Fouling Mitigation Suite: GUI Development in Excel

by

Hafiza Bismilhuda b Mohamad Zin

Dissertation submitted in partial fulfilment of
the requirements for the
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Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved by,

28/06/2010

(AP Dr. M. Ramasamy)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

July 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work 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.

HAFIZA BISMILHUDA B MOHAMAD ZIN

ABSTRACT

The objective of this project is to develop a fouling prediction model in crude preheat train (CPT) in refinery. Heat exchanger is a very important device of equipment that is commonly used in industry such as petrochemical, processing and refinery plant. Heat exchanger is used to transfer heat from a liquid on one side of a barrier to a fluid on the other side without bringing the fluid into direct contact. The crude preheat train (CPT) in a petroleum refinery consist consists of a set of large heat exchangers which recovers the waste heat from product streams to preheat the crude oil. The accumulation of unwanted deposits on heat transfer equipment results in reduced efficiency of heat recovery. This phenomenon is called heat exchanger fouling. In addition to this project, the research will be associated with the development of user interface (GUI) for reading and writing data into the model. Fouling model is developed based on the actual data taking from PETRONAS Penapisan Melaka (PPMSB). The model will predict the fouling resistance, R_f once the input which are crude and product properties, crude and product mass flowrate, crude and product inlet temperature and time. Rf will be used in the simulation of heat exchanger using PETROSIM for the calculation of actual outlet temperature of crude and product. All the product and crude properties is generated in the PETROSIM before it was exported to the Microsoft Excel. The results which are the outlet temperature of the crude and product obtained in the model will be compared with the actual data from refinery plant after the reconsilation, to justify the accurateness of the model.

ACKNOWLEDGEMENT

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I am also indebted to Graduate Assistant which is Mr. Totok R. Biyanto, Postgraduate student for teaching me on the coding in the Visual Basic Application for finishing this project and simulation of the heat exchanger network software PETROSIM. His willingness to assist me in doing this project is truly appreciated.

I cannot end without thanking our friends and family, on whose constant encouragement and love we have relied throughout our time in this whole semester. Their unflinching courage and conviction will always inspire us. It is to them that we dedicate the success of our plant design project.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Heat exchanger is a device that is used to transfer heat from a liquid on one side of a barrier to a fluid on the other side without bringing the fluid into direct contact. There are many name of heat exchanger available that were used in industry such as [1]:

a. Furnace – combustion process occur directly by fire
b. Boiler - usually used to change the liquid water to be steam
c. Reboiler – often used in distillation column
d. Chiller
e. Evaporator
f. Condenser
g. Sublimator
h. Others.

In the heat exchanger, heat is being transfer from hot fluid into cold fluid. When there is an impurities inside the fluids, there will a possibilities of fouling to occur. The fouling occurs due to the precipitation of the impurities onto the surface of the tube inside heat exchanger [1].

There are many research had been conducted to overcome this problem. Recently, several authors have decided to use artificial intelligence as an alternative method for the prediction of fouling. Neural network have been used in recent years to avoid the problems associated with deterministic approaches, and have been shown to approximate nonlinear functions up to any desired level of accuracy. They are also less sensitive to noise and incomplete information than other approaches such as empirical models and correlations. The advantage of using neural network to simulate thermal processes is that, after they trained, they represent a quick and reliable way of predicting their performance [1].

The data collection (designed data, historical data and crude oil/product properties from refinery plant), properties estimation, data processing, and calculation of heat exchanger performance such as heat transfer coefficient, efficiency and fouling resistance are needed in order to develop a model with predictive capability [2].

Neural network are a formidable tool for function approximation and classification problems. The approach suggested in this research is the application of neural networks with Multi Layer Perceptron (MLP) structure and combine with phenomenological model to predict the fouling in CPT [2].

1.2 PROBLEM STATEMENT

Fouling in Crude Preheat Train (CPT) in a refinery has been identified as a major obstacle for efficiency energy recovery. Due to fouling in the preheat exchanger, energy is lost. As a result of this phenomenon, the operational cost of the refineries increased. Maintaining optimality in the heat exchanger network becomes a trial and error procedure since lack of tools to access the fouling. This will results in the reduction of plant profit and also reduce the optimality operation of the heat exchanger network.

A large number of phenomenological models for crude oil fouling have been presented. They can explain the simplest fouling phenomena, however they are not able to predict the fouling formation by changing of the operating conditions and differing crude properties.

1.3 OBJECTIVES

The main objective of this project is to develop a fouling prediction model in crude preheat train (CPT) in refinery. This research will be associated with:

1. Development of Graphical User Interface (GUI) for reading and writing data in the neural network system for the fouling prediction.

CHAPTER 2

LITERATURE REVIEW

2.1 FOULING AND TYPE OF FOULING

Fouling, which can be defined as the deposition of foreign substances on the surfaces of heat exchangers, is strongly dependent upon a variety of ageing mechanisms such as corrosion, fatigue, wear, or pitting, and is also closely linked to the operational conditions such as fluid temperature and velocity (Kukulka and Devgun, 2007) [3].

Fouling in heat exchanger can be defined as the accumulation of unwanted deposits on heat transfer equipment result in reduced efficiency of heat recovery. Fouling is a complex process, usually involving various physiochemical processes [4].

Fouling in heat exchanger can be divided into 6 types which are [5]:

a. Crystallization – most common type fouling which occur many process streams including heat exchanger.
b. Coking – usually occur at a high temperature streams or surfaces. It was resulted by hydrocarbon deposits
c. Corrosion - this type of fouling may produce an added thermal resistance, as well as surface roughness.
d. Sedimentation - caused by deposit of particulate matter such as rust, clay and sand.
e. Polymerization – result in polymerization process that produce polymer and will cause clogging.

f. Chemical reaction – chemical reaction inside process stream may produce insoluble product or precipitate. This byproduct can cause fouling in the process stream.

It is common to classify fouling into six categories depending on the key physical or chemical process essential to the particular fouling mechanism. The six categories are precipitation, particulate fouling, corrosion, biological fouling, solidification and chemical reaction [4].

