Utility-Process Interface Optimization

By

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Dissertation submitted in partial fulfilment of
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Chemical Engineering Programme
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Approved by,

....
(Dr. Kamarul Ariffin)

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MUHAMMAD NAJMIE AHMAD

ABSTRACT

A step-by-step procedure was obtained in optimizing the utility and process by working inwards of onion model diagram. The process plant used in the case study is the palm oil refinery, while the utility is the steam generation with turbo generator. Utility system was the first part that being optimized since the source of energy is coming from this system. From the optimization of utility, the marginal steam pricing plot was constructed to visualize the scope of saving as a result of steam saving at the process site. The energy saving of the process was obtained by working out the difference of the existing to the minimum heating requirement. The amount of steam saving then used to determine the scope of saving by referring to the marginal steam pricing plot which is at $32,326.44/year. A retrofitting of the heat exchanger network was made and the estimated capital cost of installing new heat exchanger, covering the needed area was about $123,266.24. The payback period for investing the new heat exchanger with the scope saving obtained is about 4 years.

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TABLE OF CONTENTS

APPENDICES

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Background of Study

During past 25 years, the chemical industry has undergone significant changes since increasing cost of energy, increasingly stringent environmental regulations, and global competition quality and price of the product. Optimization is one of the most important engineering tools for tackling this issue. Modifications in plant design and operating procedures have been implemented to increase profitability. Optimal operating conditions can be implemented through automation at the process, plant, and company levels, often called computer-integrated manufacturing. Effective optimization techniques are now available in software for personal computers in which making working more easily- a capability that does not exist 10 years ago.

Optimization pervades the fields of science, engineering and business. In physics, many different optimal principles have been enunciated, describing natural phenomena in the fields of optics and classical mechanics. The field of statistics treats various principles termed maximum effort, minimum loss and least squares and business makes use of maximum profit, minimum cost, minimum effort, in its efforts to increase profit. In engineering problems, a process can be represented by some equations or perhaps solely by experimental data. The goal of optimization is to find the values of the variables in the process that give the best value of the performance criterion. A trade-off usually exists between capital and operating cost. The process and the performance criteria constitute the optimization problem.

Typical problems in chemical engineering process design or plant operation have many possible solutions. Optimization is concerned with selecting the best among the entire set by efficient quantitative methods. Engineers work to improve the initial design of equipment and strive to enhance the operation of that equipment once it is installed so as to realize the maximum production, the maximum profit, the minimum cost, the least energy usage and so on.

A petrochemical production plant site consists of two types of plants; production and utility plants. Production plants convert raw materials into products by consuming utilities, mainly steam and electricity. A utility plant on the other hand consumes fuel to generate utilities for the production. Utility balance between the production plants and the utility plants should be maintained at all the time to guarantee smooth operation. Whenever a change occurs in the production plant site, such as adding a new production plant, the utility plant might need to make suitable modifications to sustain the balance. To obtain the best option for the balance keeping, plant engineers currently rely mainly on their own experiences and or apply some simple material and energy balance calculating routines. Due to the complexity inside a production site, this approach is time-consuming and easily to miss out good opportunities.

1.2 Problem Statement

In order for engineers to improve the processing plant, the trade off between the process site and utility site should be taken care of. As the changes made to the process such as the heat exchanger network, it will give an impact to utility system to deliver the amount of steam that should be produced for the system.

Current practice in industry, the optimization project only emphasize on the process site without clearly focus into utility site. The cost of utility usually taken from accountant's transfer figure which is in a fixed amount. In reality, the price of steam i.e. steam price will vary overtime due to the changing in operational changes or fluctuation in fuel price. Modifying the operation of process site will give an impact to the operating cost of utility as well. Neglecting this impact to the utility system will drive to lose an opportunity to the cost-effective of the project.

In this project, interconnection between the process and utility will be determined by appropriate method that will be introduced in later part of this report.

1.3 Objective and Scope of Study

The objective of the project is to develop a steam profile from a given utility system. In this case study, a palm oil refinery will represent the process while the steam generation system will be used all the way to represent the utility system. An appropriate step by step procedure will be discussed in this report in order to oversee the interface of utility and process.

As stated in the problem statement above, the ignorance of utility site as its giving less profitability impact to the company is not an apposite way to optimize the plant operation. Using the proposed method, the utility site will be taken care first since it is a supplier of the energy in most of the chemical processing plant. Moreover, it is expected to be the appropriate way in managing the utility system. It will be optimize at the first place and a screening on the most beneficial path will be defined here.

On the later part, it will emphasize on the process site to get the energy saving that the plant could get at the end of the project. This will be set as a target to improve the plant performance. From this target, it can be relate to the utility site aided by a marginal steam pricing plot. This plot is the most important part along the way of the project. Through the case study here, we can see how the utility and process are interacting with each other as an impact of optimization.

CHAPTER 2

LITERATURE REVIEW

2.1 Assessing Marginal Energy Cost

Simplistic or faulty assumptions about the value of steam and power will lead to inaccurate assessments of the costs and benefits associated with proposed operating changes or capital projects. Conversely, proper understanding of marginal steam and power costs can pinpoint system inefficiencies and facilitate the identification of economically attractive strategies for reducing energy costs.

A steam system model can be an effective tool for predicting energy costs, particularly when there are many variables to consider. The first step is to take a look at which factors affect energy costs. Energy costs are not fixed over time. This point may need little reinforcement given the recent natural gas price escalations and the historical volatility of crude oil prices. However, even during periods of stable oil and gas prices, a single number often cannot satisfactorily represent the cost of power or steam consumed by an industrial plant.

Energy cost analyses also can be significantly influenced by site-specific and use-specific factors that affect the cost of supplying fuel, steam, and power to the plant.

For example, the cost of producing steam in a boiler will vary with the specific boiler's efficiency, which, in turn, will vary as boiler load changes. Where boilers are capable of using a variety of purchased and/or plant-generated fuels, steam costs will also vary depending on the fuel being used.

Marginal energy costs are particularly complex at industrial sites that have:

- Multiple, interconnected steam pressure levels
- Motor and turbine options for supplying shaft power
- Different categories of steam users.

The latter may include "live steam users," which consume steam but do not return condensate to the system, and heating steam users, which extract energy from the steam via heat exchangers or heating coils, but permit cost-saving condensate recovery.

The figure below illustrates the interactions of steam and power costs for three common scenarios:

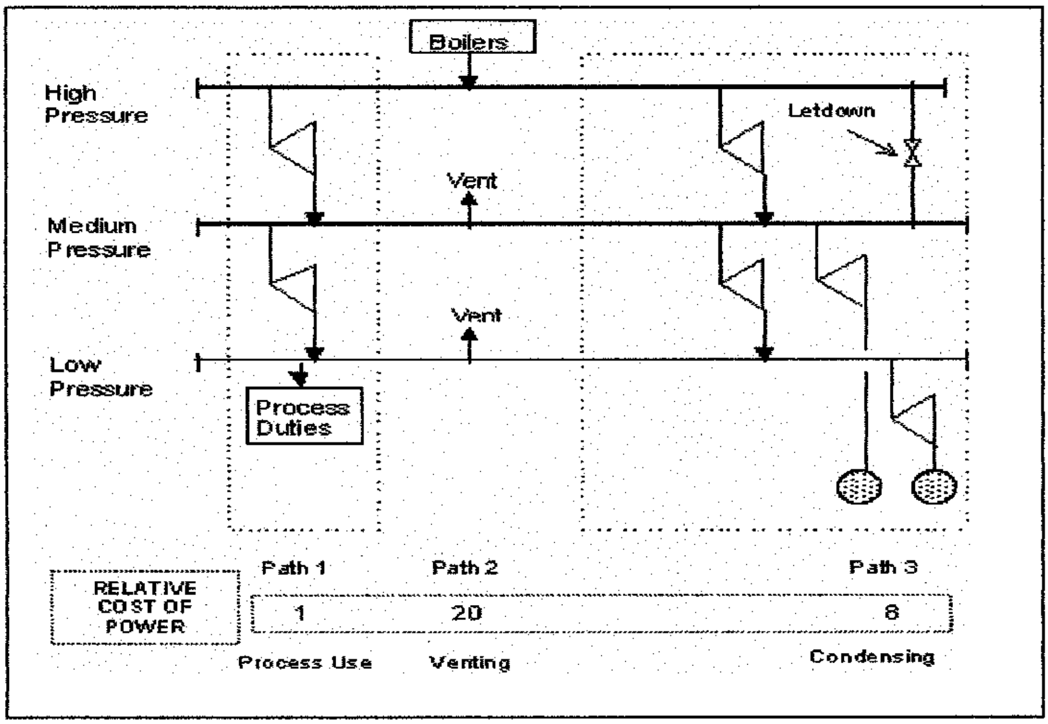

FIGURE 2.1: Steam and power costs for three scenarios

- Power is generated by backpressure turbines, with all exhaust steam being used by the process. (Path 1)
- Power is generated by backpressure turbines, but all exhaust steam is vented. (Path 2)

- Power is generated by backpressure and condensing turbines, with all steam ultimately taken to condensing. (Path 3)

The figure emphasizes the fact that the cost of generating power (or shaft work) and supplying steam at different pressure levels is highly path-dependent. That is, the cost will vary appreciably depending on how the steam gets from where it is generated to where it is used.

For example, medium-pressure steam that is produced via letdown from the high-pressure header will bear the cost of high-pressure steam generation. Medium-pressure steam that is exhausted from a steam turbine, however, will be less costly to the ultimate steam user because of the economic credit associated with the generation of shaft power.

Although the relative costs given (Figure 2.1) are strictly illustrative and vary for each set of circumstances, they highlight the dramatic differences in energy costs that can coexist at many industrial sites. As shown, power produced by backpressure turbines can be very competitive with purchased power, provided that the exhaust steam is used by the process. Conversely, such power is prohibitively costly if the exhaust steam is vented.

Purchased power is predominantly produced in large, condensing power plants. Accordingly, condensing power generation inside the plant competes directly with the electric utility on an operating cost basis.

Sorting out the complexities of steam and power values in such systems is best served by a "full thermodynamic cycle" costing for steam that includes:

- Deaerator steam impacts
- Backpressure turbine expansion impacts
- Non-fuel cost impacts, such as cooling water usage, makeup water and treatment costs, pumping costs, and fixed costs.

Although the costs and interactions of very simple steam and power systems may be readily apparent, such is not the case with many industrial sites where multiple steam generators and users and many operational "degrees of freedom" exist. Analysis of these steam systems requires a model that is easy to use, yet sufficiently rigorous to capture all significant cost factors and system interactions.

Configuring and applying such models in industrial steam systems typically offer significant opportunities for cost savings. Frequent areas of opportunity include the reduction, if not elimination, of steam venting, optimization of available turbine/motor options, and identification of rapid payback projects to further rationalize steam system operation. Proper energy costing is key to identifying appropriate cost-saving measures.

