of smooth roll crusher in tons per hour (metric ton per hour) of stone* [6]*

| Size of crusher,** in. (mm) | Speed, rpm | Power required, hp (kW) | Width of openimg between rolls, in. (mm) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | 1/4 (6.3) | 1/2 (12.7) | 3/4 (19.1) | 1 (25.4) | 1 1/2 (38.1) | 2 (50.8) | 2 1/2 (63.5) |
| 16 x 16 | 120 | 15 - 30 | 15 | 30 | 40 | 55 | 85 | 115 | 140 |
| (416 x 416) | | (11 - 22) | (13.6) | (27.2) | (36.2) | (49.7) | (77.0) | (104.0) | (127.0) |
| 24 x 16 | 80 | 20 - 35 | 15 | 30 | 40 | 55 | 85 | 115 | 140 |
| (610 x 416) | | (15 - 26) | (13.6) | (27.2) | (36.2) | (49.7) | (77.0) | (104.0) | (127.0) |
| 30 x 18 | 60 | 50 - 70 | 15 | 30 | 45 | 65 | 95 | 125 | 155 |
| (763 x 456) | | (37 - 52) | (13.6) | (27.2) | (40.7) | (59.0) | (86.0) | (113.1) | (140.0) |
| 30 x 22 | 60 | 60 - 100 | 20 | 40 | 55 | 75 | 115 | 155 | 190 |
| (763 x 558) | | (45 - 75) | (18.1) | (36.2) | (49.7) | (67.9) | (104.0) | (140.0) | (172.0) |
| 40 x 20 | 50 | 60 - 100 | 20 | 35 | 50 | 70 | 105 | 135 | 175 |
| (1016 x 508) | | (45 - 75) | (18.1) | (31.7) | (45.2) | (63.4) | (95.0) | (122.0) | (158.5) |
| 40 x 24 | 50 | 60 - 100 | 20 | 40 | 60 | 85 | 125 | 165 | 210 |
| (1016 x 610) | | (45 - 75) | (18.1) | (36.2) | (54.3) | (77.0) | (113.1) | (149.5) | (190.0) |
| 54 x 24 | 41 | 125 - 150 | 24 | 48 | 71 | 95 | 144 | 192 | 240 |
| (1374 x 610) | | (93 - 112) | (21.7) | (43.5) | (64.3) | (86.0) | (144.0) | (173.8) | (217.5) |

* Courtesy Iowa Manufacturing Company

** The first number indicates the diameter of the rolls, and the second indicates the width of the rolls.

*Table III.1.2.b*[1]

## CAPACITIES – SPECIFICATIONS – TELSMITH DOUBLE ROLL CRUSHERS

| Size of Rolls, diameter x face | 24"x16" | | 30"x18" | | (Note 2) 30"x26" | | 40"x22" | | (Note 3) 40"x30" | |
|---|---|---|---|---|---|---|---|---|---|---|
| Net weight of Roll Crusher, lbs. approx. | 5,500 | | 10,400 | | 17,000 | | 16,700 | | 28,740 | |
| Gross weight lbs. export, packed, approx | 5,900 | | 10,900 | | 17,900 | | 17,600 | | 29,740 | |
| Cubical content, cu. ft., export packed, approx | 170 | | 265 | | 370 | | 470 | | 470 | |
| Size of drive pulley, diameter x face | 36"x10" | | 36"x10" | | 48"x12" | | 48"x12" | | 64"x14" | |
| Speed of drive pulley, RPM | 260 | | 330 | | 350 | | 250 | | 290 | |
| Horsepower required (Note 2, page 19) | 30 | | 40 | | 100 | | 60 | | 200/250 | |
| Surface speed of Roll Shell, FPM † | 575 | | 550 | | 550 | | 550 | | 550 | |
| Approximate capacity, in tons per hour, with size of permissable feed at... (Note 3, page 19) | Tons per Hour | Max. Size of feed (Note1) | Tons per Hour | Max. Size of feed (Note1) | Tons per Hour | Max. Size of feed (Note1) | Tons per Hour | Max. Size of feed (Note1) | Tons per Hour | Max. Size of feed (Note1) |
| ...w/ 1/8" spacing between rolls (Notes 4/5, page 19) | 12 | 3/8" | 13 | 3/8" | 19 | 3/8" | 15 | 3/8" | 21 | 3/8" |
| ...w/ 1/4" spacing between rolls | 24 | 3/4" | 26 | 3/4" | 37 | 3/4" | 31 | 3/4" | 42 | 3/4" |
| ...w/ 3/8" spacing between rolls | 36 | 1 1/8" | 39 | 1 1/8" | 56 | 1 1/8" | 46 | 1 1/8" | 63 | 1 1/8" |
| ...w/ 1/2" spacing between rolls | 48 | *1 1/4" | 52 | *1 3/8" | 75 | *1 3/8" | 62 | 1 1/2" | 85 | *1 1/4" |
| ...w/ 3/4" spacing between rolls | 72 | *1 1/2" | 79 | *1 5/8" | 112 | *1 5/8" | 92 | *1 7/8" | 126 | *1 1/2" |
| ...w/ 1" spacing between rolls | 96 | *1 3/4" | 103 | *1 7/8" | 149 | *1 7/8" | 125 | *2 1/8" | 170 | *2 1/8" |
| ...w/ 1 1/4" spacing between rolls | 120 | *2" | 130 | *2 1/8" | 186 | *2 1/8" | 156 | *2 3/8" | 212 | *2 3/8" |
| ...w/ 1 1/2" spacing between rolls | 144 | *2 1/4" | 156 | *2 3/8" | 223 | *2 3/8" | 187 | *2 5/8" | 255 | *2 5/8" |

* NOTE 1: Indicates that, where corrugated rolls are used, somewhat larger feed is permissable, but coarser product will result.

NOTE 2: The 30" x 26" Telsmith Roll has a star gear drive. Other sizes have chain drive.

NOTE 3: The 40" x 30" Telsmith Roll is a pneumatic tired drive.

NOTE 4: Capacities are based on 50% of theoritical ribbon of material weighing 100 lbs. per ft.$^3$ bulk density. The capacities at a given setting depends on type of crushing shells, reduction ratio, slippage and horsepower employed.

† Speed indicated is for average conditions and should be maintained. Speed can be varied to suit special conditions – Consult factory.

## III.2. OUTPUT PRODUCTION OF VIBRATING SCREEN

Output production or capacity of screens is estimated in term of material passing through a unit area of screen. Production capacity of screen vary considerably depending upon various factors like inclination of screen, movement of screen, type and surface condition of material being handled. In steeply sloped screens the aggregate particles may hop rather than drop through the screen. This is also true for too violently vibrated screens. Wet materials can be screened more easily than dry material. Rounded gravel is easier to be screened than the crushed and angular aggregate. If elongated or slab type material is being screened, then there is increased likelihood that the material may ride over the screen in horizontal manner. In fact any aggregate particle traversing a screen requires several chances for dropping through the screen opening. Irregularly shaped aggregate particles may require many more opportunities before their least dimension is so oriented as to allow dropping through. It follows, therefore, that all the aggregate particles passing through a screen must have at least one of their dimension smaller than the screen opening. However, all such aggregate particles whose least dimension is less than the screen openings do not pass through the screen in mass screening operations. Thus, computation of output from a screen presents uncertainties which are difficult to be assessed.

As above stated, the production capacity is influenced by variety of factors. The influence of screening efficiency, on the capacity also warrants consideration. In general the lower the efficiency, the greater the capacity. The other factors such as shape of grains, rate of flow, slope of screen, moisture content and extent of disparity in particles sizes (i.e. percentages of aggregate particles smaller than the screen openings), tend to vary the actual top size of particles passing through the screen mesh. Hence, computation of capacity of screen or for that matter the determination of dimension of the screen is done on the basis of basic capacity in ton per hour per unit area of the screen to which suitable correction factors are applied. There by taking care of variety of variables involved. Some of the practices suggested for determination of screen capacity are present herein after.

**Peurifoy** [6] recommends basic capacity chart and corresponding factors such as shown in Figure III.2.a and Table III.2.a up to III.2.c for calculation the capacity of screen. The basic capacity curve, Figure III.2.a., gives screen capacity for dry screening and is based on material weighing 100 lbs/ft$^3$. The total correction factor which is the product of all relevant factors, namely; efficiency of screen, location of screen deck and the extent of disparity in particle size or aggregate size factor (Table III.2.a, b & c., respectively) are multiplied and being applied to basic capacity. So that the corrected capacity of screen Q, would be given by:

$$Q = A\,C\,E\,D\,G \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(III-16)}$$

Where,

Q = corrected screen capacity , ton/hr

A = area of screen, sq ft

C = theoretical capacity of screen, TPH per sq ft, as read from Fig.III.2.a

E = efficiency factor, from Table III.2.a.

D = deck factor, from Table III.2.b.

G = aggregate size factor, from Table III.2.c

The formula (III-15) for screen capacity can be rewritten in following form to determine minimum area of screen needed for a given capacity.

$$A = \frac{Q}{C\;E\;D\;G} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(III-17)}$$

It must be noted that the screen capacity as determined above is in term of quantity of aggregate that will pass through the screen in one hour.

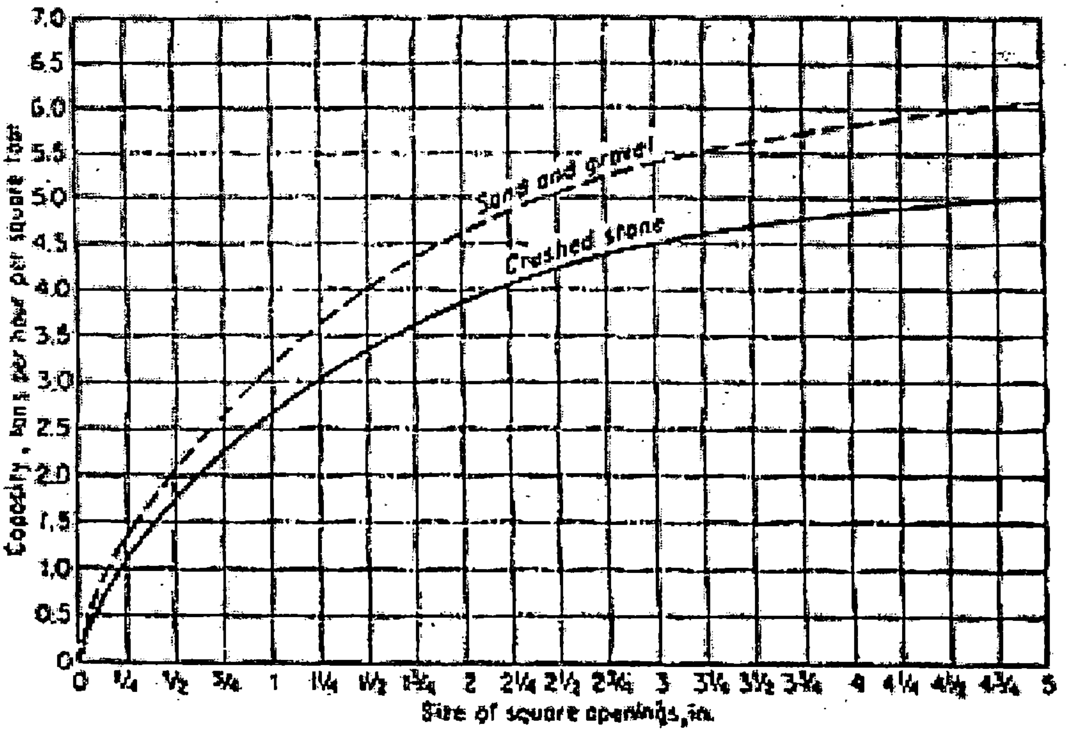

*Figure .III.2. a. Screen Capacity Chart* [6]

*Table.III.2.a. Efficiency Factor*

| Permissible Screen efficiency, % | Efficiency Factor |
|---|---|
| 95 | 1.00 |
| 90 | 1.25 |
| 85 | 1.50 |
| 80 | 1.75 |
| 75 | 2.00 |

*Table.III.2.b. Deck Factor*

| For Deck number | Deck factor |
|---|---|
| 1 | 1.00 |
| 2 | 1.25 |
| 3 | 1.50 |
| 4 | 1.75 |

*Table.III.2.c. Aggregate Size Factor*

| % of aggregate Less than ½ The size of Screen opening | Aggregate size factor |
|---|---|
| 10 | 0.50 |
| 20 | 0.70 |
| 30 | 0.80 |
| 40 | 1.00 |
| 50 | 1.20 |
| 60 | 1.40 |
| 70 | 1.80 |
| 80 | 2.20 |
| 90 | 3.00 |

**Jagman Singh,**[10] recommends use of basic capacity Tables and corresponding factors which are given in Table III.2.d and Table III.2.e, respectively. It would be seen from the table that the basic capacity based on 95 percent efficiency of screening, a unit weight of 100 lbs/ft$^3$ for gravel and crushers runs aggregates and of 135 lbs/ft$^3$ for crusher run iron ore. The correction factors take into consideration four factors, namely; deck factor A, half size factor B, wet screening factor C, and oversize actor D. Thus, in this case the corrected capacity would be;

$$Q = A_1\ C_1\ A\ B\ C\ D \qquad \text{.................................(III-18)}$$

Where,

Q = corrected screen capacity , ton/hr
$A_1$ = area of screen, sq ft
$C_1$ = Basic capacity of screen, TPH per sq ft. (Table III.2.d)
A = deck factor,
B = half size factor,
C = wet screening factor,
G = oversize factor,

As in previous case formula (III-17) can also be rewritten as :

$$A_1 = \frac{Q}{C_1\ A\ B\ C\ D} \qquad \text{..........................(III-19)}$$

to determine the screening size for screening on specified quantity of aggregates.

*Table III.2.d. Capacity in TPH (Short Ton) Per Square Foot of Screen Size of Opening* [10]

| | 1/8 | 1/4 | 3/8 | 1/2 | 5/8 | 3/4 | 7/8 | 1 | 1 1/4 | 2 | 2 | 3 1/2 | 4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Crusher run | 0.5 | 0.9 | 1.2 | 1.4 | 1.6 | 1.7 | 1.9 | 2.1 | 2.7 | 3.1 | 3.4 | 3.7 | 4.0 |
| Gravel | 0.8 | 1.0 | 1.4 | 1.7 | 1.9 | 2.1 | 2.4 | 2.5 | 3.2 | 3.7 | 4.0 | 4.4 | 4.8 |
| Crusher run iron ore | 0.6 | 1.1 | 1.5 | 1.7 | 1.9 | 2.1 | 2.4 | 2.5 | 3.2 | 3.7 | 4.0 | 4.4 | 4.8 |

Base on 95% screening effeciency
Crusher run and gravel based on 100/cu ft material
Iron ore based on 135/cu ft material

*Table III.2.e. FACTORS* [10]

| A | | B | | C | | D | |
|---|---|---|---|---|---|---|---|
| Correcting For No.of screening decks above | | Ammount of Aggregate feed to deck less than 1/2 opening | | With water Spray derectly on screen | | Estimated Percent of oversize feed screen | |
| Deck | Factor A | Factor B | | Screen Opening | Factor C | % Oversize | Factor D |
| Top | 1.00 | 10% | 0.5 | - | - | 10 | 1.05 |
| Second | 0.90 | 20% | 0.7 | - | - | 20 | 1.00 |
| Third | 0.80 | 30% | 0.8 | - | - | 30 | 1.00 |
| Fourth | 0.70 | 40% | 1.0 | - | - | 40 | 0.95 |
| | | 50% | 1.2 | 3/16 | 3.50 | 50 | 0.90 |
| | | 60% | 1.4 | 5/16 | 3.00 | 60 | 0.85 |
| | | 70% | 1.8 | 3/8 | 2.50 | 70 | 0.80 |
| | | Over 70% | Use 1.8% | 1/2 | 1.75 | 80 | 0.70 |
| | | | | 1 | 1.25 | 90 | 0.60 |
| | | | | | | 92 | 0.50 |
| | | | | | | 94 | 0.44 |
| | | | | | | 96 | 0.35 |
| | | | | | | 98 | 0.20 |

Recommendations of **Stubbs**[2] are given in Table III.2.f., which is includes basic capacity in tubular form and takes into consideration five factors, namely, over size factor O, half size factor H, condition factor K, weight factor W and deck factor D. it may noted that in this case the capacity of screen is based on quantity of total feed to the screen in contrast to the screen capacity recommendations of R.L. Peurifoy, which are based on the quantity of aggregate that will pass through the screen.

### *Table III.2.f. Capacities of Horizontal Vibrating Screens* [2]

Screen area required : A = total feed + Actual capacity
Actual Capacity : AC = (SC) x O x H x K x W x D, tph per sq ft.
Standard capacity : (SC) in tph per sq ft given in Table I

Table I gives the capacity of screen cloth in tons per hour of total feed to deck per 1 sq ft of square opening screen cloth, based on 25 per cent oversize and 40 per cent half size with 50 per cent open area, and 4 per cent moisture maximum, effeciency 90 per cent. Increase values in table 30 to 40 per cent for slotted screens 1/4 in. and less wide.

O = Oversize factor corresponding to per cent of total feed larger than the screen cloth opening ........................................ Table II
H = Half size factor corresponding to per cent of total feed smaller than half the size of the screen cloth opening ........................................ Table II
K = Condition factor corresponding to the physical condition of the material being screened ........................................ Table III
W = Weight factor corresponding to the weight of the material being screened .................... Table IV
D = Deck Factor corresponding to the location of the screen deck being figured .................... Table V

**Table I**

| Screen opening | Capacity, tons/hr | Screen opening in. | Capacity, tons/hr | Screen opening in. | Capacity, tons/hr | Screen opening in. | Capacity, tons/hr |
|---|---|---|---|---|---|---|---|
| 8M | 1.1 | 1/2 | 3.8 | 1 1/4 | 6.0 | 2 1/2 | 8.40 |
| 1/8 in. | 1.3 | 5/8 | 4.3 | 1 1/2 | 6.5 | 3 | 9.30 |
| 4M | 1.8 | 3/4 | 4.7 | 1 3/4 | 7.0 | 3 1/2 | 10.20 |
| 1/4 in. | 2.5 | 7/8 | 5 | 2 | 7.5 | 4 | 11.00 |
| 3/8 | 3.3 | 1 | 5.5 | 2 1/4 | 8.0 | 4 1/2 | 12.00 |

**Table II**

| Oversize and half size, % | Factor for oversize O | Factor for half size, H |
|---|---|---|
| 25 | 1.00 | 0.7 |
| 30 | 1.03 | 0.8 |
| 35 | 1.06 | 0.9 |
| 40 | 1.09 | 1.0 |
| 45 | 1.13 | 1.1 |
| 50 | 1.18 | 1.2 |
| 55 | 1.25 | 1.3 |
| 60 | 1.32 | 1.4 |
| 65 | 1.42 | 1.5 |
| 70 | 1.55 | 1.6 |
| 75 | 1.75 | 1.7 |
| 80 | 2.00 | 1.8 |

**Table III. Condition Factor**

| | K |
|---|---|
| Quarried material.............. | 1.00 |
| Uncrushed material............ | 1.25 |
| Gravel, uncrushed.............. | 1.25 |
| Crushed rock and gravel...... | 1.00 |

**Table IV. Weight Factor**

| | W |
|---|---|
| 75 lb cu ft | 0.75 |
| 100 lb cu ft | 1.00 |
| 150 lb cu ft | 1.50 |

**Table V. Deck Factor**

| | D |
|---|---|
| Top deck | 1.00 |
| Second deck | 0.90 |
| Third deck | 0.75 |

**Kellog,**[3] recommends use of a basic capacity chart on logarithmic scale and five correction factors are given in Figure III.2.b. It will be seen from the said Figure that correction factors take into consideration five variables namely; the deck position, A; half size factor, B; dry or wet screening factor, C; oversize factor, D; and efficiency factor, E. So that, the capacity of screen would be given by

$$Q = A_1 \; C_1 \; A \; B \; C \; D \; E \qquad \text{..........................(III-20)}$$

Where,

Q = corrected screen capacity in tons per hour

$A_1$ = area of screen in cubic feet

$C_1$ = basic capacity of screen in tons/hour per sq. ft. as read from Figure III.2.b.

A = deck factor from table in Figure III.2.b

B = half size factor from table in Figure III.2.b

C = wet screening factor from table in Figure III.2.b (in case of dry screening value of C = 1 is recommended)

D = oversize factor from table in Figure III.2.b

E = efficiency factor from table in Figure III.2.b

As in previous cases, the formula (III-19) can be used for estimating screen size as follows;

$$A_1 = \frac{Q}{C_1 \; A \; B \; C \; D \; E} \qquad \text{..........................(III-21)}$$

Recommendations of **Telsmith**,[1] are given in Table III.2.g., which have been included in this dissertation in the form of first hand information from manufacturers. It will be seen from the said table that in this case the basic capacity, A, is based upon the quantity of aggregates passing through the screen, and that five variables, considered in the form of correction factors are oversize factor, B; efficiency factor, C; half size factor, D; wet screening factor, E; and the deck factor, F.

**Havers and Stubbs**[2] gives one of the most exhaustive formulation for determination of capacity of screens which takes into account as many as ten factors. They recommend use of following formula for determining permissible total feed inclusive of oversize and undersize to the screen.

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Date 20|12|05

$$A = B\ S\ D\ V\ H\ T\ K\ P\ W\ O\ M \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\textbf{(III-22)}$$

Where,

A =permissible total feed (oversize plus undersize) to screen deck in tons/hour per sq. ft.

B =basic capacity of screen in tons/hour per sq. ft.

S = factor for angle of incline

D = deck factor

V = oversize factor

H = half size factor

T = slot factor

K = condition factor

P = shape factor

W = weight factor

O = open area factor

M =wet screening factor which is recommended to be omitted for dry screening.

While various factors as appearing on the right hand side of above equation are given in Table III.2.h. The opening area; factor O warrants use of Table III.2.i which gives percentage of open areas in screens of various types.

FACTORS

| A | | B | | C | | D | |
|---|---|---|---|---|---|---|---|
| Correcting for No.of screening decks above | | Amount of aggregate feed to deck less than 1/2 opening | | With water spray directly on screen | | Estimeted per cent of oversize feed screen | |
| Deck | A | | B | Screen opening | Factor | % over-size | Factor |
| Top.......... | 1 | 10 % | .5 | ....... | ....... | 10 | 1.05 |
| Second...... | .90 | 20 % | .7 | ....... | ....... | 20 | 1.00 |
| Third......... | .80 | 30 % | .8 | ....... | ....... | 30 | 1.00 |
| Fourth....... | .70 | 40 % | 1.0 | ....... | ....... | 40 | .95 |
| % Efficiency | Factor E | 50 % | 1.2 | 3/16 | 3.50 | 50 | .90 |
| | | 60 % | 1.4 | 5/16 | 3.00 | 60 | .85 |
| 98 | .9 | 70 % | 1.8 | 3/8 | 2.50 | 70 | .80 |
| 95 | 1 | 80 % | 1.8 | 1/2 | 1.75 | 80 | .70 |
| 90 | 1.15 | 90 % | 1.8 | 1 | 1.25 | 90 | .60 |
| 80 | 1.55 | | | | | 92 | .50 |
| 70 | 1.8 | | | | | 94 | .44 |
| 60 | 2 | | | | | 96 | .35 |
| 50 | 2.3 | | | | | 98 | .20 |

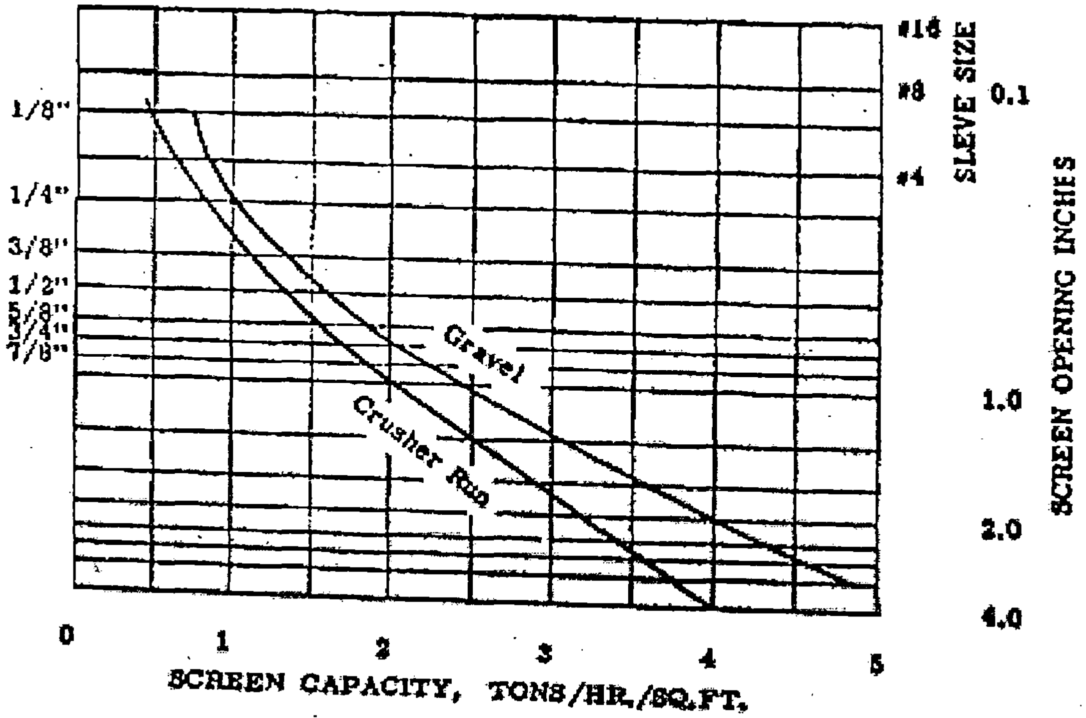


Figure *III.2.b. Capacities of vibrating screens. based on 95% screening efficiency, 110 lb per cu ft material. (Curves and Factor A, B, C, D courtesy Pioneer Engineering Work, Inc.)*[3]

## *Table III. 2. g.*[1]

## CAPACITY OF VIBRATING SCREENS

INFORMATION REQUIRED TO CALCULATE CAPACITY AND SIZE OF VIBRATING SCREENS

1. Sieve analysis of feed–obtained by testing a sample, from crusher product curves or in from plant production records.
2. Weight per ft.$^3$ material to be screened.
3. Determine if screening is to be done dry or with water sprays.
4. Shape of screen openings, i.e., round, square or rectangular.
5. If dry screening, what is moisture content, and is clay present? (see notes 4 & 5 on page 117).
6. Size of openings in screen decks and if nominal or specification sizing is required.
7. Screening efficiency required (see Note 3 below)
8. Total feed to screen, including any circulating load from crushers, in short TPH. Allow for peak tonnage.

---

1. TO DETERMINE SIZE OF SCREEN. Use the formula: Area (Sq. Ft) $= \frac{TF - \text{Oversize}}{A \times B \times C \times D \times E \times F}$ in which, TF = Total feed to screen in TPH. Oversize = Amount of feed larger than deck openings, in TPH. A, B, C, D, E & F are factors obtained from the tables below.
2. TO DETERMINE TOTAL CAPACITY OF A GIVEN SCREEN. Use the formula: C (capacity through screen) = [Area×(A×B×C×D×E×F)] plus Oversize.
3. Efficiency is the ratio of the undersize obtained in screening to the amount of undersize available in the feed. It is found by the formula: $E(\%) = \frac{100(e-v)}{e(100-v)} \times 100$ $e$ = percentage undersize in feed $v$ = percentage undersize in overproduct

## ***Table III. 2. g.***[1] CAPACITY OF VIBRATING SCREENS (Cont.)

4. When dry screening, excessive moisture in the material may cause blinding of the screen cloth. Where moisture content exceeds that given in the following table, the use of special wire cloth, ball deck trays, or electric heating may be required. Consult factory.

| Square Screen Opening | Moisture | Square Screen Opening | Moisture |
|---|---|---|---|
| 1/16" & smaller | 0% | 7/16" to 3/8" | 4% |
| 3/16" to 1/8" | 1% | 1" to 1/2" | 6% |
| 5/16" to 1/4" | 2% | larger than 1" | 8% |

5. Maximum moisture content of feed when screening with ball decks.

| Square Screen Opening | Moisture | Square Screen Opening | Moisture |
|---|---|---|---|
| 1/4" | 5% | 1/16" | 2% |
| 3/16" | 4 1/2% | 1/32" | 1% |
| 1/8" | 4% | | |

6. Where rectangular shaped screen cloth openings are used, Factor "A" in the table following may be increased 25% for openings 5 times as long as they are wide, and 50% for openings 10 times as long as they are wide. For rounc openings use 80% of Factor "A"

7. WHEN RESCREENING OR SIMILAR APPLICATION. Where Factor "D" in the table below cannot be determine screening area may be calculated by dividing one-half the screen feed in TPH by Factor "A" for the screen openir Neglect "B" and "C", use "E" and "F" if appropriate.

8. The formulae in items 1 and 2 when applied to inclined, circular motion screens at a slope of 19° requiring operati at less slope, reduce the capacity 10% for each 2 1/2° below 19°.

9. Factors given are for screen cloth having approximately 50% open area. Increase or decrease factors in proportic to percent open area of cloth selected as shown on page 124.