Precipitation fouling occurs when dissolved salts in the flowing fluid crystallize as the fluid becomes supersaturated with respect to a deposit forming material. The driving force in precipitation fouling is provided by the difference in chemical potential of the substance in the solution and that at the surface. Inorganic salts can exhibit either normal or inverse solubility tendency. Salts that exhibit normal solubility form deposits on subcooled surfaces, while those salts that have inverse solubility behaviour form deposits on superheated surfaces. The most widely encountered form of precipitation fouling is that due to crystallization [4].

In *Particulate fouling* particles that are suspended in the flowing fluid get deposited on the heat transfer surface. The source of the suspended solids could be corrosion products or crystallization products formed in the bulk or just particles such as sand. Particulate fouling and crystallization fouling have been observed to occur together [4].

Corrosion fouling is due to the chemical reaction between the heat transfer wall and the species in the fluid. The heat transfer surface is also a reactant. Corrosion products may act as catalysts in fluencing other fouling mechanisms. For instance, deposited corrosion products may lead to roughening of the surface, which, in turn would act as nucleation sites and promote crystallization and sedimentation. Corrosion problems are encountered in cooling systems when river water is used as a cooling medium or in boiler plants where fine suspensions of black magnetite particles may circulate with the boiler feed water [4].

Biological fouling occurs when an organic film consisting of microorganisms and their products develop on a heat transfer surface. Biological fouling can also result from the growth of microorganisms in the fluid and a subsequent deposition on the surface. This type of fouling is common in cooling water systems and in milk factories [4].

Solidification fouling occurs either due to the solidification of a pure liquid in contact with a subcooled surface, or the deposition of a high melting point constituent of a liquid in contact with a cold heat transfer surface. Examples of this can be found during the production of chilled water [4].

Chemical reaction fouling occurs when deposits accumulate on a heat transfer surface as a result of a chemical reaction. In this type of fouling, surface temperature is an important parameter as it affects the reaction rate. Oxidation promoters are also of importance. The material of the heat transfer surface does not take part in the reaction though it may act as a catalyst. This type of fouling is found in petrochemical industries [4].

Fouling of heat transfer surfaces presents challenges to both designers and operators of heat exchangers in many process industries_ Fouling is a process by which deposits settle and accumulate on heat transfer surfaces. Some examples of fouled surfaces are given in figures 1, 2, 3 and 4. Fluids flowing in heat exchangers may contain dissolved substances, suspended matter or may carry substances that promote growth of biological organisms. As a result deposits may accumulate on a heat transfer surface leading to the formation of a layer. The thermal conductivity of the layer so formed is mostly very low and, therefore, its presence on a heat transfer surface tends to increase the resistance to heat flow. Consequences of fouling in process industries include increased energy consumption, extra maintenance and labour costs and loss of production opportunities [4].

Figure 2.1: Fouled shell and tube heat exchanger due to calcium carbonate scaling (Bott, 1990) [4]

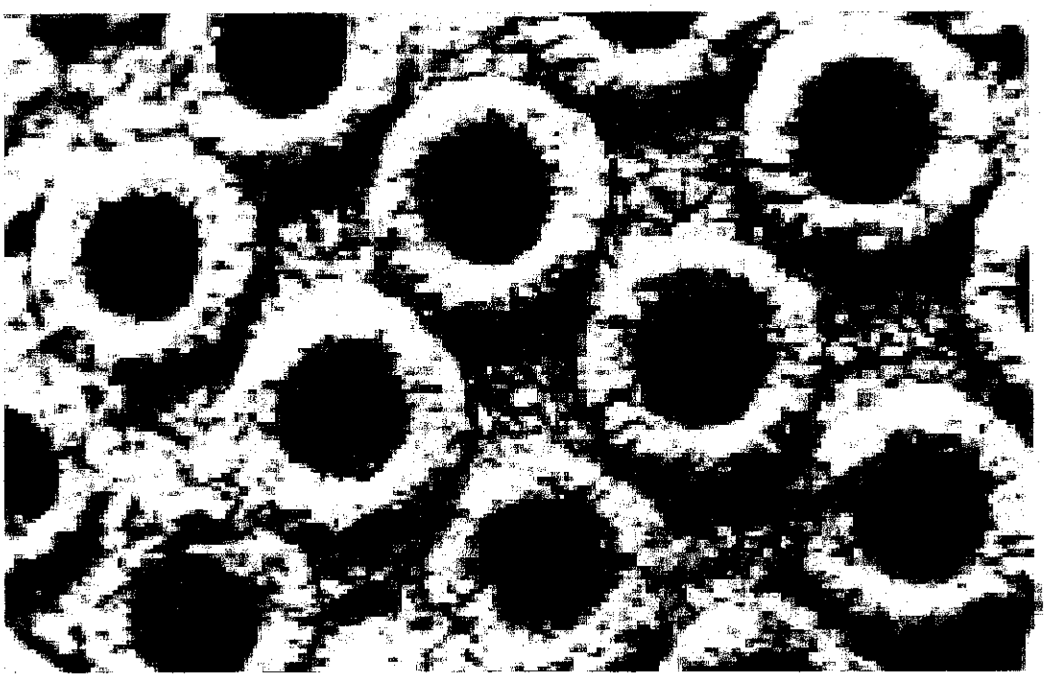

Figure 2.2: Fouled heat exchanger tubes due to chemical reaction (Bott, 1990) [4]