2.2 Steam model utilization

On many operating sites, maybe even the majority of sites, production is king and the steam system is regarded merely as a service that is far less important than the manufacturing processes themselves. Consequently, even companies that invest heavily in process modeling and simulation pay far less attention to the modeling of the steam system and, consequently, do not have the same understanding of the key players, the sensitivities and the interdependencies in this area.

Often, steam is assigned a unit value (dollars per thousand pounds) that serves to cover the perceived costs of operating the utility system when this value is apportioned across the various manufacturing cost centers. This value will, at best, represent an average cost of steam over a period of time and will often be inappropriate or downright misleading if used for evaluating potential projects.

A simple example would be a site that has a very close balance between suppliers and users at the low-pressure steam level. Site management is perhaps considering a new project to reduce the low pressure steam demand. If the project is evaluated at the accountant's transfer figure of, say, $5 per thousand pounds it may appear that the project will pay back handsomely. In reality, however, the "saved" steam may simply be vented as it has nowhere else to go. The project will therefore save nothing at all and will even lead to the additional cost of lost water and heat in the vent.

A reliable model that reflects what actually happens within the steam system would identify the real cost of the project and avoid this inappropriate capital spend.

The above example is rather simplistic but no less valid for all its simplicity. In real life, the actual cost of low-pressure steam is likely to be variable. It may take on a finite value initially as the first amounts of steam are saved and then, at some point, the above situation applies and the value of low-pressure steam reverts to zero or even a negative value, as described. There may therefore be a specific limit to the amount of steam that can be saved and further investment would be fruitless. It is obviously good to know what this limit is. If a proper understanding of the real marginal steam and power costs is obtained, then the present inefficiencies in the system can be clearly identified and the correct investment decisions taken with confidence.

The true marginal cost of steam at any time and place in the system will depend on the actual path through which the steam passes on its way from generator to consumer. Medium- or low-pressure steam that is simply produced via letdown from the high-pressure boilers will have the same cost as the high-pressure steam. On the other hand, if the medium- or low-pressure steam is exhausted from a steam turbine, then the unit cost of that steam will be less than that of high-pressure steam because of the credit associated with the generation of shaft work in the turbine.

Also, live steam for process use will have a higher value than the same steam used indirectly in heat exchangers because the latter can obtain credit for the condensate returned to the boilers. Finally, the time of day is increasingly affecting the cost of steam as power tariffs become increasingly complex following deregulation of the electrical power industry. Initial reasons for building a model of the steam system could, therefore, be:

- To calculate the real cost of steam under various operational scenarios
- To identify current energy losses
- To accurately evaluate project savings

- To forecast future steam demand versus production
- To identify the critical areas, sensitivities and bottlenecks within the system
- To identify no-cost operational improvements
- To evaluate tariffs and energy contract management
- To target and report emissions
- To form the basis of a consistent investment plan for the site

2.3 Pinch Technology

Pinch technology presents a simple methodology for systematically analyzing chemical processes and the surrounding utility systems with the help of the First and Second Laws of Thermodynamics. The first Law of Thermodynamic provides the energy equation for calculation the enthalpy changes (ΔH) in the streams passing through a heat exchanger. The Second Law determines the direction of heat flow. That is, heat energy may only flow in the direction of hot to cold. This prohibits 'temperature crossovers' of the hot and cold streams profiles through the exchanger unit.

In a heat exchanger unit, neither a hot stream can be cooled below cold stream supply temperature nor cold streams can be heated to a temperature more than the supply temperature of hot stream. In practice, the hot stream can only be cooled to a temperature defined by the 'temperature approach' of the heat exchanger. The temperature approach is the minimum allowable temperature difference (DT min) in the stream profiles, for the heat exchanger unit. The temperature level at which DT min is observed in the process is referred to as "pinch point". The pinch defines the minimum driving force allowed in the exchanger unit.

Pinch analysis is used to identify energy cost and heat exchanger network capital cost targets for a process and recognizing the pinch point. The procedure first predicts, ahead of design, the minimum requirements of external energy, network area and the number of units for a given process at the pinch point. Next heat exchanger network design that satisfies these targets is synthesized. Finally the network is optimized by comparing energy cost and the capital cost of the network so that the total annual cost is minimized. Thus the prime objective of the pinch analysis is to achieve financial savings by better process heat integration (maximizing process-to-process heat recovery and reducing the external utility loads).

CHAPTER 3

METHODOLOGY

As per title of the project, there are two areas in which will be emphasis in this project. To see the interconnection between utility and process, both systems should be taken care of. This project sequence can clearly shown by the following flowchart:

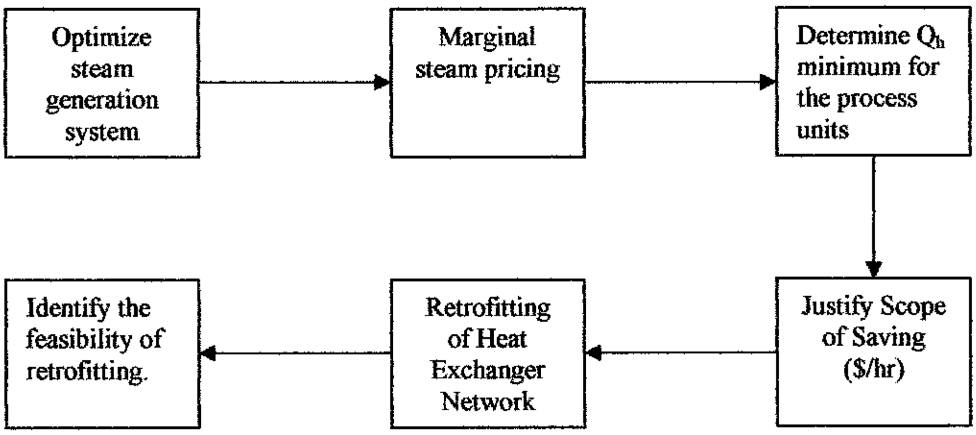

FIGURE 3.1: Step-by-step procedure of optimization

3.1 Steam Generation System Optimization

A turbo generator system is chose as a reference for steam generation system. Since our interest here is the interaction between the utility and process side, any type of utility system can be suit for the case study. A simple example of steam generation system taken from literature can be applied (Edgar, 2001). The system is illustrated in Figure 3.2. This system consists of two turbo generators whose characteristic are listed in Table 3.1.

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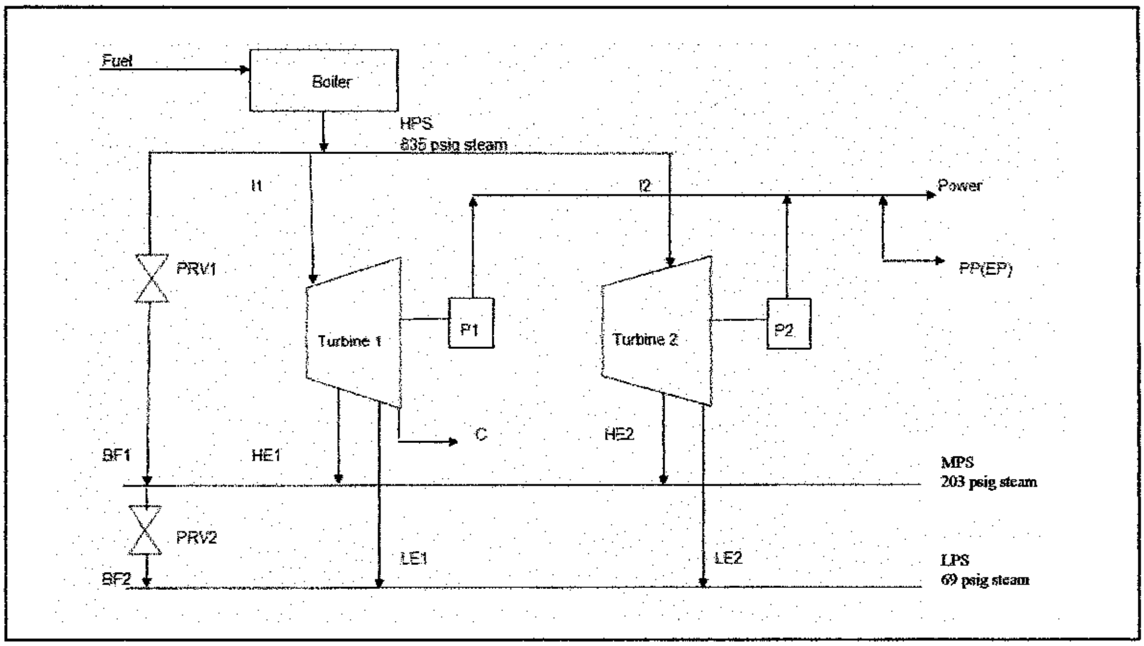

FIGURE 3.2: Schematic Diagram of Boiler/ turbo generator system

Key variables:

I_i = inlet flow rate for turbine i [lb/h]

HE_i = exit flow rate from turbine i to 203 psi header [lb/h]

LE_i = exit flow rate from turbine i to 69 psi header [lb/h]

C = condensate flow rate from turbine 1 [lb/h]

P_i = power generated by turbine I [kW]

BF_1 = bypass flow rate from 635 psi to 203 psi header [lb/h]

BF_2 = bypass flow rate from 203 psi header to 69 psi header [lb/h]

HPS = flow rate through 635 psi header [lb/h]

MPS = flow rate through 203 psi header [lb/h]

LPS = flow rate through 69 psi header [lb/h]

PP = purchased power [kW]

EP = excess power [kW] (difference of purchased power from base power)

PRV = pressure reducing valve

TABLE 3.1: Turbine data

	Turbine 1					Turbine 2			
Maximum generation capacity	6,250	kW	6,250	kW		9000	kW	9000	kW
Minimum load	2500	kW	2500	kW		3000	kW	3000	kW
Maximum inlet flow	192000	lb/h	87089.66	kg/h		244000	lb/h	110676.4	kg/h
Maximum condensate flow	62000	lb/h	28122.70	kg/h					
Maximum internal flow	132000	lb/h	59874.14	kg/h					
High pressure extract	195	psig	13.44	barg		195	psig	13.44	barg
Low pressure extract	62	psig	4.27	barg		62	psig	4.27	barg
Maximum 62psi exhaust						142000	lb/h	64410.06	kg/h

TABLE 3.2: Steam Header Data

Header	Pressure				Temperature				Enthalpy			
High Pressure	635	psig	43.78	barg	720	°F	382.22	°C	1359.8	btu/lb	3162.8	kJ/kg
Medium Pressure	203	psig	13.98	barg	383	°F	195	°C	842.6	btu/lb	1960	kJ/kg
Low Pressure	69	psig	4.76	barg	302	°F	150	°C	908.9	btu/lb	2114	kJ/kg
Feedwater									193	btu/lb	448.9	kJ/kg

TABLE 3.3: Steam Demand Data

Medium pressure	271536	lb/h	123166.55	kg/h
Low pressure	100623	lb/h	45641.78	kg/h
Electricity	24550	kW	24550	kW

TABLE 3.4: Energy Data

Fuel cost	1.68x10^{-6}	\$/Btu	1.59x10^{-06}	\$/kJ
Boiler efficiency	0.75			
Steam cost	2.24x10^{-6}	\$/Btu	4.94x10^{-06}	\$/kJ
HPS cost	0.00261	\$/lb	0.005762077	\$/kg
Purchased power	0.0239	\$/kW		
Demand penalty	0.00983	\$/kW		
Base purchased power	12000	kW		

Turbine 1 is a double extraction turbine with two intermediate streams leaving at 203 psi (13.98 bar) and 69 psi (4.76 bar). The final stream consists of condensate then will be used as boiler feed water. Turbine 2 is a single extraction turbine with one intermediate stream at 203 psi (13.98 bar) and 69 psi (4.76 bar) without condensate outlet. It is given that the first turbine is more efficient due to energy released from the condensate steam but less power produced as compared to turbine 2.