## *Table III.2.g.* CAPACITY OF VIBRATING SCREENS (Cont.)

FACTOR "A" Capacity in Tons Per Hour Passing Through 1 ft.$^2$ of Screen Cloth Based on 95% Efficiency with 25% Oversize

| Size of Clear Square Opening | .0331" | .0661" | .093" | .125" | .131" | .185" | 1/4" | 3/8" | 1/2" | 5/8" | 3/4" | 7/8" | 1" | 1 1/4" | 1 1/2" | 2" | 2 1/2" | 3" | 4" |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| U.S.S. Mesh Size | 20 | 12 | 8 | 7 | 6 | 4 | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Sand | .58 | .94 | 1.01 | 1.47 | 1.59 | 1.69 | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Stone Dust | .48 | .78 | .84 | 1.19 | 1.30 | 1.41 | – | – | – | – | – | – | – | – | – | – | – | – | – |
| *Coal Dust | .36 | .59 | .64 | .91 | .98 | 1.07 | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Natural Gravel | – | – | – | – | – | – | 2.13 | 2.40 | 2.74 | 2.90 | 3.03 | 3.23 | 3.36 | 3.56 | 3.63 | 4.12 | 4.59 | 4.98 | 6.17 |
| Crushed Stone & Crushed Gravel | – | – | – | – | – | – | 1.74 | 2.04 | 2.29 | 2.39 | 2.52 | 2.68 | 2.78 | 2.95 | 3.04 | 3.45 | 3.83 | 4.17 | 5.13 |
| *Coal | – | – | – | – | – | – | 1.35 | 1.51 | 1.26 | 1.80 | 1.91 | 2.02 | 2.10 | 2.25 | 2.27 | 2.57 | 2.87 | 3.11 | 3.87 |

### FACTOR "B"

Determine or estimate percentage of oversize in feed to screen and use proper factor as given below. For example, if screen has 1" openings and 60% of feed to screen will go thru 1" openings, there is 40% of oversize and factor .88 would apply. Other percentages accordingly.

*Note: Factor "A" based on 75 lbs./ft.$^3$ (hard coal only). For soft coal use 1/2 the factor shown for stone dust or crushed stone.

| Amount of Oversize | Factor "B" | Amount of Oversize | Factor "B" | Amount of Oversize | Factor "B" |
|---|---|---|---|---|---|
| 10% | 1.13 | 60% | .70 | 92% | .43 |
| 20% | 1.02 | 70% | .62 | 94% | .40 |
| 30% | .96 | 80% | .53 | 96% | .32 |
| 40% | .88 | 85% | .50 | 98% | .24 |
| 50% | .79 | 90% | .46 | 100% | .00 |

## Table III.2.g. CAPACITY OF VIBRATING SCREENS (Cont.)

| Desired Efficiency | 70% | 75% | 80% | 85% | 90% | 92% | 94% | 96% | 98% | Factor "C" Slight inaccuracies are seldom objectionable in screening aggregate and perfect separation (100% efficiency) is not consistent with economy. For finished products, 98% efficiency is the extreme practicable limit and 90-94% is usually satisfactory. 60% to 75% efficiency is usually acceptable for scalping purposes. |
|---|---|---|---|---|---|---|---|---|---|---|
| Factor "C" | 1.90 | 1.70 | 1.50 | 1.35 | 1.15 | 1.08 | 1.00 | .95 | .90 | |

| Amount of Feed less than 1/2 the Size of Opening | 10% | 20% | 30% | 40% | 50% | 60% | 70% | 80% | 90% | 100% | Factor "D" Consider this factor carefully where sand or fine rock is present in feed. For example, if screen has 1/2" square openings and a large percentage of the feed is 1/4" or less in size, such as sand or dust, determine percentage and use proper factor given opposite. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Factor "D" | .50 | .60 | .80 | 1.00 | 1.20 | 1.40 | 1.70 | 2.00 | 2.40 | ... | |

| Wet Screening | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Size Opening (Mesh or Inches) | 20 | 14 | 10 | 8 | 1/8" | 6 | 4 | 1/4" | 5/16" | 3/8" | 1/2" | 3/4" | 1" or more |
| Factor "E" | 1.10 | 1.50 | 2.00 | 2.25 | 2.00 | 2.50 | 2.50 | 2.00 | 2.00 | 1.75 | 1.40 | 1.30 | 1.25 |

Wet screen below 20 mesh not recommended.

Factor "E" If material is dry, use factor 1.00. If there is water in material or if water is sprayed on screen, use proper factor given opposite. Wet screening means the use of approximately 5 to 10 GPM of water per yard$^3$ of material per hour or for 50 yards$^3$ per hour of material use 250-500 GPM of water, etc.

| Deck | Top | Second | Third | Fourth | For examples, see next page. | Factor "F" For single deck screen, use factor 1.00. For multiple deck screen, be sure to use proper factor for each deck. |
|---|---|---|---|---|---|---|
| Factor "F" | 1.00 | .90 | .80 | .70 | | |

## Table III.2.h. Screen Capacity Factors [2]

| Basic capacity B* | | | | | |
|---|---|---|---|---|---|
| Screen size, U.S. Standard | B | Screen size, U.S. Standard | B | Screen size, U.S. Standard | B |
| No. 20 | 0.65 | 7/8 | 5.1 | 2 3/4 | 8.80 |
| No. 10 | 0.99 | 1 | 5.5 | 2 7/8 | 9.00 |
| No. 8 | 1.11 | 1 1/8 | 5.8 | 3 | 9.25 |
| No. 7 | 1.24 | 1 1/4 | 6,1 | 3 1/8 | 9.50 |
| No. 6 | 1.39 | 1 3/8 | 6.3 | 3 1/4 | 9.75 |
| No. 5 | 1.57 | 1 1/2 | 6.5 | 3 3/8 | 10.00 |
| No. 4 | 1.80 | 1 5/8 | 6.8 | 3 1/2 | 10.25 |
| 1/4 in. | 2.50 | 1 3/4 | 7.0 | 3 5/8 | 10.50 |
| 5/16 in. | 2.75 | 1 7/8 | 7.3 | 3 3/4 | 10.70 |
| 3/8 in. | 3.20 | 2 | 7.5 | 3 7/8 | 10.90 |
| 7/16 in. | 3.50 | 2 1/8 | 7.7 | 4 | 11.20 |
| 1/2 in. | 3.80 | 2 1/4 | 7.9 | 4 1/8 | 11.40 |
| 9/16 in. | 4.20 | 2 3/8 | 8.2 | 4 1/4 | 11.60 |
| 5/8 in. | 4.50 | 2 1/2 | 8.4 | 4 3/8 | 11.80 |
| 11/16 in. | 4.70 | 2 5/8 | 8.6 | 4 1/2 | 12.10 |
| 3/4 in. | 4.80 | | | | |

*Capacity in tph/sq ft feed to deck. Wire cloth has square openings with 50 per cent open area; feed is 40 per cent half-size, 25 per cent oversize; weight of screened material is 100 pcf. Efficiency, 90 per cent. If a 75 per cent screening efficiency is acceptable, such as in scalping, multiply th tabulated values by 1.5.

| Condition factor, K | |
|---|---|
| Tenacity and/or surface moisture condition | K |
| Wet, muddy, or otherwise sticky rock;<br>gravel, sand, etc. ......................... | 0.75 |
| Surface-wet quarried or mined material;<br>material from stockpiles with surface moisture greater than 6 per cent but nonhygroscopic ......................... | 0.85 |
| Dry pit-run material; dry, lumpy, crushed-rock. Surface moisture less than 4 percent.................................. | 1.00 |
| Naturally dy materials, uncrushed;<br>materials that have been dried prior to screening; or materials screened while hot..................................... | 1.25 |

| Shape factor, P | | | |
|---|---|---|---|
| Elongated particles, percent | P | Elongated particles, percent | P |
| 5 | 1.00 | 40 | 0.75 |
| 10 | 0.95 | 50 | 0.70 |
| 15 | 0.90 | 60 | 0.65 |
| 20 | 0.85 | 70 | 0.60 |
| 30 | 0.80 | 80 | 0.55 |

The first collumn represents the percent of elongated feed particles that have more than a 3-to-1 ratio of length of width, and that have a width larger than half the aperture width but smaller than one and a half times the aperture width.

| Factor S | | Factor D | |
|---|---|---|---|
| Angle of Incline, degrees | S | Deck | D |
| Horizontal | 1.20 | Top | 1.00 |
| 5 | 1.15 | second | 0.90 |
| 10 | 1.05 | Third | 0.80 |
| 15 | 1.00 | Fourth | 0.70 |
| 20 | 0.95 | | |

| Oversie factor, V ; half size factor, H | | | | | |
|---|---|---|---|---|---|
| Per cent of feed* | Oversize factor, V | Half size factor, H | Per cent of feed* | Oversize factor, V | Half size factor, H |
| 0 | 0.91 | 0.40 | 50 | 1.18 | 1.2 |
| 5 | 0.92 | 0.45 | 55 | 1.25 | 1.3 |
| 10 | 0.93 | 0.50 | 60 | 1.33 | 1.4 |
| 15 | 0.90 | 0.55 | 65 | 1.42 | 1.5 |
| 20 | 0.97 | 0.60 | 70 | 1.55 | 1.6 |
| 25 | 1.00 | 0.70 | 75 | 1.75 | 1.7 |
| 30 | 1.03 | 0.80 | 80 | 2.00 | 1.8 |
| 35 | 1.06 | 0.90 | 85 | 2.60 | 1.9 |
| 40 | 1.09 | 1.00 | 90 | 3.40 | 2.0 |
| 45 | 1.13 | 1.10 | 95 | 4.30 | 2.1 |

*For F factor, per cent of feed not passing opening. For H factor per cent of feed les than half the screen opening size.

**Slot factor, T**

For square openings, the factor is 1.00. For long-slot screens and round openings, the factor are;

| | |
|---|---|
| Slot length 6 or more times width ...................... | 1.60 |
| Slot length 3 to 6 more times width ...................... | 1.40 |
| Slot length 2 to 3 more times width ...................... | 1.40 |
| Rounds openings.............................................. | 0.80 |

**Weight Factor, W**

For screened material weighing 100 pcf, the factor is 1.00. For other weights, factor is proportional, e.g., 0.5 for 50 pcf; 1.25 for 125 pcf, etc.

**Open area factor, O**

For 50 per cent open area, the factor is 1.0; for 40 percent, it is 0.8; for 45 per cent, 0.9; for 60 per cent, 1.2; and so on.

| Wet screening factor, M | | | |
|---|---|---|---|
| Size opening, in. in. | M | Size opening, in. | M |
| 1/32 | 1.25 | 5/16 | 1.90 |
| 1/16 | 1.50 | 3/8 | 1.75 |
| 1/8 | 1.75 | 1/2 | 1.50 |
| 3/16 | 1.90 | 3/4 | 1.00 |
| 1/4 | 2.00 | | |

Use factor M when water is added to the material at a rate of 5 to 10 gpm for each tph. NOTE: For feed sizes larger than 1/2 in., wet screening becomes much less effective. For size 20 mesh and smaller, wet screening poses problems.

## *Table III.2.i. Clear Opening, Wire Diameter, and Open Area in Production Screens* [2]

| Clear opening, in. | Light | | Standard Light | | Standard heavy | | Heavy | |
|---|---|---|---|---|---|---|---|---|
| | Wire diameter, in. | Open area, percent | Wire diameter, in. | Open area, percent | Wire diameter, in. | Open area, percent | Wire diameter, in. | Open area, percent |
| 4 | 1/2 | 79.0 | 5/8 | 74.8 | 3/4 | 70.9 | 1 | 64.0 |
| 3 1/2 | 7/16 | 79.0 | 1/2 | 76.6 | 5/8 | 72.0 | 3/4 | 67.8 |
| 3 | 7/16 | 76.2 | 1/2 | 73.5 | 5/8 | 68.5 | 3/4 | 64.0 |
| 2 3/4 | 3/8 | 77.4 | 7/16 | 74.4 | 1/2 | 71.6 | 5/8 | 66.4 |
| 2 1/2 | 3/8 | 75.6 | 7/16 | 72.4 | 1/2 | 69.4 | 5/8 | 64.0 |
| 2 1/4 | 3/8 | 73.4 | 7/16 | 70.1 | 1/2 | 66.9 | 5/8 | 61.2 |
| 2 | 5/16 | 74.8 | 3/8 | 70.9 | 7/16 | 67.3 | 1/2 | 64.0 |
| 1 3/4 | 5/16 | 71.9 | 3/8 | 67.8 | 7/16 | 64.0 | 1/2 | 60.5 |
| 1 1/2 | 1/4 | 73.4 | 5/16 | 68.5 | 3/8 | 64.0 | 7/16 | 59.9 |
| 1 3/8 | 1/4 | 71.5 | 5/16 | 66.5 | 3/8 | 61.6 | 7/16 | 57.5 |
| 1 1/4 | 1/4 | 69.4 | 5/16 | 64.0 | 3/8 | 59.2 | 7/16 | 54.8 |
| 1 1/8 | 0.225 | 69.6 | 1/4 | 67.0 | 5/16 | 61.0 | 3/8 | 55.7 |
| 1 | 0.225 | 66.6 | 1/4 | 64.0 | 5/16 | 58.0 | 3/8 | 52.9 |
| 7/8 | 0.207 | 65.3 | 0.225 | 63.3 | 1/4 | 60.5 | 5/16 | 54.3 |
| 3/4 | 0.192 | 63.4 | 0.207 | 61.4 | 1/4 | 56.3 | 5/16 | 49.8 |
| 5/8 | 0.177 | 60.7 | 0.192 | 58.5 | 0.225 | 54.0 | 1/4 | 51.0 |
| 1/2 | 0.162 | 57.1 | 0.177 | 54.5 | 0.192 | 52.2 | 0.225 | 49.8 |
| 7/16 | 0.148 | 55.8 | 0.162 | 53.2 | 0.177 | 50.7 | 0.192 | 48.3 |
| 3/8 | 0.135 | 54.1 | 0.148 | 51.4 | 0.162 | 48.7 | 0.177 | 46.1 |
| 5/16 | 0.12 | 52.2 | 0.135 | 48.8 | 0.148 | 46.0 | 0.162 | 43.4 |
| 1/4 | 0.105 | 49.6 | 0.12 | 45.6 | 0.135 | 42.2 | 0.148 | 39.4 |
| 3/16 | 0.08 | 49.1 | 0.092 | 45.1 | 0.12 | 37.2 | 0.135 | 33.8 |
| 1/8 | 0.054 | 48.7 | 0.072 | 40.2 | 0.092 | 33.4 | 0.105 | 29.5 |

## III.3. ANALYSIS OF SIZE OF AGGREGATE PRODUCED BY CRUSHERS

After a lump of solid has been crushed, it usually breaks into pieces apparently irregular in number, shape and size. On entry of the feed to the machine, the largest pieces might be thought most susceptible to attack and the smallest the least susceptible, because they can most easily evade the crushing agents whatever they might be. The intermediate sizes might be thought to be affected according to their size, but not necessarily directly proportionally. The general affect of crushing would therefore be expected to be narrowing of the size range, with remnants of the largest particles gradually disappearing but still forming the size through which 100% passes though with decreasing claims to significance. A series of changes such as are shown in Figure III.3.a might be thought possible as the product is charged and recharged to the machine. The feed graph is represented as a straight line for simplicity. The first run through (I) contains a significant part of the original larger fractions, the second (II) less and so on.

For quantifying size distribution, the Gaussian relationship is used as per suggested by Lowrison [4], the Gaussian relationship has the form:

$$y = \frac{1}{h\sqrt{\pi}} \exp\left(-\frac{x^2}{h^2}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{(III-23)}$$

in which '*y*' is the number of items having the dimension '*x*' in the quality being considered; *h* is the constant and $\pi$ has its usual constant value. Such a relationship, when plotted as a graph, produced a bell-shaped curve, as shown in Figure III.3.b. The integrated form of this equation, i.e. the summation of the numbers of of items between two limit of the dimension *x*, e.g. $x_1$ and $x_2$, is given by

$$y = \int_{x_2}^{x_1} \frac{1}{h\sqrt{\pi}} \exp \frac{x^2}{h^2}\, dx = \frac{1}{h\sqrt{\pi}} \left[\left(\frac{\tan^{-1} x/h}{2}\right)\right]_{x_1}^{x_2} \quad \ldots\ldots\ldots \textbf{(III-24)}$$

This equation when plotted as a function of $x$ has the form indicated in Figure III.3.b. If in the size distribution of a particle in a product of crushing, $y$ is taken to be the weight or volume of material in the mean of a narrow sieve range defined by $x$, $x$ may be plotted against $y$ and a distribution curve obtained. If the integrated form is taken to be the sum of the weights or volumes of the particles less than a certain size, say $x_2$, i.e. if the probability equation is the equivalent of the integral between the limit of zero size and $x_2$, and this integrated form is plotted against $x$, a cumulative curve is obtained (Figure III.3.b.).

It is known that the setting of the discharge opening of a crusher will determine the maximum size stone produced, the aggregate size will range from slightly greater than the crusher setting to fine dust. Experience indicate that for any given setting for a jaw and also for roll crusher, approximately 15 percent of the total amount of stone passing through the crusher will be greater than the setting.

Generally, instead of theoretically formulation, for determining passing quantity through a certain sieve or gradation, the manufacturers has provide some product gradation tables/ charts/ graph that indicate the amount of stone aggregate in different size ranges for any given setting of crusher. Chart in Figure III.3.c, graph in Fig. III.3.d. and Table III.3, give representative values for the percent of crushed stone passing through or retained on screens having various sizes of openings for different jaw crusher settings. While, graph in Figure III.3.e supplies the percentage of product gradation of roll crushers. Similarly, tables, graph, and charts have also been recommended by manufacturers for assessing the gradation from the roll crusher. Some of the recommended gradation charts and tables are common between roll and other crusher. For example Figure III.3.c., has been recommended for estimating product gradation of both roll and jaw crusher.

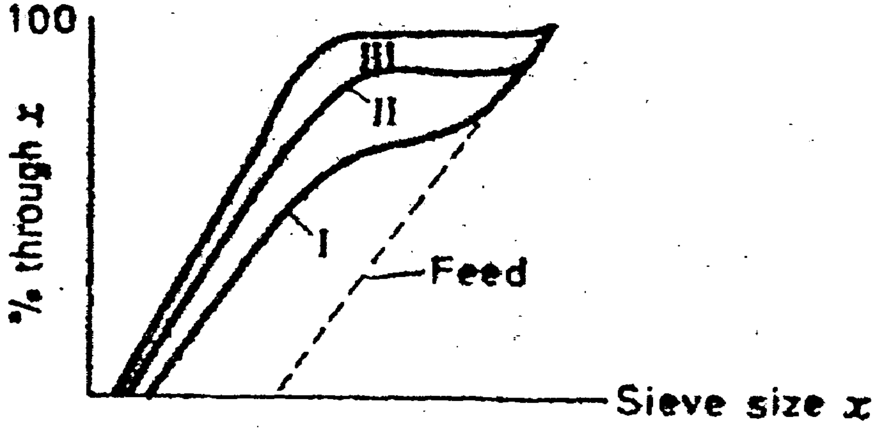


*Figure III.3.a. Repeated Passage through Crushing Machine at Fixed Setting* [4]

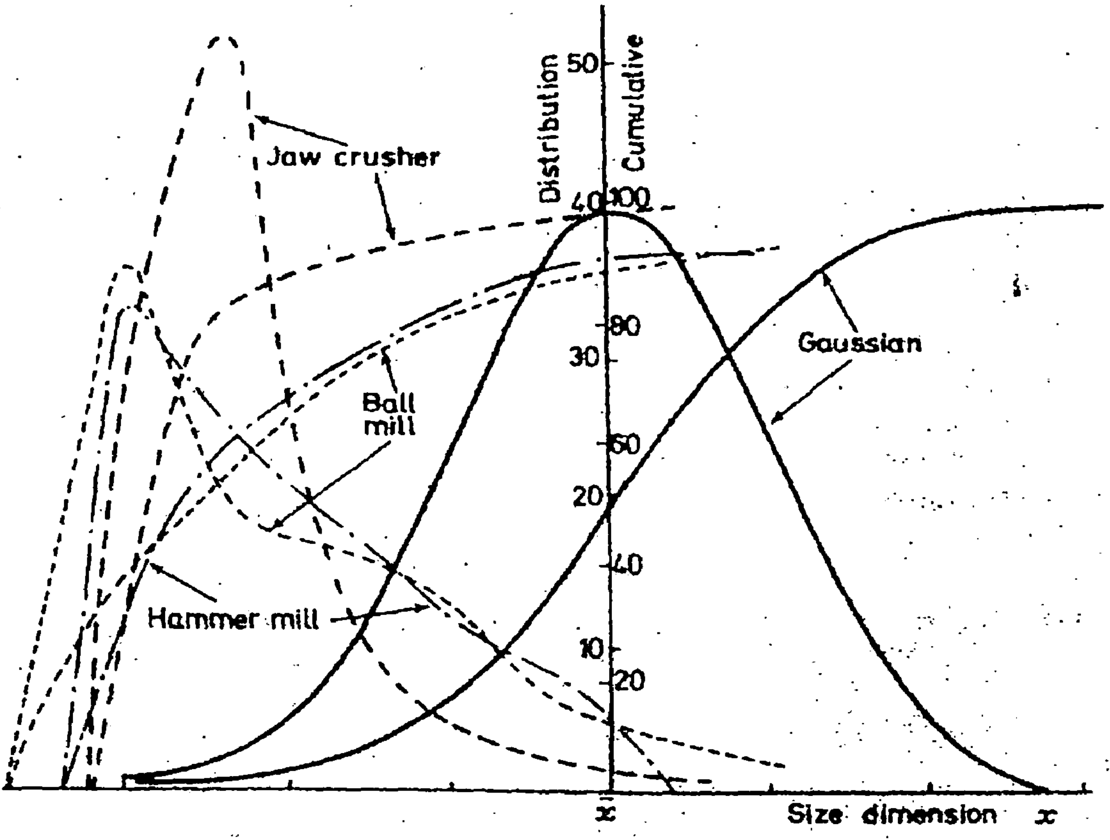


*Figure III.3.b. Particle Size Distribution and Cumulative Curves for Gaussian and Actual Case* [4]

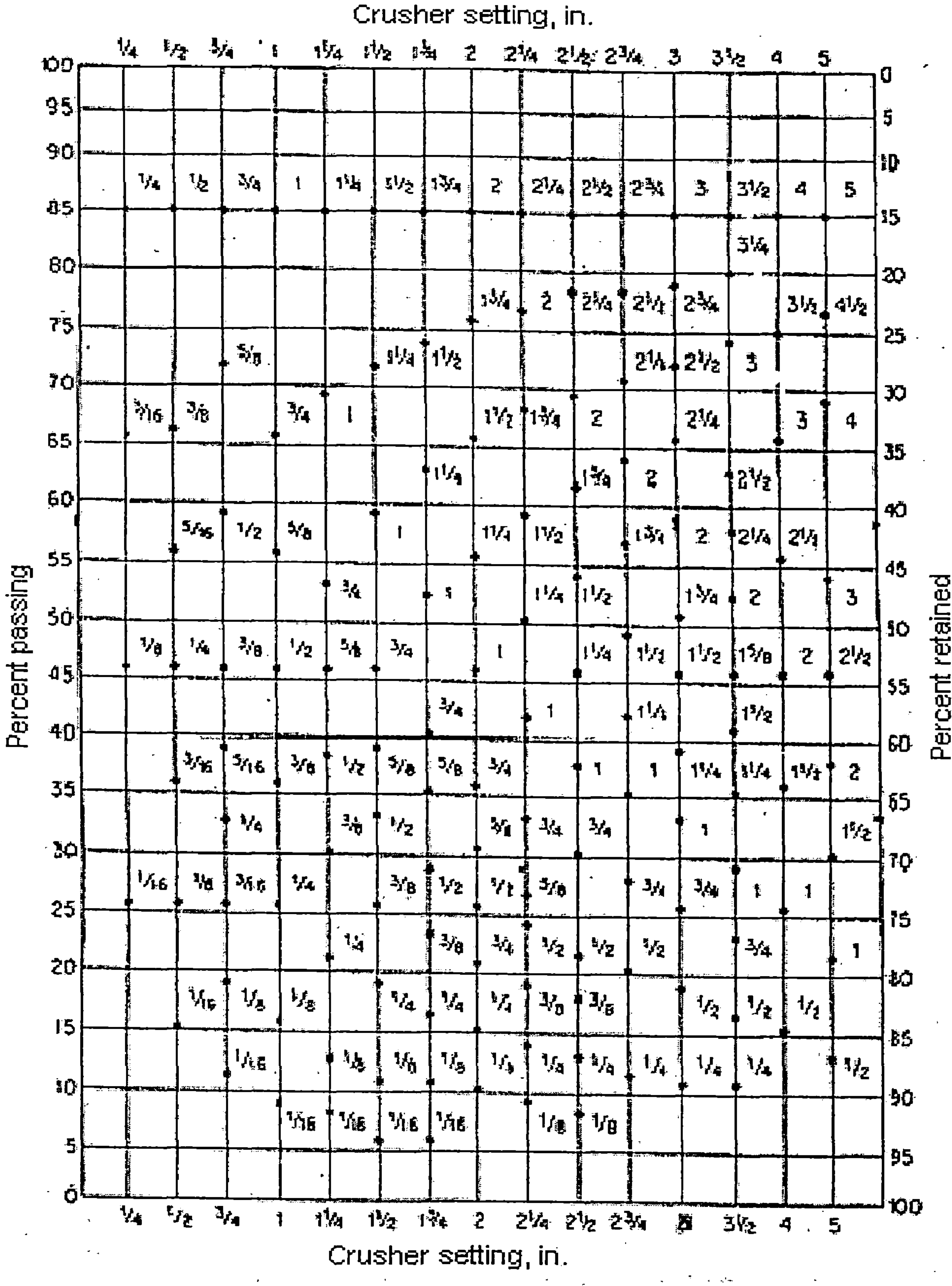


***Figure III.3.c. Analysis of the Size of Aggregate Produced by Jaw and Roll Crusher (Universal Engineering Company)*** [6]