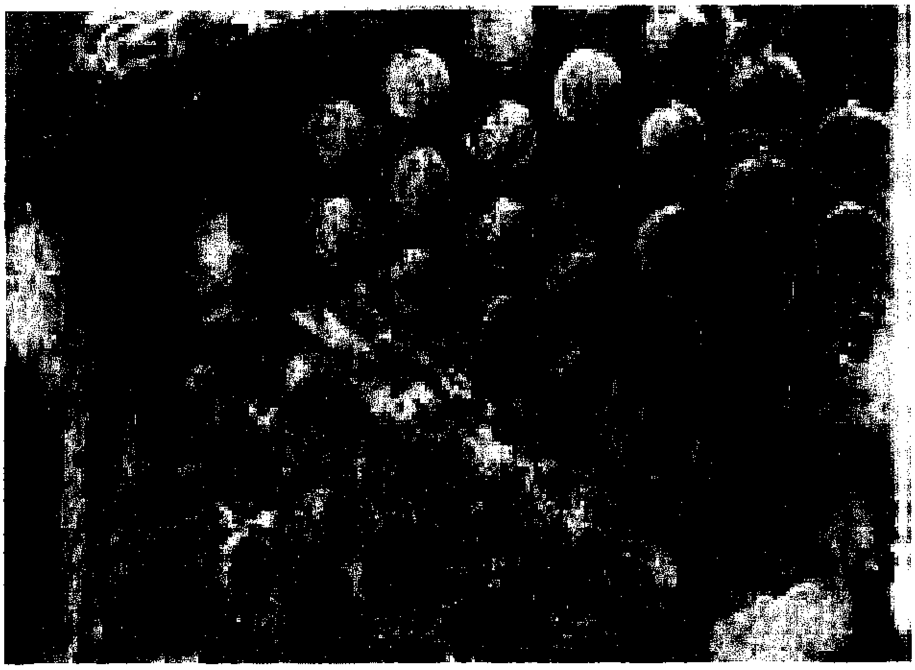
Figure 2.3: Fouled tubes of a juice heater in the sugar factory in Zambia [4]

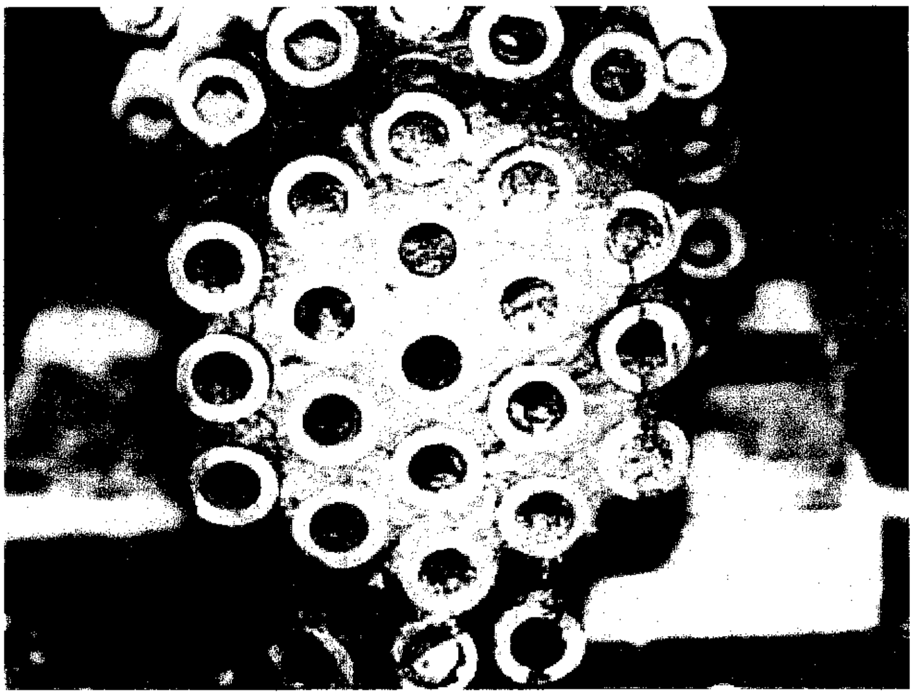
Figure 2.4: Fouling on the shell side of an ammonia reactor effluent cooler operated with treated cooling water [8]

Fouling in heat exchanger has been the subject of intensive research by researchers. Some research that had been done before [6]:

a. Crittenden et al. in a series of papers reported that their research on the mass transfer and chemical kinetics in hydrocarbon fouling.
b. Ebert and Panchal were the first to introduce theoretical concept to the phenomenon of fouling. They modelled the fouling process using a rate equation and introduced the concept of threshold temperature below which fouling is minimum. They also investigate the effect of tube inserts on the reduction of fouling.
c. Watkinson investigate the fouling of heat exchangers by organic fluids.
d. Watkinson and Epstein investigate the effect of particulate on fouling.
e. Saleh et al. studied the effect of blending on the rate of fouling of Australian crude oils.
f. Some researchers had published a complete review of the state of the art in the area of fouling mitigation by various techniques.
g. Markowski and Urbaniec have presented an optimal scheduling of cleaning interventions in a heat exchanger network base on computational approach to minimize losses.

The performance reduction due to fouling is mitigated by periodic cleaning of the heat exchangers. However, during cleaning, the heat exchanger is out of the heat recovery loop and hence the overall heat recovery goes down, if the rate of fouling can be predicted a priori, cleaning of heat exchangers can be prescheduled to minimize operational disruptions. The fouling model was developed using neural network technique [6].

The process to overcome this problem is called fouling mitigation. It is done either by preventing the deposition process from taking place or by "online" or "offline" cleaning, generally imposes a severe cost penalty. Furthermore, to allow for the fouling problem, additional heat transfer area has to be accommodated in the heat exchanger, which requires additional capital cost. The combination of the additional operating and maintenance cost and the increased capital investment required, not only for additional heat transfer area, but also for equipment associated with cleaning, affect the profitability of the whole process [7].

Fouling in industrial heat exchangers leads to economic penalties. Efforts have been made to assess the costs of fouling, either for a particular industry or for a particular country. Steinhagen et al (1993) estimated that in New Zealand, the annual fouling related costs amounted to 45M$. Thackery (1979) studied fouling costs in the United Kingdom and estimated the overall costs of fouling to be in the range 300-500 M£ per annum. For the United States, Garrett-Price (1985) suggested that the annual costs of fouling could be between 8 000 and 10 000 M$. On the industry level, Van Nostrand (1981) studied fouling costs in the refinery industry and gave a figure of 10M$ per annum as being typical for a refinery processing 100 000 barrels of crude oil per day [4].

The effect of fouling is not confined to the process itself. In general, heat exchanger inefficiencies will result in shortfall in heat recovery to be made up from fuel sources, usually the combustion of fossil or other fuel [7].