From a few set of data given in table 3.1, 3.2, 3.3 and 3.4, a mathematical modeling correspond to the turbo generator system can be obtained. These sets of data, energy and material balance are used for the model constraints and objective function. For this case study, a Linear Programming is used as it often used in the design and operation of steam system in the chemical industry.

The objective of this step is to optimize the steam generating system. The optimum operating condition from the optimization is used as a basic or reference point in order to do a marginal steam pricing in subsequent step. Using the constraints and the objective function carried out, optimization of the steam generation system can be applied. Care should be taken to coding all this constraints and objective function since the programming is a case sensitive. The model in GAMS interface are visualize in Appendix 1.

After the optimal cost value obtained, the screening technique then will take place, which is a marginal steam pricing. The values obtained are the optimum operating condition that the steam generation plant should operated for optimum operating cost.

3.2 Marginal Steam Pricing.

Marginal steam pricing is a screening technique in such a way that at the end of the process, it will visualize and relate to the steam flow with the price of the steam (Linholff, 2002). It is also can be use as an indicator for the system to observe at which point the amount of saving that the system could get. The steam balance of a header may be changed by these 3 possibilities:

1. Increase/decrease in process steam demand.
2. Increase/decrease in process steam generation.
3. Change in the utility system such as shutdown of a boiler.

Before going further, we need to understand the definition of marginal cost is since this is the crucial part for utility and process optimization. Marginal steam pricing is an amount of incremental the operating cost to the increment of the steam consumption by the process. This statement can further translated by the subsequent equation:

$$\textit{Marginal Pricing} = \frac{\textit{Incremental Operating Cost}}{\textit{Incremental Steam Consumption}} = \frac{\Delta \mathrm{Cost}}{\Delta\, \mathrm{m}_{\mathrm{Header}}} \qquad \ldots\ldots.(1)$$

For evaluating the energy conservation and efficiency improvement projects, it is the marginal pricing that should be determined. The steps to obtain the marginal pricing are as shown by Figure 3.3

This process requires iteration so that a trend of steam pricing per steam reduction can be conceived. GAMS interface is best programming that suit with the iteration required. The results calculated are then observed by plotted the price per mass of steam to reduction of steam flow rate. A typical example of the plot is shown in Figure 3.4. This plot is the most crucial part as it can interpreted how much saving that can be obtained as a result of a reduction in energy consumption in heat exchanger network. It is work as an indicator to visualize how much scope of saving that can be utilized. This plot also can tell how long the payback period of the project as retrofitting the heat exchanger network on the later part take place. Then only the decision on retrofitting the network can be decide.

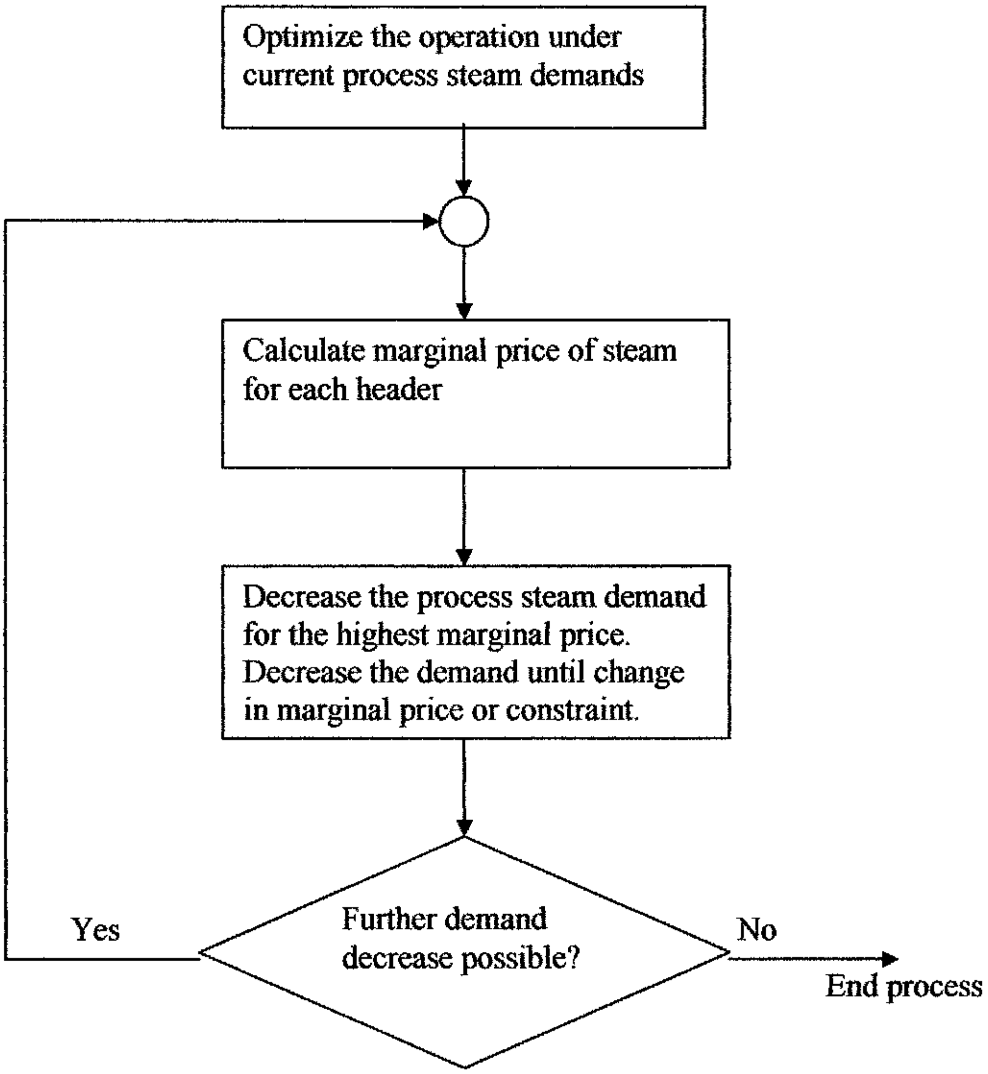

FIGURE 3.3: Process flow to determine the marginal steam price.

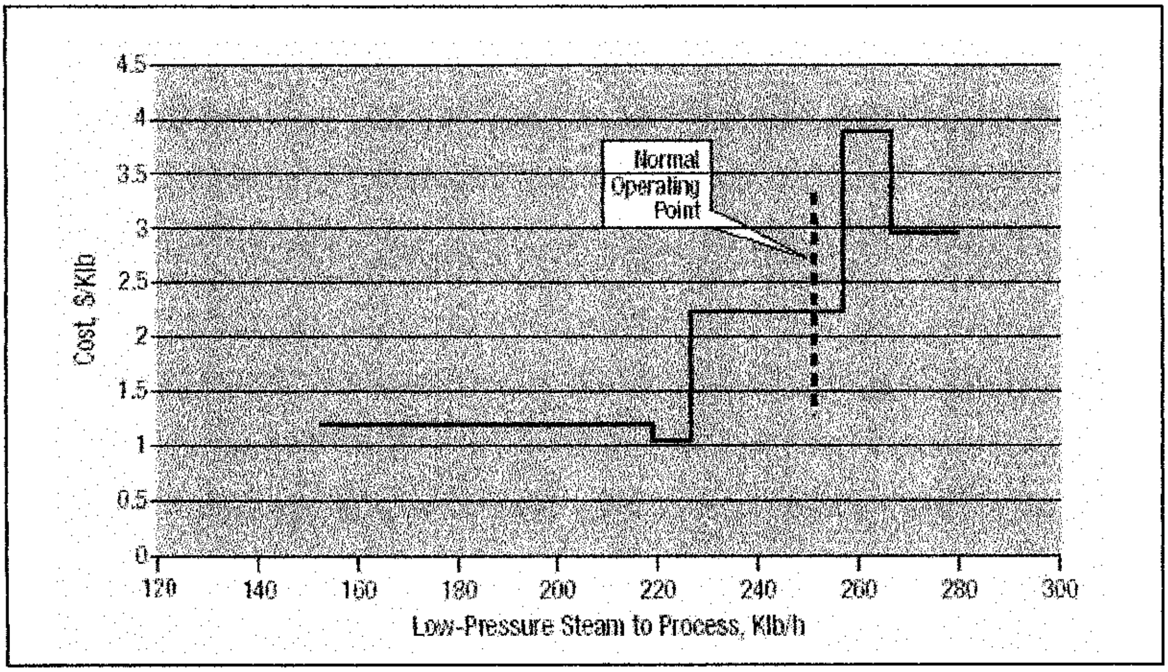

FIGURE 3.4: A typical example of marginal steam pricing plot

3.3 Minimum Utility Requirement by the Process

In this project, a palm oil refinery is chose as a case study (Ooi Boon Lee, 2003). Figure 3.5 illustrate the process flow diagram of the plant. Since in this project interests are on the optimization of hot utility requirement, only the heat exchanger network will be emphasized. The type of component and process involved will be neglected here. For this refinery plant, there are only three existing heat exchanger installed. They are E 205, E 302/1 and E 302/2. The current hot utility requirement is 558.61 kW. The concern governs here is that how the heat exchanger network would give the best structure for the optimum utility requirement for the process.

A minimum hot utility requirement is identified by constructing a grand composite curve of the streams data. This approach will easily visualize the hot utility requirement needed for the process.

