Faculty of Engineering

# APPLICATION OF WATER PINCH TECHNOLOGY IN MINIMIZATION OF WATER CONSUMPTION AT A PALM OIL MILL

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Bachelor of Engineering with Honours
(Chemical Engineering)
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**UNIVERSITI MALAYSIA SARAWAK**

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This final year project which entitled **"Application of Water Pinch Technology in Minimization of Water Consumption at a Palm Oil Mill"** was prepared by Oudrey Thomas Ngau (43699) as KNC 4344 Final Year Project course fulfillment for the Degree of Bachelor of Chemical Engineering is hereby read and approved by:

MADAM NORLISA BT MILI
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26 MAY 2016
Date

APPLICATION OF WATER PINCH TECHNOLOGY IN MINIMIZATION OF WATER CONSUMPTION AT A PALM OIL MILL

OUDREY THOMAS NGAU

A dissertation submitted in partial fulfillment

Of the requirement for the degree of

Bachelor of Engineering with Honours

(Chemical Engineering)

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2017

Dedicated to my beloved grandmother, my parents, and my love, Christopher for their unwavering encouragements and supports

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# ABSTRACT

Due to the limited resource of freshwater available globally, many have been motivated to bring forth solutions to rectify the shortage of water. Especially in this era of globalization where there are many large-scale industries that thirst for a resolution for their extensive water consumption. This research proposes to establish property integration technique, in graphical targeting and mathematical modelling by using reuse, regeneration reuse, and regeneration recycle in order come up with the accurate targets for maximum direct recycle of process resources, with the minimum effluent produced and minimum fresh water consumption at a palm oil mill in Sarawak. The problems are treated as single contaminant problems where the contaminants are the biochemical oxygen demand (BOD) and the hardness properties of the process streams. The graphical method for both contaminants are solved with the help of Microsoft Excel software, meanwhile the mathematical programming is executed by using MATLAB software. The results show a fresh water demand reduction by 42.6% for both contaminants for graphical targeting; mathematical modelling by using reuse approach shows a reduction 63.1% and 60.3% for BOD and hardness properties respectively; regeneration reuse approach shows a reduction of 78.1% and 64.7% for BOD and hardness respectively; lastly, regeneration recycle approach shows a reduction of 90.7% and 69.5% for BOD and hardness respectively. Thus, regeneration recycle process is the best choice to be implemented in the palm oil mill to reduce the consumption of fresh water.

# ABSTRAK

Oleh sebab sumber air tawar di dunia makin terhad, ramai yang telah terdorong untuk mencari penyelesaian untuk mengurang menggunaan air. Terutamanya dalam era globalisasi di mana terdapat banyak industri berskala besar yang ingin mencari penyelesaian untuk mengatasi masalah air. Kajian ini bercadang untuk menggunakan teknik integrasi, dalam sasaran grafik dan pemodelan matematik dengan menggunakan penggunaan semula, pertumbuhan penggunaan semula, dan pertumbuhan kitar semula agar dapat mencari jumlah maksimum air untuk kitar semula terus dari sumber proses, dengan minimum efluen dihasilkan dan minimum penggunaan air di sebuah kilang pemprosesan minyak sawit di Sarawak. Masalah diambilkira sebagai masalah pencemaran tunggal di mana bahan cemar adalah permintaan biokimia oksigen (BOD) dan sifat-sifat kekerasan aliran proses. Kaedah grafik untuk kedua-dua bahan cemar diselesaikan dengan bantuan perisian Microsoft Excel, sementara itu pengaturcaraan matematik dilakukan dengan menggunakan perisian MATLAB. Keputusan menunjukkan pengurangan penggunaan air segar sebanyak 42.6% bagi kedua-dua bahan cemar untuk penyasaran grafik: bagi pemodelan matematik yang menggunakan pendekatan penggunaan semula, ia menunjukkan pengurangan sebanyak 63.1% dan 60.3% bagi BOD dan kekerasan sifat; pendekatan pertumbuhan penggunaan semula menunjukkan penurunan sebanyak 78.1% dan 64.7% bagi BOD dan kekerasan; akhir sekali, pendekatan pertumbuhan kitar semula menunjukkan penurunan sebanyak 90.7% dan 69.5% bagi BOD dan kekerasan. Oleh itu, proses pertumbuhan kitar semula adalah pilihan yang terbaik untuk dilaksanakan di kilang minyak sawit untuk mengurangkan penggunaan air tawar