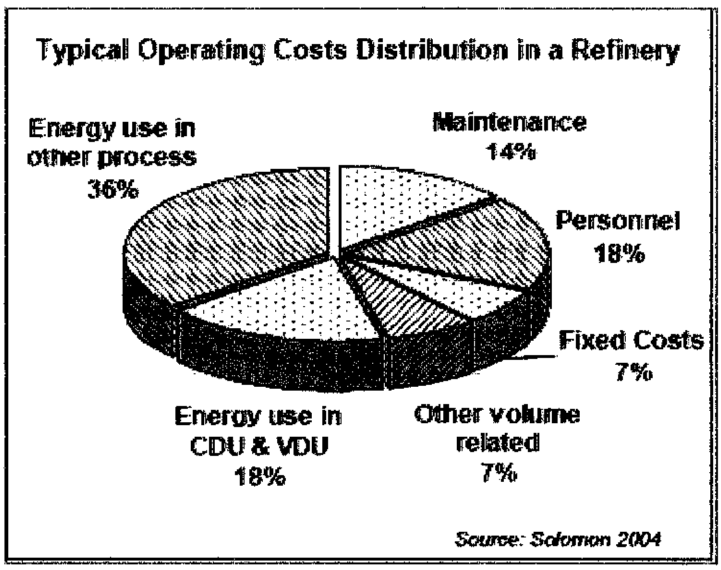

Figure 2.5: Operating Cost Distribution in refinery [8]

The problem of fouling in heat exchanger has existed since the beginning of the industrial revolution. A lot of conference had been done on the subject of heat exchanger fouling. The result of the conference were a greater awareness of fouling mechanisms, encouragement of experimentation, and research in the field toward a better understanding of the phenomena and its mitigation [7].

2.2 RATE OF FOULING

Rate of fouling or fouling resistance is a function of time. Systematic research on fouling is relatively recent and extremely limited. The few research data which exist usually are proprietary or obtained from qualitative observations in plants. Below is shown the common equation used in determining the rate of fouling [9]:

$$1/U = 1/h_1 + 1/h_2 + R_f$$

Where,

U = overall heat transfer coefficient (Btu/hr.ft^2.°F)

h_1, h_2 = film coefficient of the two heat transfer fluids (Btu/hr.ft^2.°F

R_f = fouling resistance (hr.ft^2.°F/Btu)

At steady state conditions, the heat flux, q" across a clean surface is given as:

$$q" = U_C \Delta T_{lmtd}$$

$$\Delta T_m = \frac{\Delta T_1 - \Delta T_2}{\ln \frac{\Delta T_1}{\Delta T_2}}$$

$$\frac{1}{U_c} = R_{TC} = \frac{1}{h_h} + R_W + \frac{A_h}{A_C h_C}$$

Where: q" = heat flux

U_c = overall heat transfer coefficient for clean condition

ΔT_{lmtd} = log mean temperature difference between hot and cold fluids

ΔT_1 = temperature difference between hot fluid

ΔT_2 = temperature difference between cold fluid

R_{TC} = total resistance to heat flow

`A_c = cold fluid side heat transfer area

$\frac{1}{h_h}$ = film resistance of the hot fluid

$\frac{A_h}{A_C h_C}$ = film resistance of the cold fluid

R_W = resistance to heat flow of the metal wall

The heat flux across a fouled surface is given as:

$$q = U_D \Delta T_m$$

Where:

$$\frac{1}{U_D} = R_{TF} = \frac{1}{h_h} + R_W + R_f + \frac{1}{h_C}$$

Where R_f is the resistance of fouling to heat transfer. So;

$$R_f = \frac{1}{U_D} - \frac{1}{U_C}$$

and

$$q'' = \frac{1}{\frac{1}{U_C} + R_f}(T_w - T_b)$$

Where: T_W = wall temperature

T_b = bulk temperature

As we can see the equation above, let T_w is to be kept constant, heat flux q" decreases with the increasing R_f, thus results in a lower temperature of cold fluid. Alternatively, if the heat reflux q" remains constant (the deposit/fluid interface temperature remains the same as the clean wall temperature value), T_w must be increased with the increasing R_f [9].

In determining the fouling resistance in heat exchanger some physical properties of fluid is needed which are density, Cp, viscosity and thermal conductivity. In addition, process data is also needed which are product and crude inlet temperature and product and crude mass flowrate. By using this data fouling resistance, crude outlet temperature and hot liquid outlet temperature can be calculated [9].

2.3 EBERT & PANCHAL MODEL

The Ebert and Panchal fouling model was used to assess the fouling tendency of the exchangers of an industrial crude distillation unit (CDU) preheat train [9]. The ranking obtained through a monitoring and processing of the performances of the different exchangers matched quite well the predictions of the Ebert and Panchal fouling model [11].

The Ebert and Panchal model can be used to predict tube side fouling conditions for crude oil and is expressed as a competition between deposition and removal term [11]:

$$\frac{dR_f}{dt} = \alpha \, Re^{-0.66} \, Pr^{-0.33} \exp\left(-\frac{E}{RT_{film}}\right) - \gamma \tau_w$$

Where:

R_f = fouling resistance (m^2K/W)

α = Ebert and Panchal model constant

Re = Reynolds number

Pr = prandtl number

E = activation energy

R = perfect gas constant

T_{film} = film temperature

γ = Ebert and Panchal model constant

τ_w = wall shear stress

From equation above, when $dR_f/dt = 0$ means that we are in a situation where either no or asymptotic fouling occurs. However, this model was not developed to predict asymptotic fouling but to provide certain combinations of film temperature, T_{film}, and tube flow velocity giving rise to zero or negligible fouling [11].

The film temperature, T_{film} can be calculated using equation below:

$$T_{film} = (T_{wall} + T_t)/2$$

Where; T_{wall} = wall temperature

T_t = bulk temperature of the fluid flowing in tubes

The wall shear stress τw is linked to bulk velocity through the friction factor:

$$\tau_w = \frac{1}{2}\rho v^2 f \quad with \quad f = \frac{0.0791}{Re^{1/4}}$$

Without considering heat transfer resistance through tube wall, wall temperature can reliably be assessed by the following formula:

$$T_{wall} = \frac{h_o d_o T_s + h_i d_i T_t}{h_o + h_i}$$

Where; h_o = tube outside film heat transfer coefficient

h_i = tube inside film heat transfer coefficient

d_o = tube outside diameter

d_i = tube inside diameter

T_s = bulk temperature on shell side

T_t = bulk temperature on tube side

2.4 ROETZEL-SPANG EQUATION WITH FOULING MODEL

Roetzel-Spang (1989) have analysed the performance of multi-pass shell and tube heat exchanger in which either the amount of surface area contained within the individual passes or the overall heat transfer coefficients encounter in the individual passes differed [14].