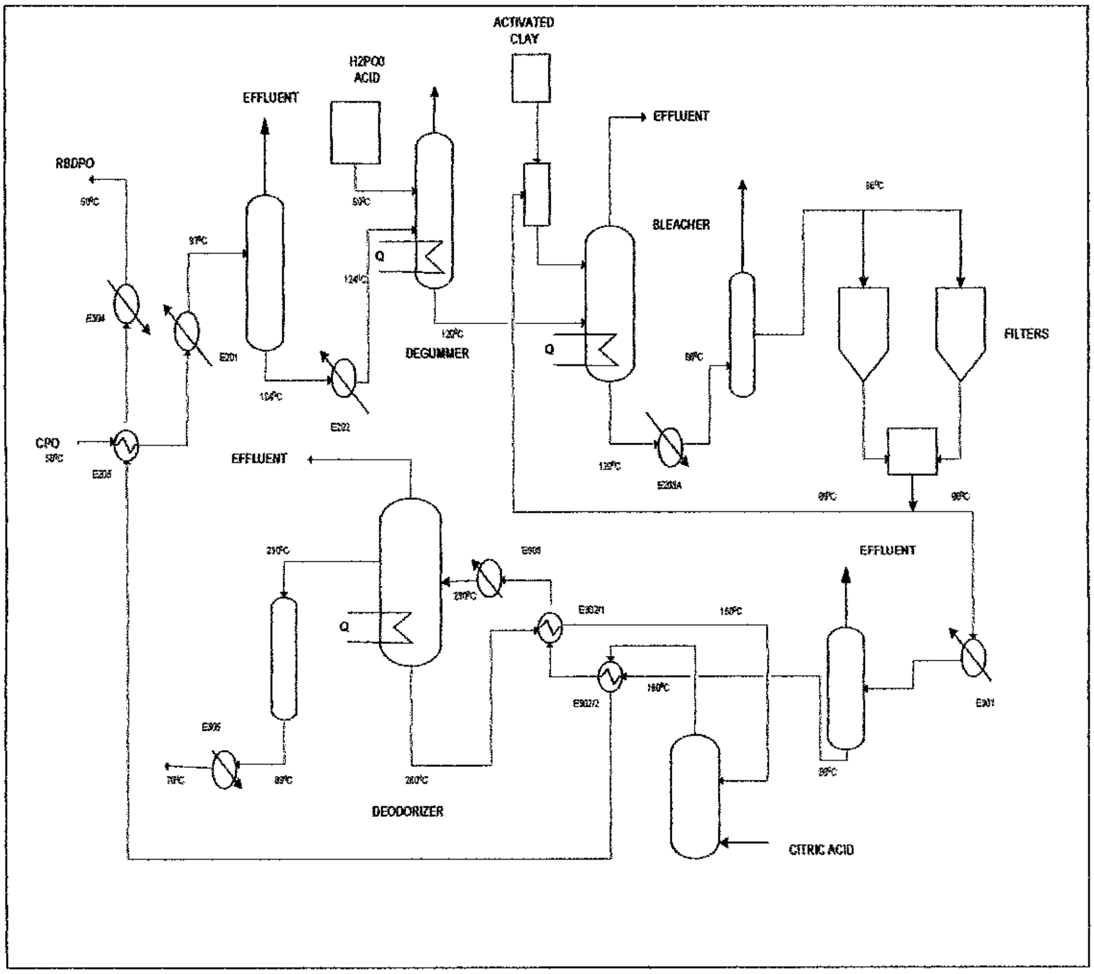

FIGURE 3.5: Process flow diagram of a palm oil refinery.

3.4 Scope of Saving Justification

The amount of energy saving is the different between Qh minimum from grand composite curve and Qh required as per existing setup.

$$\text{Energy Saving} = Q_{saving} = Q_{h\ minimum} - Q_{h\ existing} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

The scope of saving obtained then can further interpreted in more interesting way which is money. This interpretation amount of money saving is by virtue of marginal steam pricing plot obtained in the preceding step. In this project, we are assuming that the source of energy to the process is only by supplying steam at MP. Thus, the amount of steam flowrate from the scope of energy saving is the energy saving per latent heat of the steam supplied;

$$\text{Steam Flowrate} = \frac{Q_{saving}}{\Delta H_{latent}} \qquad \ldots\ldots\ldots\ldots\ldots(3)$$

From the marginal steam pricing plot;

Scope Saving = **Area under the curve**

3.5 Retrofitting the Heat Exchanger Network.

The scope of saving obtained in preceding step is range of saving that can be visualize at the end of the optimization project. It is irrelevant to say that all of the energy saving is the total amount of the payback. Not the entire saving obtained can recovered at the end of the day but it express that the scope of saving that can be utilize for the respective optimization project.

The objective retrofitting is to find the best heat exchanger network for the onside process. As the best heat exchanger network obtained then the overall heat transfer area can be justified. The significance of heat transfer area in this project is that, it could give the cost of installing a new heat exchanger and relate it with the scope of saving obtained by the preceding step.

A best practice in retrofitting the heat exchanger network is by using the Pinch Analysis. Pinch technology presents a simple methodology for systematically analyzing chemical processes and the surrounding utility systems with the help of the First and Second Laws of Thermodynamics. Pinch Analysis is used to identify energy cost and heat exchanger network (HEN) capital cost targets for a process and recognizing the pinch point. The procedure first predicts, ahead of design, the minimum requirements of external energy, network area, and the number of units for a given process at the pinch point.

As the best network achieved using Pinch Analysis, the required heat transfer area for the process then calculated. Assuming the true countercurrent heat transfer, the area requirement for a given duty of heat exchanger is given by:

$$A_{min} = \sum \frac{Q_k}{U\Delta T_{LMTD}} \quad \ldots\ldots\ldots\ldots\ldots(4)$$

Where;

Q_k = Stream duty in enthalpy interval k

U = Overall heat transfer coefficient

ΔT_{LMTD} = log mean temperature difference for interval k

The cost of heat exchanger can be estimated by equation below (Linnholf, 1984);

$$\text{Exchanger cost} = a + b\,(A_{min})^{c} \quad \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Where a, b and c are the constant in exchanger cost law. Assumption to be made in the estimation is that the material used in designing the exchanger is made of carbon-steel. From literature, for carbon-steel heat exchanger type, the a, b and c constant are 16,000, 3,200 and 0.7 respectively.

3.6 Feasibility Justification

As the area of heat exchanger needed for retrofitting has justified, estimation of capital cost for installing new heat exchanger can be estimated. The cost of heat exchanger can simply obtained by a given correlation between the surface area and the type of heat exchanger that need to be installed. For the purpose of the project, a detailed type of heat exchanger is not specific and assumption on type of heat exchanger can be applied here.

The most important thing in optimization project is the feasibility of the solution obtained. How can we know the feasibility of the solution which in this case retrofitting of heat exchanger network? Now the marginal steam pricing which had obtained in preceding steps can be applied here. From the marginal plot, it can tell the scope of saving that we could get. Then, the payback period for retrofitting is the total cost of heat exchanger per scope of saving;

$$\text{Payback period} = \frac{\text{Total cost of heat exchanger}}{\text{Scope of saving}} \quad \ldots\ldots\ldots\ldots (6)$$

The payback period obtained then will be evaluated the feasibility of the project. If the payback period is nicely justified then only the project can proceed. In this project, the acceptable payback period would be around 1 year since the process involved is not complex.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Result

The optimization method used in this project first emphasize on the optimization of the utility system since the source of heat are produced mostly from the utility system. The model used to optimize the system is as per Appendix 1, using GAMS interface.

TABLE 4.1: Optimum solution for steam system using Linear Programming

Name	Value	Unit
I1	136329	lb/hr
I2	244000	lb/hr
HE1	128158	lb/hr
HE2	143377	lb/hr
LE1	0	lb/hr
LE2	100623	lb/hr
C	8170	lb/hr
BF1	0	lb/hr
BF2	0	lb/hr
HPS	380329	lb/hr
MPS	271536	lb/hr
LPS	100623	lb/hr
P1	6250	kW
P2	7061	kW
PP	11239	kW
EP	761	kW
Z	1268.75	$/hr

Table 4.1 shows all process variable for the steam generation system operated at an optimum operating cost, given in variable z. This is the basic setting to operate at optimum cost. However, this variable may change as the demands of steam whether MP or LP steam from the process are reduced or increased. Besides, other variables also will experience the effect of changing the steam demand. The effect clearly visualize as the determination of marginal steam price are take place.

Result above is use as a basic variable for determining the marginal steam pricing. The first step is to determine on which header will give the higher value of marginal cost as a reduction on the steam demand is simulated. The basis of reduction in this case is 10 klb/hr. A reduction of steam is implied here instead of increase the steam is to meet the objective of the project to minimize the process heating requirement and thus reducing the cost of utility. It is observed that MP steam generate higher marginal price and thus it is used for further reduction. Table 4.2 shows the result of this reduction until the marginal cost start to fall. This result is plotted as shown in Figure 4.1.

TABLE 4.2: Result of MP steam demand reduction

MPS	Operating Cost	Marginal Steam cost	P1	P2
klb/hr	$/hr	$/klb	kW	kW
271.536	1268.75	-	6250	7060.714
261.536	1244.71	2.40	6250	7060.714
251.536	1220.67	2.40	6250	7060.714
241.536	1196.62	2.40	6250	7060.714
231.536	1172.58	2.40	6250	7060.714
221.536	1148.54	2.40	6250	7060.714
211.536	1124.49	2.40	6250	7060.714
201.536	1100.45	2.40	6250	7060.714
191.536	1076.40	2.40	6250	7060.714
181.536	1052.36	2.40	6250	7060.714
171.536	1028.32	2.40	6250	7060.714
161.536	1004.27	2.40	6250	7060.714
151.536	980.23	2.40	6250	7060.714
141.536	956.51	2.37	6250	7060.714

From the table above, it clearly shown that as the MP steam is reduced, the power produced from the turbo-generator remain the same. It means that there is no effect of power produce and hence no trade-off of between the power generated with power purchased. The table also showed that at steam demand of 141.536 klb/hr, the marginal price is starting to drop. If the reduction of steam continues, it will not give a beneficial trade-off. Thus, the next steam header will be take place for further reduction, maintaining the demand of MP steam.

Now the steam reduction is taken care off by LP steam. It is expected that the cost to produce LP steam will much lower compared to MP steam. The same basis of reduction of 10 klb/hr is being used for this process. The different impact between the MP and LP reduction is that, in reducing the LP steam, it will affect the power produce at turbine 2. This impact is shown in Table 4.3 and the result is illustrated in Figure 4.2.