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| | |
|---|---|
| BOD | Biochemical Oxygen Demand |
| CBD | Concentration Block Diagram |
| CPO | Crude Palm Oil |
| EFB | Empty Fruit Bunch |
| FFA | Free Fatty Acids |
| FFB | Fresh Fruit Bunch |
| HENS | Heat Exchanger Network System |
| LP | Linear Programming |
| LTDS | Light Tiny Debris Separation |
| MEN | Mass Exchange Network |
| MILP | Mixed Integral Linear Programming |
| MSA | Mass Separating Agent |
| MWR | Minimum Water Network |
| NLP | Non-Linear Programming |
| NNA | Nearest Neighbour Algorithms |
| POME | Palm Oil Mill Effluent |
| SHARPS | Systematic Hierarchy Approach for Resilient Process Screening |
| TAC | Total Annual Cost |
| WCA | Water Cascade Analysis |
| WMH | Water Management Hierarchy |

# LIST OF NOMENCLATURE

| | |
|---|---|
| $C_i$ | Source Impurity Concentration |
| $C_j$ | Sinks Impurity Concentration |
| $F_i$ | Sources Flowrate |
| $F_j$ | Sinks Flowrate |
| $f_i$ | Flowrate |
| $G_j$ | Sinks Flowrate |
| $m_i$ | Impurity Loads |
| $m^3/h$ | Meter Cube Per Hour |
| $M_i$ | Maximum Property Load of Source Stream |
| $M_j$ | Maximum Property Load of Sink Stream |
| N1 | Nearest Neighbour 1 |
| N2 | Nearest Neighbour 2 |
| ppm | Parts Per Million |
| SK | Sink |
| $W_i$ | Source Flowrate |
| $y_i$ | Source Impurity Concentration |
| $Z_j$ | Sink Impurity Concentration |

# CHAPTER 1

# INTRODUCTION

Any large scale industrial processes are known for their high demand of water. However, one cannot defy the theory of conservation of mass where high water consumption leads to ramification of high amount of effluent produced. Besides high amount of effluent, another matter to be concerned of is the shortage of raw water for the process. On that account, insufficient water supply is a stumbling block for a large-scale process which case in point is the palm oil milling process in Malaysia where our country herself is known as the preeminent producer and exporter of crude palm oil (Vijaya, Ma, Choo, & Meriam, 2008). This particular problem is faced by Lambir Palm Oil Mill in 2016 due to the drought brought by *El Nino* from February to the end of April. The extreme weather has caused most of the reservoir ponds to subside to critical level, and the only mitigation available is to pump water from a river located far from the mill. Therefore, it is paramount to find a panacea for the water shortage problem. This is when pinch analysis comes into light as a process integration tool. This chapter outlines the background of this research, the palm oil industry in Malaysia, the introduction to pinch technology on water minimization, the problem statement, the research objectives, and the research scopes.

## 1.1 Research background

Although water covers most of the surface of the earth than the land, not all of the source of water can be used for human activities. Only 2.5 percent of freshwater is available where just a little more than 1.2 percent of it is the surface freshwater (Shiklomanov, 1993). According to Shiklomanov (1993), roughly 96.5 percent of the total global water comprises of the oceans, seas, and bays which do not contain any freshwater meanwhile the freshwater resources are from the ice caps, glaciers, & permanent snow with 1.74 percent, ground water with 0.76 percent, soil moisture with

0.001 percent, ground ice and permafrost with 0.022 percent, lakes with 0.007 percent, the atmosphere with 0.001 percent, swamp water with 0.0008 percent, rivers with 0.0002 percent, and finally the biological water with 0.0001 percent. The data substantiates the limited amount of freshwater to be withdrew which eventually will confine any human activities in the future. **Table 1.1** shows the estimated global water distribution.