The analysis showed that the overall effectiveness of the exchanger was a function of the Number Transfer Units (NTU) contained in the individual passes (parallel and counter flow) and is given by [13]:

$$\frac{1}{\varepsilon} = v + R + \frac{1}{NTU_T}\,\frac{m_1 e^{m1} - m_2 e^{m2}}{e^{m1} - e^{m2}} \tag{1}$$

Where: NTU_T = total number of transfer unit in heat exchanger.

ε = overall heat transfer effectiveness

R = ratio of tube side to shell side CP

m_1, m_2 = mean fouling resistance

$$NTUT = NTUcf + NTFpf \tag{2}$$

And,

$$v = \frac{NTU_{pf}}{NTU_T} \tag{3}$$

$$R = \frac{CP_t}{CP_s} \tag{4}$$

$$m_1 = \left(\frac{NTU_T}{2}\right)\left(-\left[\{R + 2v - 1\}^2 + 4v(1 - v)\right]^{1/2} - [R + 2v - 1]\right) \qquad (5)$$

$$m_2 = \left(\frac{NTU_T}{2}\right)\left(-\left[\{R + 2v - 1\}^2 + 4v(1 - v)\right]^{1/2} - [R + 2v - 1]\right) \qquad (6)$$

If we have a suitable means of specifying a mean fouling resistance to each pass then these equation can be used to predict overall heat exchanger performance without the need to integrate detailed equation over space [14].

CHAPTER 3

METHODOLOGY

The project work for the fouling prediction model development is show in Figure 3.1 below.

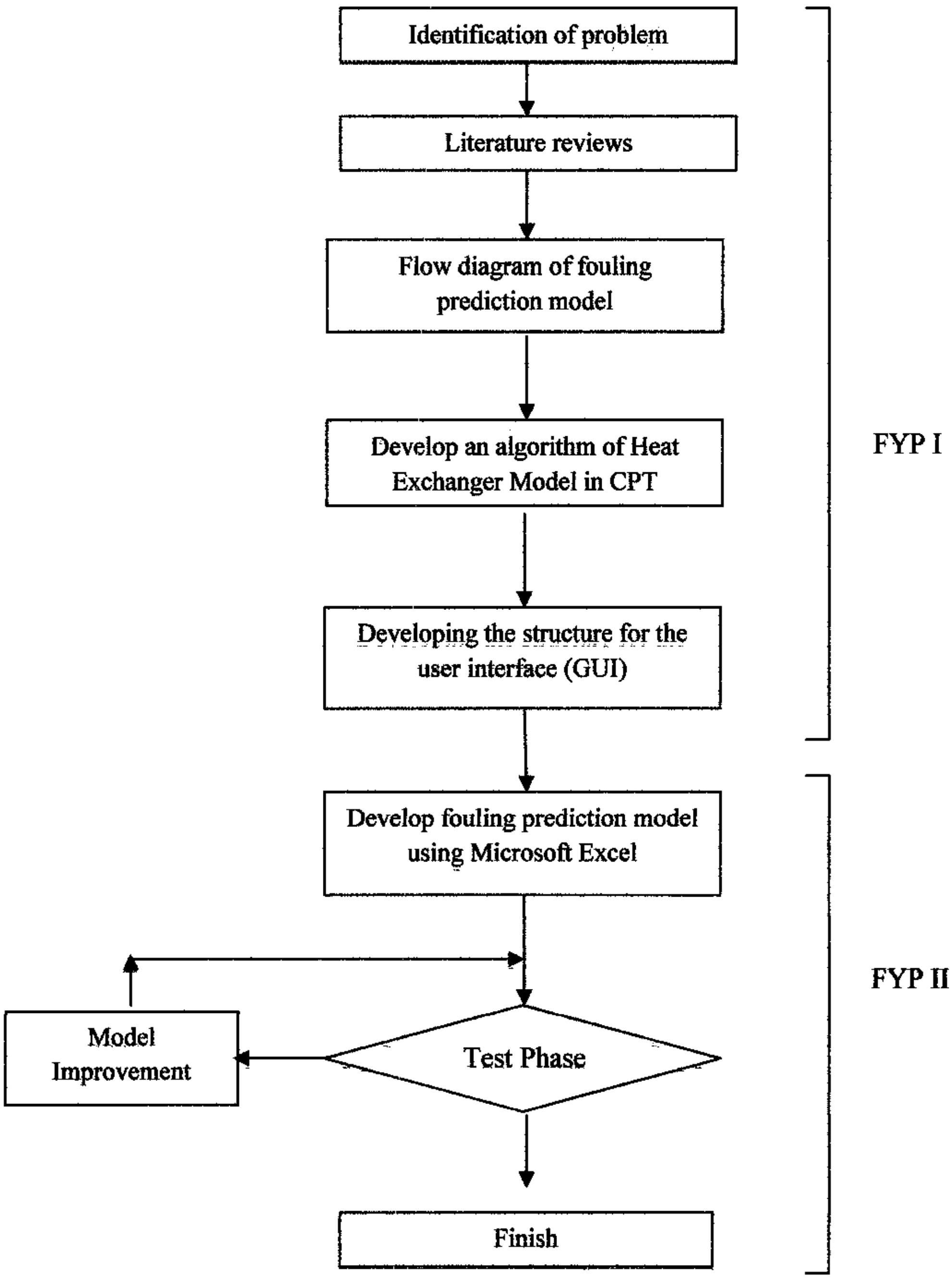

Figure 3.1: Project Flow Chart

Problem identification is the first phase in order and become the starting point of this project. As stated in the Chapter 1 at the Problem Statement section, the problem is regarding the major obstacle for efficiency energy recovery in the Crude Preheat Train (CPT) in refinery due to fouling.