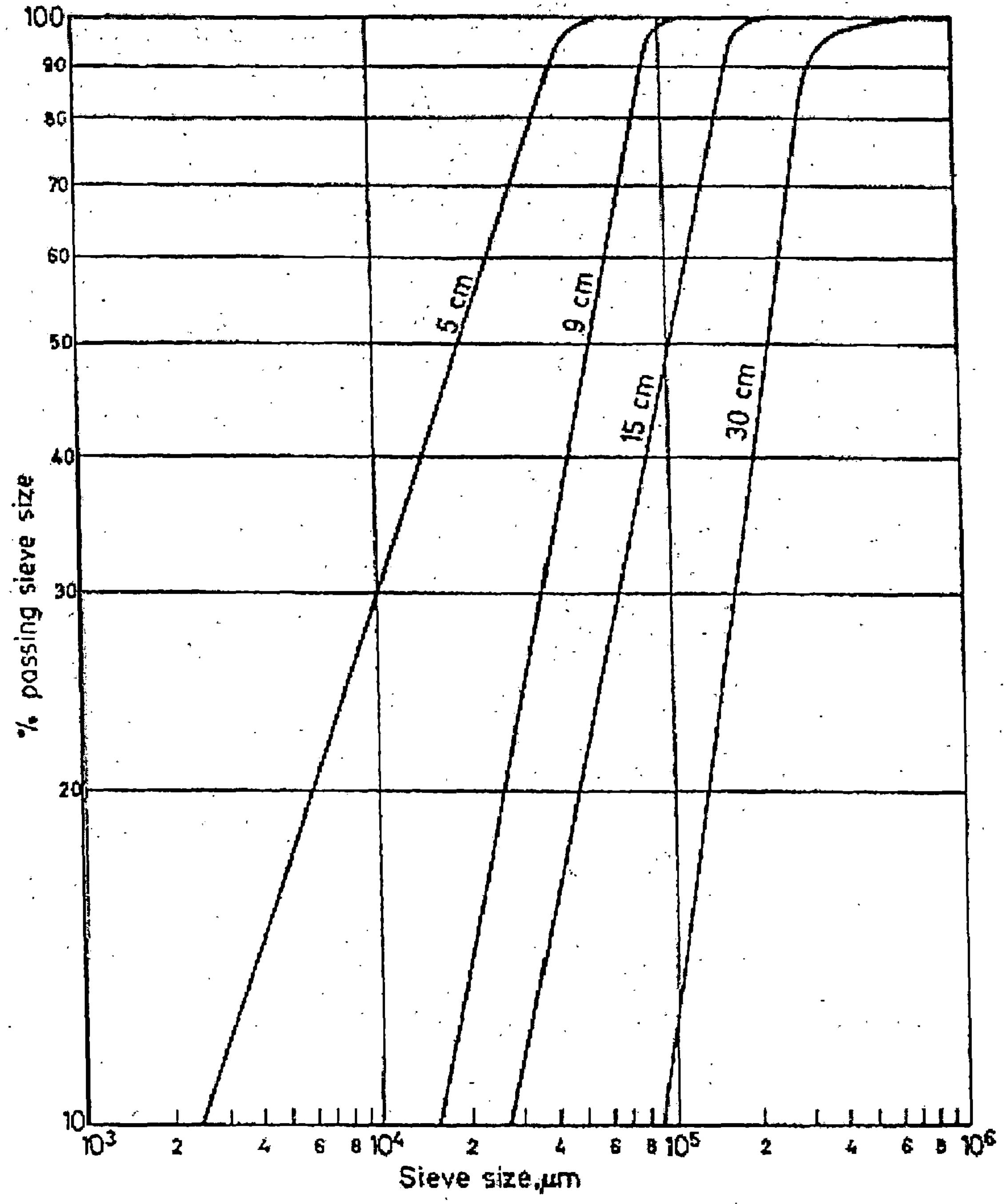


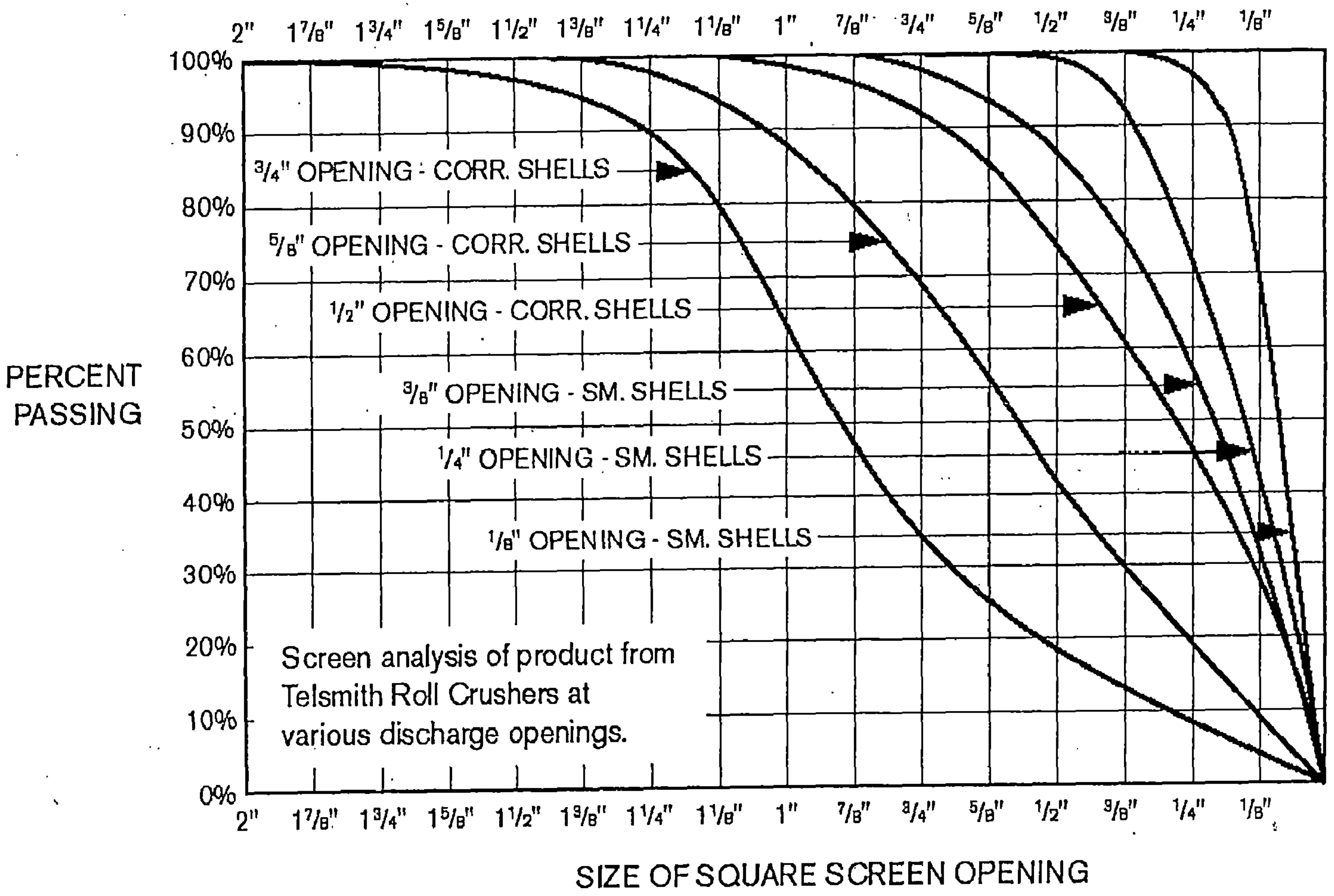
*Figure III.3.d. Jaw Crusher Product Size (Different Crusher) at Different Setting* [4]

**Table III.3** [1]

## SCREEN ANALYSIS OF PRODUCT FROM TELSMITH JAW CRUSHER

| Sieve Designation Standard | | | Closed Side Setting | | | | | | | | | Sieve Designation Standard | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| US | mm | Decimal | 1/4" | 1/2" | 3/4" | 1" | 11/2" | 2" | 21/2" | 3" | 31/2" | US | mm | Decimal |
| 6" | 150.0 | 6.00 | | | | | | | | | 100 | 6" | 150.0 | 6.00 |
| 5" | 125.0 | 5.00 | | | | | | | 100 | 100 | 95 | 5" | 125.0 | 5.00 |
| 41/2" | 112.5 | 4.50 | | (% Passing) | | | | | 98 | 95 | 89 | 41/2" | 112.5 | 4.50 |
| 4" | 100.0 | 4.00 | | | | | | | 96 | 89 | 82 | 4" | 100.0 | 4.00 |
| 31/2" | 90.0 | 3.50 | | | | | | 100 | 89 | 82 | 73 | 31/2" | 90.0 | 3.50 |
| 3" | 75.0 | 3.00 | | | | | 100 | 93 | 82 | 72 | 62 | 3" | 75.0 | 3.00 |
| 21/2" | 63.0 | 2.50 | | | | 100 | 95 | 81 | 69 | 60 | 52 | 21/2" | 63.0 | 2.50 |
| 2" | 50.0 | 2.00 | | | 100 | 97 | 80 | 65 | 55 | 47 | 41 | 2" | 50.0 | 2.00 |
| 11/2" | 37.5 | 1.50 | | 100 | 88 | 80 | 63 | 48 | 39 | 33 | 28 | 11/2" | 37.5 | 1.50 |
| 11/4" | 31.5 | 1.25 | 100 | 93 | 78 | 70 | 56 | 40 | 33 | 29 | 24 | 11/4" | 31.5 | 1.25 |
| 1" | 25.0 | 1.00 | 98 | 82 | 68 | 55 | 43 | 28 | 25 | 24 | 18 | 1" | 25.0 | 1.00 |
| 3/4" | 19.0 | 0.75 | 80 | 62 | 50 | 38 | 30 | 22 | 18 | 18 | 14 | 3/4" | 19.0 | 0.75 |
| 1/2" | 12.5 | 0.50 | 60 | 42 | 33 | 25 | 19 | 14 | 12 | 12 | 10 | 1/2" | 12.5 | 0.50 |
| 3/8" | 9.5 | 0.375 | 41 | 30 | 27 | 19 | 13 | 11 | 9 | 9 | 8 | 3/8" | 9.5 | 0.375 |
| 4M | 4.75 | 0.187 | 15 | 12 | 11 | 9 | 7 | 6 | 5 | 6 | 5 | 4M | 4.75 | 0.187 |
| 8M | 2.36 | 0.094 | 8 | 7 | 6 | 5 | 5 | 3 | 3 | 4 | 3 | 8M | 2.36 | 0.094 |
| 16M | 1.18 | 0.047 | 4 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 16M | 1.18 | 0.047 |
| 30M | 0.60 | 0.023 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 30M | 0.60 | 0.023 |
| 50M | 0.30 | 0.012 | 1 | 1 | 1 | 1 | | | | | | 50M | 0.30 | 0.012 |

**Figure III.3.e. Gradation of product of roll crusher [1]**



# CHAPTER-IV

# MATHEMATICAL MODEL FOR OPTIMIZATION AGGEGATE PROCESSING PLANT

## IV.1. INTRODUCTION

Mathematical model is generally constructed to represent the system being studied. A model is an idealized representation of the real life situation. The objective of the model is to provide a means for analyzing the behavior of the system for the purpose of improving its performance. Mathematical model or conceptual model may be in the form of equations or formulae developed to relate important factors or variables of the operations under study. The model then can be tested and operated upon mathematically to determine the effect of changing the values of variables.

When a physical problem is expressed mathematically or as is generally known, in form of a mathematical model, the expression defining the objective (minimization or maximization) is termed objective function, different conditions which the objective has to satisfy are termed constraints, and the entire problem consisting of the objective function and constraints is termed optimization problem. Mathematically, such an optimization problem can be expressed as

Optimize, $Z = f(x_1, x_2, \ldots\ldots, x_n)$ ..............................................(IV-a)

Subject to

$$\left.\begin{array}{l} g_1(x_1, x_2 \ldots\ldots, x_n) \\ g_2(x_1, x_2 \ldots\ldots, x_n) \\ \cdot \\ \cdot \\ g_m(x_1, x_2 \ldots\ldots, x_n) \end{array}\right\} \begin{array}{c} \le \\ = \\ \ge \end{array} \left\{\begin{array}{l} b_1 \\ b_2 \\ \cdot \\ \cdot \\ b_m \end{array}\right. \qquad \text{..................................(IV-b)}$$

Equation (IV-a) represents the objective function which involves optimization (minimization or maximization) of Z having *n* parameters or decision variables $x_1$, $x_2$,.....,$x_n$. Equation (IV-b) represents a set of *m* constraints, expressed as equalities or inequalities.

An optimization method that can be used for the optimization production of aggregate processing plant is linear programming. Linear programming is applicable for optimization of problems when the objective function and constraints are linear functions of the decisions variables. Each problem in linear optimization can differ in terms of the objective function (the objective can be either to minimize or maximize a function), as well as in terms of the linear constraints (equality constraints, inequality constraints, smaller or equal).

The standard form of a linear programming problem is as follow:

Objective

$$\text{Max} \quad Z = c_1x_1 + c_2x_2 + \ldots + c_nx_n$$

Subject-to

$$\left.\begin{array}{l} a_{1-1}\; x_1 + a_{1-2}\; x_2 + \cdots + a_{1-n}\; x_n = b_1 \\ a_{2-1}\; x_1 + a_{2-2}\; x_2 + \cdots + a_{2-n}\; x_n = b_2 \\ \qquad\qquad\qquad \vdots \\ a_{m1}\; x_1 + a_{m2}\; x_2 + \cdots + a_{mn}\; x_n = b_m \end{array}\right\}$$

And $x_1 \geq 0$ , $x_2 \geq 0$ ,........, $x_n \geq 0$

In which ,

$c_1$ ,......, $c_n$ ; $b_1$ ,......., $b_m$ ; and $a_{1-1}$,......, $a_{mn}$ are known as constants and $x_1$,.......,$x_n$ are the decision variables.

## IV.2. GENERAL MODEL FOR CRUSHER [8]

### IV.2.1. Crusher's Setting

The output capacity of a crusher depends upon the closed side opening of crusher. If '*j*' is labeled as setting option of closed side opening and there are a total of ***n*** options for the setting (i.e.: ***j = 1,2,..........n***) then the output capacity of a crusher (say **S**), corresponding to each setting can be labeled as $S_1$, $S_2$, . . . , $Sn$ at option 1, 2, . . . , $n$, respectively. It can be obtained from manual of crusher.

### IV.2.2. Crusher's Streams

The material flowing through a conveyor is defined as a flow stream. A flow stream has two major attribute; flow rate and gradation. Flow rate is defined as the quantity of materials flowing through the stream per hour (in tons per hour). Gradation is defined as the percent of the flow stream passing through a serial of sieve sizes.

Figure IV.2.2 shows flow streams of a crusher.

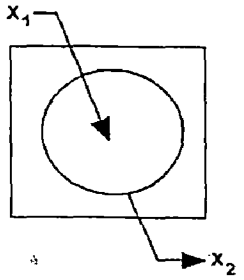


***Figure IV.2.2. Flow streams of a crusher.***

#### *a. Flow rate of crusher's streams*

The variables $x_1$ and $x_2$ shown in Figure IV.2.2 are the flow streams of the input and output of the crusher, respectively, and they should satisfy the following constraint at the steady state:

$$x_1 = x_2 \text{ (input = output)} \qquad \text{.............} \textbf{(IV-1)}$$

Output stream can not be higher than given capacity of the crusher. So, the output capacity of stream, $x_2$ illustrated in Figure.IV.2.2 can be expressed as

$$x_2 \leq S_j \quad \text{.....................................(IV-2)}$$

As, the given capacity of crusher, $\mathbf{S}_j$ in the right hand side of above expression depend on its given setting, range between **1** to **n** and only one setting option is allowed to be selected then a decision variable with a value of either 0 or 1 is defined corresponding to each setting option as follow

$$z_i = \begin{cases} 1 & ifoption \ i \ selected \\ 0 & ifoption \ i \ notselected \end{cases} \quad \{1 \leq i \leq n\}$$

Then, $S_j$ can be rewritten as

$$S_j = \sum_{j=0}^{n} z_j S_j$$

And, equation (IV-2) can be expressed as,

$$x_2 \leq \sum_{j=0}^{n} z_j S_j \quad \text{.....................................................(IV-3)}$$

***b. Gradation of crusher's streams***

Gradation of the output stream of a crusher depends upon the closed side opening of crusher and opening size of screen. If '*j*' is labeled as setting option of crusher where there are a total of *n* options for the setting (i.e.: *j* = *1*, *2*,..........*n*) and also if '**k**' is labeled as opening size option of screen where there are a total of *l* options (i.e.: *k* = *1*, *2*,..........*l*) then the gradation corresponding to the both setting can be labeled generally as $D_{jk}$ at option j and k, respectively. It can be obtained from manual.

So, the gradation of the output stream ($x_2$) in Figure IV.2.2 is calculated by

$$C_{2k} = \sum_{j=0}^{n} z_j D_{jk} \quad , k = 1, 2, \text{..........} i \text{ (sieve options)} \quad \text{..............(IV-4)}$$

## IV.3. GENERAL MODEL FOR SCREENS [8]

### IV.3.1. Screen's Setting

Since, the size of graded stone produced by a plant should fulfill the job requirement in which the output product should pass through selected sieve sizes which is varies in range, then the opening of a screen deck should be set also with the same selected sizes.

Generally we can arrange the gradation of output stream $x_i$ which passed through the sieve sizes $a_k$ labeled by $C_{ik}$ as in Table IV.3.1.

***Table IV.3.1. An example of general tabulation of gradation of flow streams***

| Stream | $a_0 > 5\frac{1}{2}$" | $a_1 = 5\frac{1}{2}$" | $a_2 = 4\frac{1}{2}$" | $a_3 = 3\frac{3}{4}$" | ..... | ..... | ...... | ...... | $a_k = \frac{1}{8}$" |
|---|---|---|---|---|---|---|---|---|---|
| **(1)** | **(2)** | **(3)** | **(4)** | **(5)** | **....** | **....** | **.....** | **.....** | **(26)** |
| $x_i$ | $C_{i0}$ | $C_{i1}$ | $C_{i2}$ | $C_{i3}$ | ...... | ..... | ...... | ..... | $C_{i,k}$ |

So, the opening of a screen deck can be set at any size in the range from $a_1$ to $a_k$.

Let all feasible settings of the screen deck be represented in an increasing order labeled as $b_1, b_2, \ldots, bq$ in which 'q' denotes the number of opening options. The percent of the input stream passing through the corresponding opening sizes of $b_1, b_2, \ldots, b_q$ are represented by : $B_{d1}, B_{d2}, \ldots, B_{dq}$, respectively; then

$$B_{di} = C_{ik}\text{, likewise } b_i = a_k \ \{1 \le k \le \ldots\} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\text{(IV-5)}$$

where

$C_{1k}$ = percent of the input stream passing through sieve size $a_k$; and

d = either t or b, corresponding to the top or bottom deck of a screen.

A decision variable whose value is 1 or 0 is defined to associate with the setting of a screen deck. The variable takes a value of one if its corresponding option is selected; otherwise, it takes zero. Mathematically,

$$y_{di} = \begin{cases} 1 & iftheopening = b_i \\ 0 & iftheopening \neq b_i \end{cases} \quad i = 1, 2, 3, \ldots\ldots\ldots, q \qquad \ldots\ldots\ldots\ldots\ldots\ldots(IV\text{-}6)$$

or,

$$\sum_{i=0}^{q} y_{di} = 1 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(IV\text{-}7)$$

Equation (IV-7) means that only one option can be selected for each deck.

### IV.3.2. Screen's Streams

A screen separates input materials into multiple output streams based on the numbers of deck in which each output stream will have its own flow rate and gradation. Generally, double deck screens are widely used in aggregate production plant. There are three possible models of the double deck screen inside a plant, i.e.

1) Screen with one input stream
2) Screen with two input streams
3) Screen with cycling crusher

#### IV.3.2.1. Screen with one input stream

A double deck screen, as shown in Figure IV.3.2.1, separates the fed material of $x_1$ into three output stream, i.e. $x_2$, $x_3$, $x_4$ respectively.

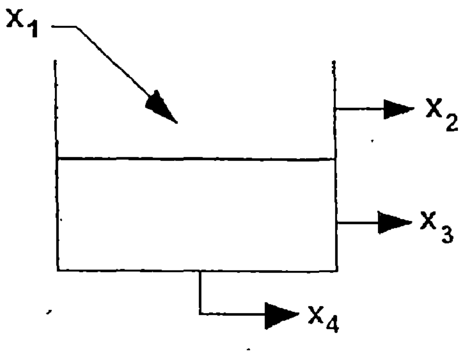


***Figure IV.3.2.1. Flow streams of double deck screen with one input stream***

The following constraints should be satisfied:

The production rate of a screen cannot exceed its capabilities, i.e.

$x_1 \leq Q_t$ ................................................................**(IV-8)**

$x_1 - x_2 \leq Q_b$ ................................................................**(IV-9)**

where, $Q_t$ and $Q_b$ are capacities of the top deck and the bottom deck, respectively.

**Stream $x_1$**

The quantity of materials in a size range should be unchanged before and after screening separation. Therefore, we get the expression of $x_1$ as follow

$x_1 = x_2 + x_3 + x_4$ (input = output) ................................**(IV-10)**

From Figure IV.3.2.1, the stream $x_1$ is as input stream. It may be raw material dumped by loader or output material from other equipment such as crusher. Gradation of the input material can be determined by passing it through the series of sieve. Usually, gradation of the output product of crushers can be found from the crusher's manual.

**Stream $x_2$**

**a. Flow rate of stream $x_2$**

The stream retained ($x_2$) on the top deck is the portion of input stream whose size is larger than the opening size of the top deck of the screen.

If the top deck of the screen have the opening size of $b_m$, then referring to equation (V-7) $y_{tm} = 1$ where $\{1 \leq m \leq q\}$. The flow rate of the retained stream ($x_2$) can be calculated by

$x_2 = \frac{(100 - B_{tm})}{100} x_1$ ................................................**(IV-11)**

Where, $B_{tm}$ denotes the percent of the stream passing through the top deck.

Because only one opening option can be selected, then

$B_{tm} = \sum_{i=0}^{q} y_{ti} B_{ti}$ ................................................**(IV-12)**

Replacing $B_{tm}$ in equation (IV-11) with (IV-12), we get :

$$x_2 = \frac{\left(100 - \sum_{i=0}^{q} y_{ti} \quad B_{ti}\right)}{100} x_1 \qquad \text{.............................( IV-13)}$$

**b. Gradation of stream $x_2$**

It is said that, gradation can be determined by passing the material through the series of sieves having different size labeled by $a_i$.

Gradation of material is influenced by the retain rate on a given sieve size $a_i$. On the sieve size $a_i$, retain rate, $r_i$ is equals to the retain quantity, $R_i$ divided by the stream flow rate, $x_i$.

Refers to Figure IV.3.2.1., the quantity of retain material on sieve size $a_i$ can be calculated by

$$R_i = \frac{(100 - C_{1i})}{100} x_1 \qquad \text{..............................................(IV-14)}$$

Then, the retain rate on the sieve size $a_i$ is

$$r_i = \frac{100\, R_i}{x_2} = \frac{(100 - C_{1i})\, x_1}{x_2} \qquad \text{..................................(IV-15)}$$

So, the gradation of stream $x_2$ (i.e. percentage of material will pass through sieve size $a_i$), is calculated by **100% minus the retained rate** as follows

$$C_{2i} = \begin{cases} 100 - r_i = 100 - \dfrac{(100 - C_{1i})\, x_1}{x_2} & if\ a_i \geq b_m \\ 0 & if\ a_i < b_m \end{cases} \quad \text{...(IV-16)}$$

Where,

$a_i \geq b_m$ denotes sieve sizes greater than the opening $b_m$ of the top deck.

$a_i < b_m$ denotes sieve sizes smaller than screen opening.

It is known that gradation of $x_2$ will be found only after passing it through the series of sieve sizes and the size of these series of sieve may have dimension that either less than the oversize material or bigger than that, then by referring to equation (IV-5), (IV-6), (IV-7) a decision variable is introduced as follow,

$$\sum_{j=0}^{i} y_{tj} = \begin{cases} 1 & if \quad a_i \leq b_m \\ 0 & if \quad a_i > b_m \end{cases} \qquad \text{.............................(IV-17)}$$

Finally, the gradation of the oversize stream $x_2$ can be determined by combining equation (IV-16) and (IV-17) into

$$C_{2i} = \left( \frac{100 - (100 - C_{1i})\, x_1}{x_2} \right) \cdot \left( 1 - \sum_{j=0}^{i} y_{tj} \right) \qquad \text{.............. (IV-18)}$$

$x_2$ is replaced by that of in equation (IV-11) then

$$C_{2i} = 100 \left( 1 - \frac{100 - C_{1i}}{100 - \sum_{j=0}^{q} y_{tj} \; B_{tj}} \right) \left( 1 - \sum_{j=i}^{i} y_{tj} \right) \qquad \text{........(IV-19)}$$

**Stream $x_4$**

**a. Flow rate of stream $x_4$**

Stream $x_4$ is the portion of the input stream (i.e. stream $x_1$) whose size of material is smaller than the opening size of the bottom deck.

If the bottom deck of the screen have the opening size of $b_n$, then $y_{bn} = 1$ $\{0 \leq n \leq q\}$. The flow rate of the stream passing through $x_4$ can be calculated as

$$x_4 = \frac{B_{bn}}{100} x_1 \qquad \text{..........................................................(IV 20)}$$

As only one opening option can be selected, then

$$B_{bn} = \sum_{i=0}^{q} y_{bi} \, B_{bi} \qquad \text{..........................................................(IV 21)}$$

$$\text{So,} \quad x_4 = \frac{\left( \sum_{i=0}^{q} y_{bi} \; B_{bi} \right)}{100} x_1 \qquad \text{..........................................................(IV 22)}$$

**b. Gradation of stream $x_4$**

Retain material on sieve size $a_i$ as per equation (IV-14) is

$$R_i = \frac{(C_{1n} - C_{1i})}{100} x_1$$

Retained rate of stream $x_4$ on sieve size $a_i$ is calculated by,

$$r_i = \frac{100 R_i}{x_4} = \frac{(C_{1n} - C_{1i}) x_1}{x_4} \quad \text{.......................................(IV-23)}$$

The gradation of stream $x_4$ is calculated by **100% minus the retained rate** as follows

$$C_{4i} = 100 - \frac{(C_{1n} - C_{1i}) x_1}{x_4} \quad , \text{ for } a_i < b_n \qquad \text{.....(IV-24)}$$

Where,

$a_i < b_n$ denotes sieve sizes less than the opening $b_n$ of the bottom deck.

Similarly, a decision variable is introduced as follow,

$$\sum_{j=0}^{i} y_{bj} = \begin{cases} 1 & if \quad a_i \leq b_n \\ 0 & if \quad a_i > b_n \end{cases} \quad \text{...............................(IV-25)}$$

The gradation of stream $x_4$ is

$$C_{4i} = \left(100 - \frac{(C_{1n} - C_{1i}) x_1}{x_4}\right)\left(\sum_{j=0}^{i} y_{bj}\right) \quad \text{...............................(IV-26)}$$

Substituting the value of $x_4$ from equation (IV-22) to (V-26) we get

$$C_{4i} = 100 \left(1 - \frac{C_{1n} - C_{1i}}{\sum_{j=0}^{q} y_{bj} \quad B_{bj}}\right)\left(\sum_{j=0}^{i} y_{bj}\right) \quad \text{........................(IV-27)}$$

**Stream $x_3$**

**a. Flow rate of stream $x_3$**

Stream $x_3$ is the portion of the input stream between the opening sizes of the top deck and the bottom deck. Then $x_3$ can be expressed as:

$$x_3 = \frac{\left(\sum_{i=0}^{q} Y_{ti} \quad B_{ti} - \sum_{i=0}^{q} Y_{bi} \quad B_{bi}\right)}{100} x_1 \qquad \text{..................(IV-28)}$$

**b. Gradation of stream $x_3$**

Retained material on sieve size $a_i$ as per equation (IV-14) is as

$$R_i = \frac{(C_{1n} - C_{1i})}{100} x_1$$

Retained rate of stream $x_1$ on sieve size $a_i$ is

$$r_i = \frac{100 \, R_i}{x_3} = \frac{(C_{1m} - C_{1i}) \, x_1}{x_3} \qquad \text{...............................(IV-29)}$$

The gradation of stream $x_3$ is calculated by 100% minus the retained rate as follows

$$C_{3i} = 100 - \frac{(C_{1m} - C_{1i}) \, x_1}{x_3} \quad , \text{ for } b_m \geq a_i \geq b_n \qquad \text{..........(IV-30)}$$

Where, $b_m \geq a_i \geq b_n$ , denotes sieve sizes lesser than the opening size $b_m$ of the top deck but greater than the opening size $b_n$ of the bottom deck.

As the gradation of stream $x_3$ is in range between the opening of top and bottom deck then two decision variable is introduced corresponding to opening size of each deck as follow,

$$\sum_{j=0}^{i} Y_{tj} = \begin{cases} 1 & if \quad a_i \leq b_m \\ 0 & if \quad a_i > b_m \end{cases}$$

which is similar to equation (IV-17).

And

$$\sum_{j=0}^{i} Y_{bj} = \begin{cases} 1 & if \quad a_i \leq b_n \\ 0 & if \quad a_i > b_n \end{cases} \qquad \text{....................................(IV-31)}$$

Gradation of stream $x_3$ can be calculated by

$$C_{3\,i} = \left(\frac{100 - (C_{1m} - C_{1i}) \, x_1}{x_3}\right)\left(\sum_{j=0}^{i} Y_{tj}\right)\left(1 - \sum_{j=0}^{i} Y_{bj}\right) \qquad \text{..............(IV-32)}$$

Substituting the value of $x_4$ from equation (IV-28) to (V-32) we get

$$C_{3i} = 100 \left( 1 - \frac{C_{1m} - C_{1i}}{\sum_{j=0}^{q} Y_{tj} \; B_{tj} - \sum_{j=0}^{q} Y_{bj} \; B_{bj}} \right) \left( \sum_{j=0}^{i} Y_{tj} \right) \left( 1 - \sum_{j=0}^{i} Y_{bj} \right)$$

……………………………………………………………………………………(IV-33)

### IV.3.2.2. Screen with two input streams

It is common to see two input stream feeding a screen or a crusher as in Fig.IV.3.2.2, $x_1$ and $x_5$ are the input stream.

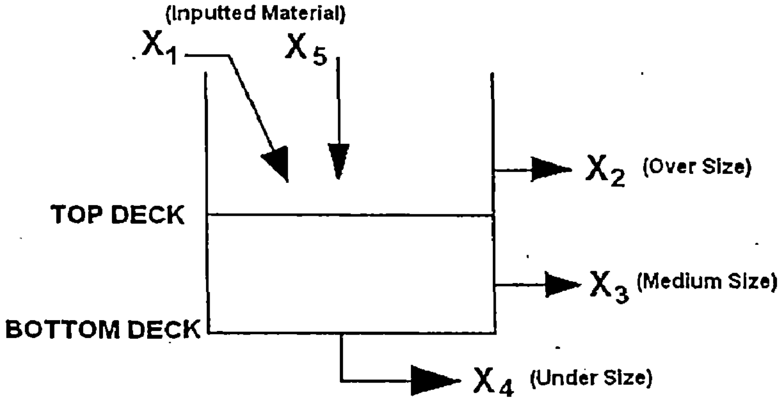


*Figure IV.3.2.2. Flow streams of double deck screen with two input streams*

**a. Flow rate**

Obviously, the flow rate of the combined stream is equal to the sum of the flow rates of the two original streams. The combined flow rates can be labeled as $x^{15}$.

$x^{15} = x_1 + x_5$ ……………………………(IV-34)

**b. Gradation**

According to equation (IV-14), the quantity of material retain at size $a_i$ for both streams can be calculated by:

$R_{1i} = \frac{(100 - C_{1i})\, x_1}{100}$ for stream $x_1$ which is similar to equation (IV-14)

and for stream $x_5$ ;

$R_{5i} = \frac{(100 - C_{5i})\, x_5}{100}$ ……………………………………………………(IV-35)

The retain rate of the combined stream on sieve size $a_i$ is

$$r_i = \frac{100\ (R_{1i} + R_{5i})}{(x_1 + x_5)} = \frac{(100 - C_{1i})\,x_1 + (100 - C_{5i})\,x_5}{x_1 + x_5} \quad \text{.....(IV-36)}$$

The gradation of the combined stream can be calculated as

$$C_i^{15} = 100 - r_i = 100 - \frac{(100 - C_{1i})\,x_1 + (100 - C_{5i})\,x_5}{x_1 + x_5} \quad \text{.....(IV-37)}$$

### IV.3.2.3. Screen with closed circuit operating crusher

A crusher is often used with a screen as illustrated in Fig.IV.2.2.3. The crusher reduces the size of the oversize stream (stream $x_2$), and the crushed materials from the crusher are routed back to the same screen for further separation.