Table 1.1: Estimated Global Water Distribution

| Source of Water | Percent of freshwater, % | Percent of total water, % |
|---|---|---|
| Oceans, Seas, & Bays | 0 | 96.5 |
| Ice caps, glaciers, & permanent snow | 68.7 | 1.74 |
| Ground water | 30.1 | 1.69 |
| Soil Moisture | 0.05 | 0.001 |
| Ground ice & Permafrost | 0.86 | 0.022 |
| Lakes | 0.26 | 0.013 |
| Atmosphere | 0.04 | 0.001 |
| Swamp water | 0.03 | 0.0008 |
| Rivers | 0.006 | 0.0002 |
| Biological water | 0.003 | 0.0001 |

Ergo, scarcity of resource of freshwater is considered as a great concern especially in this day and age where the demand of water skyrocketed. The high demand of water is the result of population growth, the booming of industries, and agricultural activities (United Nations Educational, 2012).

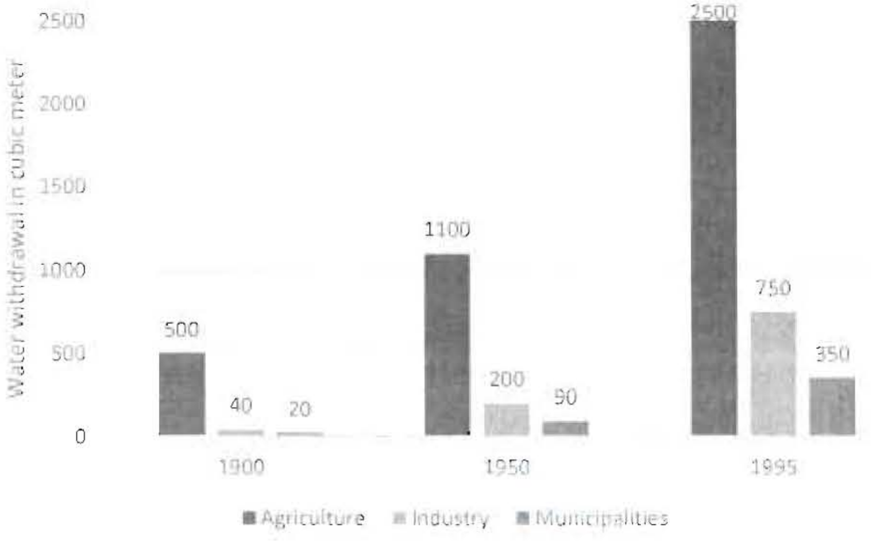


**Figure 1.1**: Global Water Use

**Figure 1.1** shows the global water use in the 20[th] century based on Cosgrove & Rijsberman (2000) on their journal article entitled '*A Vision Today for Water Tomorrow*'. Generally, the figure shows an increasing amount of water withdrawal for human activities from 560 cubic meters in the 1900 to 3600 cubic meters in the year of 1995.

The agricultural sector is in the leading position with a total of 4100 cubic meters of water withdrawal within 10 years meanwhile municipalities take the last place with a total of 460 cubic meters.

Nonetheless, these water-intensive sectors will eventually deplete the freshwater resources available if no mitigation is effectuated by any responsible parties. Hence, many researches have been motivated to come up with attractive solutions to overcome this difficult situation.

## 1.2 Palm Oil Industry in Malaysia

The size of horticulture of oil harvests has stupendously surge in the last decades due to the increasing global demand for comestible oils, particularly oil palm (Care Ratings, 2016). As the largest extensively commerce edible oil, in 2001, the palm oil production had an increase of nearly two folds since 1990 (from 8,195 kilo tons to 17,371 kilo tons), with Malaysia and Indonesia contributing to a lion's share of the production (Teoh, 2002). The statistics clearly indicate that Malaysia was the largest palm oil exporter by the year of 2001. **Table 1.2** shows the world major palm oil exporters.

Table 1.2: World Major Palm Oil Exporters (kilo tons) (Teoh, 2002)

| Country | 1990 | 1995 | 2001 |
|---|---|---|---|
| Malaysia | 5,727 | 5,613 | 10,618 |
| Indonesia | 1,163 | 1,856 | 4,800 |
| Singapore | 679 | 399 | 259 |
| Others | 626 | 1,405 | 1,694 |
| Total | 8,195 | 10,815 | 17,371 |

Besides, the palm oil production in Malaysia is expected to reach more than 15 million tons in 2020 which is triple folds since the year of 1990, and dominating about 37.7 percent of the world total palm oil production (Teoh, 2002). **Table 1.3** shows the expected production of palm oil in Malaysia from 2001 to 2020.