Once the problem had been identified, the next step that needs to be done is doing the research by literature review. Some previous research regarding fouling mitigation model had been reviewed for more understanding of the problem. Besides, the research on the literature review also went through the mathematical equation for the calculation of fouling resistance prediction (R_f). R_f will then be used to calculate the actual outlet temperature of crude and product.

Also during this process, flow diagram of fouling prediction model was developed for easy understanding of the conceptual design. The flow diagram is just a block diagram of integrated model combining about 5 models which are:

1. Look up table
2. PETROSIM: generate properties
3. **Fouling Prediction Model**
4. Shell and tube heat transfer coefficient calculation
5. Heat exchanger simulation using PETROSIM.

This project only focusing on the 3rd model, which is Fouling Prediction Model. Once the overall schematic diagram of integrated model obtained, the next step is to develop an algorithm of heat exchanger model in CPT. The algorithm is actually the simplify of the schematic diagram of integrated model.

The next step involve in this project is a development of structure for user interface (GUI). GUI is develop for writing and reading the data or result from the database. In doing this part, programming software was needed which is Visual Basic Application (VBA) in Microsoft Excel.

All the steps discussed above were done in the first semester which is during FYP I. for FYP II, two more steps need to be finished before completing this project; develop fouling prediction model using Microsoft Excel and test phase. This is the most important part that will determine whether this project is successful or not. Model improvement is needed if some error or mistake had been done during the process. The project is finally considered finish after the test phase.

Test phase is done by comparing the results gained with the actual data since the data for this model is taken from previous years which are from 18th November 2007 until 10th March 2008. The error between calculated and actual crude and product outlet temperature is calculated and evaluated. If the error not exceeding the maximum allowable error, then the model can be used.

3.1 HEAT EXCHANGER NETWORK (HEN) FOR CPT

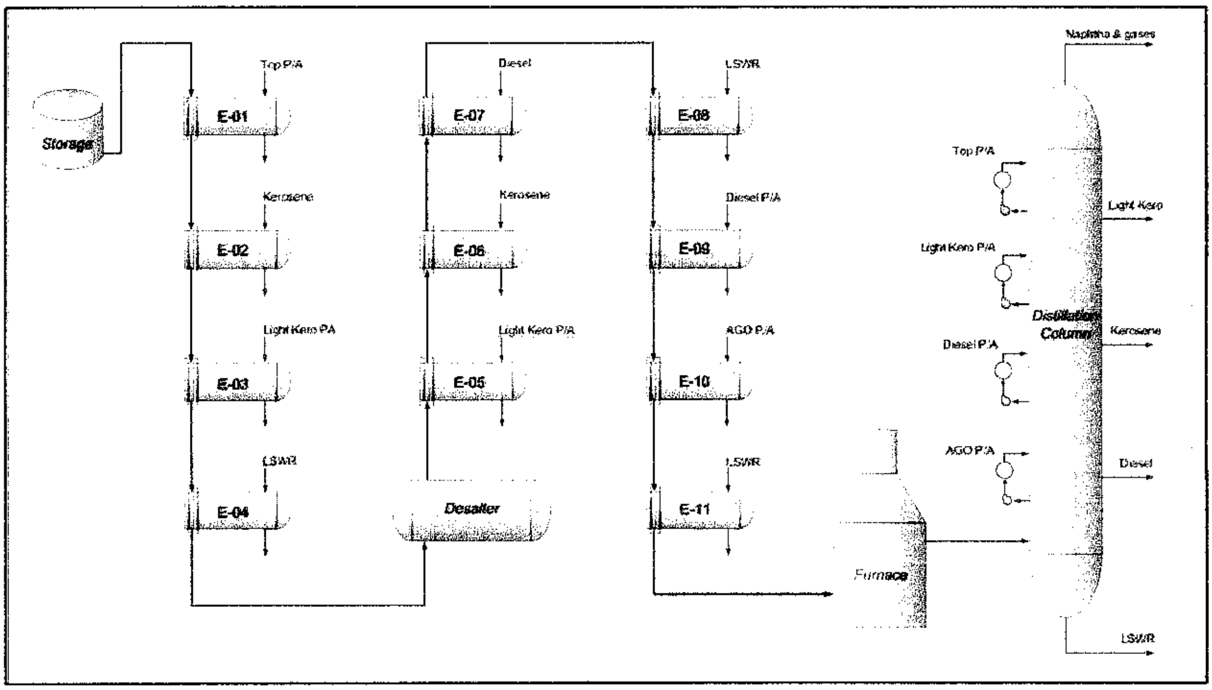

Figure 3.2: Heat Exchanger Network in CPT

Figure 3 above shows us the brief overview of the heat exchanger network (HEN) in CPT that is used in this model. There are 11 in total heat exchangers in the network:

a. E-01
b. E-02
c. E-03
d. E-04
e. E-05
f. E-06
g. E-07
h. E-08
i. E-09
j. E-10
k. E-11

The unprocessed crude will go through the heat exchanger from E-01 to E-11 in a tube side except for the E-04, E-08 and E-11, crude will flow in shell side. The products that were used to cool the crude are shown in the table below:

Table 3.1: Shell Side and Tube Side for the respective Heat Exchanger

Heat Exchanger	**Shell Side**	**Tube Side**
E-01	Top P/A	Crude
E-02	Kerosene	Crude
E-03	Light Kero	Crude
E-04	Crude	LSWR
E-05	Light Kero	Crude
E-06	Kerosene	Crude
E-07	Diesel	Crude
E-08	Crude	LSWR
E-09	Diesel P/A	Crude
E-10	AGO P/A	Crude
E-11	Crude	LSWR

The sketch of individual heat exchangers is shown in the appendix.

Chapter 4

RESULT AND DISCUSSION

4.1 NEURAL NETWORK FOR HEAT EXCHANGER FOULING MODEL

The uniqueness of this fouling neural network model is that the neural network input data are coming from measurement and estimation. The uniqueness of this fouling neural network model is that the neural network input data are coming from measurement and estimation.