TABLE 4.3: Result of LP steam reduction

LPS	Operating Cost	Marginal Steam cost	P1	P2
klb/hr	$/hr	$/Klb	kW	kW
100.623	980.23	-	6250	7060.714
90.623	957.18	2.30	6250	6963.037
80.623	935.55	2.16	6250	6645.428
70.623	913.92	2.16	6250	6327.819
60.623	895.14	1.88	6250	6010.21
50.623	876.63	1.85	6250	5692.6
40.623	858.12	1.85	6250	5374.991
30.623	839.61	1.85	6250	5057.382
20.623	821.10	1.85	6250	4739.773
10.623	802.59	1.85	6250	4422.164

From the table above, the power produce at turbine 2 reduces as LP steam is reduced. Here we can see the trade-off between the power produced and power purchased. The base of power purchase is 12,000 kW in this case study. If the power produce from the turbine is sufficient to produce in such a way that fulfilling the base power demand, it will help to minimize the power purchase from outside. On the other hand, if the power demand is less than the basis purchase power, the power that is not used will be charged at a penalty cost. The reduction for LP steam process will only stop at the minimum demand of LP steam. In this case it is stop at 10.623 klb/hr since this is the least number it can be reduce.

Using the reduction of steam data above, it can be applied to obtain the marginal steam pricing plot. A graph of marginal cost versus amount of steam reduction on both headers is plotted in Figure 4.3.