Table 1.3: Expected Production of Palm Oil in Malaysia (kilo tons) (Teoh, 2002)

| Average for Five Years | Palm Oil Production | World Total Production (%) |
|---|---|---|
| 2001-2005 | 11,066 | 47.0 |
| 2006-2010 | 12,700 | 43.4 |
| 2011-2015 | 14,100 | 40.2 |
| 2016-2020 | 15,400 | 37.7 |

Hence, the numbers have substantiated Malaysia as a growing palm oil exporter in the world and reflecting the attribute of a greater water-intensive industry.

### 1.2.1 Palm Oil Milling Process

Every end product originates with specific raw materials which are then processed and refined. In the case of production of palm oil, the raw material is *fresh fruit bunches (FFB)* reaped from the palm trees at the planted estates. The process of extraction of *crude palm oil (CPO)* and *palm kernels (PK)* from FFB at the palm oil mill involves water-intensive procedures. Correlatively, when the amount of FFB processed increases, the freshwater requires for the mill increases too.

The production of CPO and PK begin as soon as the FFBs are harvested at the estate. Once they are reaped by the estate workers, it is crucial that these bunches are transported to the nearest mill to be processed to avoid an increase in free fatty acids (FFA) which will commence when the fruits are bruised as the percentage of FFA will significantly affect the quality of CPO (Azeman, Yusof, & Othman, 2015). **Figure 1.2** shows the general palm oil milling process to recover CPO and PK from FFBs via physical extraction.