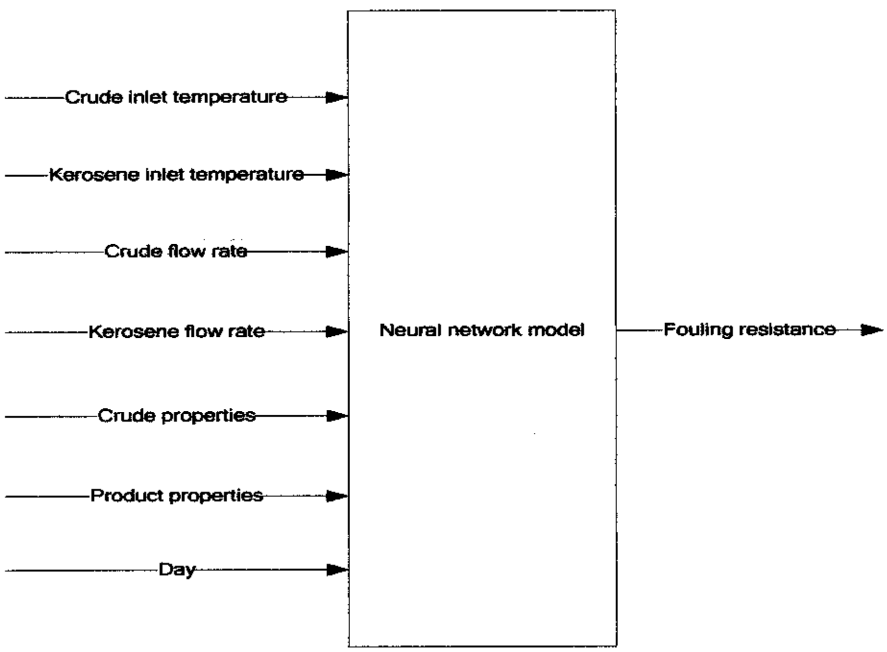

Figure 4.1: Input and output of neural network for the heat exchanger fouling model

In general, the predicted fouling resistance by the neural networks model is in good agreement with the actual values. The complex nature of the heat exchanger fouling characteristics due to changes in operating conditions and crude oil blends (feed stocks) has been captured reasonably well by the model.

The properties of crude and product are predicted using PETROSIM from the in-out average temperatures of product and crude together with crude blend information. Input variables of neural network model consist of, inlet temperatures of crude and product, flow rates, product properties and crude properties. The output variables of the model are the fouling resistance, product and crude outlet temperature. In the same time shell and tube heat transfer coefficients are calculated. The ETROSIM simulation had been done by other person and it is connected to this Neural Network.

4.2 SCHEMATIC DIAGRAM OF INTEGRATED MODEL

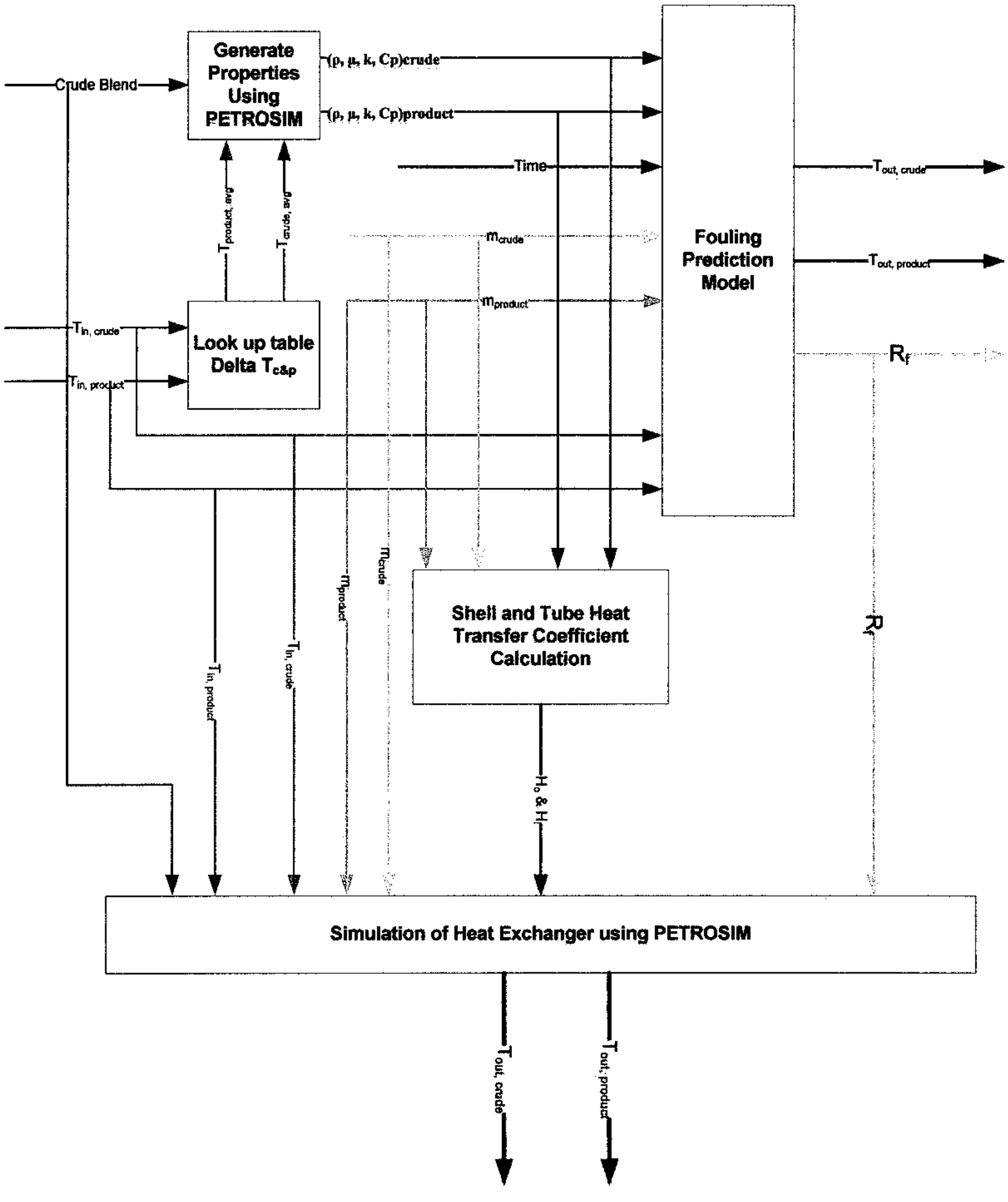

Figure 4.2: Schematic diagram of integrated model

Figure 4.2 shows the schematic diagram of integrated model. There are 5 separated model that doing the different job. Inlet temperature of crude and product enter the first block which then will calculate the average inlet temperature of crude and product. Average inlet crude and product temperature will be send to 'properties generator using PETROSIM' block along with the crude blend data. Coming out from this block are the properties of the product and crude which are:

a. Density, ρ
b. Dynamic viscosity, μ
c. Thermal conductivity, k
d. Heat capacity, C_p