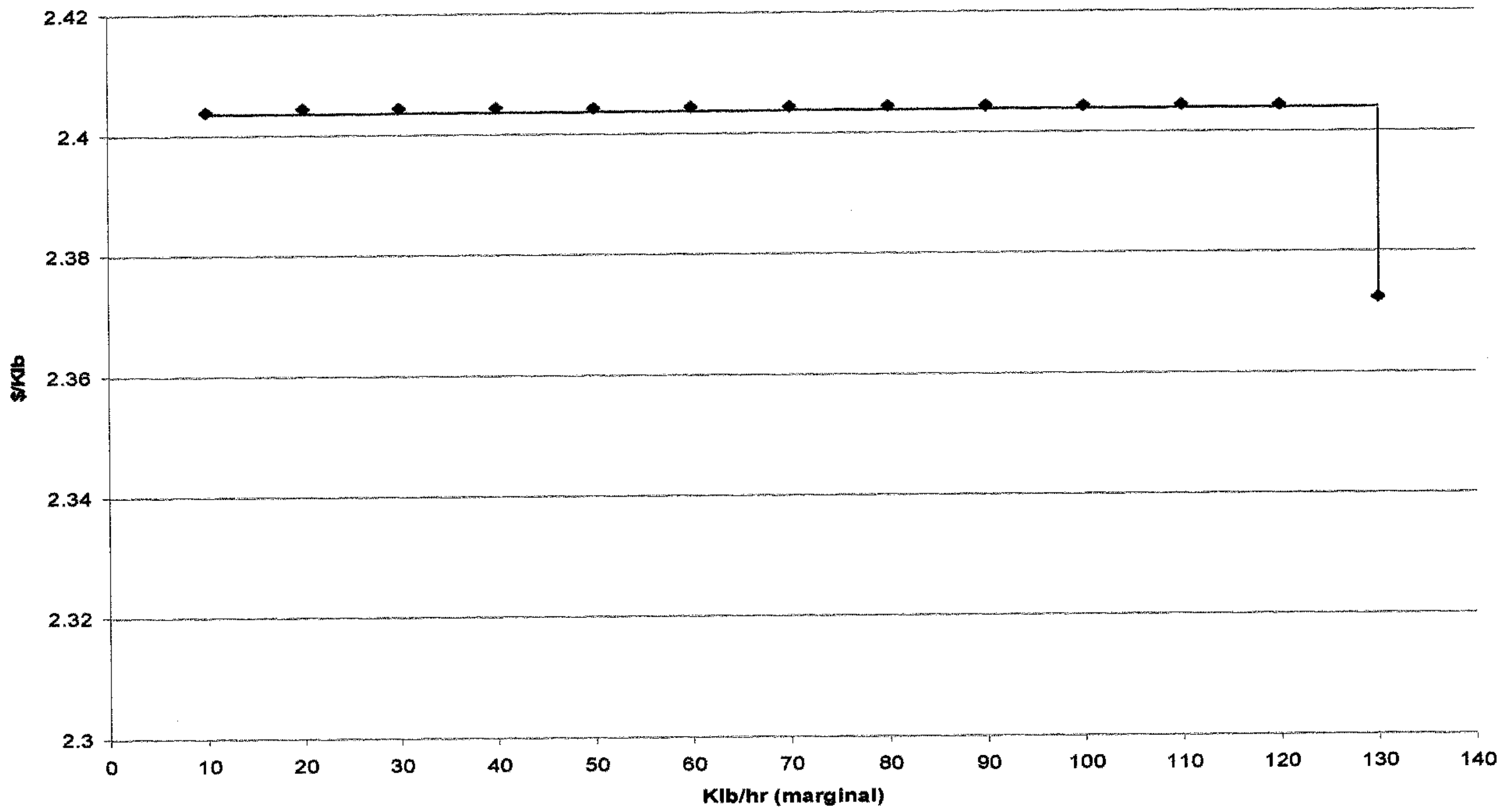

FIGURE 4.1: Marginal Steam Pricing Plot for MP steam reduction

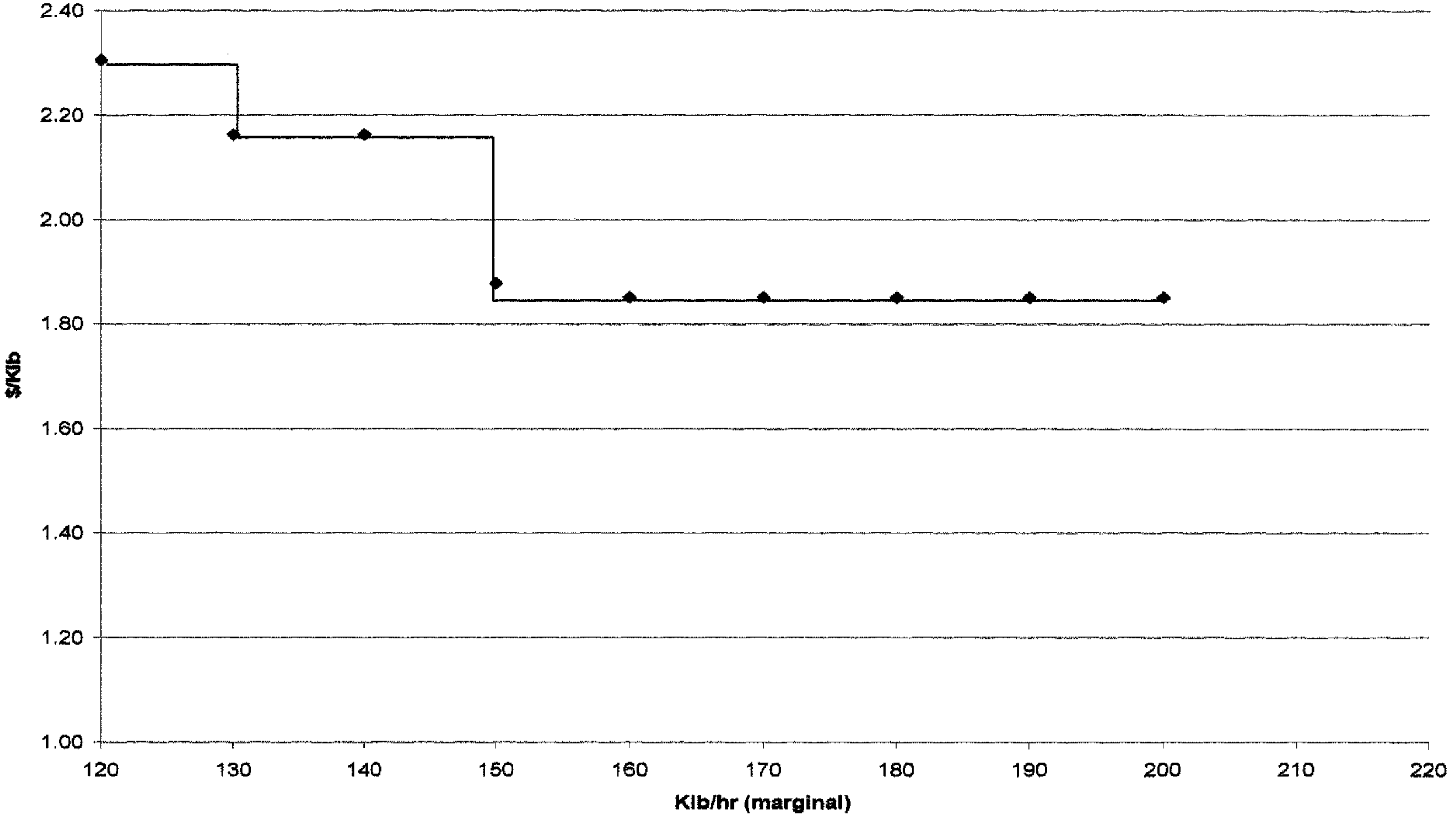

FIGURE 4.2: Marginal Steam Pricing Plot for LP steam reduction

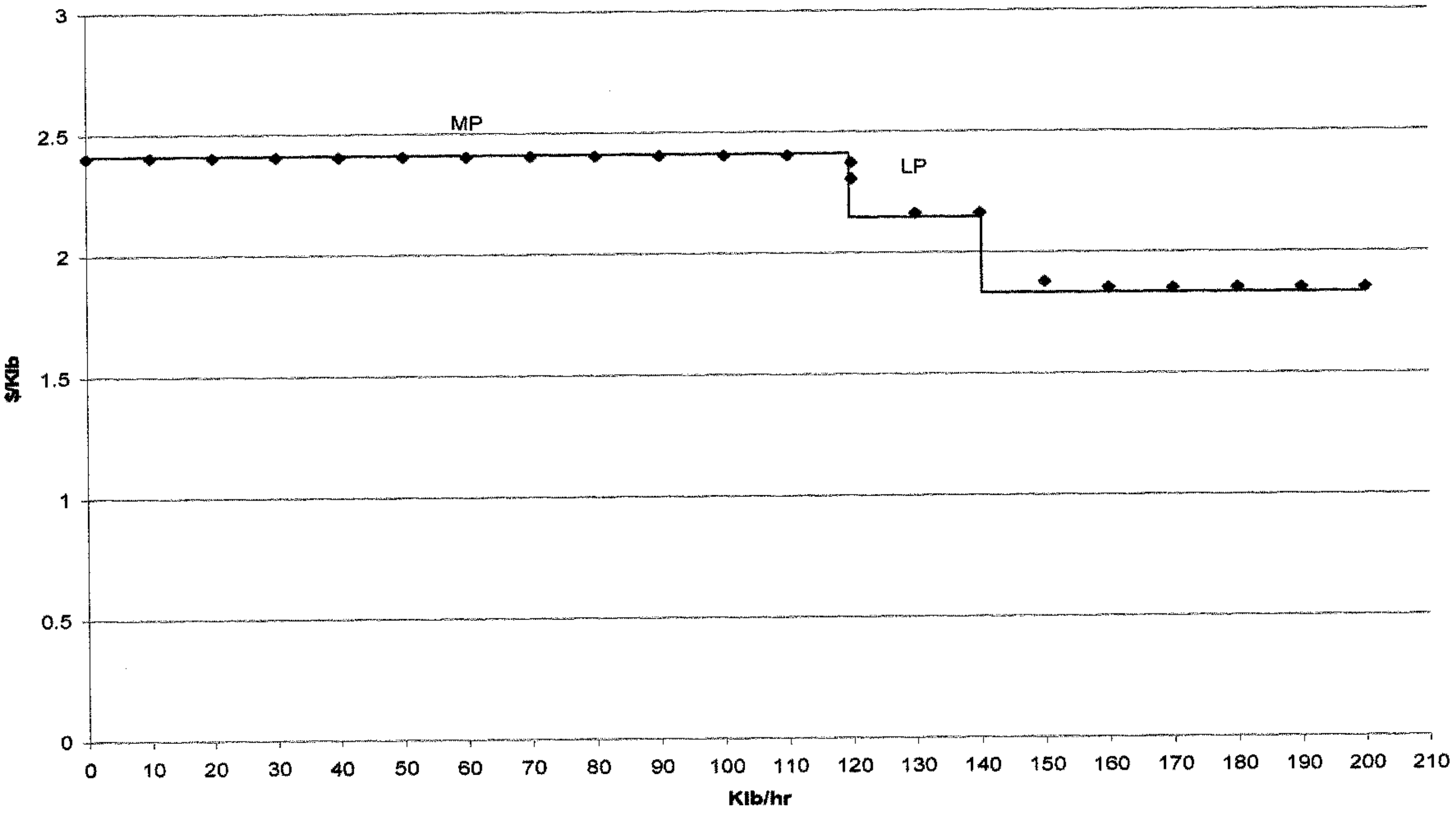

FIGURE 4.3: Marginal Steam Pricing Plot from combination of MP and LP steam

This graph can determined the scope of saving returned as a reduction of steam demand, i.e minimizing the process heating requirement. The area under the curve tells us the amount of saving. In other words, the marginal pricing plot can be used as an indicator for minimizing the process demand. This will simplify the optimization process.

The preceding result are only covered the utility system only. Next step will be on the process site, i.e the heat exchanger network. Since we are focusing on the steam generation system, heating requirement only will be taken care off here. By extracting the stream from the process shown in Figure 3.2, composite and grand composite curves are determined here.

TABLE 4.4: Stream Data

Stream		Supply Temperature (°C)	Target Temperature (°C)	Heat Capacity Flowrate (kW/°C)
No	Type			
1	Hot	120	86	10.99
2	Hot	260	160	6.29
3	Hot	83.3	70	13.13
4	Hot	160	50	6.56
5	Cold	97	50	11.83
6	Cold	124	104	14.89
7	Cold	230	86	5.69

Table 4.4 shows all the stream data from the process flow diagram. From the available data here, the minimum hot utility requirement can be obtained by plotting the grand composite curve. The particular curve is shown in Figure 4.4. The significance of finding the minimum hot utility is to find the energy saving from the current energy requirement. By assuming that the steam supplied to the heat exchanger network is taken care off by MP steam, the amount of steam per existing operation and per minimum heating requirement can calculated here.

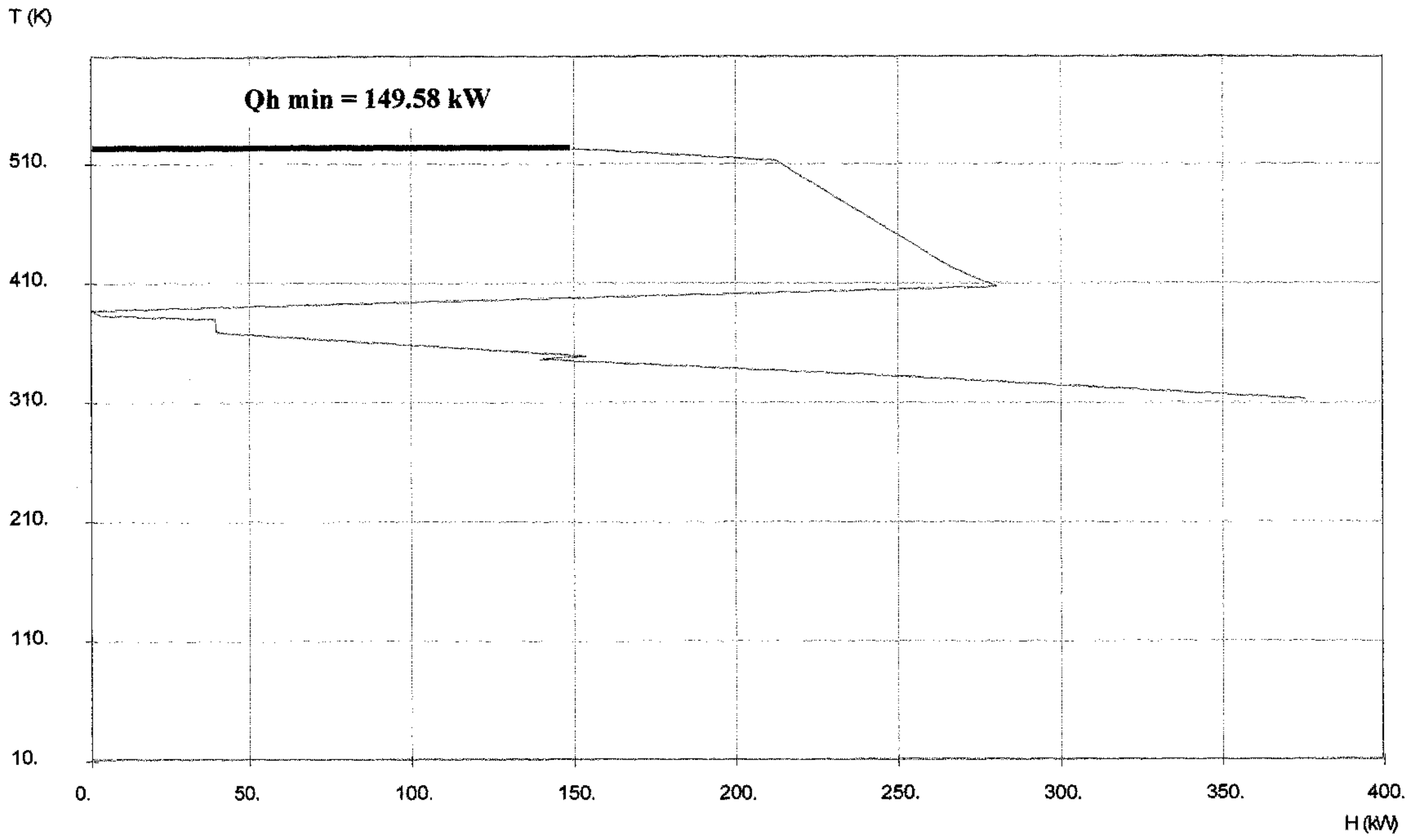

FIGURE 4.4: Grand Composite Curve of the process

From steam table at 195°C of MP steam, latent heat is about 1960 kJ/kg. Thus the steam flow rates are;

Steam flow rate at current operating condition, taking from the plant operation;

$$F = \frac{Q_{Existing}}{\Delta H_{Latent}}$$

$$= \frac{558.61\ \text{kW}}{1960\ \text{kJ/kg}} = 1026.0184\ \text{kg/hr}$$

Steam flow rate at minimum heating requirement;

$$F = \frac{Q_{Min}}{\Delta H_{Latent}}$$

$$= \frac{149.58\ \text{kW}}{1960\ \text{kJ/kg}} = 274.7388\ \text{kg/hr}$$

Thus, steam saving is the difference between the current operating condition and minimum hot utility requirement;

$$F_{saving} = 1026.0184 - 274.7388$$

$$= 751.27\ \text{kg/hr}$$

$$= 1.65\ \text{klb/hr}$$

From the amount of steam saving above, the scope of money saving of this purpose easily can be obtained from the area under the curve of marginal pricing plot, Figure 4.5. At 1.65 klb/hr, the scope of saving is about **$32,326.44/year.** The assumption made here is that the plant operated at 8150 hours per year (Douglas, 1988).

Before going further and utilize the saving obtained, the heat exchanger network need to retrofit to realize the minimum heating requirement. A Pinch Analysis is used to retrofit the heat exchanger network. Figure 4.6 showing the existing heat exchanger installed and Figure 4.7 showing the retrofitted of heat exchanger network.