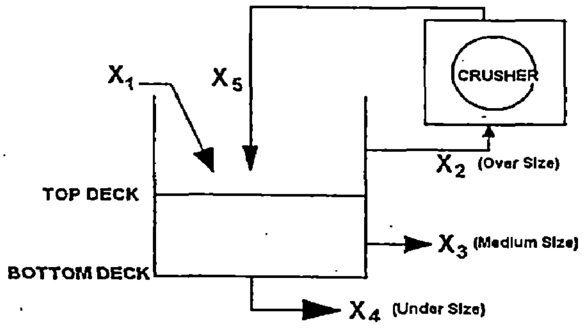


*Figure IV.3.2.3. Flow Stream of double deck screen with closed circuit operating crusher*

**a. Flow rate**

It was shown that oversize, medium size and under size portion is influenced only by one input stream. Likewise, the procedure for determining these same portions from two input stream is processed. The portion of two original inputted streams must be combined.

The openings size of the top and bottom decks of screen in Figure IV.3.2.3, are represented by $b_m$ and $b_n$. The percent of the stream passing through the two sizes are $C_{1m}$ and $C_{1n}$ for stream $x_1$, and $C_{5m}$ and $C_{5n}$ for stream $x_5$, respectively.

The flow rate of the oversize stream can be calculated as

$$x_2 = \frac{(100 - C_{1m})}{100} x_1 + \frac{(100 - C_{1n})}{100} x_5 \qquad \ldots\ldots\ldots\ldots\ldots\ldots \text{(IV-38)}$$

The first part of the right-hand side of equation (IV-38) represents the oversize portion from stream $x_1$, and the second part is the re-separated oversize portion from the crushed stream $x_5$.

The input and output of the crusher should be balanced, i.e.

$$x_2 = x_5 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(IV-39)}$$

Equation (IV-38) can be rewritten as

$$x_2 = \frac{(100 - C_{1m})}{C_{5m}} x_1 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(IV-40)}$$

**b. Gradation**

Procedure to determine the gradation of input material of this model is similar to that of equation (IV-37). For this model, stream $x_5$ should be replaced by $x_5$ from equation (IV-40). Then, the gradation is labeled with the same label in above model as $C_i^{15}$, in which

$$C_i^{15} = 100 - \frac{(100 - C_{1i})\, x_1 + (100 - C_{5i})\, x_5}{x_1 + x_5} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \text{(IV-41)}$$

Replacing $x_5$ with $\frac{(100 - C_{1m})}{C_{5m}} x_1$, the gradation can be calculated by

$$C_i^{15} = 100 - \frac{(100 - C_{1i})\, C_{5m} + (100 - C_{5i})(100 - C_{1m})}{100 + C_{5m} - C_{1m}} \qquad \ldots \text{(IV-42)}$$

## IV.4. LINEAR MODEL OF SCREEN AND CRUSHER

If the setting of each screen and crusher are fixed at one option, two sets of the setting variables *Y* and *Z* can be removed from the non-linear model, and is simplified into a linear one with flow rates as the only variables.

With reference to Figure IV.3.2.1, if the top and bottom decks of the screen are set at opening size $b_1$ and $b_2$, the percent of the feed stream passing through the two sizes are $C_{1m}$ and $C_{1n}$, respectively. $C_{1m}$ and $C_{1n}$

are the constant value that may be taken from manual provided by manufacture.

By referring to equations (IV-8) to (IV-33), the constraints of a double deck screen can be summarized as follows with capacity constraints (IV-8) and (IV-9) unchanged:

$$x_2 = \frac{(100 - C_{1m})}{100} x_1 \qquad \text{.......... (IV-43)}$$

$$x_4 = \frac{(C_{1n})}{100} x_1 \qquad \text{.......... (IV-44)}$$

$$x_3 = \frac{(C_{1m} - C_{1n})}{100} x_1 \qquad \text{.......... (IV-45)}$$

$$x_1 = x_2 + x_3 + x_4 \text{ (input = output)} \qquad \text{.......... (IV-46)}$$

$$C_{2i} = \begin{cases} 100 \left(1 - \dfrac{100 - C_{1i}}{100 - C_{1m}}\right) & a_i \geq b_1 \\ 0 & a_i < b_1 \end{cases} \qquad \text{.......... (IV-47)}$$

$$C_{3i} = \begin{cases} 100 & a_i \geq b_1 \\ 100 \left(1 - \dfrac{C_{1m} - C_{1i}}{C_{1m} - C_{1n}}\right) & b_1 \geq a_j \geq b_2 \\ 0 & a_i < b_2 \end{cases} \qquad \text{.......... (IV-48)}$$

$$C_{4i} = \begin{cases} 100 & a_k > b_2 \\ 100 \left(1 - \dfrac{C_{1n} - C_{1i}}{C_{1n}}\right) & a_k \leq b_2 \\ & \end{cases} \qquad \text{.......... (IV-49)}$$

Where,

$C_{1m}$ is percentage of material in stream '$x_1$' passing through top deck of screen having opening size '$a_m$'

$C_{1n}$ is percentage of material in stream '$x_1$' passing through bottom deck of screen having opening size '$a_n$'

$C_{1i}$ is percentage of material in stream '$x_1$' passing through sieve having opening size '$a_i$'

**Crusher**

If gradation of the output stream is represented by $D_i$ , which can be obtained from the manual or in situ test , then

$C_{2i} = D_i$ , i = 1,2, ..........k (sieve sizes options)

If a crusher's closed side opening is set at a constant value, $b_3$ then equation (IV-3) become as follow

$x_2 \leq S_3$ ........................................................... **(IV-50)**

# METHODOLOGY

## V.1. INTRODUCTION

For determining the maximum production from an aggregate processing plant, following is needed:

a) gradation of all streams within the plant

b) actual capacity of crushers and screens

c) constraints of the plant

On the basis of this information, it is desired:

i) to calculate maximum production rate of aggregate plant at a certain setting of equipment

ii) to calculate the highest production rate of aggregate plant from all possible settings of equipments

## V.2. METHOD FOR DETERMINATION OF STREAM GRADATION AND CONSTRAINTS OF PLANT

Streams of every type of equipment within an aggregate processing plant have two attributes, namely

1. gradation
2. flow rate

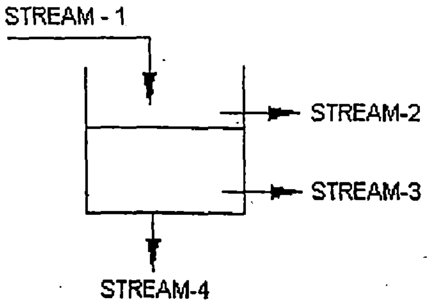


*Figure V.2. Input / output streams of double deck screen*

For constructing mathematical model of equipment then the gradation and the flow rate of any stream within the plant should be expressed or symbolized mathematically. In this chapter, gradation is symbolized by 'C' and flow rate is symbolized by 'x'.

Usually stream of equipment is more than one, so that its gradation and flow rate are symbolized differently. For example a double deck screen shown in Figure V.2., have four streams then

Flow rate of stream – 1 is symbolized by $x_1$
Flow rate of stream – 2 is symbolized by $x_2$
Flow rate of stream – 3 is symbolized by $x_3$
Flow rate of stream – 4 is symbolized by $x_4$
While,
Gradation of stream – 1 is symbolized by $C_1$
Gradation of stream – 2 is symbolized by $C_2$
Gradation of stream – 3 is symbolized by $C_3$
Gradation of stream – 4 is symbolized by $C_4$

Followed by a suffix 'm', 'n' or ' i ', like $C_{1m}$ , $C_{1n}$ , or $C_{1i}$ indicating percentage of stream-1 that passes through an opening size '$a_m$' or '$a_n$' or '$a_i$' of a screen.

To know gradation of every stream then, the material within the stream should be passed through the series of sieves having different opening sizes $a_1$, $a_2$, $a_3$, .....,$a_n$. Generalized by ' $a_i$ ' , where i = 1, 2, 3, ....,n. such that suffix ' i ' refers to the sequence of sieve in the series. This process is known as sieving process.

After sieving process, we will know percentage of material of any stream for different sizes. For example if top deck of screen in Figure V.2 have opening size 2 ½ " , then by referring to the result of sieving process, we know how much should be the gradation of material of stream-1 at this opening size.

In general, gradation of any stream can be determined using the following formulation.

Percentage of a stream ‘x‘ passing through a screen having opening size ‘$a_i$’ = 100% - Retained rate of the stream ‘x’ on sieve size ‘$a_i$’

or

$$\mathbf{C_{xi} = 100\% - r_i}$$

Where,

$r_i$ = 100 x (quantity retained from stream ‘x’ at sieve size ‘$a_i$’ labeled by $R_{xi}$) / flow rate of stream ‘x’

As an example, gradation of stream $x_2$ (Figure V.2) with reference to the top deck of screen having opening size ‘ $a_m$ ’ is calculated as follow:

$$R_{2m} = \frac{100 - c_{2i}}{100} \cdot x_1$$

Retained rate of the stream $x_2$ on sieve size ‘$a_i$’ is

$$r_{2i} = \frac{100 \left[\left(\frac{100 - C_{1i}}{100}\right) X_1\right]}{X_2}$$

$$= \frac{(100 - C_{1i})}{X_2} X_1$$

Since, the top deck of screen (Figure V.2.) having opening size ‘ $a_m$’ then,

$$x_2 = \frac{(100 - C_{1m})}{100} X_1$$

Thus,

Gradation or percentage of material of stream-2 passes through of the top deck having opening size ‘ $a_m$ ’ is

$$C_{2m} = 100 - \frac{(100 - C_{1i})\ X_1}{\frac{100 - C_{1m}}{100} X_1} \quad \text{or}$$

$$C_{2m} = 100\left(1 - \frac{100 - C_{1i}}{100 - C_{1m}}\right)$$

Similarly, the same principal of calculation is used for determining the others streams gradation within a plant.

### V.2.1. Stream gradation and constraints of crusher

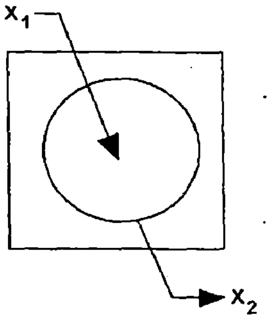


*Figure V.2.1. Input / output streams from crusher*

Using symbols in Figure V.2.1 we have,

Stream gradation of crusher:

1. Gradation of the output stream ($x_2$) of crusher can be estimated using

$$C_{2k} = \sum_{j=0}^{n} z_j D_{jk} \quad , k = 1, 2, \ldots\ldots\ldots\, i \text{ (sieve options)}$$

Constraints of crusher:

1. $x_1 = x_2$ (input stream = output stream)
2. Output stream can not be higher than given capacity of the crusher, $Q_c$

   $x_2 \leq Q_c$
3. quantity of input stream can't be higher than loader or shovel capacity, $Q_L$

   $x_1 \leq Q_L$

### V.2.2. Streams gradation and constraints of screen

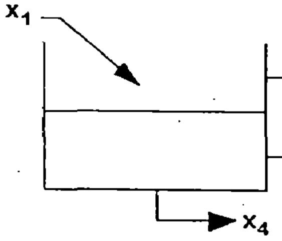


***Figure V.2.2. Input / output streams from screen with one input streams***

Using symbols in Figure IV.3.2.2, Figure IV.3.2.3, and Figure V.2.2 we have streams gradation of screen as follows:

1. Gradation of stream-2 up to stream-4 in Figure V.2.2 are

$$C_{2i} = \begin{cases} 100\left(1 - \dfrac{100 - C_{1i}}{100 - C_{1m}}\right) & a_i \geq b_1 \\ 0 & a_i < b_1 \end{cases}$$

$$C_{3i} = \begin{cases} 100 & a_i \geq b_1 \\ 100\left(1 - \dfrac{C_{1m} - C_{1i}}{C_{1m} - C_{1n}}\right) & b_1 \geq a_j \geq b_2 \\ 0 & a_i < b_2 \end{cases}$$

$$C_{4i} = \begin{cases} 100 & a_k > b_2 \\ 100\left(1 - \dfrac{C_{1n} - C_{1i}}{C_{1n}}\right) & a_k \leq b_2 \end{cases}$$

2. Gradation of input material from a screen with two input streams (Figure IV.3.2.2) is

$$C_i^{15} = 100 - r_i = 100 - \frac{(100 - C_{1i})\,x_1 + (100 - C_{5i})\,x_5}{x_1 + x_5}$$

3. Gradation of input material from a closed circuit operating crusher (Figure IV.3.2.3) is

$$C_i^{15} = 100 - \frac{(100 - C_{1i})C_{5m} + (100 - C_{5i})(100 - C_{1m})}{100 + C_{5m} - C_{1m}}$$

Using symbols in Figure V.2.2 we have constraints of screen as follow:

1. The production rate of a screen can not exceed its capacity

   $x_1 \leq Q_t$ where $Q_t$ = capacity of top deck

   $x_1 - x_2 \leq Q_b$ where $Q_b$ = capacity of bottom deck

2. The quantity of materials should be unchanged before and after screening separation.

   $x_1 = x_2 + x_3 + x_4$ (input = output)

## V.3. METHOD FOR CALCULATION OF ACTUAL CAPACITY OF SCREEN AND CRUSHER

Actual capacity of screen is determined be based on formula given by Telsmith Inc.[1]

Capacity = Area x Correction Factor

where, area refers to the dimension of screen in square feet. And correction factor consists of factors labeled by A, B, C, D, E, and F in which the meaning and value of these factor given in Table III.2.g.

An example given by Telsmith to determine the size of a double deck screen under the following conditions:

1. The material to be screened is crushed stone.
2. Capacity to be handled is 80 tons per hour.
3. Square openings in top deck are 1".
4. Square openings in bottom deck are 1/4".
5. 20% of the 80 TPH is over 1" in size.
6. An efficiency of 96% is required.
7. 40% of the material is less than one-half the size of the top deck or 1" openings.

8. There is 15% of minus 1/4" material to be taken out through the bottom deck; and of this 1/4" material, 10% is less than one-half the size of the 1/4" opening.
9. The oversize from the top deck is to be re-crushed to minus 1" and returned to the screen.

A problem of this kind must be treated as two separate computations, one for the top deck and one for the bottom deck.

The solution is as follows:

$$Area = \frac{80\ TPH}{AxBxCxDxExF} = \frac{80\ TPH}{2.78x1.02x0.95x1.0x1.0x1.0} = 29.7 =$$

No. of Sq. Ft. screen surface required for the top deck = 3'×10' screen

Considering the lower deck, we find that 15% of the total of 80 TPH must pass through the bottom deck or 12 TPH must pass through the 1/4" openings. This makes 85% of oversize on the bottom deck. Using formula No. 3 and factors again, we have the following for the bottom deck:

$$Area = \frac{12\ TPH}{AxBxCxDxExF} = \frac{80\ TPH}{1.74x.50x.95x.5x1.0x0.9} = 29.7 = \text{No. of}$$

Sq. Ft. screen surface required for the top deck = 4'×8' screen

In problems like this example, especially where the bottom deck as a fairly small opening, it will usually be found that the size of the bottom deck determines the size of the screen.

The actual capacity of crusher in this dissertation is obtained by simulation using excel worksheet with reference to the flow diagram of plant, gradation of raw material, and gradation of crushers. By the simulation, the actual capacity of material being received by crusher can be determined for all possible settings of equipments.

## V.4. METHOD FOR CALCULATION OF MAXIMUM PRODUCTION RATE OF AGGREGATE PROCESSING PLANT

An aggregate processing plant usually produces more than one size range of aggregate, therefore there are always more than one output stream. In this dissertation, the calculation is carried out to determine maximum production rate of an output stream only. The output stream is selected and treated as the objective function and it is subjected to the constraints. By using a computer software call as 'Mathcad 2001i Professional' the problem is solved.

It is known that the main equipments within a plant can be set at its all possible settings. In this dissertation, the maximum production of a selected output stream of a plant is determined at different settings in order to obtain the setting that can give the highest production rate. Following is needed to be determined:

1) all possible settings combination of aggregate plant
2) objective function and constraints of the plant, in which the objective function is subjected to the constraints

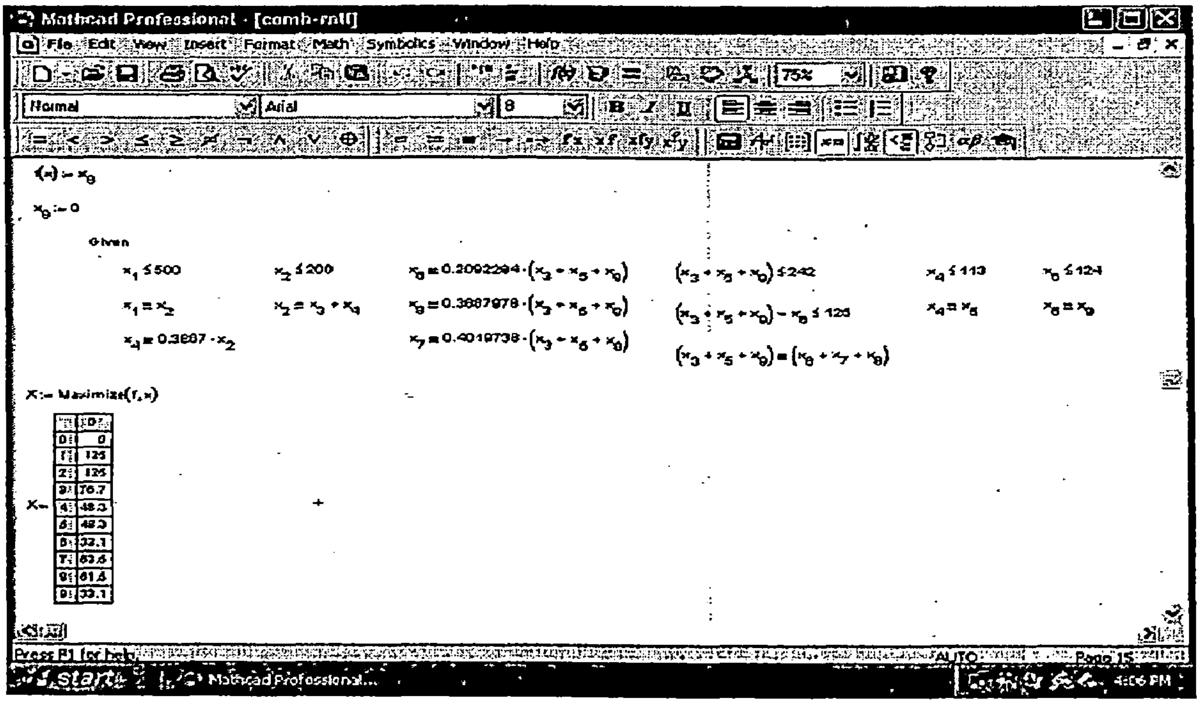
On the basis of this information the calculation is carried out for each possible setting and the results are compared to determine the highest production rate.

## V.5. DESCRIPTION OF ` Mathcad 2001i Professional `

### V.5.1. General

'Mathcad 2001i Professional' is the industry standard calculation software for technical professionals, educators, and college students. Mathcad is as versatile and powerful as programming languages, yet it's as easy to learn as a spreadsheet. Mathcad combines the live document interface of a spreadsheet with the WYSIWYG (What You See Is What You Get) interface of a word processor.

A worksheet is a collection of equations, text, graphics, and other items. Each equation, piece of text, graphic, or other item that inserted into the worksheet is a "region." An invisible rectangle holds each region. Equations, text, and graphics can be placed anywhere in the worksheet.



$f(x) := x_9$

$x_9 := 0$

Given

$x_1 \le 500$ $x_2 \le 200$ $x_6 = 0.2092294\cdot(x_3 + x_5 + x_9)$ $(x_3 + x_5 + x_9) \le 242$ $x_4 \le 113$ $x_6 \le 124$

$x_1 = x_2$ $x_2 = x_3 + x_4$ $x_8 = 0.3887978\cdot(x_3 + x_5 + x_9)$ $(x_3 + x_5 + x_9) - x_6 \le 125$ $x_4 = x_5$ $x_8 = x_9$

$x_4 = 0.3887\cdot x_2$ $x_7 = 0.4019738\cdot(x_3 + x_5 + x_9)$ $(x_3 + x_5 + x_9) = (x_6 + x_7 + x_8)$

$X := \text{Maximize}(f, x)$

| | 0 |
|---|---|
| 0 | 0 |
| 1 | 125 |
| 2 | 125 |
| 3 | 76.7 |
| 4 | 48.3 |
| 5 | 48.3 |
| 6 | 32.1 |
| 7 | 63.6 |
| 8 | 61.6 |
| 9 | 33.1 |

*Figure V.5.1. Worksheet of Mathcad 20001i Professional*

The equations are WYSIWYG and live. That is, equations appear as we're used to seeing them on blackboards or in reference books, and as soon as we make a change anywhere in our worksheet, Mathcad updates results and redraws graphs. This makes it easy keep track of the most complex calculations. As we insert various equations, text and graphics into a worksheet, we can arrange them and format them however we like.

To build mathematical expressions, we simply need to position the crosshair in our worksheet and begin typing letters, numbers or operators such as + or - . When typing letters or numbers, we'll see them appear surrounded by editing lines which show us which characters are selected. Use Space and the arrow keys to select various parts of an expression. Operators can be inserted by clicking on the appropriate button in the operator toolbars or by pressing the keystroke for the operator.

### V.5.2. Optimizing Overview

An optimization problem can numerically be solved by this software (i.e. Mathcad) using built-in functions (i.e., *Minimize* and *Maximize* functions). The *Minimize* and *Maximize* functions solve optimization problems in which we are finding values that minimize or maximize a function. These problems include linear programming.

To use *minimize* or *maximize* function:

Step-1, Define the objective function to maximize or minimize at defining block

Step-2, Define guess values for the variables being solved for at defining block

Step-3, Type the word *Given* to start the solve block.

Step-4, Beneath the *Given*, type equalities and inequalities which act as constraints using boolean operators.

Step-5, Enter the *Minimize* or *Maximize* function with the appropriate arguments.

**Minimize (*f*, *var1*, *var2*, ...)** Returns the values of *var1*, *var2*, ... which satisfy the constraints in a solve block and which make the function *f* take on its smallest value. **Maximize (*f*, *var1*, *var2*, ...)** Returns the values of *var1*, *var2*, ... which satisfy the constraints in a solve block and which make the function *f* take on its largest value.

*var1*, *var2*, ... are variables found in the solve block. They are defined above the solve block as guess values. *f* is a function defined above the solve block. For example, an argument *g* could refer to the function g(*x*, *y*):=*x*/*y*.

The example below shows linear optimization using the *Maximize* function taken from the Mathcad's spreadsheet.

Defining Block

Step – 1

$f(x) := x_8$

Step – 2

$x_9 := 0$

Solving Block

Step – 3

Given

Step – 4

$x_1 \le 500$

$x_1 = x_2$

$x_4 = 0.39 \cdot x_2$

$x_2 \le 200$

$x_2 = x_3 + x_4$

$x_6 = 0.209 \cdot (x_3 + x_5 + x_9)$

$x_8 = 0.399 \cdot (x_3 + x_5 + x_9)$

$x_7 = 0.392 \cdot (x_3 + x_5 + x_9)$

$(x_3 + x_5 + x_9) \le 242$

$(x_3 + x_5 + x_9) - x_6 \le 125$

$(x_3 + x_5 + x_9) = (x_6 + x_7 + x_8)$

$x_4 \le 113$

$x_4 = x_5$

$x_6 \le 124$

$x_6 = x_9$

Step – 5

$X := \text{Maximize}\ (f, x)$

X =

| | 0 |
|---|---|
| 0 | 0 |
| 1 | 125 |
| 2 | 125 |
| 3 | 76.25 |
| 4 | 48.75 |
| 5 | 48.75 |
| 6 | 33.028 |
| 7 | 61.947 |
| 8 | 63.053 |
| 9 | 33.028 |

## V.6. GRADATION OF RAW MATERIAL AND PRODUCT OF CRUSHER

### V.6.1. Gradation of Raw Material

For the purpose of calculation, the gradation of raw material should be determined. In this dissertation, the gradation data of raw material has been taken from the project report of Embung Bendo Project, Indonesia. The gradation of the raw material is determined through laboratory test where the result is shown in Table V.6.1.

### V.6.2. Gradation of Product of Crushers

Generally, gradation of output product of any type of crusher has been provided by manufacture. Since, the type of crushers used in this dissertation be based on that of issued by Telsmith Inc, then, from its manual, the gradation of the output product of crusher is taken. The manual provides gradation of output product for all possible settings of crusher. Gradation data of jaw crusher is given in Table III.3 while gradation of roll crusher is given by graphic in Figure III.3.e.

For using Table III.3, the close side setting of crusher should be selected initially. With reference to the selected setting and indicated sieve size at left side of table, the gradation or percentage of material passing through the indicated sieve is obtained.

Gradation of roll crusher is determine using a graph in which setting/opening of shells is selected initially followed by determination of screen size at which material will pass. From the screen size point, a line is drawn upward to intersect with selected graph. From the intersection point, a line is drawn to the left side horizontally until intersect with the vertical axis. This intersection indicates the desired gradation.

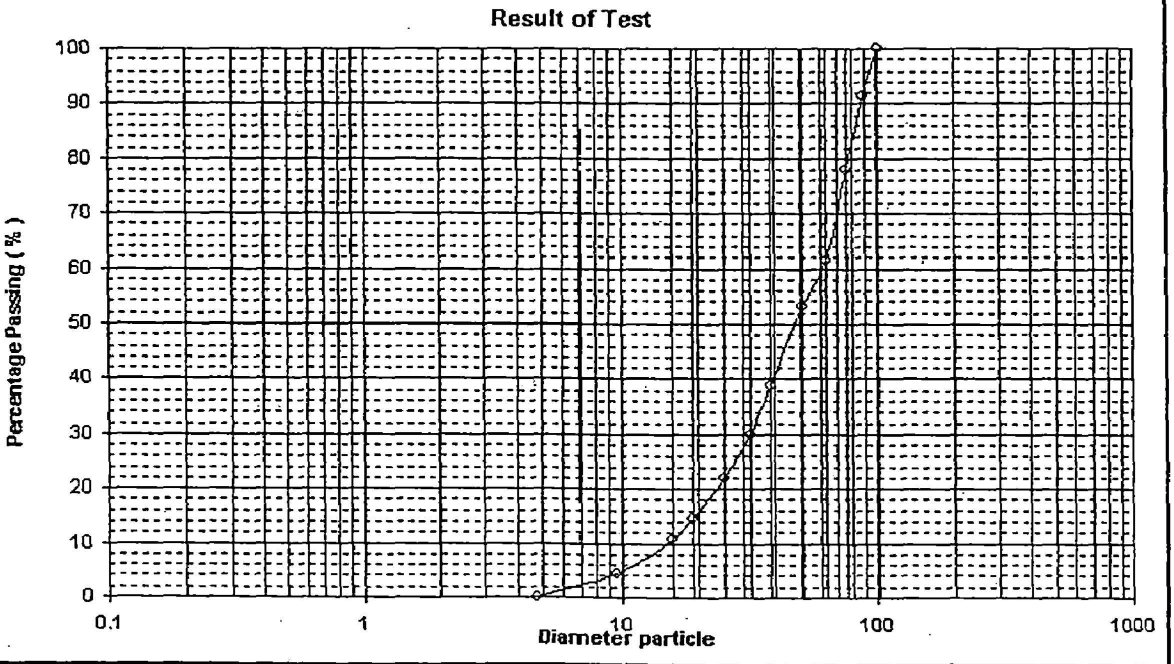
***Table V.6.1. Gradation of raw material***

GRADATION OF COARSE AGGREGATE ( ASTM C.136 - 46 )

| | | | | | |
|---|---|---|---|---|---|
| Proyect | EMBUNG BENDO | | | Date | AUGUST14,2003 |
| Location | BLIMBING RIVER ( DS. SAWOO ) | Sample no : 2 | | Tested by | LABORATORY |

Weight of Sample + Container ( S + C ) = 38780.0 gr
Weight of Container ( C ) = 6250.0 gr
Weight of Sample ( S ) = 32530.0 gr

| SIEVE mm | Cumulative weight retained. ( S + C ) ( gr ) | ( C ) ( gr ) | ( S ) ( gr ) | Retained ( % ) | Passing ( % ) | Remark |
|---|---|---|---|---|---|---|
| 101.6 | | | | 0 | 100 | |
| 88.9 | 9050 | 6250 | 2800 | 8.61 | 91.39 | |
| 76.2 | 10650 | | 4400 | 13.53 | 77.87 | |
| 63.5 | 11630 | | 5380 | 16.54 | 61.33 | |
| 50.8 | 21500 | | 15250 | 46.88 | 53.12 | |
| 38.1 | 26150 | | 19900 | 61.17 | 38.83 | |
| 31.7 | 29050 | | 22800 | 70.09 | 29.91 | |
| 25.4 | 31600 | | 25350 | 77.93 | 22.07 | |
| 19.1 | 34030 | | 27780 | 85.40 | 14.60 | FM = |
| 15.9 | 35250 | | 29000 | 89.15 | 10.85 | 7.56 |
| 9.52 | 37350 | | 31100 | 95.60 | 4.40 | |
| 4.76 | 38780 | | 32530 | 100 | 0.00 | |



## V.7. GRADATION CONTROL

### V.7.1. Introduction

Generally, crushed stone aggregate which is used in a construction project is specified in the form of size range and its quantity required. For example:

| Size range required | Quantity required |
|---|---|
| 3" - 1/2" | 4.50 TPH |
| 1/2" - 3/4" | 1.50 TPH |

With reference to such requirement, then operating of an aggregate processing plant is necessary to achieve two main purposes, namely

1. to produce size range required
2. to produce the quantity for each size range as per requirement.