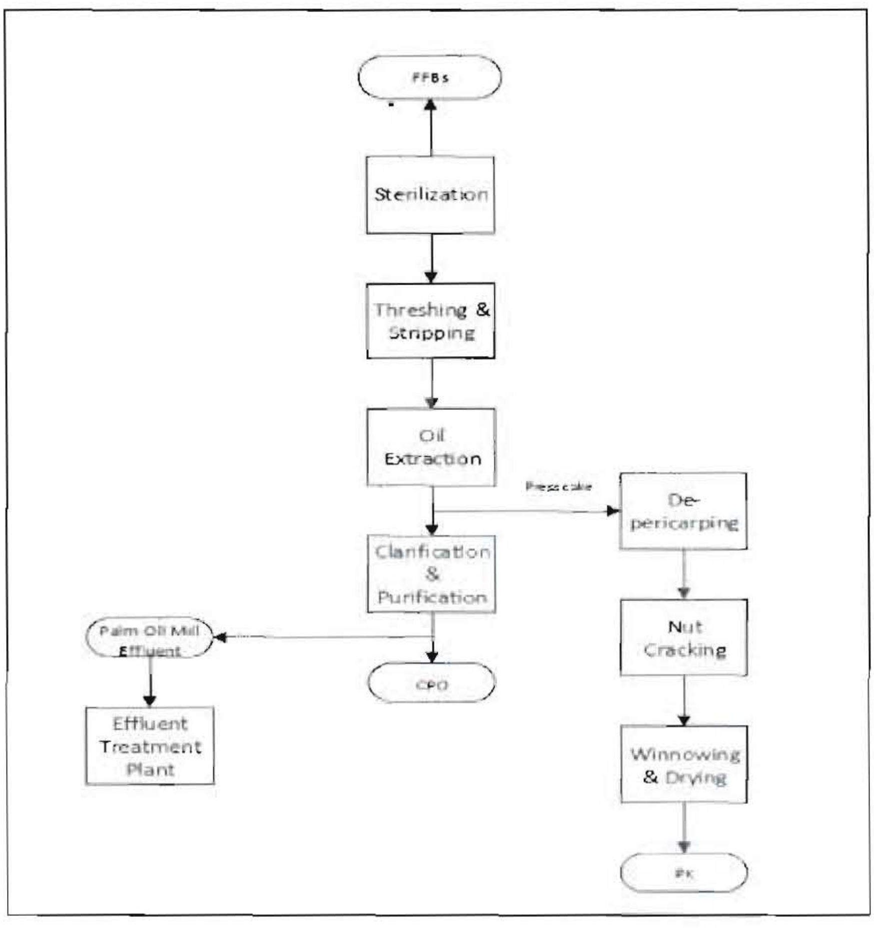


**Figure 1.2**: General Palm Oil Milling Process (Teoh, 2002)

The milling process begins by sterilizing the FFBs in a pressurized vessel by the mean of saturated steam up to a specific pressure to halt the hydrolysis of free fatty acids. The pressurized vessels are called sterilizers and this process is usually discontinuous (batch). The sterilized bunches are then transported to the rotary drum (thresher) to strip the fruits off the bunches. The empty fruit bunches (EFB) are then either to be brought to the plantation estates to be utilized as fertilizers or to be pressed further to extract the remaining oil in the EFB. Meanwhile, the stripped fruits are conveyed into multiple digesters with stirring arms where steams are fed into the vessels as the heat source. Due to the high temperature steam, the mesocarp are separated from the nuts and also allowing the oil bearing cells in the mesocarp to burst. Next, the mesocarp mesh is pressed by the mean of mechanical pressing (screw press) to extract the oil. The press cake is brought to the kernel recovery section to separate the kernels from the nuts and fibers by using ripper mill (nut cracker), Light Tiny Debris Separation (LTDS), hydro cyclone, and kernel silos. In the meantime, the oil extracted from the mechanical pressing is diluted with desired ratio before being pumped to the oil clarification and purification section. The oil clarification and purification section comprises of complex unit operation system with multiple recycling to obtain standardize pure CPO. The common unit operations utilized in this section are the continuous stirred tank, desander, decanter. separator, reclaimed oil tank, pure oil tank, and vacuum dryer. The palm oil mill effluent (POME) produced from the section is discharged to the water treatment plant for treating processes.

Freshwater supply is an inevitable necessity in the palm oil milling process where it is tremendously used at the sterilization of FFB, the oil extraction process, the hydro cyclone and the clarification and purification of the CPO. Thus, shortage of water will severely impact the production of CPO and PK.

## 1.3 Pinch Technology on Water Minimization

Process integration serves the purpose of material and energy integration and minimizing the emissions and wastes produced from an industrial plant (Mann, 1999). It is branched into two approaches which are the pinch technology for energy and mass integration, and mathematical optimization comprises of linear and nonlinear programming (Mann, 1999; Zhelev et al., 2002). **Figure 1.3** shows the process integration tools. Pinch analysis method is originally introduced as heat recovery systems design back in the 70's which implementing the similitude between heat transfer and mass transfer (Linnhoff and Flower, 1978; Linnhoff 1979).

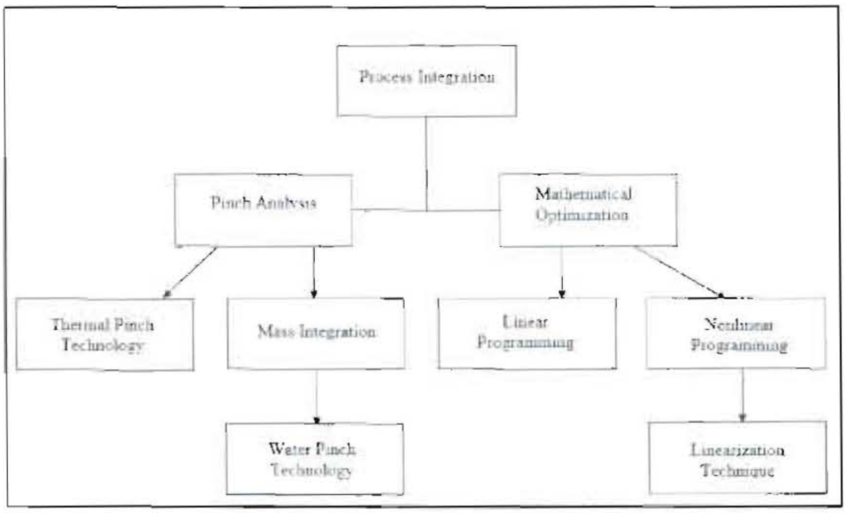


**Figure 1.3**: Process Integration Tools

This is the basis that bring forth water pinch analysis. It is a systematic method as a tool to reduce the water consumption and wastewater generation by mass integration for an example, the water pinch analysis and water pinch synthesis. Nonetheless, the effluents from a process comprise of different qualities influenced by contaminants such as biochemical oxygen demand (BOD) and hardness properties. These qualities will determine the availability of the effluents or streams to be reused or recycled into the processes. By depending to the number of the contaminants, water-using operations at a plant can be divided into simple and complex models. **Figure 1.4** shows the solution techniques for wastewater minimization (Mann, 1999).