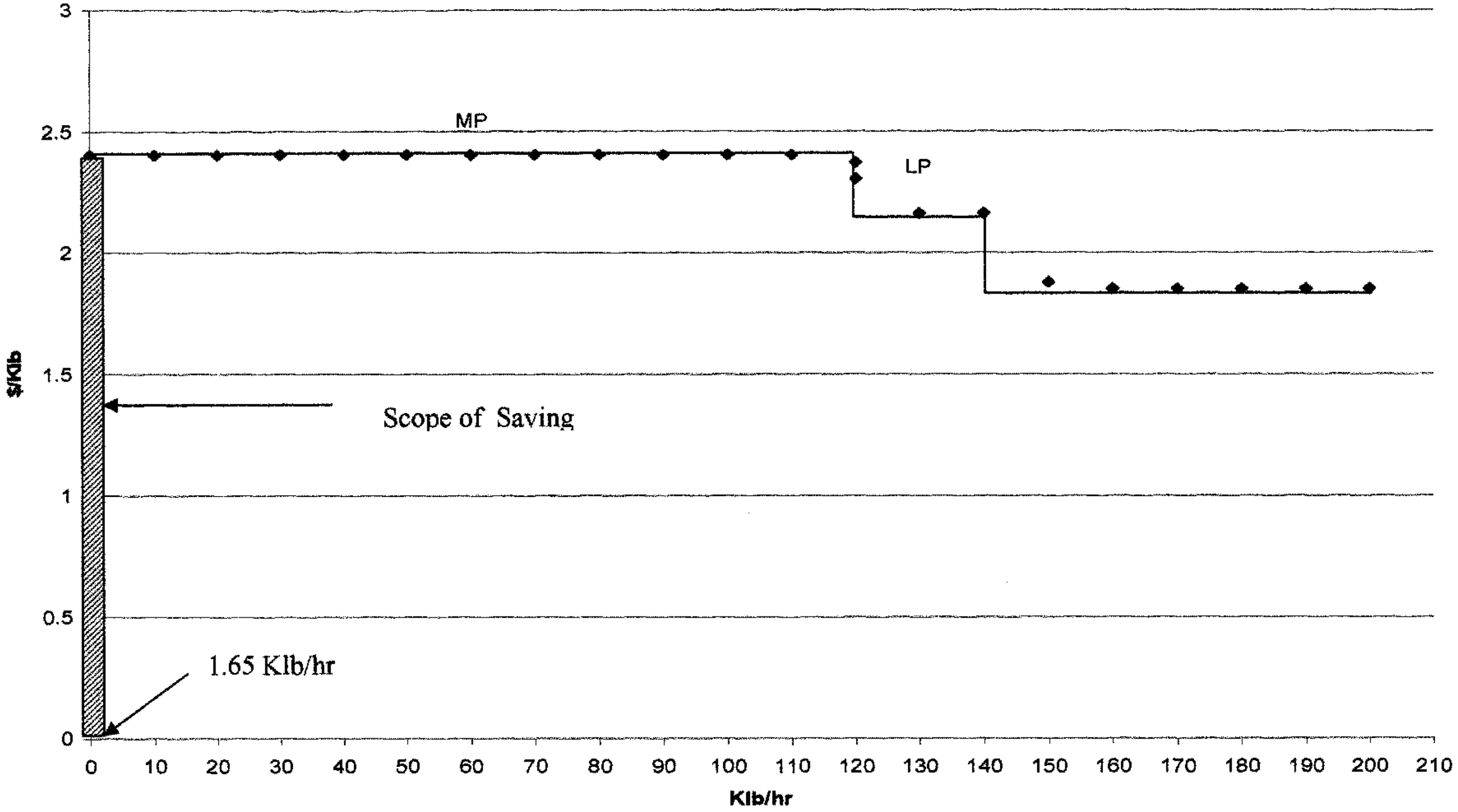

FIGURE 4.5: Amount of Steam Saving

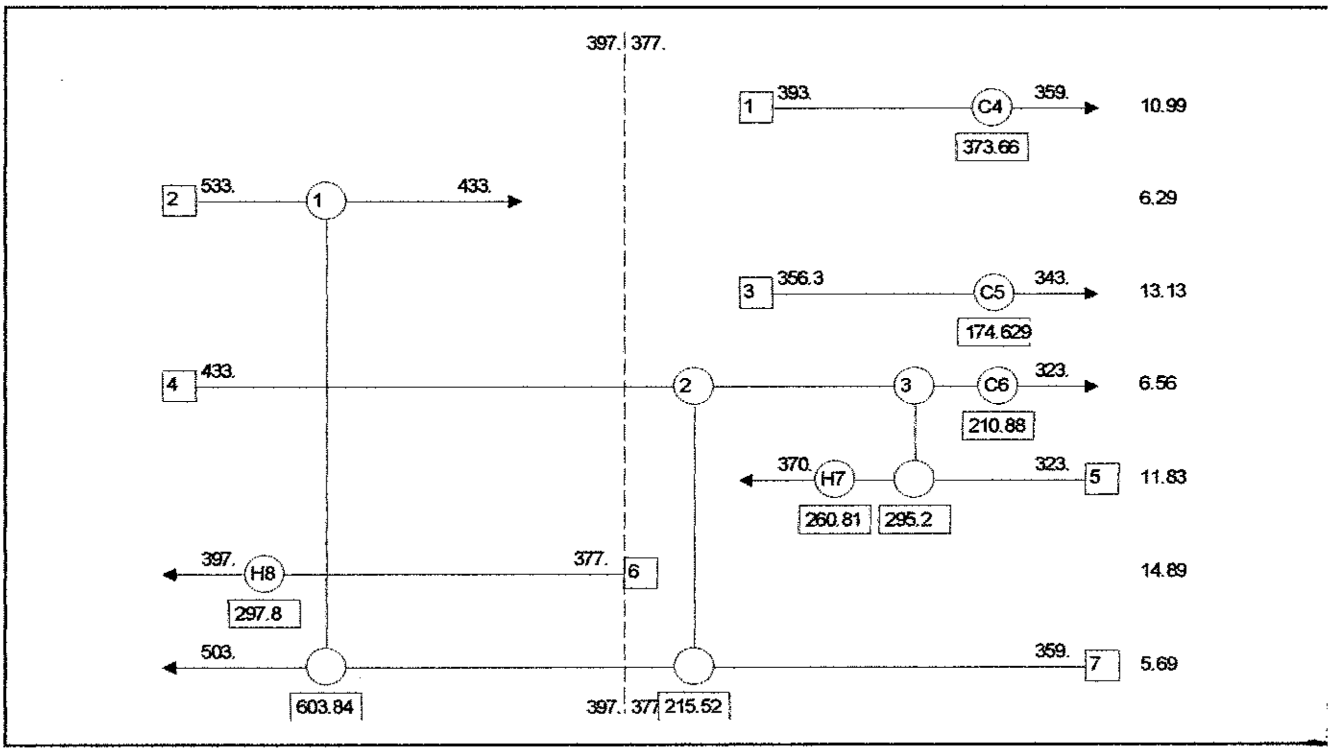

FIGURE 4.6: Existing Heat exchanger network for the palm oil refinery

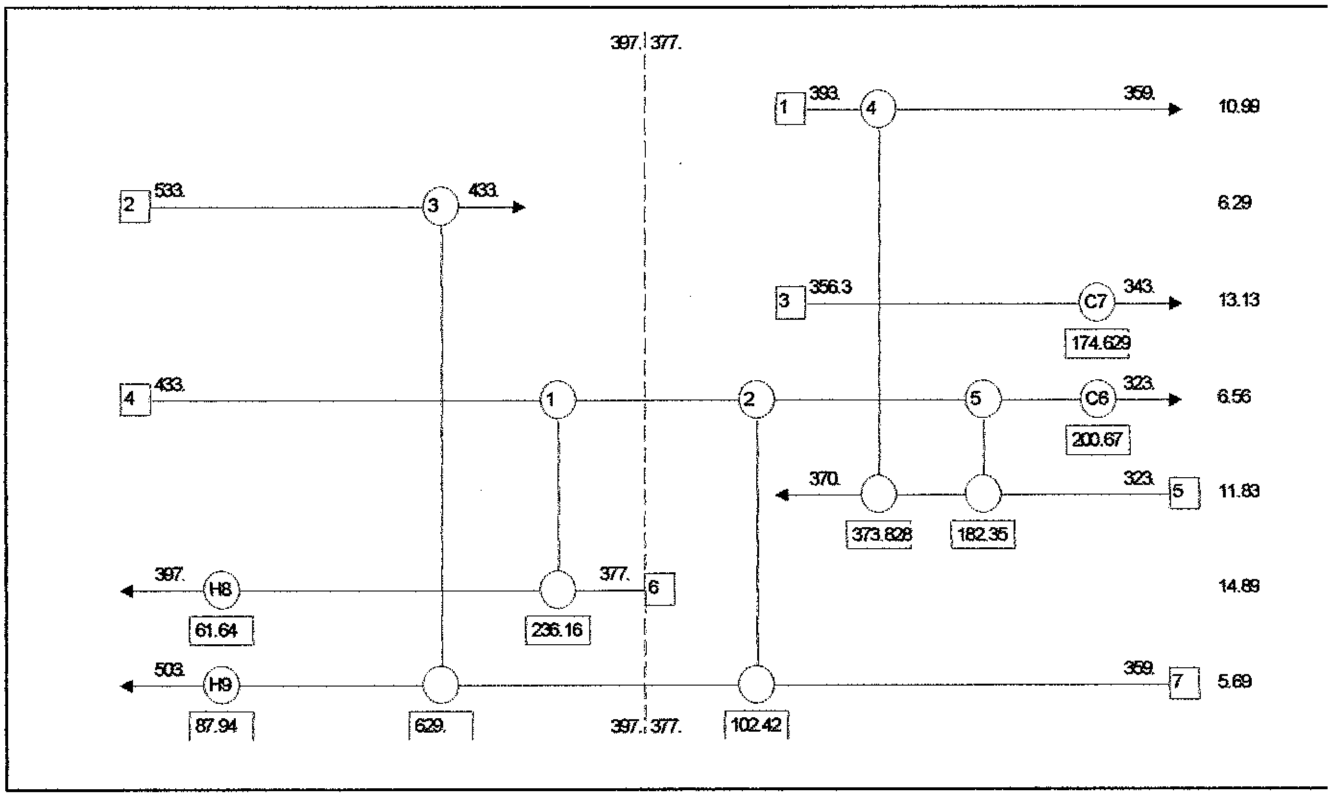

FIGURE 4.7: The retrofitted heat exchanger network for palm oil plant

The new retrofitted of heat exchanger network giving more heat exchanger compared to the existing heat exchanger but the reverse effect of the hot utility requirement. Now suppose the retrofitted exchanger can achieve the minimization target, the heat exchanger area should calculate in order to estimate the installation cost. Table 4.5 below shows the cost estimation for installing the heat exchanger after retrofitted the network.

TABLE 4.5: Cost estimation of heat exchanger

HE no	Tin °C	Tout °C	tin °C	tout °C	ΔT_{LMTD} °C	ΔH kW	U kW/°C.m^2	Area required m^2	Capital Cost $
1	160	124	104	119.86	28.91015	236.16	0.3	27.22919	48335.104
2	124	108.38	86	104	21.16771	102.42	0.3	-	-
3	260	160	104	214.54	50.54698	25.16	0.3	1.659182	4561.166
4	120	86	65.41	97	21.77277	373.66	0.3	57.206	70369.969
5	108.38	80.58	50	65.41	36.42446	182.35	0.3	-	-
							Total		**123,266.24**

The area required for heat exchanger no 2 and 3 for the retrofitted network is neglected since the existing heat exchanger duty is sufficient to deliver the amount of heat after retrofitted. For heat exchanger no 1, the new heat duty is exceed the existing capacity and thus required some addition of area of heat exchanger. The extra area needed by heat exchanger 3 is about 1.69 m^2. In the estimation of heat exchanger cost, it is assume that the overall heat transfer coefficient is fixed throughout process streams. From the cost estimation above, the payback period now can be calculated. The payback period is the total cost of installing the heat exchanger per scope of saving;

$$\text{Payback period} = \frac{\$\ 123{,}266.24}{\$\ 32{,}326.44/\text{year}}$$

$$\approx 4 \text{ years.}$$

4.2 Discussion.

In the case study, the objective is to oversee the interface of utility and process in the optimization point of view. A step by step procedure to observe this interaction has discussed in the preceding chapter is a guideline or rather a method of optimization covering both utility and process site. The way its work is just like moving inwards of the onion diagrams (Figure 4.8).