As usual an aggregate processing plant in water resources development project is run in closed circuit operation having jaw crusher as primary crushing unit and roll crusher as secondary crushing unit.

The setting of crushers within the plant plays the main role for achieving the first purpose (i.e. to produce size range required). By taking above example, the setting of jaw crusher should be at least equal to the top size required (i.e. 3") while, setting of roll crusher should be less than the setting of jaw crusher.

After crushers' settings have been fixed, then the second purpose (i.e. to produce the quantity for each size range) can be achieved by feeding an amount of material to the plant. It is known that an amount of material which is fed to plant may cause the quantity of a particular size range required to be excess or it may be less than requirement. So that, the quantity of fed material to the plant should be so adjusted that the quantity of each size range required can be obtained exactly. It may be done by trial of feeding where many trials may be done at site. In this dissertation the problem is approached by simulation using excel. The only data required is the gradation of crusher.

The formulation which is used for determining amount of material produced in every size range required (tons per hour) subject to closed setting is:

Gradation of each size range of material (%) x Fed material (TPH)

Where, gradation of a size range of material produced by a crusher is usually do not change when setting has been fixed so as to fulfill the quantity of each size range required, the fed material is changed continuously. It means that trial of feeding must be done. The feeding trial is done by using computer.

### V.7.2. Illustrative Example of Gradation Control

Data required:

1) Gradation of jaw and roll crushers ( refers to Figure III.3.c)
2) Available setting of jaw crusher are 2", 2.25", 2.5", 2.75",3", 3.5", 4", and 5"
3) Available setting of roll crusher are 1.5", 1.75", 2", 2.25", 2.5", 2.75", and 3"

Size range and quantity of material required:

| Size range required | Quantity required |
|---|---|
| 3" - 1/2" | 4.50 TPH |
| 1/2" - 3/4" | 1.50 TPH |

With reference to size range required, the setting of jaw crusher is 3" and setting of roll crusher is ½".

For purpose of comparison, two feeding trials with 40 TPH and 32.85 TPH, respectively are presented. Table V.7.1 gives output of jaw crusher at different setting and different size ranges with feed rate of 40 tons/hr. Table V.7.2 gives summary of output in required size ranges, as expected from Table V.7.1 and the summary is presented graphically in Figure V.7.1. Table V.7.3 gives short fall or surplus in output with reference to requirement. Table V.7.4 gives output of roll crusher at different setting and different size ranges with feed rate of 13.85 tons/hr.

Table V.7.5 gives summary of output in required size ranges, as extracted from Table V.7.4 and the summary is presented graphically in Figure V.7.2. Table V.7.6 gives short fall or surplus in output with reference to requirement.

Graph such as shown in Figure V.7.1 is used to describe quantity of material produced by jaw crusher that may not satisfy the requirement of a certain size range. It is shown in Table V.7.2 and graph in Figure V.7.1 that quantity of size range (1.5" – ¾") produced by jaw crusher is less than requirement but that of size range (3" – 1.5") is excess. To fulfill the short fall of quantity in size range (1.5" – ¾"), then the excess material of size range (3" – 1.5") is re-crushed through roll crusher to produce additional quantity. Graph such as shown in Figure V.7.2 is used to indicate whether the required quantity of a particular size range has been fulfilled or not with feeding an amount of material to the crusher. Horizontal dotted line in Figure V.7.1, V.7.2, V.7.3, and V.7.4 indicate quantity required, while vertical dotted line is a line which is drawn vertically with reference to the selected setting of crushers. The requirement is fulfilled when the graph, the horizontal and the vertical lines intersect in one point.

Actually, many feeding trials have been conducted before the requirement if fulfilled. Some trials cause the production of size range (1.5" – ¾") of roll crusher to be excess but some others trials cause it less than requirement. Graph in Figure V.7.2 show that quantity of material which is fed to the plant is too high so that additional production of size range (1.5" – ¾") which is initially deficit in quantity (see Figure V.7.1) becomes excessive. Feeding trial is repeatedly done until the production of size range (1.5" – ¾") is equal to its requirements indicated by graph in Figure V.7.4. In this illustrative example, total quantity of raw material that should be fed to the plant in order that the production of each specified size range is obtained exactly as per requirement is as much as 32.35 ton per hour. The kind of simulation can be conducted for all possible setting of crushers.

***Table V.7.1. Output of Jaw Crusher With Feeding 40 Tph***

| Size Range (in) | Requirement (tons/h) | Rate of Production (tons/h) Subjected to Closed Setting (in.) With Feeding Of 40 (tons/h) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2 | 2.25 | 2.5 | 2.75 | 3 | 3.5 | 4 | 5 |
| 5 - 4.5 | | - | - | - | - | - | - | - | 3.76 |
| 4.5 - 4 | | - | - | - | - | - | - | - | 4.00 |
| 4 - 3.5 | | - | - | - | - | - | - | 4.71 | 3.06 |
| 3.5 - 3 | | - | - | - | - | - | 5.18 | 4.24 | 1.41 |
| 3 - 2.75 | **4.50** | - | - | - | - | **3.06** | 3.06 | 2.35 | 4.24 |
| 2.75 - 2.5 | | - | - | - | 3.29 | **3.06** | 2.35 | 2.35 | 1.88 |
| 2.5 - 2.25 | | - | - | 3.29 | 3.29 | **2.82** | 2.12 | 2.35 | 1.88 |
| 2.25 - 2 | | - | 3.76 | 4.00 | 0.94 | **3.53** | 2.82 | 2.35 | 1.88 |
| 2 - 1.75 | | 4.24 | 4.24 | 3.06 | 5.65 | **3.53** | 1.65 | 2.35 | 2.12 |
| 1.75 - 1.5 | | 4.71 | 4.24 | 1.88 | 7.06 | **2.35** | 3.53 | 2.12 | 1.65 |
| 1.5 - 1 | **9.50** | 9.41 | 8.00 | 9.88 | 3.29 | **3.29** | 5.65 | 4.94 | 4.00 |
| 1 - 3/4 | | 4.71 | 4.00 | 3.53 | 3.29 | **2.59** | 0.47 | 2.35 | 2.12 |
| 3/4 - 3/8 | 0.00 | 7.06 | 7.06 | 5.88 | 5.18 | 3.53 | 7.06 | 5.88 | 4.24 |
| 3/8 - 3/16 | 0.00 | 4.71 | 4.47 | 4.71 | 4.24 | 5.88 | 3.29 | 1.65 | 1.88 |
| 3/16 - 0 | 0.00 | 5.18 | 4.24 | 3.76 | 3.76 | 6.35 | 2.82 | 2.35 | 1.88 |
| Total (tons/h) | 14.00 | 40.00 | 40.00 | 40.00 | 40.00 | 40.00 | 40.00 | 40.00 | 40.00 |

***Table V.7.2. Summary of Output of Jaw Crusher in Required Size Ranges with Feeding 40 Tph***

| Size Range (in.) | Requirement (ton/h) | Total Production (tons/h) subjected to Closed Setting | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2 | 2.25 | 2.5 | 2.75 | 3 | 3.5 | 4 | 5 |
| 3 - 1.5 | **4.50** | 8.94 | 12.24 | 12.24 | 20.24 | **18.35** | 15.53 | 13.88 | 13.65 |
| 1.5 - 3/4 | **9.50** | 14.12 | 12.00 | 13.41 | 6.59 | **5.88** | 6.12 | 7.29 | 6.12 |
| 3/4 - 3/8 | 0.00 | 7.06 | 7.06 | 5.88 | 5.18 | 3.53 | 7.06 | 5.88 | 4.24 |
| 3/8 - 3/16 | 0.00 | 4.71 | 4.47 | 4.71 | 4.24 | 5.88 | 3.29 | 1.65 | 1.88 |
| Total production in specific range (tons/h) | | 30.12 | 31.29 | 31.53 | 32.00 | 27.76 | 28.71 | 27.06 | 24.00 |

***Table V.7.3. Surplus (+) or Short Fall (-) in Requirement by Feeding the Jaw Crusher with 40 Tph***

| Size Range in. | Requirement tons/h | Surplus (+) or Short Fall (-) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | tons/h | tons/h | tons/h | tons/h | tons/h | tons/h | tons/h | tons/h |
| 3 - 1.5 | **4.50** | 4.44 | 7.74 | 7.74 | 15.74 | **13.85** | 11.03 | 9.38 | 9.15 |
| 1.5 - 3/4 | **9.50** | 4.62 | 2.50 | 3.91 | -2.91 | **-3.62** | -3.38 | -2.21 | -3.38 |
| 3/4 3/8 | 0.00 | 7.06 | 7.06 | 5.88 | 5.18 | 3.53 | 7.06 | 5.88 | 4.24 |
| 3/8 - 1/8 | 0.00 | 4.71 | 4.47 | 4.71 | 4.24 | 5.88 | 3.29 | 1.65 | 1.88 |

**Figure V.7.1.**
**Production Rate VS Closed Side Setting Of Jaw Crusher with Feeding of 40 tons/h**

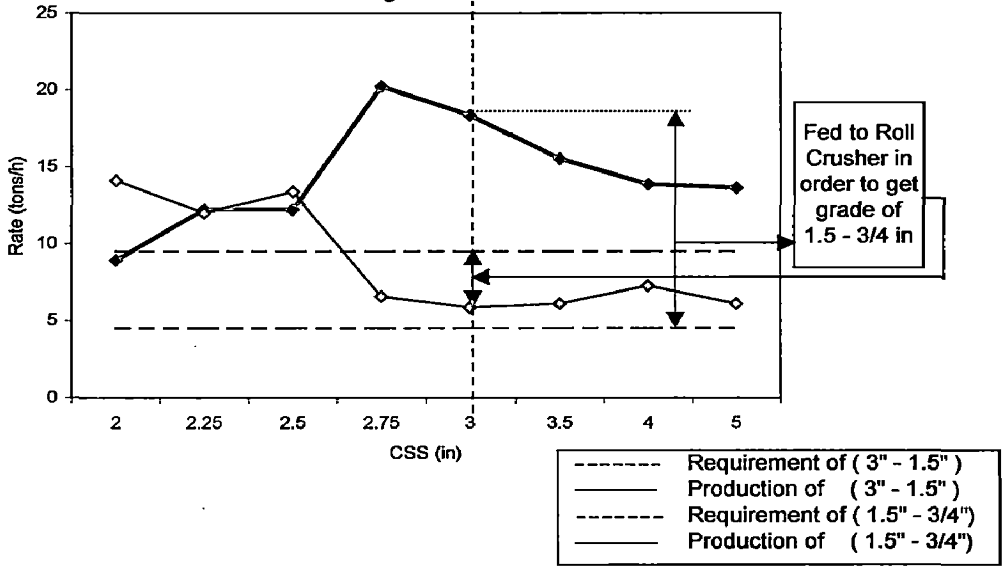


***Table V.7.4. Output of Jaw Crusher With Feeding 13.85 Tph***

| Size Range (in) | Requirement (tons/h) | Rate of Production (tons/h) Subject to Closed Side Setting (in.) With Feeding Of 13.85 (tons/h) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1.5 | 1.75 | 2 | 2.25 | 2.5 | 2.75 | 3 |
| 3 - 2.75 | 0.00 | - | - | - | - | - | - | 1.06 |
| 2.75 - 2.5 | | - | - | - | - | - | 1.14 | 1.06 |
| 2.5 - 2.25 | | - | - | - | - | 1.14 | 1.14 | 0.98 |
| 2.25 - 2 | | - | - | - | 1.30 | 1.39 | 0.33 | 1.22 |
| 2 - 1.75 | | - | | 1.47 | 1.47 | 1.22 | 1.96 | 1.22 |
| 1.75 - 1.5 | | - | 1.87 | 1.63 | 1.47 | 0.49 | 2.44 | 0.81 |
| **1.5** - 1 | **3.62** | **4.24** | 2.61 | 3.26 | 2.77 | 3.42 | 1.14 | 1.14 |
| 1 - **3/4** | | **2.12** | 2.77 | 1.63 | 1.39 | 1.22 | 1.14 | 0.90 |
| 3/4 - 3/8 | 0.00 | 3.26 | 2.77 | 2.44 | 2.44 | 2.04 | 1.79 | 1.22 |
| 3/8 - 3/16 | 0.00 | 2.04 | 1.87 | 1.63 | 1.39 | 1.47 | 1.47 | 2.04 |
| 3/16 - 0 | 0 | 2.20 | 1.96 | 1.79 | 1.63 | 1.47 | 1.30 | 2.20 |
| Total (tons/h) | | 13.85 | 13.85 | 13.85 | 13.85 | 13.85 | 13.85 | 13.85 |

***Table V.7.5. Summary of Output of Roll Crusher in Required Size Ranges with Feeding 13.85 Tph***

| Size Range (in.) | Requirement (ton/h) | Total Production (tons/h) subject to Closed Setting | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1.5 | 1.75 | 2 | 2.25 | 2.5 | 2.75 | 3 |
| 3 - 1.5 | 0.00 | 0.00 | 1.87 | 3.10 | 4.24 | 4.24 | 7.01 | 6.36 |
| **1.5 - 3/4** | **3.62** | **6.36** | 5.38 | 4.89 | 4.16 | 4.64 | 2.28 | 2.04 |
| 3/4 - 3/8 | 0.00 | 3.26 | 2.77 | 2.44 | 2.44 | 2.04 | 1.79 | 1.22 |
| 3/8 - 3/16 | 0.00 | 2.04 | 1.87 | 1.63 | 1.39 | 1.47 | 1.47 | 2.04 |
| Total produced in specific range (tons/h) | | 9.62 | 10.02 | 10.43 | 10.84 | 10.92 | 11.08 | 9.62 |

***Table V.7.6. Surplus (+) or Short Fall (-) in Requirement by Feeding the Roll Crusher with 13.85 Tph***

| Size Range in. | Requirement tons/h | Surplus (+) or Short Fall (-) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | tons/h | tons/h | tons/h | tons/h | tons/h | tons/h | tons/h |
| 3 - 1.5 | 0.00 | 0.00 | 1.87 | 3.10 | 4.24 | 4.24 | 7.01 | 6.36 |
| 1.5 - 3/4 | **3.62** | **2.74** | 1.76 | 1.27 | 0.54 | 1.03 | -1.34 | -1.58 |
| 3/4 3/8 | 0.00 | 3.26 | 2.77 | 2.44 | 2.44 | 2.04 | 1.79 | 1.22 |
| 3/8 - 3/16 | 0.00 | 2.04 | 1.87 | 1.63 | 1.39 | 1.47 | 1.47 | 2.04 |

**Figure V.7.2.**
**Production Rate VS Closed Side Setting of Roll Crusher with Feeding of 13.85 tons/h**

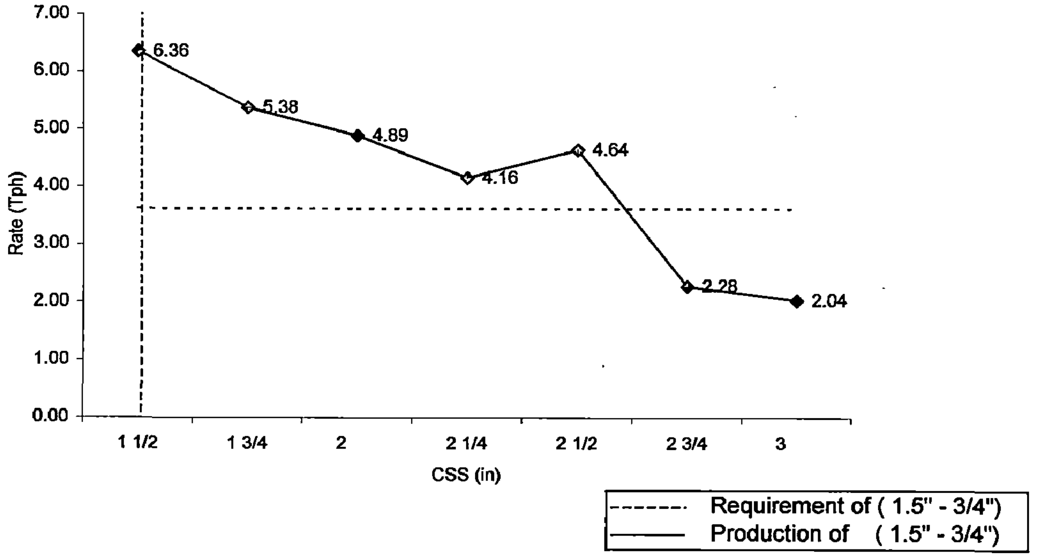


***Table V.7.7. Output of Jaw Crusher With Feeding 32.35 Tph***

| Size Range (in) | Requirement (tons/h) | Rate of Production (tons/h) Subjected to Closed Setting (in.) With Feeding Of 32.35 (tons/h) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2 | 2.25 | 2.5 | 2.75 | 3 | 3.5 | 4 | 5 |
| 5 - 4.5 | | - | - | - | - | - | - | - | 3.04 |
| 4.5 - 4 | | - | - | - | - | - | - | - | 3.24 |
| 4 - 3.5 | | - | - | - | - | - | - | 3.81 | 2.47 |
| 3.5 - 3 | | - | - | - | - | - | 4.19 | 3.43 | 1.14 |
| 3 - 2.75 | **4.50** | - | - | - | - | **2.47** | 2.47 | 1.90 | 3.43 |
| 2.75 - 2.5 | | - | - | - | 2.66 | **2.47** | 1.90 | 1.90 | 1.52 |
| 2.5 - 2.25 | | - | - | 2.66 | 2.66 | **2.28** | 1.71 | 1.90 | 1.52 |
| 2.25 - 2 | | - | 3.04 | 3.24 | 0.76 | **2.85** | 2.28 | 1.90 | 1.52 |
| 2 - 1.75 | | 3.43 | 3.43 | 2.47 | 4.57 | **2.85** | 1.33 | 1.90 | 1.71 |
| 1.75 - **1.5** | | 3.81 | 3.43 | 1.52 | 5.71 | **1.90** | 2.85 | 1.71 | 1.33 |
| **1.5** - 1 | **9.50** | 7.61 | 6.47 | 7.99 | 2.66 | **2.66** | 4.57 | 4.00 | 3.24 |
| 1 - **3/4** | | 3.81 | 3.24 | 2.85 | 2.66 | **2.09** | 0.38 | 1.90 | 1.71 |
| 3/4 - 3/8 | 0.00 | 5.71 | 5.71 | 4.76 | 4.19 | 2.85 | 5.71 | 4.76 | 3.43 |
| 3/8 - 3/16 | 0.00 | 3.81 | 3.62 | 3.81 | 3.43 | 4.76 | 2.66 | 1.33 | 1.52 |
| 3/16 - 0 | 0.00 | 4.19 | 3.43 | 3.04 | 3.04 | 5.14 | 2.28 | 1.90 | 1.52 |
| Total (tons/h) | 14.00 | 32.35 | 32.35 | 32.35 | 32.35 | 32.35 | 32.35 | 32.35 | 32.35 |

***Table V.7.8. Summary of Output of Jaw Crusher in Required Size Ranges with Feeding 32.35 Tph***

| Size Range (in.) | Requirement (ton/h) | Total Production (tons/h) subjected to Closed Setting | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2 | 2.25 | 2.5 | 2.75 | 3 | 3.5 | 4 | 5 |
| 3 - 1.5 | **4.50** | 7.23 | 9.90 | 9.90 | 16.37 | **14.84** | 12.56 | 11.23 | 11.04 |
| 1.5 - 3/4 | **9.50** | 11.42 | 9.71 | 10.85 | 5.33 | **4.76** | 4.95 | 5.90 | 4.95 |
| 3/4 - 3/8 | 0.00 | 5.71 | 5.71 | 4.76 | 4.19 | 2.85 | 5.71 | 4.76 | 3.43 |
| 3/8 - 3/16 | 0.00 | 3.81 | 3.62 | 3.81 | 3.43 | 4.76 | 2.66 | 1.33 | 1.52 |
| Total production in specific range (tons/h) | | 24.36 | 25.31 | 25.50 | 25.88 | 22.45 | 23.22 | 21.88 | 19.41 |

***Table V.7.9. Surplus (+) or Short Fall (-) in Requirement by Feeding the Jaw Crusher with 32.35 Tph***

| Size Range in. | Requirement tons/h | **Surplus (+) or Short Fall (-)** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | tons/h | tons/h | tons/h | tons/h | tons/h | tons/h | tons/h | tons/h |
| 3 - 1.5 | **4.50** | 2.73 | 5.40 | 5.40 | 11.87 | **10.34** | 8.06 | 6.73 | 6.54 |
| 1.5 - 3/4 | **9.50** | 1.92 | 0.21 | 1.35 | -4.17 | **-4.74** | -4.55 | -3.60 | -4.55 |
| 3/4 3/8 | 0.00 | 5.71 | 5.71 | 4.76 | 4.19 | 2.85 | 5.71 | 4.76 | 3.43 |
| 3/8 - 1/8 | 0.00 | 3.81 | 3.62 | 3.81 | 3.43 | 4.76 | 2.66 | 1.33 | 1.52 |

**Figure V.7.3.**
**Production Rate VS Closed Side Setting Of Jaw Crusher with Feeding of 32.35 tons/h**

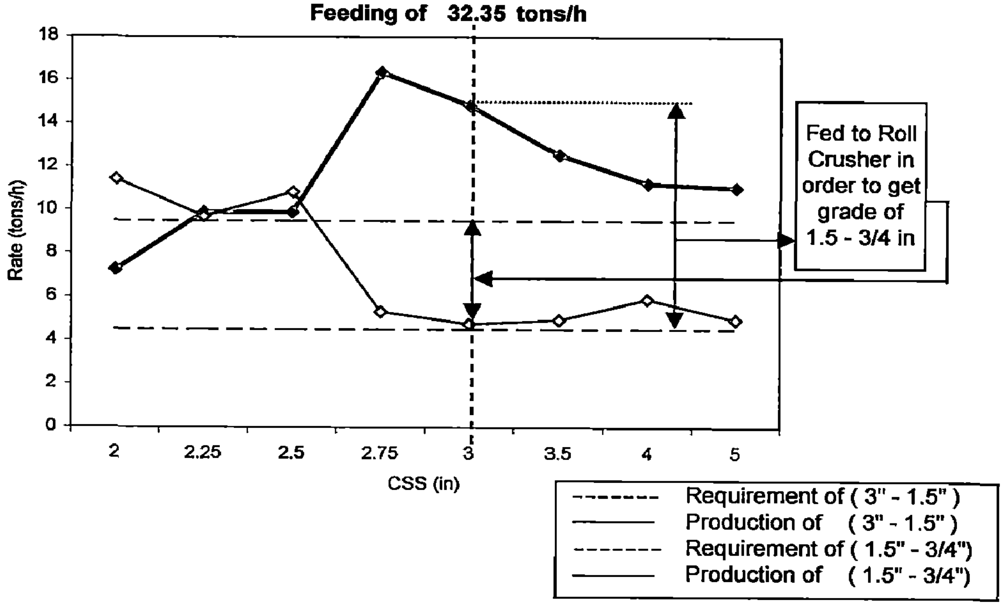


***Table V.7.10. Output of Jaw Crusher With Feeding 10.34 Tph***

| Size Range (in) | Requirement (tons/h) | Rate of Production (tons/h) Subject to Closed Side Setting (in.) With Feeding Of 10.34 (tons/h) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1.5 | 1.75 | 2 | 2.25 | 2.5 | 2.75 | 3 |
| 3 - 2.75 | 0.00 | - | - | - | - | - | - | 0.79 |
| 2.75 - 2.5 | | - | - | - | - | - | 0.85 | 0.79 |
| 2.5 - 2.25 | | - | - | - | - | 0.85 | 0.85 | 0.73 |
| 2.25 - 2 | | - | - | - | 0.97 | 1.03 | 0.24 | 0.91 |
| 2 - 1.75 | | - | | 1.10 | 1.10 | 0.91 | 1.46 | 0.91 |
| 1.75 - 1.5 | | - | 1.40 | 1.22 | 1.10 | 0.37 | 1.83 | 0.61 |
| **1.5 - 1** | 4.74 | **3.16** | 1.95 | 2.43 | 2.07 | 2.56 | 0.85 | 0.85 |
| **1 - 3/4** | | **1.58** | 2.07 | 1.22 | 1.03 | 0.91 | 0.85 | 0.67 |
| 3/4 - 3/8 | 0.00 | 2.43 | 2.07 | 1.83 | 1.83 | 1.52 | 1.34 | 0.91 |
| 3/8 - 3/16 | 0.00 | 1.52 | 1.40 | 1.22 | 1.03 | 1.10 | 1.10 | 1.52 |
| 3/16 - 0 | 0 | 1.64 | 1.46 | 1.34 | 1.22 | 1.10 | 0.97 | 1.64 |
| Total (tons/h) | | 10.34 | 10.34 | 10.34 | 10.34 | 10.34 | 10.34 | 10.34 |

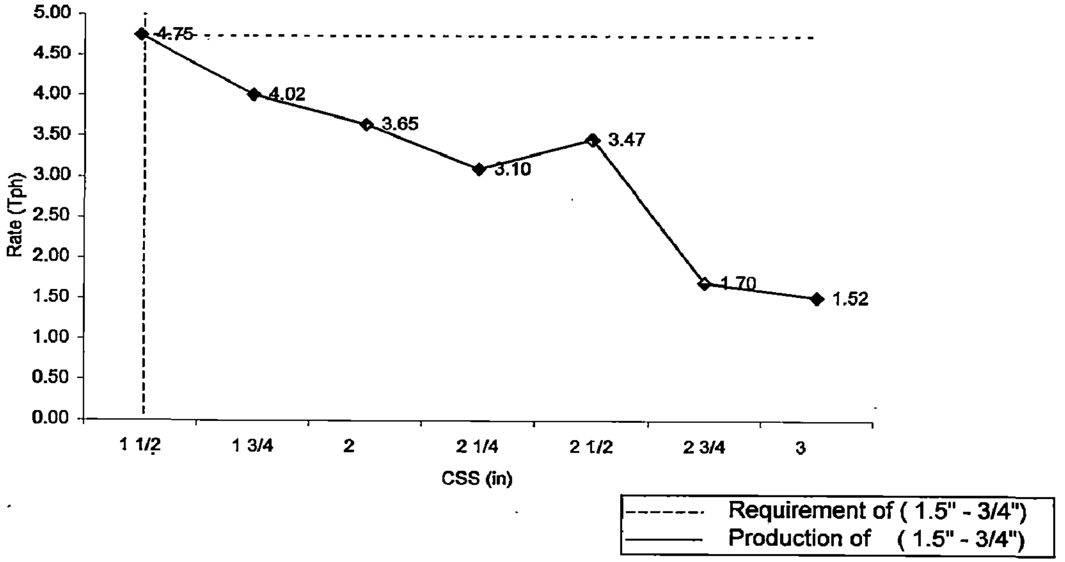
***Table V.7.11. Summary of Output of Roll Crusher in Required Size Ranges with Feeding 10.34 Tph***

| Size Range (in.) | Requirement (ton/h) | Total Production (tons/h) subject to Closed Setting | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1.5 | 1.75 | 2 | 2.25 | 2.5 | 2.75 | 3 |
| 3 - 1.5 | 0.00 | 0.00 | 1.40 | 2.31 | 3.16 | 3.16 | 5.23 | 4.75 |
| **1.5 - 3/4** | **4.74** | **4.75** | 4.02 | 3.65 | 3.10 | 3.47 | 1.70 | 1.52 |
| 3/4 - 3/8 | 0.00 | 2.43 | 2.07 | 1.83 | 1.83 | 1.52 | 1.34 | 0.91 |
| 3/8 - 3/16 | 0.00 | 1.52 | 1.40 | 1.22 | 1.03 | 1.10 | 1.10 | 1.52 |
| Total produced in specific range (tons/h) | | 7.18 | 7.48 | 7.79 | 8.09 | 8.15 | 8.27 | 7.18 |

***Table V.7.12. Surplus (+) or Short Fall (-) in Requirement by Feeding the Roll Crusher with 10.34 Tph***

| Size Range in. | Requirement tons/h | Surplus (+) or Short Fall (-) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | tons/h | tons/h | tons/h | tons/h | tons/h | tons/h | tons/h |
| 3 - 1.5 | 0.00 | 0.00 | 1.40 | 2.31 | 3.16 | 3.16 | 5.23 | 4.75 |
| 1.5 - 3/4 | **4.74** | **0.00** | -0.73 | -1.09 | -1.64 | -1.27 | -3.04 | -3.22 |
| 3/4 3/8 | 0.00 | 2.43 | 2.07 | 1.83 | 1.83 | 1.52 | 1.34 | 0.91 |
| 3/8 - 3/16 | 0.00 | 1.52 | 1.40 | 1.22 | 1.03 | 1.10 | 1.10 | 1.52 |

**Figure V.7.4.**
**Production Rate VS Closed Side Setting of Roll Crusher with Feeding of 10.34 tons/h**



# CHAPTER - VI

## RESULT, ANALYSIS, AND DISCUSSION

### VI.1. GENERAL

In this chapter, the maximization of aggregate plant production is carried out by using linear mathematical model. Calculations are carried out after the plant's arrangement is finalized, disposition of main equipments is completed and size of product required are determined.