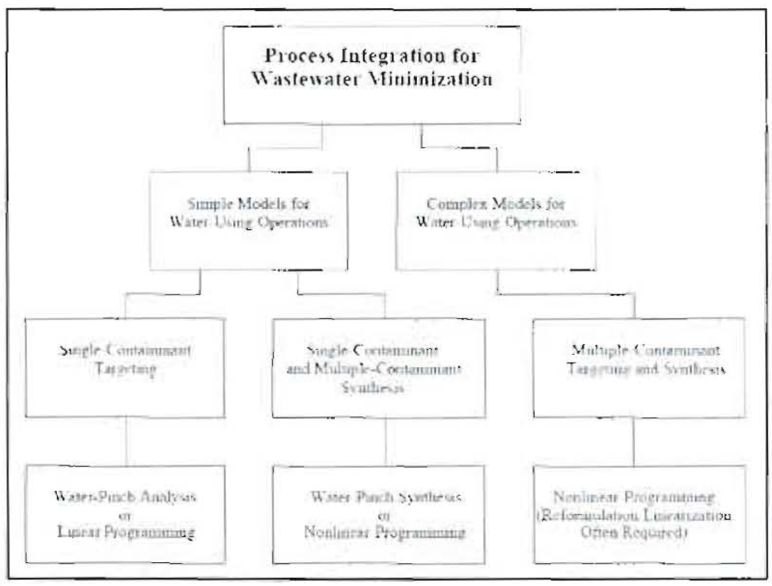


**Figure 1.4**: Recommended solution for wastewater minimization

Based on the complexity of the operation and the objective of the implementer, specific methods are outlined as an effort to reduce the production of wastewater.

## 1.4 Problem Statement

Conserving water is viewed as a good practice as source of fresh water available globally is limited. This virtuous sight has put a pressure on the sectors that extensively consumed fresh water such as the palm oil milling process. Considering any large scale industrial plant consumes a large amount of water, Lambir Palm Oil Mill too is a water-intensive plant located in Lambir, Sarawak. Due to the high-water consumption, the mill produces a hefty amount of POME to be treated at the effluent treatment plant. Moreover, the drought caused by El Nino from February to end of April of 2016 had critically affected the palm oil processing mill which had led the mill to experience water shortage. The extreme weather has caused most of the reservoir ponds to subside to the critical level.

## 1.5 Research Objectives

This research outlines several objectives as follow:

i. To apply water pinch technology on palm oil milling process at Lambir Palm Oil Mill, Lambir Sarawak
ii. To optimize fresh water requirement via graphical method by using Microsoft Excel for single contaminant approach
iii. To optimize fresh water requirement via mathematical programming for reuse, regeneration reuse, and regeneration recycle methods by using MATLAB software for single contaminant approach

## 1.6 Research Scopes

This research project utilizes water pinch technology on a water-intensive plant, a palm oil mill located at Lambir, Sarawak where two methods are implemented to optimize the fresh water consumption. The approaches are water pinch analysis for single contaminant targeting and mathematical programming. The two methods are the graphical method conducted by using Microsoft Excel software, and the mathematical programming method (reuse, regeneration reuse, and regeneration recycle) analyzed by using MATLAB software.

## 1.7 Summary

Fresh water is a precious resource globally due to its limited amount. Thus, any large-scale sectors should bring forth a solution to minimize their water consumption for water conservation purposes. One solution comes to light is the water pinch technology which serves the right purpose for fresh water minimization. The methods implemented at the chosen plant, Lambir Palm Oil Mill, is the graphical methods and the mathematical programming by using appropriate software.