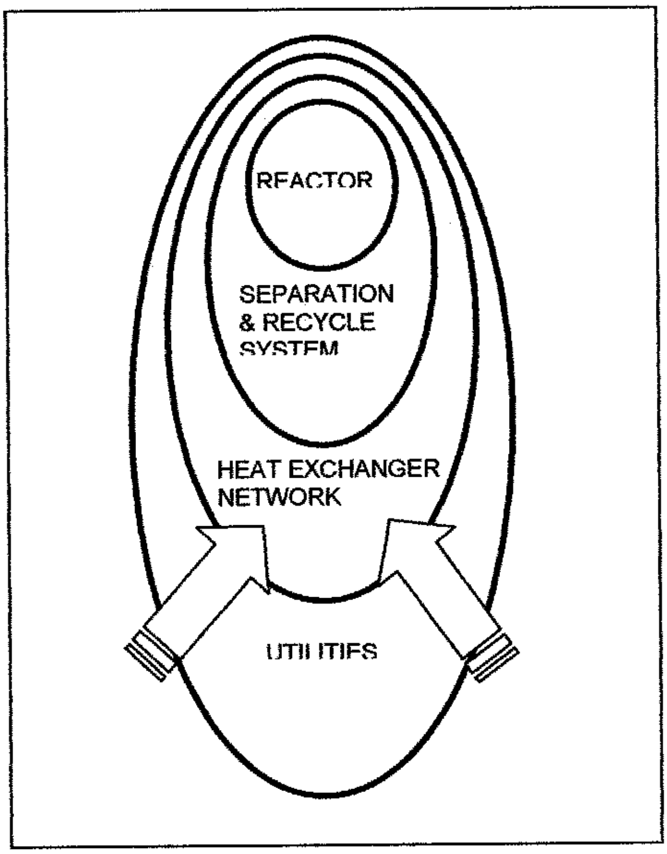

FIGURE 4.8: Onion model of process design

The first part of the process, it emphasize on the utility plant optimization. The reason why it started from utility rather than process is to obtain optimum cost of operating the utility plant. In this case study, only the heating duty is giving prominence to the process site which is a steam generation plant. In most cases, the reported cost of steam is the average cost of generation at a particular production rate. The total operating costs – fuel, power, water, chemical additives, labor, maintenance, depreciation, interest and administrative overheads – are divided by the total amount of steam produced. This may be a convenient corporate financial benchmark, but is not particularly useful for managing the steam system to minimize costs.

From the optimum operating cost calculated then the price of steam produce can be calculated. It is observed that the cost of steam produce is varied as the steam demand changing. This is one of the effects that may vary the steam price. Knowing the cost of steam is important for many reasons, and all of them have to do with improving the company's bottom line, including:

- To properly evaluate the economics of proposed process efficiency or capacity-improvement projects.
- To serve as basis for optimizing the steam generation system.

The most crucial part over all the process is obtaining the marginal steam pricing plot. It is obtained by virtue of reducing the steam demand by the process in a certain amount of reduction. In optimizing the steam system, a reduction of steam should be followed rather than increase the steam demand. The target here is to obtain a trend of steam price with respect steam saving at different header with the most beneficial path of steam header. From the result obtained, the MP steam gives the most beneficial decrement of steam demand at first place. At some point of reduction, when the marginal price starts to drop, it is not beneficial to further reduce the steam demand. Instead, the next header will be chose for further decrement.

A marginal steam pricing plot, Figure 4.5, is used as an indicator to give the scope of saving as a result of reducing the steam demand by the process. The plot also dictates the interface of utility and process site on the same impact. Result obtained in Table 4.2 showing that the effect of marginal steam price as a result of reducing the demand from the steam header. The marginal price is reducing as the demand of steam from the process is reduce. Steam at lower pressure is produced by the exhaust of the turbine after expanding the HP steam to produce power. The HP steam is produce from a boiler in which requires a source of fuel, water, power, chemical additives and more. The steam price produced in the header is reflected by the charge of these sources to produce HP steam. Thus, clearly shown that the steam price is not fix and it is varies as the demand are changes.

At process site, the determination of minimum heating requirement is use to obtain the energy saving. The difference between the existing heating requirement to the minimum heating requirement is the energy saving that the process will achieve. Since the energy or heating medium is coming from the steam supplied by the utility system, we can translate the energy saving in term of steam flow rate. Suppose the heat transfer of steam to the process is by virtue of latent heat transfer, thus the steam saving is the energy saving per latent heat of steam at a given temperature.

The amount of steam saving from the process can further translate into a sense of money by using the marginal steam pricing plot. Amount of saving can easily taken out from this plot by taking the area under the curve. The saving obtained now is more realistic as the true steam price is carried out by taking into account the other related causes. From the marginal steam pricing plot, the scope of saving is $32,326.44/year. This amount of saving obtained is quiet low to implement the optimization project. Using this figure, we can estimate that the payback time will give a high number of years. In reality, it is not feasible to further invest into a project in which will give low saving at the end of the day. In this case study we want to observe the utility-process interface with assumption that the two system i.e. utility and process is link to each other even though both systems are taking from a different sources.

This process is not end until this point but it can further used to estimates the number of years to get the payback of the capital investment on the project. The estimation of capital cost of heat exchanger is as shown in Table 4.5 by using equations (4) and (5). The assumptions made in the estimation are;

- Overall heat transfer coefficient is constant throughout the process
- The material of construction is carbon steel type

The overall heat transfer coefficient of 0.3 kW/°C.m^2 is taken because from literature it was found that this is the estimation used for the palm oil streams of heat exchanger. We will expect that the coefficient is low enough for the organic oil. As the capital cost for heat exchanger obtained, the payback period can be obtain by dividing the scope of saving to the capital cost. From the calculation performed, the payback period is around 4 years time. The number of years obtained is not a good figure to implement the project. We would expect the return on investment will be less than 2 years to make it feasible to implement the optimization project. However, in this case study, focus are on the method that can be applied in optimization project but not the value obtained.

The payback period then can be used to evaluate the feasibility of the project. By using this approach, it is more practical to relate process to utility in such a way that it can clearly shown and estimate the scope of saving.

Conventional optimizer used in industry nowadays didn't overlook on this interaction of utility and process site. Even though the impact on the profitability of the company is not much in utility site but it still give an impact of operating cost as modifying the process operation. Moreover, the steam price is not fixed at certain amount. It is rather to vary as the operational changes in the utility system, as well as the demand from the process. This kind of aspect should be covered in order to drive to the most cost-effectiveness of optimizing the plant operation. For instance, the energy drive into the process being supplied by utility. At the end of the month, the bill only figures out at the utility only. Thus, modifying on process site will then give an impact to the bill of utility. This kind of trade off should be covered before the optimization of the plant can be carried out.

As we can see, the result obtained for the calculation of saving amount and payback period giving the value that not meet the expectation. The reason is that the utility system and the process that being used in this case study is not tally to the palm oil process. Assumption made upfront that any utility system can be used for a give process plant is not accurate. However, the focus is on the procedure of optimizing the utility and process, thus the error in the case study is not the major causes towards the end of the optimization process.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The interconnection of utility and the process is essentially important in optimization project. Dependency of each sites is important and negligence of those effect is inappropriate. It is more feasible to start to optimize the utility system first and moving towards the process site since most of the energy sources is from utility. The approach obtained dictates the significance of marginal steam pricing plot in optimization project. In real situation, the actual cost of steam is likely to be variable. It may take on a finite value initially as the first amounts of steam are saved then, at some point, the value of steam reverts to zero or even negative value. Therefore it has to be a specific limit to the amount of steam that can be saved and further investment would be fruitless. Marginal steam pricing is an approach to cater this situation.

As the utility system is optimize then only the process site will be focus. The objective is to determined the energy target at the process sites and hence the amount of steam saving can be obtained. The interest on obtaining the amount of steam saving is to discover the amount of saving in dollar and cents.

The tool that has been used in this project is easy to implement and it is more realistic to visualize. Working inward of the onion diagram in such a way that could give a clear picture of the interaction between the process and utility system.

5.2 Recommendation

The case study used in this project is base on separate system of utility and process. Since the objective is to observe the interaction between these system, assumption that had been made is that any type of system is applicable to demonstrate the interface. However, the link between utility and process using this method may not give an accurate value since those system are not tally with each other. To make it more realistic, a case study from industry that could apply the same principle should be carried out and hence reducing the number of assumption made in the process of optimization. Base from the actual plant setup and data's it will help more to visualize the approach being propose here.

For simplified the optimization process, the method proposed can be automated. Automated in this context is to develop a software programming that could cover the specific area of optimization process. The method proposed is more towards managing an appropriate way of utility system. Nowadays in industry, there is plenty of software covering on the process. If the automation on the utility and the process could combine together, it will make thing easier and more coverage. This will help user to optimize utility-process interface with short time period and more organize.

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APPENDICES

APPENDIX 1: Linear programming model using GAMS interface optimizing the steam generation

```
$Title Example of utility optimization

$Ontext

        This programme is used for Steam Generation System optimization.
        Written by Najmie Ahmad

$Offtext

variables
        p1   power turbine 1
        p2   power turbine 2
        he1  exit flow from turbine 1 to mps
        he2  exit flow from turbine 2 to mps
        c    condensate from turbine 1
        i1   inlet flow to turbine 1
        i2   inlet flow to turbine 2
        le1  exit flow from turbine 1 to lps
        le2  exit flow from turbine 2 to lps
        bf1  bypass flow from hps to mps
        bf2  bypass flow from mps to lps
        hps  high pressure steam
        mps  medium pressure steam
        lps  low pressure steam
        ep   excess power
        pp   purchased power

        f    objective ;

positive variable p1, p2,he1,he2,c,i1,i2,le1,le2,bf1,bf2,hps,mps,
            lps,ep,pp ;

        p1.up = 6250;
        p1.lo = 2500;
        p2.up = 9000;
        p2.lo = 3000;
        he1.up = 192000;
        mps.lo = 271536;
        lps.lo = 100623;
        c.up = 62000;
        i2.up = 244000;
        le2.up = 142000 ;

equations
```

```
     turb  turbine 2 inequalities
     mbln1 material balance 1
     mbln2 material balance 2
     mbln3 material balance 3
     mbln4 material balance 4
     mbln5 material balance 5
     mbln6 material balance 6
     ebln1 energy balance 1
     ebln2 energy balance 2
     power power purchased
     demn  demand
     cost  define objective ;


turb..  i1 - he1 =l= 132000 ;

mbln1..  hps-i1-i2-bf1 =e= 0;
mbln2..  i1+i2+bf1-c-mps-lps =e= 0;
mbln3..  i1-he1-le1-c =e= 0   ;
mbln4..  i2-he2-le2 =e= 0     ;
mbln5..  he1+he2+bf1-bf2-mps =e= 0;
mbln6..  le1+le2+bf2-lps =e= 0 ;

power..  ep+pp =g= 12000 ;

demn..  p1+p2+pp =g= 24550 ;

ebln1..  1359.8*i1 - 1267.8*he1 - 1251.4*le1 - 192*c - 3413*p1 =e= 0;
ebln2..  1359.8*i2 - 1267.8*he2 - 1251.4*le2 - 3413*p2 =e= 0 ;

cost..  f =e= 0.00261*hps + 0.0239*pp +0.00983*ep;

model optimum /all/ ;


solve optimum using lp minimizing f;
```

APPENDIX 2: Cascade Diagram of the process