### VI.1.1. Plant Arrangement

In this thesis, as a case study, a general arrangement of aggregate plant is constructed such as shown in Figure VI.1.1.a.

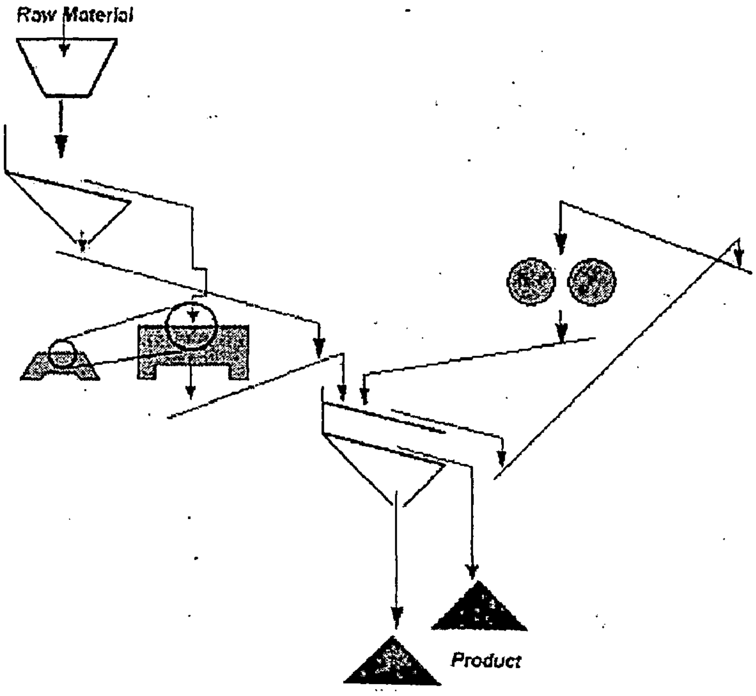


*Figure VI.1.1.a. Lay-out of aggregate processing plant*

The plant include, one unit each of:

1) hopper, (used for delivering raw material exactly to single deck screen)
2) single deck screen,
3) double deck screen,
4) jaw crusher, as primary crusher
5) roll crusher , as secondary crusher

Flow diagram of the plant is shown in Figure VI.1.1.b.

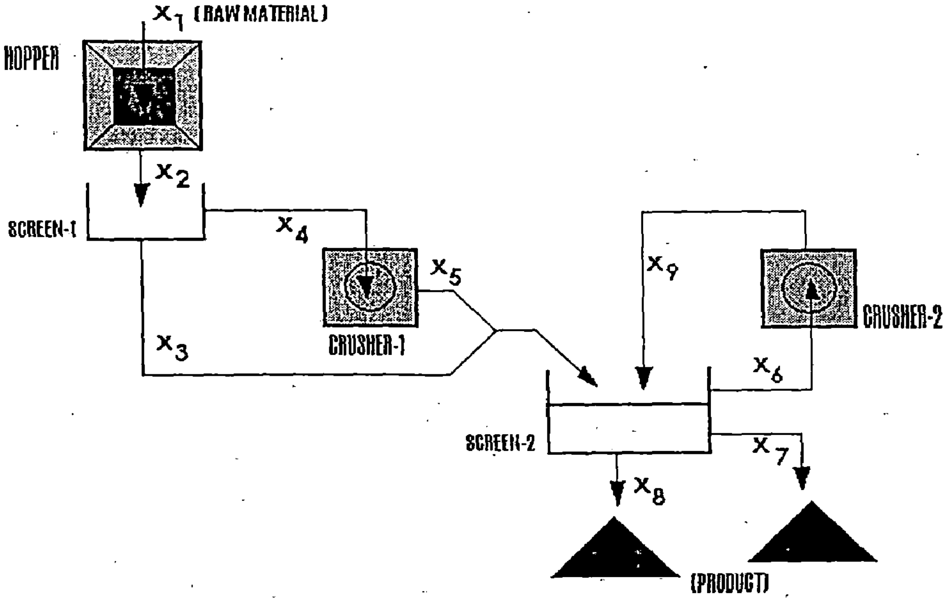


***Figure VI.1.1.b. Flow diagram of aggregate processing plant***

Material flowing in the plant which is called as **stream** is represented by arrows. Every arrow is labeled by ' $x_i$ '. $x_1$ and $x_2$ are input and output material (stream) of hopper, respectively. Then, $x_2$ become input stream to screen-1, while $x_3$ and $x_4$ are its output stream contain material that passing through, call as undersize and retained material, call as oversize, respectively. Input and output streams of crusher-1(i.e. jaw crusher) are represented by $x_4$ and $x_5$. For crusher-2 (i.e. roll crusher), the Input and output streams are represented by $x_6$ and $x_9$. Screen-2 have three input come from screen-1, jaw crusher and roll crusher which is represented by stream $x_3$ , $x_5$ , and $x_9$. As, the screen-2 is a double deck screen, then, there are three output. Retained material on top deck (oversize of screen-2) is represented by stream $x_6$. Material passing through top deck but retain on bottom deck (medium size of screen-2) is represented by $x_7$. The under size material or material passing through bottom deck of screen-2 is represented by stream $x_6$.

### VI.1.2. Type and Setting of Main Equipment

The aggregate processing plant that is constructed as a case study in this thesis is limited for receiving raw material up to 200 ton per hour. Two type of product are needed. They are product of range 2" - 1" and below 1", In which the product below 1" is assumed to be maximized.

From mechanical point of view, it is common practice in a project to use equipments that are manufactured by one company. The equipments which are used in the aggregate processing plant for case study in this dissertation are manufactured by TELSMITH Inc.

All data related to each equipment is available in manual hand book of Telsmith [1]. It has been used as guidance to select the setting and to select the specification of main equipment.

***Table VI.1.2. Selected type and setting of equipments***

| **Name** | **Type** | **Setting** | |
|---|---|---|---|
| | | Close Side Setting (CSS) | |
| Crusher-1 | Telsmith-Overhead Eccentric Jaw Crusher | 2 ½" | |
| Crusher-2 | Telsmith-Double Roll Crusher | ½" | |
| | | Top Deck | Bottom Deck |
| Screen-1 | Vibro-King Screen (Single Deck) | 2 ½" | |
| Screen-2 | Vibro-King Screen (Double Deck) | 2" | 1" |

Capacity of the crushers is determined be based on its total input material. It is obvious from Figure VI.1.1b that input material of both crushers is equal to the oversize material of screen. By simulation, the capacity of crusher is determined. Data used for the purpose of the simulation are the gradation of raw material and the gradation of the output material from crusher at its given setting.

Capacity of screen is determined using the formula given by Telsmith [1], in which percentage of input material passing through opening size of screen is required in the calculation. As the input material of screen-1 is raw material, then the percentage of the input material passing through opening size of screen-1 can be determined with reference to the percentage of raw material passing through the same opening size that has been obtained by laboratory test, shown in Table V.6.1. Determination of gradation of material of screen-1 can be easily determined because there is only one input stream to the screen. For screen-2 the input material comes from three streams. In order to determine percentage of the combined three input material passing through screen-2, then, the calculation is done refers to equations IV.37 and IV.42.

## VI.2. CALCULATIONS

### VI.2.1. Calculation of Streams' Gradation

Gradation states the percentage of material passing through series of sieves. In this thesis the gradation of material is determined for the material that passing through sieves, ranged from size 4 in. to 3/16 in. For the purpose of calculation, then the gradation of material which is needed as original data are the gradation of raw material (Table V.6.1), gradation of jaw crusher and roll crusher at their given settings which is taken from Table III.3 and Figure III.3.e, respectively. Gradation data of raw material and gradation data of both crushers at its required setting is summarized in a Table VI.2.1a.

**Table VI.2.1.a. Gradation data of raw material & product of crushers**

| Sieve Size | Raw-Material | Setting | |
|---|---|---|---|
| | | Crusher-1 | Crusher-2 |
| | | 2.5 " | 0.5 " |
| 4" | **100.00** | 100.00 | 100 |
| $3^1/_2$" | **91.39** | 92.71 | 100 |
| 3" | **77.87** | 85.42 | 100 |
| $2^1/_2$" | **61.33** | 71.88 | 100 |
| 2" | **53.12** | 57.29 | 100 |
| $1^1/_2$" | **38.83** | 40.63 | 100 |
| $1^1/_4$" | **29.91** | 34.38 | 100 |
| 1" | **22.07** | 26.04 | 98.5 |
| $^3/_4$" | **14.60** | 18.75 | 91.5 |
| $^1/_2$" | **10.85** | 12.50 | 73.5 |
| $^3/_8$" | **4.40** | 9.38 | 60.5 |
| $^3/_{16}$" | **0.00** | 5.21 | 36.5 |

Calculation of the gradation of all streams within the plant are carried out refer to the equations: (IV-37), (IV-42), (IV-47), (IV-48), and (IV-49) discussed in Chapter-IV, in which the result is summarized in Table VI.2.1b.

| Streams | Gradation | |
|---|---|---|
| $x_1$ | $C_{1i}$ | equal to data of raw material |
| $x_2$ | $^*C_{2i}$ | equal to data of raw material |
| $x_3$ | $C_{3i}$ | $100\,[1 - (C_{2m} - C_{2i}) / C_{2m})]$ |
| $x_4$ | $C_{4i}$ | $100\,[1 - (100 - C_{2i}) / (100 - C_{2m})]$ |
| $x_5$ | $C_{5i}$ | equal to the gradation of jaw crusher at its given close side setting |
| $x_{35}$ | $C_i^{35}$ | $100 - \dfrac{(100 - C_{3i})\,x_3 + (100 - C_{5i})\,x_5}{x_3 + x_5}$<br>$x_3 = (C_{2m} / 100) \cdot x_2$<br>$x_5 = x_4 = [(100 - C_{2m}) / 100]\; x_2$ |
| $x_9$ | $C_{9i}$ | equal to the gradation of roll crusher at its given close side setting |
| $x_{359}$ | $C_i^{35,9}$ | $= 100 - \dfrac{(100 - C_i^{35})\;C_{9m} + (100 - C_{9i})\;(100 - C_m^{35})}{100 + C_{9m} - C_m^{35}}$ |
| $x_6$ | $C_{6i}$ | $= 100\,[1 - (100 - C_i^{35,9}) / (100 - C_m^{35,9})]$ |
| $x_7$ | $C_{7i}$ | $= 100\,[1 - (C_m^{35,9} - C_i^{35,9}) / (C_m^{35,9} - C_n^{35,9})]$ |
| $x_8$ | $C_{8i}$ | $= 100\,[1 - (C_n^{35,9} - C_i^{35,9}) / (C_n^{35,9})]$ |

FOR,

| SETTING (in.) | | |
|---|---|---|
| **Screen-1** , $a_m$ | : | 2.5 |
| **Crusher-1** , $a_m$ | : | 2.5 |
| **Crusher-2** , $a_m$ | : | 0.5 |
| **Screen-2** | | |
| Top Deck, $a_m$ | : | 2 |
| Bottom Deck, $a_n$ | : | 1 |

THEN,

| | | |
|---|---|---|
| $^{**}C_{2m}$ | : | 61.33 |
| $C_m^{35}$ | : | 75.27 |
| $\mathbf{C_{9m}}$ | : | 100.0 |
| $C_m^{35,9}$ | : | 80.18 |
| $C_n^{35,9}$ | : | 45.30 |

* is percentage of stream $x_2$ passing through all given sieve size

** is percentage of stream $x_2$ passing through a sieve which have the same size with screen setting, $a_m$

*Table VI.2.1b. Summarized of the calculation of streams gradation*

| sieve, i | sieve size, $a_i$ (in.) | $C_{1i}$ (%) | $C_{2i}$ (%) | $C_{3i}$ (%) | $C_{4i}$ (%) | $C_{5i}$ (%) | $C_i^{35}$ (%) | $C_{9i}$ (%) | $C_i^{359}$ (%) | $C_{6i}$ (%) | $C_{7i}$ (%) | $C_{8i}$ (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* | *10* | *11* | *12* | *13* |
| 1 | 4 | **100** | **100** | 100 | 100.00 | **100** | 100.00 | **100** | 100.00 | 100 | 100 | 100 |
| 2 | $3^1/_2$ | **91.39** | **91.39** | 100 | 77.73 | **92.71** | 97.18 | **100** | 97.74 | 88.60 | 100 | 100 |
| 3 | 3 | **77.87** | **77.87** | 100 | 42.77 | **85.42** | 94.36 | **100** | 95.48 | 77.19 | 100 | 100 |
| 4 | $2^1/_2$ | **61.33** | **61.33** | **100** | **0.00** | **71.88** | 89.12 | **100** | 91.28 | 56.01 | 100 | 100 |
| 5 | 2 | **53.12** | **53.12** | 86.61 | 0 | **57.29** | 75.27 | **100** | 80.18 | 0 | **100** | 100 |
| 6 | $1^1/_2$ | **38.83** | **38.83** | 63.31 | 0 | **40.63** | 54.54 | **100** | 63.55 | 0 | 52.34 | 100 |
| 7 | $1^1/_4$ | **29.91** | **29.91** | 48.77 | 0 | **34.38** | 43.20 | **100** | 54.46 | 0 | 26.28 | 100 |
| 8 | 1 | **22.07** | **22.07** | 35.99 | 0 | **26.04** | 32.14 | **98.50** | 45.30 | 0 | **0.00** | **100** |
| 9 | $^3/_4$ | **14.60** | **14.60** | 23.81 | 0 | **18.75** | 21.85 | **91.50** | 35.66 | 0 | 0 | 78.72 |
| 10 | $^1/_2$ | **10.85** | **10.85** | 17.69 | 0 | **12.50** | 15.68 | **73.50** | 27.15 | 0 | 0 | 59.93 |
| 11 | $^3/_8$ | **4.40** | **4.40** | 7.17 | 0 | **9.38** | 8.03 | **60.50** | 18.43 | 0 | 0 | 40.68 |
| 12 | $^3/_{16}$ | **0** | **0** | 0 | 0 | **5.21** | 2.01 | **36.50** | 8.85 | 0 | 0 | 19.54 |

## VI.2.2. Calculation of Capacity of Crushers and Screens

### Capacity of crushers

Capacity of crusher -1 (i.e. jaw crusher) is 113 ton per hour. Capacity of crusher-2 (i.e. roll crusher) is 117 ton pr hour. It is found by following simulation.

**SCREEN-1**

Setting : 2.5

Input : 200.00 tph

| Sieve Size | Passing |  | Retained |  |
|---|---|---|---|---|
|  | % | Ton/hr | % | Ton/hr |
| 4" | 100 | 200 | 0 | 0 |
| 3½" | 91.39 | 182.8 | 8.61 | 17.22 |
| 3" | 77.87 | 142.3 | 22.13 | 40.45 |
| 2½" | 61.33 | 87 | 38.67 | 55.04 |
| 2" | 53.12 | 46.4 | 46.88 | 40.92 |
| 1½" | 38.83 | 18.0 | 61.17 | 28.36 |
| 1¼" | 29.91 | 5.4 | 70.09 | 12.62 |
| 1" | 22.07 | 1.2 | 77.93 | 4.20 |
| ¾" | 14.60 | 0.2 | 85.40 | 1.02 |
| ½" | 10.85 | 0.0 | 89.15 | 0.15 |
| ⅜" | 4.40 | 0.0 | 95.60 | 0.02 |
| 3/16" | 0.00 | 0.0 | 100.00 | 0.00 |
|  |  |  |  | 200.00 |

**SCREEN-2**

Top : 2"

Bottom : 1" Input : 87 tph

| Sieve Size | Passing |  | Retained |  |
|---|---|---|---|---|
|  | % | Ton/hr | % | Ton/hr |
| 4" | 100 | 87 | 0.0 | 0.0 |
| 3½" | 100 | 87 | 0.0 | 0.0 |
| 3" | 100 | 87 | 0.0 | 0.0 |
| 2½" | 100 | 87 | 0.0 | 0.0 |
| 2" | 53.12 | 46.4 | 46.9 | 40.92 |
| 1½" | 38.83 | 18.0 | 61.2 | 28.4 |
| 1¼" | 29.91 | 5.4 | 70.1 | 12.6 |
| 1" | 22.07 | 1.2 | 77.9 | 4.2 |
| ¾" | 14.60 | 0.2 | 85.4 | 1.0 |
| ½" | 10.85 | 0.0 | 89.2 | 0.2 |
| ⅜" | 4.40 | 0.0 | 95.6 | 0.0 |
| 3/16" | 0.00 | 0.0 | 100.0 | 0.0 |
|  |  |  |  | 87 |

retained at top deck of screen-2

A

Product (2" - 1")

(Product: < 1")

113

**CRUSHER-1**

Setting : 2.5 Input : 113 tph

passing top deck of screen-2

| Sieve Size | Passing % | Passing Ton/hr | Retained % | Retained Ton/hr |
|---|---|---|---|---|
| 4" | 100.00 | 113 | 0.00 | 0.000 |
| 3½" | 92.71 | 104.49 | 7.29 | 8.218 |
| 3" | 85.42 | 89.25 | 14.58 | 15.238 |
| 2½" | 71.88 | 64.15 | 28.13 | 25.102 |
| 2" | 57.29 | 36.75 | 42.71 | 27.397 |
| 1½" | 40.63 | 14.93 | 59.38 | 21.82 |
| 1¼" | 34.38 | 5.13 | 65.63 | 9.80 |
| 1" | 26.04 | 1.34 | 73.96 | 3.80 |
| ¾" | 18.75 | 0.25 | 81.25 | 1.09 |
| ½" | 12.50 | 0.03 | 87.50 | 0.22 |
| 3/8" | 9.38 | 0.00 | 90.63 | 0.03 |
| 3/16" | 5.21 | 0.00 | 94.79 | 0.00 |
|  |  |  |  | 113 |

(Product: < 1")

retained at top deck of screen-2 — B

Product (2" - 1")

retained at top deck of screen-2 — A + B

**CRUSHER-2**

Setting : 0.5 Input : 117 tph

| Sieve Size | Passing % | Passing Ton/hr | Retained % | Retained Ton/hr |
|---|---|---|---|---|
| 4" | 100 | 117 | 0.00 | 0.00 |
| 3½" | 100 | 117 | 0.00 | 0.00 |
| 3" | 100 | 117 | 0.00 | 0.00 |
| 2½" | 100 | 117 | 0.00 | 0.00 |
| 2" | 100 | 117 | 0.00 | 0.00 |
| 1½" | 100 | 117 | 0.00 | 0.00 |
| 1¼" | 100 | 117 | 0.00 | 0.00 |
| 1" | 98.5 | 115 | 1.50 | 1.75 |
| ¾" | 91.5 | 105 | 8.50 | 9.79 |
| ½" | 73.5 | 77 | 26.50 | 27.91 |
| 3/8" | 60.5 | 47 | 39.50 | 30.58 |
| 3/16" | 36.5 | 17 | 63.50 | 29.74 |
|  |  |  |  | 117 |

## Capacity of screens

SCREEN -1 (Single deck)

- Input material : **200 tph**
- Square opening of deck : **2.5”**
- Correction factors (refers to Table III.1g.) :

**Basic Capacity Factor (A)**

Type of material : Crushed Stone, (with capacity in TPH passing 1 $ft^2$ of screen cloth, at setting 2.5” ).

Factor A : **3.83**

**Oversize Factor (B)**

% of the 200 TPH is over 2.5” size : 38.7%

Factor B : **0.891**

**Efficiency Factor (C)**

Efficiency required : 96%

Factor C : **0.95**

**Half Size Factor (D)**

(i.e. : % of material is less than one-half the size of the deck)

Deck setting : 2.5”

1/2 of top deck setting is : 1.25”

Factor D : **0.641**

**Wet Screening Factor (E)**

Factor E : **1** (for dry material)

**Deck Factor (F)**

Factor F : **1** (single deck)

Area of screen-1 is:

$$\text{Area} = \frac{\text{Total feed} - \text{Oversize}}{A \times B \times C \times D \times E \times F} \text{ sq.ft.}$$

Known, oversize on the deck at setting 2.5" : 100 – 61.3 = 38.7%
(Table VI.2.1b, column 4) or 38.7% x 200 tph = 77 tph
Thus,

$$\text{Area} = \frac{200 - 77}{3.83 \times 0.891 \times 0.95 \times 0.641 \times 1 \times 1} \text{ sq.ft.}$$

$$\text{Area} = 59 \text{ sq.ft.}$$

SCREEN -2 (Double deck)

**Capacity of Top Deck of Screen-2**

- Input material : **200 tph** (From Stream-$x^{359}$)
- Square opening of Top deck : **2"**
- Correction factors (refers to Table III.1g.) :

**Basic Capacity Factor (A)**

Type of material : Crushed Stone, (with capacity in TPH passing 1 $ft^2$ of screen cloth, at setting 2" ).

Factor A : **3.45**

**Oversize Factor (B)**

% of the 200 TPH is over 2.5" size : 19.8%

Factor B : **1.002**

**Efficiency Factor (C)**

Efficiency required : 96%

Factor C : **0.95**

**Half Size Factor (D)**

(i.e. : % of material is less than one-half the size of the deck)

Deck setting : 2"

1/2 of top deck setting is : 1"

Factor D : **1.1**

**Wet Screening Factor (E)**

Factor E : **1** (for dry material)

**Deck Factor (F)**

Factor F : **1** (top deck)

Capacity = [area x (A x B x C x D x E x F)] + oversize

Where,

Area of screen-1 is:

$$\text{Area} = \frac{\text{Total feed}}{A \times B \times C \times D \times E \times F} \text{ sq.ft.}$$

$$\text{Area} = \frac{200}{3.45 \times 1.002 \times 0.95 \times 1.1 \times 1 \times 1} \text{ sq.ft.}$$

$$\text{Area} = \frac{200}{3.7} \text{ sq.ft.}$$

$$\text{Area} = 54 \text{ sq.ft.}$$

And

known, oversize on the deck at setting 2" : 100 – 80.2 = 19.8%

(Table VI.2.1b, column 10, row 5) or 19.8% x 200 tph : 40 tph

Thus,

Capacity = [54 x (3.7)] + 40 = **240** tph.

## Capacity of Bottom Deck of Screen-2

- Input material : **90.6 tph** (From Stream-x[359] )
- Square opening of Bottom deck : **1"**
- Correction factors (refers to Table III.1g.) :

**Basic Capacity Factor (A)**

Type of material : Crushed Stone, (with capacity in TPH passing 1 $ft^2$ of screen cloth, at setting 1" ).

Factor A : **2.78**

**Oversize Factor (B)**

% of the 90.6 TPH is over 2.5" size : 54.7%

Factor B : **0.748**

**Efficiency Factor (C)**

Efficiency required : 96%

Factor C : **0.95**

**Half Size Factor (D)**

(i.e. : % of material is less than one-half the size of the deck)

Deck setting : 1"

1/2 of top deck setting is : 0.5"

Factor D : **0.74**

**Wet Screening Factor (E)**

Factor E : **1** (for dry material)

**Deck Factor (F)**

Factor F : **0.9** (bottom deck)

$$\text{Capacity} = [\text{area} \times (A \times B \times C \times D \times E \times F)] + \text{oversize}$$

Where,

Area of screen-1 is :

$$\text{Area} = \frac{\text{Total feed}}{A \times B \times C \times D \times E \times F} \text{ sq.ft.}$$

$$\text{Area} = \frac{90.6}{2.78 \times 0.478 \times 0.95 \times 0.74 \times 1 \times 0.9} \text{ sq.ft.}$$

$$\text{Area} = \frac{90.6}{1.32} \text{ sq.ft.}$$

$$\text{Area} = 69 \text{ sq.ft.}$$

It's known, oversize on the deck at setting 1" : 100 – 45.3 = 54.7% (Table VI.2.1b, column 10, row 8) or 54.7% x 90.6 tph : 50 tph

Thus,

$$\text{Capacity} = [69 \times (1.32)] + 50 = \mathbf{140} \text{ tph.}$$

### VI.2.3. Determination of Aggregate Plant Constraints

The constraints in the form of mathematical expression that can be derived from the real aggregate processing plant in Figure VI.1.1b., are as follows,

1. Capacity of stream $x_1$ should be less than capacity of Loader (assuming loader capacity 500 tph) or

$$x_1 \leq 500$$

2. input and output stream of hopper is equal

$$x_1 = x_2$$

3. Capacity of stream $x_2$ can not more than capacity of loader

$$x_2 \leq 200$$

4. Input and output stream of screen-1 should be equal

$$x_2 = x_3 + x_4$$

5. Capacity of inputted stream of screen-2 can not more than capacity of top deck

$$x_3 + x_5 + x_9 \leq 240$$

6. Capacity of stream passing top deck of screen-2 can not more than capacity of bottom deck

$$[x_3 + x_5 + x_9] - x_6 \leq 140$$

7. Input and output material of screen-2 must be equal

$$[x_3 + x_5 + x_9] = [x_6 + x_7 + x_8]$$

8. Capacity of inputted stream x4 can not more than capacity of crusher-1

$$x_4 \leq 113$$

9. Input and output stream of crusher-1 should be equal

$$x_4 = x_5$$

10. Capacity of inputted stream x6 can not more than capacity of crusher-2

$$x_6 \leq 117$$

11. Input and output stream of crusher-2 should be equal

$$x_6 = x_9$$

where,

$x_4 = [(100 - C_{2m}) / 100] . x_2$

$x_6 = [(100 - C_m^{359}) / 100].[x_3 + x_5 + x_9]$

$$\mathbf{x_7 = [(C_m^{359} - C_n^{359}) / 100].[x_3 + x_5 + x_9]}$$

$$\mathbf{x_8 = [C_n^{359} / 100]. [x_3 + x_5 + x_9]}$$

By substitution $C_{2m}$, $C_m^{359}$ and $C_n^{359}$ with its constant value contain in Table VI.2.1b., then the above constraints become as follows,

1. $x_1$ <= 500
2. $x_1$ = $x_2$
3. $x_2$ <= 200
4. $x_2$ = $x_3 + x_4$
5. $[x_3 + x_5 + x_9]$ <= 240
6. $[x_3 + x_5 + x_9] - x_6$ <= 140
7. $[x_3 + x_5 + x_9]$ = $[x_6 + x_7 + x_8]$
8. $x_4$ <= 113
9. $x_4$ = $x_5$
10. $x_6$ <= 117
11. $x_6$ = $x_9$
12. $x_4$ = $0.386700\ x_4$
13. $x_6$ = $0.19823812829\ [x_3 + x_5 + x_9]$
14. $x_7$ = $0.34880854428\ [x_3 + x_5 + x_9]$
15. $x_8$ = $0.45295332744\ [x_3 + x_5 + x_9]$

Since the objective should be subjected to the constraints, then, the objective namely maximize production rate of stream $\mathbf{x_8}$ (product below 1 inch in size) is subjected to these above fifth-teen constraints.

By using Mathcad 2001i Professional, this linear model is solved and the results are as follow,

Setting :
Screen-1= 2 1/2 "
Crusher-1= 2 1/2"
Crusher-2= 1/2 "

$f(x) := x_8$

$x_9 := 0$

Given

$x_1 \le 500$

$x_1 = x_2$

$x_4 = 0.3867 \cdot x_2$

$x_2 \le 200$

$x_2 = x_3 + x_4$

$x_6 = 0.19824 \cdot (x_3 + x_5 + x_9)$

$x_8 = 0.45295 \cdot (x_3 + x_5 + x_9)$

$x_7 = 0.34881 \cdot (x_3 + x_5 + x_9)$

$(x_3 + x_5 + x_9) \le 240$

$(x_3 + x_5 + x_9) - x_6 \le 140$

$(x_3 + x_5 + x_9) = (x_6 + x_7 + x_8)$

$x_4 \le 113$

$x_4 = x_5$

$x_6 \le 117$

$x_6 = x_9$

X:= Maximize (f, x)

X=

| | 0 |
|---|---|
| 0 | 0 |
| 1 | 140 |
| 2 | 140 |
| 3 | 85.9 |
| 4 | 54.1 |
| 5 | 54.1 |
| 6 | 34.6 |
| 7 | 60.9 |
| 8 | 79.1 |
| 9 | 34.6 |

The result shows that the maximum production rate of stream **$x_8$** (material below 1 inch in size) of the aggregate plant is equal to **79.1** ton per hour. The plant can handle **140** ton per hour inputted material. These result is obtained by fixed setting condition of jaw crusher and roll crusher at **2 ½"** and **½ "** respectively; screen-1 at **2 ½"**; and screen-2 at **2"** and **1"** belongs to its top and bottom deck, respectively.

### VI.2.4. Calculation and Result for All Combination of Settings

Since this study is also aimed to know the setting that can give the highest production of the aggregate plant, then the scenario which is developed to achieve the objective is by determination all possible setting of crushers and screens, then, similar calculation as above is carried out for each combination setting.

From the available data, there are 30 possible combinations setting that can be applied, as in Table VI.2.4.

***Table VI.2.4. Possible settings of crushers and screens***

| | SETTING | | | | |
|---|---|---|---|---|---|
| No. | Screen-1 | Crusher-1 | Crusher-2 | Screen-2 | |
| | | | | Top | Bottom |
| | (in.) | (in.) | (in.) | (in.) | (in.) |
| 1 | 2 | 2 | 1/2 | 2 | 1 |
| 2 | 2 | 2 | 5/8 | 2 | 1 |
| 3 | 2 | 2 | 3/4 | 2 | 1 |
| 4 | 2 | 2 1/2 | 1/2 | 2 | 1 |
| 5 | 2 | 2 1/2 | 5/8 | 2 | 1 |
| 6 | 2 | 2 1/2 | 3/4 | 2 | 1 |
| 7 | 2 | 3 | 1/2 | 2 | 1 |
| 8 | 2 | 3 | 5/8 | 2 | 1 |
| 9 | 2 | 3 | 3/4 | 2 | 1 |
| 10 | 2 | 3 1/2 | 1/2 | 2 | 1 |
| 11 | 2 | 3 1/2 | 5/8 | 2 | 1 |
| 12 | 2 | 3 1/2 | 3/4 | 2 | 1 |
| 13 | 2 1/2 | 2 1/2 | 1/2 | 2 | 1 |
| 14 | 2 1/2 | 2 1/2 | 5/8 | 2 | 1 |
| 15 | 2 1/2 | 2 1/2 | 3/4 | 2 | 1 |
| 16 | 2 1/2 | 3 | 1/2 | 2 | 1 |
| 17 | 2 1/2 | 3 | 5/8 | 2 | 1 |
| 18 | 2 1/2 | 3 | 3/4 | 2 | 1 |
| 19 | 2 1/2 | 3 1/2 | 1/2 | 2 | 1 |
| 20 | 2 1/2 | 3 1/2 | 5/8 | 2 | 1 |
| 21 | 2 1/2 | 3 1/2 | 3/4 | 2 | 1 |
| 22 | 3 | 3 | 1/2 | 2 | 1 |
| 23 | 3 | 3 | 5/8 | 2 | 1 |
| 24 | 3 | 3 | 3/4 | 2 | 1 |
| 25 | 3 | 3 1/2 | 1/2 | 2 | 1 |
| 26 | 3 | 3 1/2 | 5/8 | 2 | 1 |
| 27 | 3 | 3 1/2 | 3/4 | 2 | 1 |
| 28 | 3 1/2 | 3 1/2 | 1/2 | 2 | 1 |
| 29 | 3 1/2 | 3 1/2 | 5/8 | 2 | 1 |
| 30 | 3 1/2 | 3 1/2 | 3/4 | 2 | 1 |

For the purpose of easily tabulation of all constraints, then, in general the mathematical expression of the constraints is given as follow,

$$
\begin{array}{lcl}
X_1 & <= & C_1 \\
X_1 & = & C_2 \; X_2 \\
X_4 & = & C_3 \; X_2 \\
X_4 & <= & C_4 \\
X_2 & = & C_5 \; X_3 + C_6 \; X_4 \\
X_6 & = & C_7 \; (X_3 + X_5 + X_9) \\
X_7 & = & C_8 \; (X_3 + X_5 + X_9) \\
X_8 & = & C_9 \; (X_3 + X_5 + X_9) \\
(X_3 + X_5 + X_9) & <= & C_{10} \\
(X_3 + X_5 + X_9) - X_6 & <= & C_{11} \\
(X_3 + X_5 + X_9) & = & C_{12} \; (X_3 + X_5 + X_9) \\
X_4 & <= & C_{13} \\
X_4 & = & C_{14} \; X_5 \\
X_6 & <= & C_{15} \\
X_6 & = & C_{16} \; X_9
\end{array}
$$

Where, $C_1$ until $C_{16}$ is the coefficients of variables in this linear model

Calculation of these 30 combinations carried out one by one, where, the results are shown in Table VI.2.4a to VI.2.4j. It has shown that there are some coefficients in each combination that always in variation compare with others combination.

**Objective :**

Maximize, Production Rate of Stream $x_8$

**Constraints :**

$x_1 \leq C_1$
$x_1 = C_2 \; x_2$
$x_4 = C_3 \; x_2$
$x_4 \leq C_4$
$x_2 = C_5 \; x_3 + C_6 \; x_4$
$x_6 = C_7 \; (x_3 + x_5 + x_9)$
$x_7 = C_8 \; (x_3 + x_5 + x_9)$
$x_8 = C_9 \; (x_3 + x_5 + x_9)$
$(x_3 + x_5 + x_9) \leq C_{10}$
$(x_3 + x_5 + x_9) - x_6 \leq C_{11}$
$(x_3 + x_5 + x_9) = C_{12} \; (x_3 + x_5 + x_9)$
$x_4 \leq C_{13}$
$x_4 = C_{14} \; x_5$
$x_6 \leq C_{15}$
$x_6 = C_{16} \; x_9$

***Table IV.3.a. Coefficient of Variable of Constraints for:***

| | |
|---|---|
| Screen-I, | 2" |
| Screen-II , Top : | 2" |
| Bottom : | 1" |

| Coeff. | Crusher-I | 2 | |
|---|---|---|---|
| | Crusher-II | | |
| | 1/2 | 5/8 | 3/4 |
| $C_1$ | 500 | 500 | 500 |
| $C_2$ | 1 | 1 | 1 |
| $C_3$ | 0.46880 | 0.46880 | 0.46880 |
| $C_4$ | 200 | 200 | 200 |
| $C_5$ | 1 | 1 | 1 |
| $C_6$ | 1 | 1 | 1 |
| $C_7$ | 0.14095 | 0.14095 | 0.14095 |
| $C_8$ | **0.44119** | **0.42569** | **0.39115** |
| $C_9$ | **0.41786** | **0.43336** | **0.46789** |
| $C_{10}$ | 228 | 228 | 228 |
| $C_{11}$ | **138** | **134** | **126** |
| $C_{12}$ | 1 | 1 | 1 |
| $C_{13}$ | 154 | 154 | 154 |
| $C_{14}$ | 1 | 1 | 1 |
| $C_{15}$ | 100 | 100 | 100 |
| $C_{16}$ | 1 | 1 | 1 |

***Table IV.3.b. Coefficient of Variable of Constraints for:***

| | |
|---|---|
| Screen-I, | 2" |
| Screen-II , Top : | 2" |
| Bottom : | 1" |

| Coeff. | Crusher-I | 2 1/2" | |
|---|---|---|---|
| | Crusher-II | | |
| | 1/2 | 5/8 | 3/4 |
| $C_1$ | 500 | 500 | 500 |
| $C_2$ | 1 | 1 | 1 |
| $C_3$ | 0.46880 | 0.46880 | 0.46880 |
| $C_4$ | 200 | 200 | 200 |
| $C_5$ | 1 | 1 | 1 |
| $C_6$ | 1 | 1 | 1 |
| $C_7$ | 0.16682 | 0.16682 | 0.16682 |
| $C_8$ | **0.44992** | **0.43157** | **0.39069** |
| $C_9$ | **0.38327** | **0.40162** | **0.44249** |
| $C_{10}$ | 233 | 233 | 233 |
| $C_{11}$ | **139** | **135** | **128** |
| $C_{12}$ | 1 | 1 | 1 |
| $C_{13}$ | 154 | 154 | 154 |
| $C_{14}$ | 1 | 1 | 1 |
| $C_{15}$ | 125 | 125 | 125 |
| $C_{16}$ | 1 | 1 | 1 |

***Table IV.3.a1. Result of Maximizing Stream $x_8$***

| Steam | Crusher-I: | 2" | |
|---|---|---|---|
| | Setting of Crusher-II | | |
| $x_{i=1...9}$ | 1/2 | 5/8 | 3/4 |
| 1 | 138 | 134 | 126 |
| 2 | 138 | 134 | 126 |
| 3 | 73.3 | 71.2 | 66.9 |
| 4 | 64.7 | 62.8 | 59.1 |
| 5 | 64.7 | 62.8 | 59.1 |
| 6 | 22.6 | 22 | 20.7 |
| 7 | 67.1 | 67.6 | 68.6 |
| 8 | 70.9 | 66.4 | 57.4 |
| 9 | 22.6 | 22 | 20.7 |

***Table IV.3.b1. Result of Maximizing Stream $x_8$***

| Steam | Crusher-I: | 2 1/2" | |
|---|---|---|---|
| | Setting of Crusher-II | | |
| $x_{i=1...9}$ | 1/2 | 5/8 | 3/4 |
| 1 | 139 | 135 | 128 |
| 2 | 139 | 135 | 128 |
| 3 | 73.8 | 71.7 | 68 |
| 4 | 65.2 | 63.3 | 60 |
| 5 | 65.2 | 63.3 | 60 |
| 6 | 27.8 | 27 | 25.6 |
| 7 | 63.9 | 65.1 | 68 |
| 8 | 75.1 | 69.9 | 60 |
| 9 | 27.8 | 27 | 25.6 |

**Objective :**

Maximize, Production Rate of Stream $x_8$

**Constraints :**

$x_1 \quad <= \quad C_1$

$x_1 \quad = \quad C_2 \; x_2$

$x_4 \quad = \quad C_3 \; x_2$

$x_4 \quad <= \quad C_4$

$x_2 \quad = \quad C_5 \; x_3 + C_6 \, x_4$

$x_6 \quad = \quad C_7 \; (x_3 + x_5 + x_9)$

$x_7 \quad = \quad C_8 \; (x_3 + x_5 + x_9)$

$x_8 \quad = \quad C_9 \; (x_3 + x_5 + x_9)$

$(x_3 + x_5 + x_9) \quad <= \quad C_{10}$

$(x_3 + x_5 + x_9) - x_6 \quad <= \quad C_{11}$

$(x_3 + x_5 + x_9) \quad = \quad C_{12} \; (x_3 + x_5 + x_9)$

$x_4 \quad <= \quad C_{13}$

$x_4 \quad = \quad C_{14} \; x_5$

$x_6 \quad <= \quad C_{15}$

$x_6 \quad = \quad C_{16} \; x_9$

*Table IV.3.c. Coefficient of Variable of Constraints for:*

| | |
|---|---|
| Screen-I, | 2" |
| Screen-II , Top : | 2" |
| Bottom : | 1" |

| Coeff. | Crusher-I 3" | | |
|---|---|---|---|
| | Crusher-II | | |
| | 1/2 | 5/8 | 3/4 |
| $C_1$ | 500 | 500 | 500 |
| $C_2$ | 1 | 1 | 1 |
| $C_3$ | 0.46880 | 0.46880 | 0.46880 |
| $C_4$ | 200 | 200 | 200 |
| $C_5$ | 1 | 1 | 1 |
| $C_6$ | 1 | 1 | 1 |
| $C_7$ | 0.18115 | 0.18115 | 0.18115 |
| $C_8$ | **0.46267** | **0.46267** | **0.46267** |
| $C_9$ | **0.35617** | **0.37609** | **0.42048** |
| $C_{10}$ | 236 | 236 | 236 |
| $C_{11}$ | **142** | **138** | **128** |
| $C_{12}$ | 1 | 1 | 1 |
| $C_{13}$ | 154 | 154 | 154 |
| $C_{14}$ | 1 | 1 | 1 |
| $C_{15}$ | 135 | 135 | 135 |
| $C_{16}$ | 1 | 1 | 1 |

*Table IV.3.c1. Result of Maximizing Stream $x_8$*

| Steam | Crusher-I: 3" | | |
|---|---|---|---|
| | Setting of Crusher-II | | |
| $x_{i=1...9}$ | 1/2 | 5/8 | 3/4 |
| 1 | 142 | 138 | 128 |
| 2 | 142 | 138 | 128 |
| 3 | 75.4 | 73.3 | 68 |
| 4 | 66.6 | 64.7 | 60 |
| 5 | 66.6 | 64.7 | 60 |
| 6 | 31.4 | 30.5 | 28.3 |
| 7 | 61.7 | 63.4 | 65.8 |
| 8 | 80.3 | 74.6 | 62.2 |
| 9 | 31.4 | 30.5 | 28.3 |

*Table IV.3.d. Coefficient of Variable of Constraints for:*

| | |
|---|---|
| Screen-I, | 2" |
| Screen-II , Top : | 2" |
| Bottom : | 1" |

| Coeff. | Crusher-I 3 1/2" | | |
|---|---|---|---|
| | Crusher-II | | |
| | 1/2 | 5/8 | 3/4 |
| $C_1$ | 500 | 500 | 500 |
| $C_2$ | 1 | 1 | 1 |
| $C_3$ | 0.46880 | 0.46880 | 0.46880 |
| $C_4$ | 200 | 200 | 200 |
| $C_5$ | 1 | 1 | 1 |
| $C_6$ | 1 | 1 | 1 |
| $C_7$ | 0.18988 | 0.18988 | 0.18988 |
| $C_8$ | **0.44919** | **0.42831** | **0.38179** |
| $C_9$ | **0.36091** | **0.38179** | **0.42832** |
| $C_{10}$ | 238 | 238 | 238 |
| $C_{11}$ | **139** | **135** | **124** |
| $C_{12}$ | 1 | 1 | 1 |
| $C_{13}$ | 154 | 154 | 154 |
| $C_{14}$ | 1 | 1 | 1 |
| $C_{15}$ | 143 | 143 | 143 |
| $C_{16}$ | 1 | 1 | 1 |

*Table IV.3.d1. Result of Maximizing Stream $x_8$*

| Steam | Crusher-I: 3 1/2" | | |
|---|---|---|---|
| | Setting of Crusher-II | | |
| $x_{i=1...9}$ | 1/2 | 5/8 | 3/4 |
| 1 | 139 | 135 | 124 |
| 2 | 139 | 135 | 124 |
| 3 | 73.8 | 71.7 | 65.9 |
| 4 | 65.2 | 63.3 | 58.1 |
| 5 | 65.2 | 63.3 | 58.1 |
| 6 | 32.6 | 31.6 | 29.1 |
| 7 | 61.9 | 63.6 | 65.6 |
| 8 | 77.1 | 71.4 | 58.4 |
| 9 | 32.6 | 31.6 | 29.1 |

**Objective :**

Maximize, Production Rate of Stream $x_8$

**Constraints :**

$x_1 \quad <= \quad C_1$

$x_1 \quad = \quad C_2 \; x_2$

$x_4 \quad = \quad C_3 \; x_2$

$x_4 \quad <= \quad C_4$

$x_2 \quad = \quad C_5 \; x_3 + C_6 \, x_4$

$x_6 \quad = \quad C_7 \; (x_3 + x_5 + x_9)$

$x_7 \quad = \quad C_8 \; (x_3 + x_5 + x_9)$

$x_8 \quad = \quad C_9 \; (x_3 + x_5 + x_9)$

$(x_3 + x_5 + x_9) \quad <= \quad C_{10}$

$(x_3 + x_5 + x_9) - x_6 \quad <= \quad C_{11}$

$(x_3 + x_5 + x_9) \quad = \quad C_{12} \; (x_3 + x_5 + x_9)$

$x_4 \quad <= \quad C_{13}$

$x_4 \quad = \quad C_{14} \; x_5$

$x_6 \quad <= \quad C_{15}$

$x_6 \quad = \quad C_{16} \; x_9$

***Table IV.3.e. Coefficient of Variable of Constraints for:***

| | | |
|---|---|---|
| Screen-I, | | 2 1/2" |
| Screen-II , | Top : | 2" |
| | Bottom : | 1" |

| Coeff. | Crusher-I | 2 1/2" | |
|---|---|---|---|
| | Crusher-II | | |
| | 1/2 | 5/8 | 3/4 |
| $C_1$ | 500 | 500 | 500 |
| $C_2$ | 1 | 1 | 1 |
| $C_3$ | 0.38670 | 0.38670 | 0.38670 |
| $C_4$ | 200 | 200 | 200 |
| $C_5$ | 1 | 1 | 1 |
| $C_6$ | 1 | 1 | 1 |
| $C_7$ | 0.19824 | 0.19824 | 0.19824 |
| $C_8$ | **0.45295** | **0.43115** | **0.38258** |
| $C_9$ | **0.34881** | **0.37062** | **0.41918** |
| $C_{10}$ | 240 | 240 | 240 |
| $C_{11}$ | **140** | **135** | **124** |
| $C_{12}$ | 1 | 1 | 1 |
| $C_{13}$ | 113 | 113 | 113 |
| $C_{14}$ | 1 | 1 | 1 |
| $C_{15}$ | 117 | 117 | 117 |
| $C_{16}$ | 1 | 1 | 1 |

***Table IV.3.e1. Result of Maximizing Stream $x_8$***

| Steam $x_{i=1...9}$ | Crusher-I: | 2 1/2" | |
|---|---|---|---|
| | Setting of Crusher-II | | |
| | 1/2 | 5/8 | 3/4 |
| 1 | 140 | 135 | 124 |
| 2 | 140 | 135 | 124 |
| 3 | 85.9 | 82.8 | 76 |
| 4 | 54.1 | 52.2 | 48 |
| 5 | 54.1 | 52.2 | 48 |
| 6 | 34.6 | 33.4 | 30.7 |
| 7 | 60.9 | 62.4 | 64.8 |
| 8 | 79.1 | 72.6 | 59.2 |
| 9 | 34.6 | 33.4 | 30.7 |

***Table IV.3.f. Coefficient of Variable of Constraints for:***

| | | |
|---|---|---|
| Screen-I, | | 2 1/2" |
| Screen-II , | Top : | 2" |
| | Bottom : | 1" |

| Coeff. | Crusher-I | 3" | |
|---|---|---|---|
| | Crusher-II | | |
| | 1/2 | 5/8 | 3/4 |
| $C_1$ | 500 | 500 | 500 |
| $C_2$ | 1 | 1 | 1 |
| $C_3$ | 0.38670 | 0.38670 | 0.38670 |
| $C_4$ | 200 | 200 | 200 |
| $C_5$ | 1 | 1 | 1 |
| $C_6$ | 1 | 1 | 1 |
| $C_7$ | 0.20923 | 0.20923 | 0.20923 |
| $C_8$ | **0.46307** | **0.44006** | **0.38879** |
| $C_9$ | **0.32769** | **0.35071** | **0.40197** |
| $C_{10}$ | 242 | 242 | 242 |
| $C_{11}$ | **142** | **137** | **125** |
| $C_{12}$ | 1 | 1 | 1 |
| $C_{13}$ | 113 | 113 | 113 |
| $C_{14}$ | 1 | 1 | 1 |
| $C_{15}$ | 124 | 124 | 124 |
| $C_{16}$ | 1 | 1 | 1 |

***Table IV.3,f1. Result of Maximizing Stream $x_8$***

| Steam $x_{i=1...9}$ | Crusher-I: | 3" | |
|---|---|---|---|
| | Setting of Crusher-II | | |
| | 1/2 | 5/8 | 3/4 |
| 1 | 142 | 137 | 125 |
| 2 | 142 | 137 | 125 |
| 3 | 87.1 | 84 | 76.7 |
| 4 | 54.9 | 53 | 48.3 |
| 5 | 54.9 | 53 | 48.3 |
| 6 | 37.6 | 36.2 | 33.1 |
| 7 | 58.8 | 60.8 | 63.5 |
| 8 | 83.2 | 76.2 | 61.5 |
| 9 | 37.6 | 362 | 33.1 |

**Objective :**

Maximize, Production Rate of Stream $x_8$

**Constraints :**

$x_1 \quad <= \quad C_1$

$x_1 \quad = \quad C_2 \; x_2$

$x_4 \quad = \quad C_3 \; x_2$

$x_4 \quad <= \quad C_4$

$x_2 \quad = \quad C_5 \; x_3 + C_6 \, x_4$

$x_6 \quad = \quad C_7 \; (x_3 + x_5 + x_9)$

$x_7 \quad = \quad C_8 \; (x_3 + x_5 + x_9)$

$x_8 \quad = \quad C_9 \; (x_3 + x_5 + x_9)$

$(x_3 + x_5 + x_9) \quad <= \quad C_{10}$

$(x_3 + x_5 + x_9) - x_6 \quad <= \quad C_{11}$

$(x_3 + x_5 + x_9) \quad = \quad C_{12} \; (x_3 + x_5 + x_9)$

$x_4 \quad <= \quad C_{13}$

$x_4 \quad = \quad C_{14} \; x_5$

$x_6 \quad <= \quad C_{15}$

$x_6 \quad = \quad C_{16} \; x_9$

***Table IV.3.g. Coefficient of Variable of Constraints for:***

Screen-I, 2 1/2"
Screen-II , Top : 2"
Bottom : 1"

| Coeff. | Crusher-I 3 1/2" | | |
|---|---|---|---|
| | Crusher-II | | |
| | 1/2 | 5/8 | 3/4 |
| $C_1$ | 500 | 500 | 500 |
| $C_2$ | 1 | 1 | 1 |
| $C_3$ | 0.38670 | 0.38670 | 0.38670 |
| $C_4$ | 200 | 200 | 200 |
| $C_5$ | 1 | 1 | 1 |
| $C_6$ | 1 | 1 | 1 |
| $C_7$ | 0.21596 | 0.21596 | 0.21596 |
| $C_8$ | **0.45231** | **0.42856** | **0.37565** |
| $C_9$ | **0.33172** | **0.35548** | **0.40839** |
| $C_{10}$ | 243 | 243 | 243 |
| $C_{11}$ | **140** | **135** | **122** |
| $C_{12}$ | 1 | 1 | 1 |
| $C_{13}$ | 113 | 113 | 113 |
| $C_{14}$ | 1 | 1 | 1 |
| $C_{15}$ | 130 | 130 | 130 |
| $C_{16}$ | 1 | 1 | 1 |

***Table IV.3.g1. Result of Maximizing Stream $x_8$***

| Steam $x_{i=1...9}$ | Crusher-I: 3 1/2" | | |
|---|---|---|---|
| | Setting of Crusher-II | | |
| | 1/2 | 5/8 | 3/4 |
| 1 | 140 | 135 | 122 |
| 2 | 140 | 135 | 122 |
| 3 | 85.9 | 82.2 | 74.8 |
| 4 | 54.1 | 52.2 | 47.2 |
| 5 | 54.1 | 52.2 | 47.2 |
| 6 | 38.6 | 37.2 | 33.6 |
| 7 | 59.2 | 61.2 | 63.5 |
| 8 | 80.8 | 73.8 | 58.5 |
| 9 | 38.6 | 37.2 | 33.6 |

***Table IV.3.h. Coefficient of Variable of Constraints for:***

Screen-I, 3"
Screen-II , Top : 2"
Bottom : 1"

| Coeff. | Crusher-I 3" | | |
|---|---|---|---|
| | Crusher-II | | |
| | 1/2 | 5/8 | 3/4 |
| $C_1$ | 500 | 500 | 500 |
| $C_2$ | 1 | 1 | 1 |
| $C_3$ | 0.22130 | 0.22130 | 0.22130 |
| $C_4$ | 200 | 200 | 200 |
| $C_5$ | 1 | 1 | 1 |
| $C_6$ | 1 | 1 | 1 |
| $C_7$ | 0.26032 | 0.26032 | 0.26032 |
| $C_8$ | **0.46380** | **0.43517** | **0.37139** |
| $C_9$ | **0.27589** | **0.30451** | **0.36829** |
| $C_{10}$ | 252 | 252 | 252 |
| $C_{11}$ | **142** | **136** | **121** |
| $C_{12}$ | 1 | 1 | 1 |
| $C_{13}$ | 58 | 58 | 58 |
| $C_{14}$ | 1 | 1 | 1 |
| $C_{15}$ | 109 | 109 | 109 |
| $C_{16}$ | 1 | 1 | 1 |

***Table IV.3.h1. Result of Maximizing Stream $x_8$***

| Steam $x_{i=1...9}$ | Crusher-I: 3" | | |
|---|---|---|---|
| | Setting of Crusher-II | | |
| | 1/2 | 5/8 | 3/4 |
| 1 | 142 | 136 | 121 |
| 2 | 142 | 136 | 121 |
| 3 | 110.6 | 105.9 | 94.2 |
| 4 | 31.4 | 30.1 | 26.8 |
| 5 | 31.4 | 30.1 | 26.8 |
| 6 | 50 | 47.9 | 42.6 |
| 7 | 53 | 56 | 60.2 |
| 8 | 89 | 80 | 60.8 |
| 9 | 50 | 47.9 | 42.6 |

**Objective :**

Maximize, Production Rate of Stream $x_8$

**Constraints :**

$x_1 \quad <= \quad C_1$

$x_1 \quad = \quad C_2 \; x_2$

$x_4 \quad = \quad C_3 \; x_2$

$x_4 \quad <= \quad C_4$

$x_2 \quad = \quad C_5 \; x_3 + C_6 \; x_4$

$x_6 \quad = \quad C_7 \; (x_3 + x_5 + x_9)$

$x_7 \quad = \quad C_8 \; (x_3 + x_5 + x_9)$

$x_8 \quad = \quad C_9 \; (x_3 + x_5 + x_9)$

$(x_3 + x_5 + x_9) \quad <= \quad C_{10}$

$(x_3 + x_5 + x_9) - x_6 \quad <= \quad C_{11}$

$(x_3 + x_5 + x_9) \quad = \quad C_{12} \; (x_3 + x_5 + x_9)$

$x_4 \quad <= \quad C_{13}$

$x_4 \quad = \quad C_{14} \; x_5$

$x_6 \quad <= \quad C_{15}$

$x_6 \quad = \quad C_{16} \; x_9$

***Table IV.3.i. Coefficient of Variable of Constraints for:***

Screen-I, 3"

Screen-II, Top : 2"

Bottom : 1"

| Coeff. | Crusher-I | 3 1/2" | |
|---|---|---|---|
| | Crusher-II | | |
| | 1/2 | 5/8 | 3/4 |
| $C_1$ | 500 | 500 | 500 |
| $C_2$ | 1 | 1 | 1 |
| $C_3$ | 0.22130 | 0.22130 | 0.22130 |
| $C_4$ | 200 | 200 | 200 |
| $C_5$ | 1 | 1 | 1 |
| $C_6$ | 1 | 1 | 1 |
| $C_7$ | 0.26370 | 0.26370 | 0.26370 |
| $C_8$ | **0.45802** | **0.42901** | **0.36440** |
| $C_9$ | **0.27828** | **0.30729** | **0.37189** |
| $C_{10}$ | 253 | 253 | 253 |
| $C_{11}$ | **141** | **135** | **119** |
| $C_{12}$ | 1 | 1 | 1 |
| $C_{13}$ | 58 | 58 | 58 |
| $C_{14}$ | 1 | 1 | 1 |
| $C_{15}$ | 112 | 112 | 112 |
| $C_{16}$ | 1 | 1 | 1 |

***Table IV.3.i1. Result of Maximizing Stream $x_8$***

| Steam | Crusher-I: | 3 1/2" | |
|---|---|---|---|
| | Setting of Crusher-II | | |
| $x_{i=1...9}$ | 1/2 | 5/8 | 3/4 |
| 1 | 141 | 135 | 119 |
| 2 | 141 | 135 | 119 |
| 3 | 109.8 | 105.1 | 92.7 |
| 4 | 31.2 | 29.9 | 26.3 |
| 5 | 31.2 | 29.9 | 26.3 |
| 6 | 50.5 | 48.3 | 42.6 |
| 7 | 53.3 | 56.3 | 60.1 |
| 8 | 87.7 | 78.7 | 58.9 |
| 9 | 50.5 | 48.3 | 42.6 |

***Table IV.3.j. Coefficient of Variable of Constraints for:***

Screen-I, 3 1/2"

Screen-II, Top : 2"

Bottom : 1"

| Coeff. | Crusher-I | 3 1/2" | |
|---|---|---|---|
| | Crusher-II | | |
| | 1/2 | 5/8 | 3/4 |
| $C_1$ | 500 | 500 | 500 |
| $C_2$ | 1 | 1 | 1 |
| $C_3$ | 0.08610 | 0.08610 | 0.08610 |
| $C_4$ | 200 | 200 | 200 |
| $C_5$ | 1 | 1 | 1 |
| $C_6$ | 1 | 1 | 1 |
| $C_7$ | 0.29862 | 0.29862 | 0.29862 |
| $C_8$ | **0.46219** | **0.42934** | **0.35618** |
| $C_9$ | **0.23919** | **0.27205** | **0.34521** |
| $C_{10}$ | 260 | 260 | 260 |
| $C_{11}$ | **142** | **135** | **117** |
| $C_{12}$ | 1 | 1 | 1 |
| $C_{13}$ | 17 | 17 | 17 |
| $C_{14}$ | 1 | 1 | 1 |
| $C_{15}$ | 99 | 99 | 99 |
| $C_{16}$ | 1 | 1 | 1 |

***Table IV.3.j1. Result of Maximizing Stream $x_8$***

| Steam | Crusher-I: | 3 1/2" | |
|---|---|---|---|
| | Setting of Crusher-II | | |
| $x_{i=1...9}$ | 1/2 | 5/8 | 3/4 |
| 1 | 142 | 135 | 117 |
| 2 | 142 | 135 | 117 |
| 3 | 129.8 | 123.4 | 106.9 |
| 4 | 12.2 | 11.6 | 10.1 |
| 5 | 12.2 | 11.6 | 10.1 |
| 6 | 60.5 | 57.5 | 49.8 |
| 7 | 48.4 | 52.4 | 57.6 |
| 8 | 93.6 | 82.6 | 59.4 |
| 9 | 60.5 | 57.5 | 49.8 |

## VI.3. VALIDATION OF RESULT AND ANALYSIS

### VI.3.1. Validation of Result Using Mathcad 2001i Professional

Results of calculation from the software Mathcad 2001i Professional, have been validated by comparing the result obtained from another software i.e. WinQSB which has got a limitation with reference to accuracy in term of input data beyond decimal. Also the hand calculations have been done for simplified case having less number of constraints to validate the result using Mathcad 2001i Professional.

For validation, a following simple case is solved by using hand calculation and by using computer software - Mathcad 2001i Professional, The case is as follow:

Objective function

Maximize, $12x_1 + 3x_2 + x_3$

Subjected to the contraints

$$\begin{aligned} 12x_1 + 2x_2 + x_3 &\le 100 \\ 7x_1 + 3x_2 + 2x_3 &\le 77 \\ 2x_1 + 4x_2 + x_3 &\le 80 \\ x_1 &\ge 0 \\ x_2 &\ge 0 \end{aligned}$$

It is shown that the result of both methods found the same value for $x_1$, $x_2$, and $x_3$ as follows:

$x_1 = 9.125$

$x_2 = 4.375$

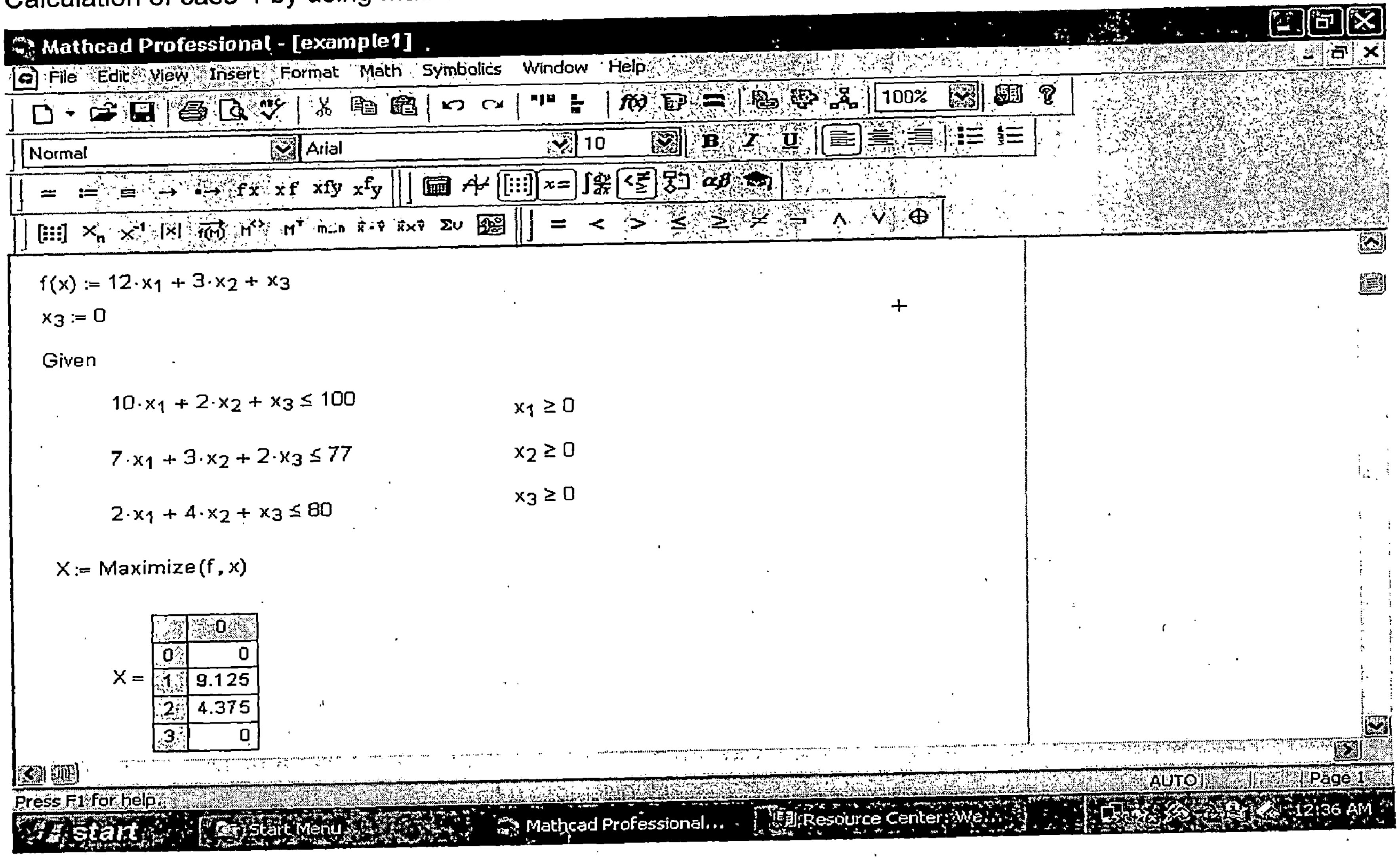
$x_3 = 0$

Also, another case has been taken as second case to be solved by using Mathcad and WinQSB. It is shown that the same coefficients of variable which is used in Mathcad produce invisible result when it is used as input data of WinQSB.

Calculation of case-1 with simplex method (i.e. hand calculation).

| | | | 12 | 3 | 1 | 0 | 0 | 0 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **$C_{BV}$** | **Basic Variable** | **$C_j$** | **$x_1$** | **$x_2$** | **$x_3$** | **$x_4$** | **$x_5$** | **$x_6$** | **Ratio Test** | **Remark** |
| 0 | $x_4$ | 100 | 10 | 2 | 1 | 1 | 0 | 0 | 100/10 = **10** | I |
| 0 | $x_5$ | 77 | 7 | 3 | 2 | 0 | 1 | 0 | 77/7 = 11 | II |
| 0 | $x_6$ | 80 | 2 | 4 | 1 | 0 | 0 | 1 | 80/2 = 40 | III |
| | $Z_J$ - $C_J$ | | ***-12*** | *-3* | *-1* | *0* | *0* | *0* | | There are still '-ve' value |
| 12 | $x_1$ | 10 | **1** | 0.2 | 0.1 | 0.1 | 0 | 0 | 10/0.2 = 50 | IV = I / 10 |
| 0 | $x_5$ | 7 | **0** | 1.6 | 1.3 | -0.7 | 1 | 0 | 7/1.6 = **4.375** | V = II – 7 IV |
| 0 | $x_6$ | 6 | **0** | 3.6 | 0.8 | -0.2 | 0 | 1 | 60/0.8 = 16.67 | VI = III – 2 IV |
| | $Z_J$ - $C_J$ | | *0* | ***-0.6*** | *0.2* | *1.2* | *0* | *0* | | There is still '-ve' value |
| 12 | $x_1$ | **9.125** | 1 | **0** | 0.04 | 0.13 | -0.53 | 0 | | VIII = IV – 0.2 VII |
| 3 | $x_2$ | **4.375** | 0 | **1** | 0.81 | -0.16 | 0.67 | 0 | | VII = V / 4.375 |
| 0 | $x_6$ | 44.25 | 0 | **0** | -0.27 | 0.38 | -9.61 | 1 | | IX = VI – 3.6VII |
| | $Z_J$ - $C_J$ | | *0* | *0* | *0.37* | *1.10* | *1.60* | *0* | | No '-ve' value. Calculation is terminated |

Calculation of case-1 by using Mathcad 2001i Professional



$f(x) := 12\cdot x_1 + 3\cdot x_2 + x_3$

$x_3 := 0$

Given

$10\cdot x_1 + 2\cdot x_2 + x_3 \le 100$ $x_1 \ge 0$

$7\cdot x_1 + 3\cdot x_2 + 2\cdot x_3 \le 77$ $x_2 \ge 0$

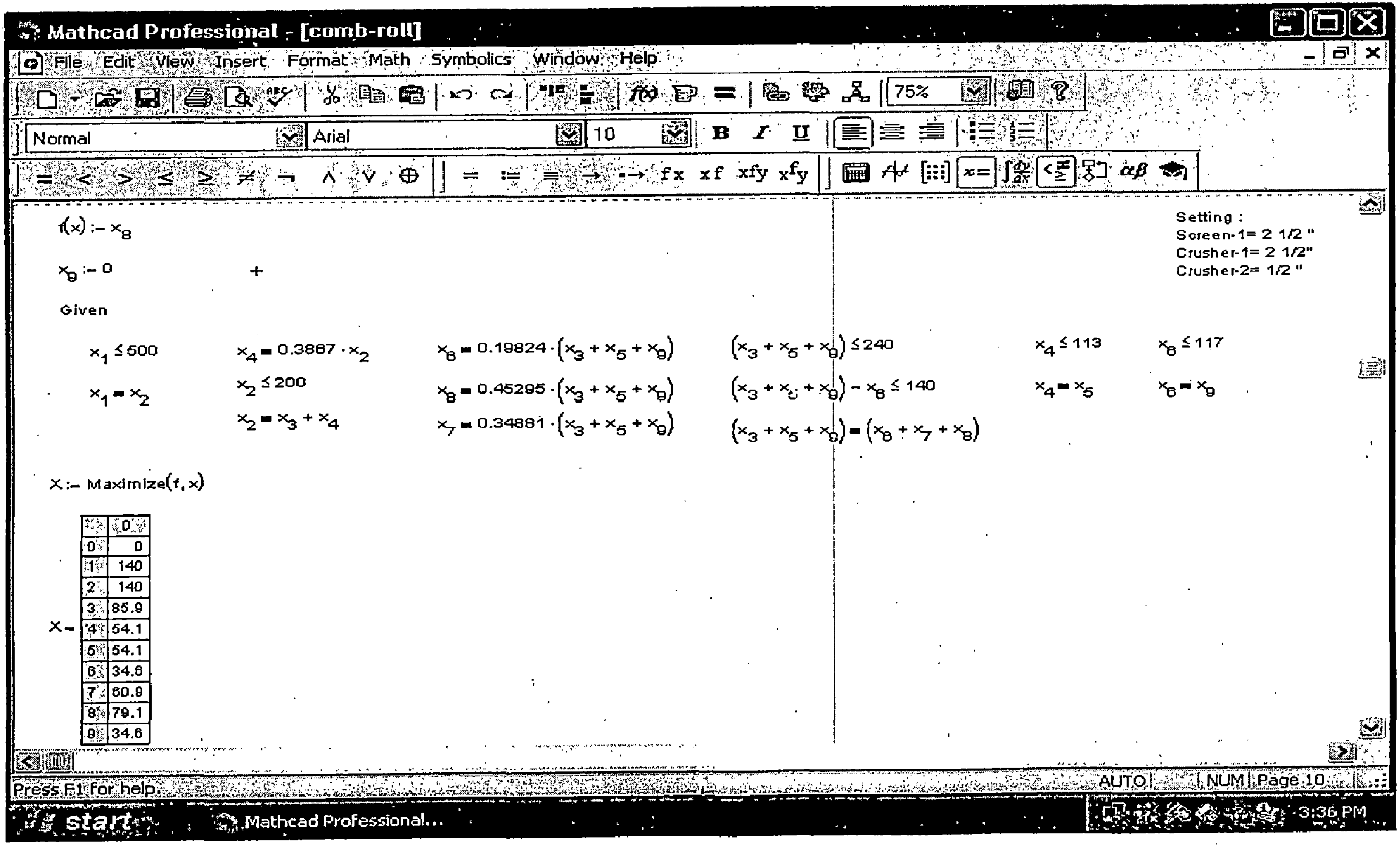
$2\cdot x_1 + 4\cdot x_2 + x_3 \le 80$ $x_3 \ge 0$

$X := \text{Maximize}(f, x)$

X =

| | 0 |
|---|---|
| 0 | 0 |
| 1 | 9.125 |
| 2 | 4.375 |
| 3 | 0 |

Calculation of case-2 by using Mathcad 2001i Professional



$f(x) := x_8$

$x_9 := 0$

Given

$x_1 \le 500$

$x_1 = x_2$

$x_4 = 0.3887 \cdot x_2$

$x_2 \le 200$

$x_2 = x_3 + x_4$

$x_6 = 0.19824 \cdot (x_3 + x_5 + x_9)$

$x_8 = 0.45295 \cdot (x_3 + x_5 + x_9)$

$x_7 = 0.34881 \cdot (x_3 + x_5 + x_9)$

$(x_3 + x_5 + x_9) \le 240$

$(x_3 + x_5 + x_9) - x_6 \le 140$

$(x_3 + x_5 + x_9) = (x_6 + x_7 + x_8)$

$x_4 \le 113$

$x_4 = x_5$

$x_6 \le 117$

$x_6 = x_9$

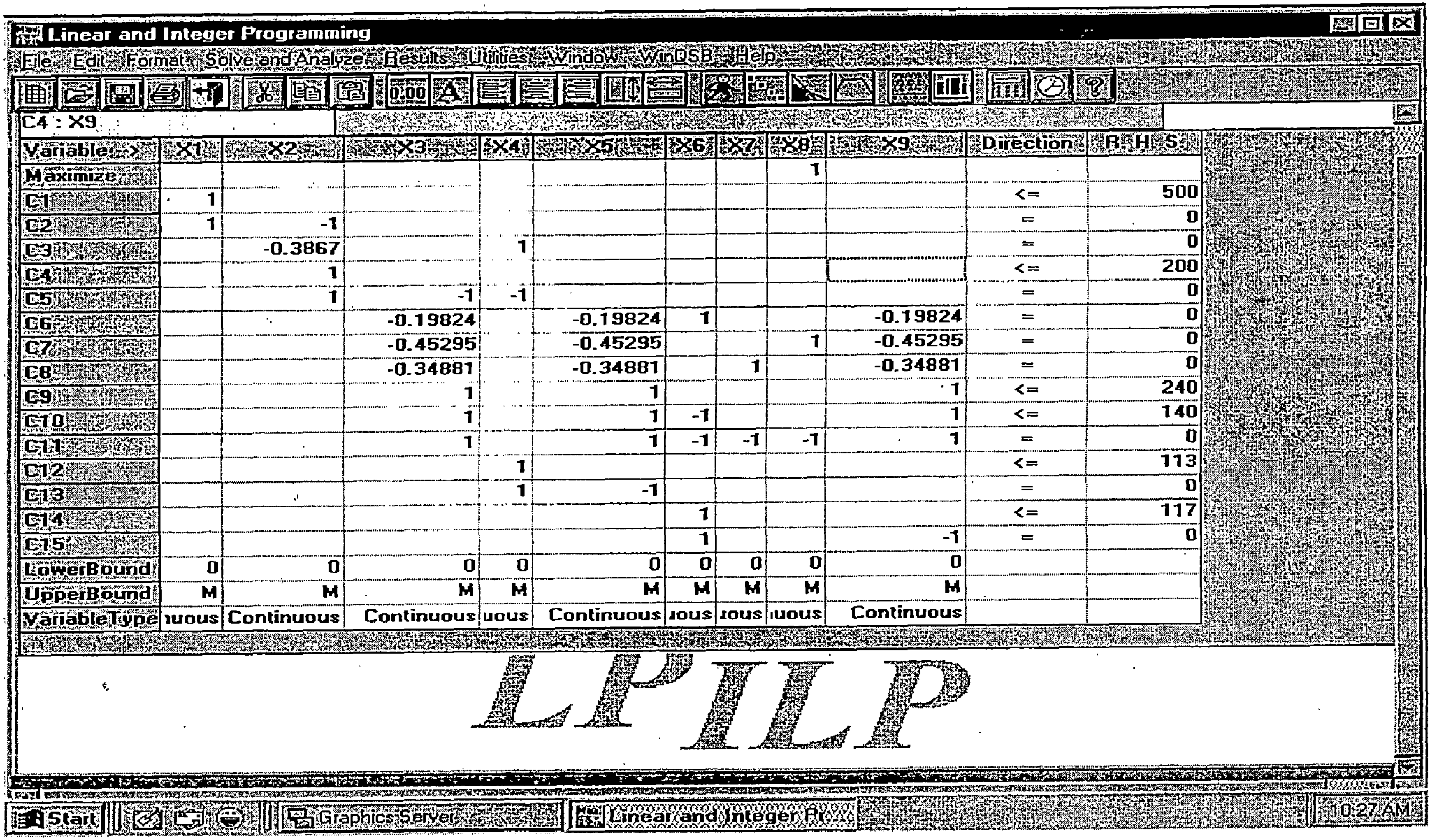
Setting :
Screen-1= 2 1/2 "
Crusher-1= 2 1/2"
Crusher-2= 1/2 "

$x := \text{Maximize}(f, x)$

$x =$

|   | 0 |
|---|---|
| 0 | 0 |
| 1 | 140 |
| 2 | 140 |
| 3 | 85.9 |
| 4 | 54.1 |
| 5 | 54.1 |
| 6 | 34.6 |
| 7 | 60.9 |
| 8 | 79.1 |
| 9 | 34.6 |

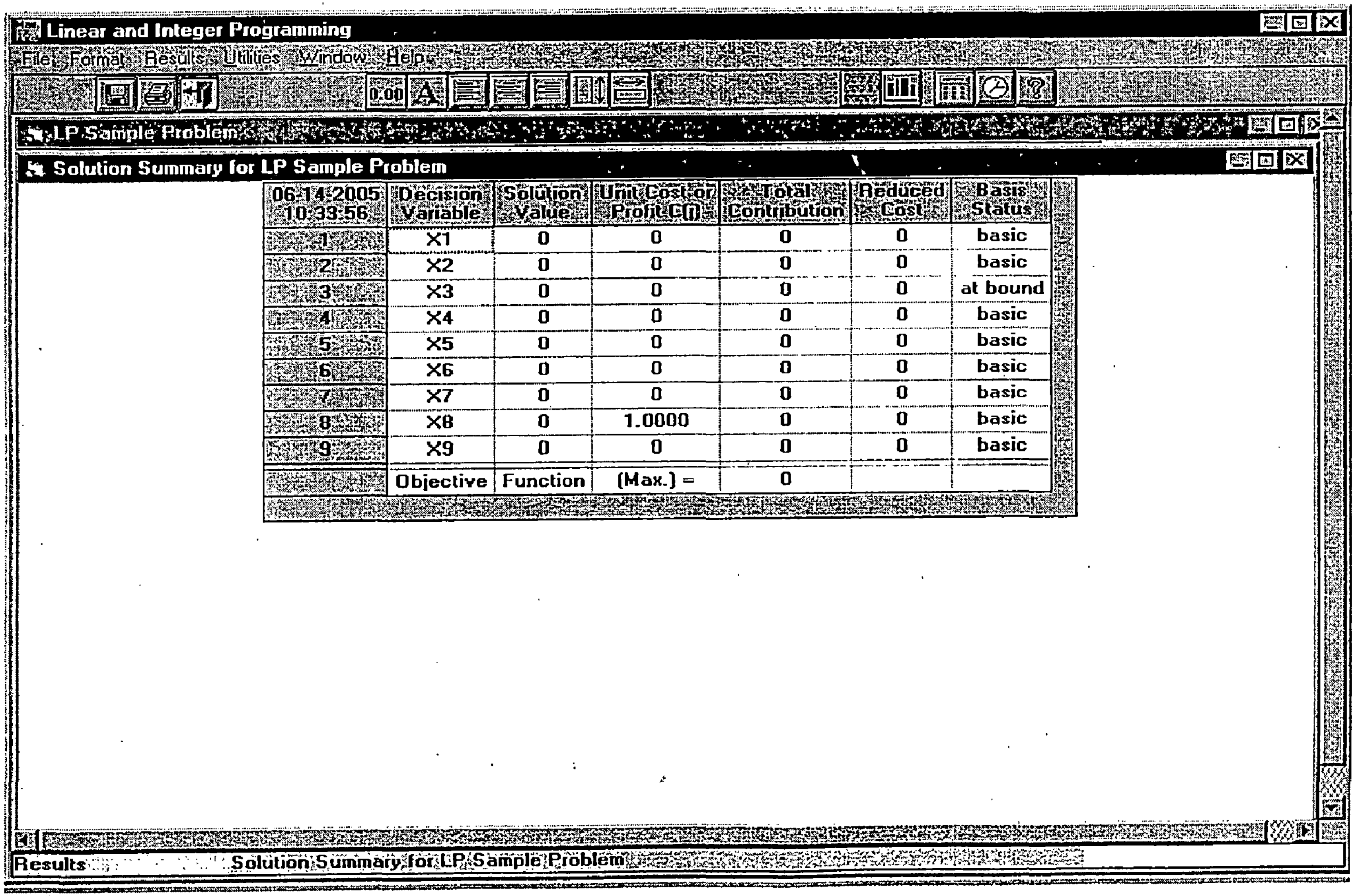
Calculation of case-2 by using Win QSB (input data to spreadsheet)



C4 : X9

| Variable--> | X1 | X2 | X3 | X4 | X5 | X6 | X7 | X8 | X9 | Direction | R. H. S. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Maximize | | | | | | | | 1 | | | |
| C1 | 1 | | | | | | | | | <= | 500 |
| C2 | 1 | -1 | | | | | | | | = | 0 |
| C3 | | -0.3867 | | 1 | | | | | | = | 0 |
| C4 | | 1 | | | | | | | | <= | 200 |
| C5 | | 1 | -1 | -1 | | | | | | = | 0 |
| C6 | | | -0.19824 | | -0.19824 | 1 | | | -0.19824 | = | 0 |
| C7 | | | -0.45295 | | -0.45295 | | | 1 | -0.45295 | = | 0 |
| C8 | | | -0.34881 | | -0.34881 | | 1 | | -0.34881 | = | 0 |
| C9 | | | 1 | | 1 | | | | 1 | <= | 240 |
| C10 | | | 1 | | 1 | -1 | | | 1 | <= | 140 |
| C11 | | | 1 | | 1 | -1 | -1 | -1 | 1 | = | 0 |
| C12 | | | | 1 | | | | | | <= | 113 |
| C13 | | | | 1 | -1 | | | | | = | 0 |
| C14 | | | | | | 1 | | | | <= | 117 |
| C15 | | | | | | 1 | | | -1 | = | 0 |
| LowerBound | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| UpperBound | M | M | M | M | M | M | M | M | M | | |
| VariableType | uous | Continuous | Continuous | uous | Continuous | ous | ous | uous | Continuous | | |

Result of calculation of case-2 by using Win QSB



| 06-14-2005 10:33:56 | Decision Variable | Solution Value | Unit Cost or Profit C(j) | Total Contribution | Reduced Cost | Basis Status |
|---|---|---|---|---|---|---|
| 1 | X1 | 0 | 0 | 0 | 0 | basic |
| 2 | X2 | 0 | 0 | 0 | 0 | basic |
| 3 | X3 | 0 | 0 | 0 | 0 | at bound |
| 4 | X4 | 0 | 0 | 0 | 0 | basic |
| 5 | X5 | 0 | 0 | 0 | 0 | basic |
| 6 | X6 | 0 | 0 | 0 | 0 | basic |
| 7 | X7 | 0 | 0 | 0 | 0 | basic |
| 8 | X8 | 0 | 1.0000 | 0 | 0 | basic |
| 9 | X9 | 0 | 0 | 0 | 0 | basic |
|  | Objective | Function | (Max.) = | 0 |  |  |

### VI.3.2. Analysis

It is shown from the result of the calculation, that the capacity of crusher and screen are determined by its setting. Coefficients of variables in the linear model are also determined by settings of crusher and screen. Changing the setting of crushers and screens is also means changing the gradation of its output material, in which, in its turn, it will influence the calculation of the capacity of crusher and screen and also the coefficient of variable in the linear model. Therefore, this analysis can only been carried out by changing the settings of crusher and screen.

If the setting of crusher-1 is variably changed to its all possible settings (i.e.: 2", 2 ½ ", 3", 3 ½ "), while the setting others equipment is fixed, for example, screen-1 is fixed at 2", crusher-2 at ½ " and screen-2 at 2" and 1" , respectively (Table VI.2.4.a. to j.), then the gradation of streams $x_1$ to $x_4$ remain unchanged because it can be seen from the lay-out of plant that any setting of crusher-1 will affect in changing the gradation of streams after crusher-1 only (i.e. stream $x_6$ , $x_7$, $x_8$). So that, it is shown in Table VI.2.4.a to j, the coefficient of streams $x_6$ , $x_7$, $x_8$ always change. The Table also indicates the changing of the capacity of crusher-2 and screen-2 but the capacity of crusher-1 remains same because screen-1 is in its fixed setting, 2", so that the total oversize material on the screen-1 which is delivering to crusher-1 is always same. In this setting scenario where crusher-1 one is variably changed and others equipment is in fixed setting, the highest production of product below 1" is 80.3 ton per hour. It is obtained when the setting of crusher-1 equal to 3".

After all possible combination of settings are determined and calculation is conducted, then, the highest production rate of stream $x_8$ (i.e. material below 1 inch size) is obtained equal to **93.6** ton per hour at the setting of screen-1, crusher-1 and crusher-2 are **3 ½"** , **3 ½"**, and **½"**, respectively. Where, setting of screen-2 is fixed at **2"** for its top deck and **1"** for its bottom deck (Table VI.2.4.j1).

All combination settings of equipments in a plant and its influence to the production rate of material which is obtained by the linear model calculation also bring a beneficial when we deal with time consume for doing work for setting of the equipment. If the plant has been set to produce, for example 62.2 ton/hour material, and after sometimes, it is needed to be increased up to 74.6 ton/hour, (refers to Table VI.2.4.c1.) then we have a decision to set crusher-2 only, from its original setting, (i.e. from setting ½ " to 5/8 ").

## CHAPTER-VII

# CONCLUSIONS

The main purpose of an aggregate processing plant is to provide crushed material in specified size range as per project requirement. For achieving the purpose, three main processes are conducted within an aggregate processing plant. These processes are reduction, screening or size separation and conveyance processes.

There are many types of equipment which can be used as an integrated system to carry out the three main processes. An aggregate processing plant in the area of water resources development project use reduction equipment such as jaw crusher or gyratory crusher and roll crusher as its primary and secondary crushing, respectively, for doing reduction process. While, vibrating screen is commonly used for size separation. For conveyance process, a system of belt conveyor is installed.

It is beneficial to operate a plant in such manner that it can produce maximum possible amount of material of specified gradation in a size range within a period of time (usually, in an hour). In this dissertation the study is conducted to determine the maximum production rate of an aggregate processing plant which consists of one single deck screen feeding the oversize to jaw crusher discharging on to double deck screen feeding oversize from top deck to roll crusher operating in close circuit and the system of belt conveyor for handling material between equipment.

To know the maximum production rate of graded aggregate produced by the plant, then mathematical approach is used by which maximization of an output stream is stated as the objective function to be subjected to all constraints of the aggregate plant system.

The results of study are summarized as below:

1. Practically, in site, the amount of input material, which is delivered by loader or dump truck to a plant is based only on common consideration that the amount should not more than the capacity of the equipment that receives it initially followed by trials to know the maximum production rate of material. This study has determined the exact amount of material that should be fed to the plant which has been set at a certain fixed setting of equipment so that its output rate becomes of maximum. It can be shown from the result of calculation in Table VI.2.4.a1 to Table VI.2.4.j1 labeled by variable $x_1$ that indicates the total amount of material should be fed to the plant in order to achieve maximum production rate of stream $x_8$ (product below 1") at different setting of equipment where it does not depend upon the maximum permissible feed rate of equipment which receives the material initially.

2. The operation of aggregate processing plant in this dissertation has been analyzed for 30 possible settings combination. Each combination is applied to the plant and calculation has been carried out, in which the highest production rate of stream $x_8$ is selected. It has been found that the highest production rate of stream $x_8$ is equal to 93.6 ton per hour corresponding to the input feed rate of stream $x_2$ which is 142 ton per hour at the settings shown in Table VI.2.4.j1.

3. There is dependence between size of screen-1, setting of crusher-1, and the maximum feed size of material. Size of screen-1 should not be equal to or more than the feed size to it. Also, size of screen-1 should be followed by setting of crusher-1 in which the rule is the setting of crusher-1 should be equal or more than size of screen-1 but less than size of material being fed.

4. Setting of crusher-2 is obviously less than setting of crusher-1 because its function is to reduce size of material (that has been processed by crusher-1 or pass from screen-1) so that the material can pass whether through the top deck or bottom deck of screen-2 as product in range 2"-1" and below 1".

5. This study indicates that setting of crushers and size of screens play the main role to govern the production rate of the plant, because the gradation is changed at their different setting. It has indicated that,
   a. If the setting of screen-1, screen-2 and crusher-1 are fixed while setting of crusher-2 is changed to increasing size of setting then the output production rate of stream $x_8$ will decrease. For example, Table VI.2.4.a1., shows production rate of stream $x_8$ as 70.9 TPH, 66.4 TPH, 57.4 TPH when the size of setting of crusher-2 is increased from ½ " to 5/8", ¾", respectively. The trend also indicated by Tables VI.2.4.b1 up to Table VI.2.4.j1
   b. The possible increase in size of screen-1 while setting and size of other equipment are fixed as has been indicated from Tables VI.2.4.d1, VI.2.4.g1, VI.2.4.i1, and VI.2.4.j1, the production rate of stream $x_8$ also increases.
6. Since, this study has indicated production rate of material of the aggregate processing plant for its all possible setting, then it can be used as a data base to know which setting should be applied to give the highest production rate of material and also which setting should be applied for a certain production required.

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