All these properties will be sent to fouling prediction model along with time, mass flowrate of both crude and product and inlet crude and product temperature. This block or model will then calculate the fouling resistance, R_f as well as predicted outlet crude and product temperature.

The results from properties generator using PETROSIM' block which are the properties of crude and product with the mass flowrate of crude and product will be used to calculate the heat transfer coefficient of the heat exchanger in the 'Shell and Tube heat Transfer Coefficient Calculation' block to give h_i and h_o.

Up to these four blocks or models, all the needed values for the calculation in the last model are available, which are:

a. Fouling resistance, R_f
b. Heat transfer coefficient, H_i and H_o
c. Crude blending data
d. Inlet and crude temperature, $T_{in, crude}$
e. Inlet and product temperature. $T_{in, product}$
f. Crude mass flowrate, m_{crude}
g. Product mass flowrate, $m_{product}$

In the last block or model which is simulation of heat exchanger using PETROSIM, the actual outlet crude and product temperature were calculated. All the process above can be describe in the algorithm of heat exchanger model in CPT in the next page:

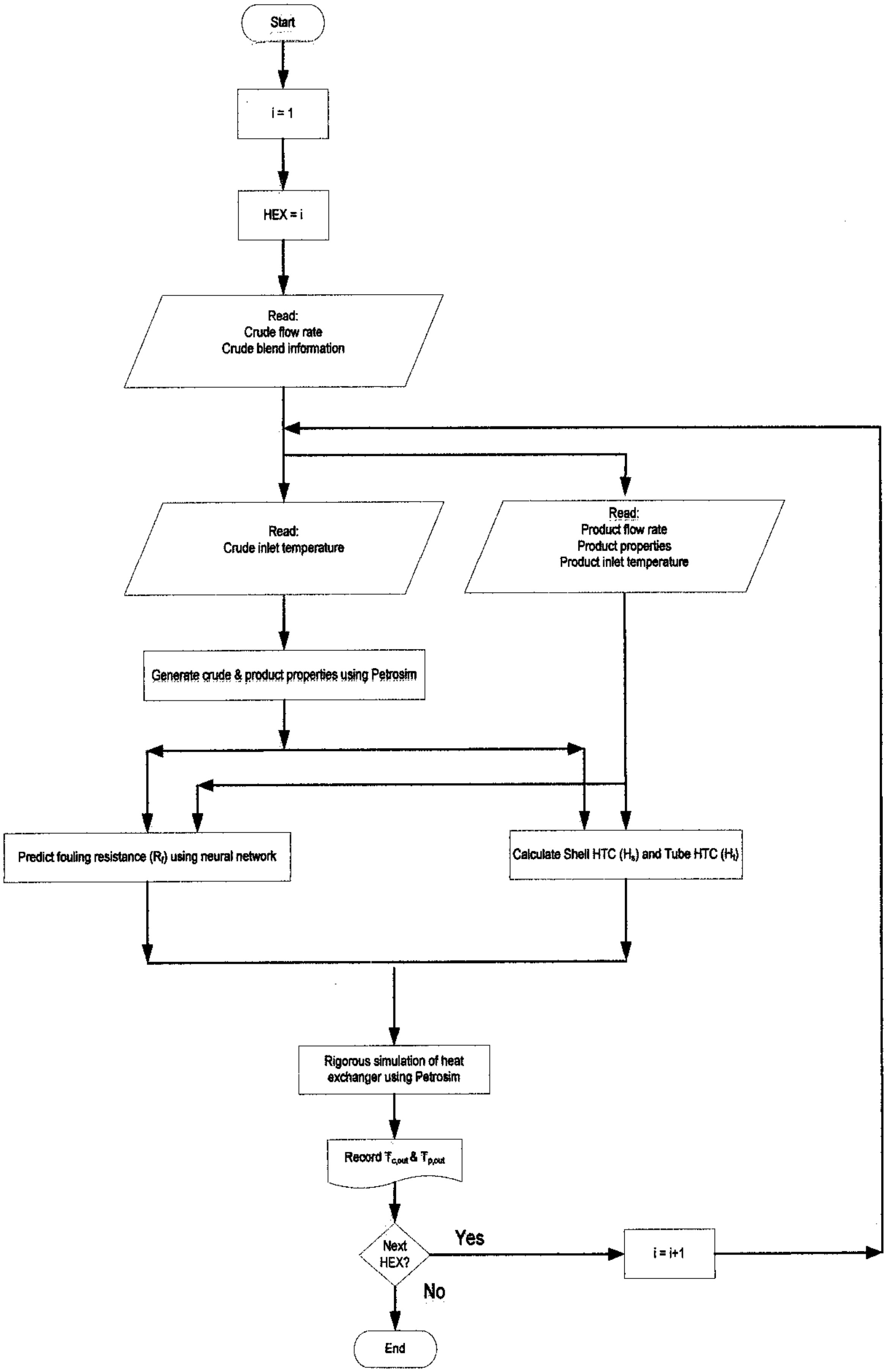

Figure 4.3: Algorithm of heat exchanger model in CPT

PETROSIM as describe before, is a simulation of heat exchanger network that was simulated based on the design data. PETROSIM will generate the properties of the crude and product and it will be exported to Visual Basic Application in the Microsoft Excel. The figure below shows the example of exporting the data from PETROSIM to excel.

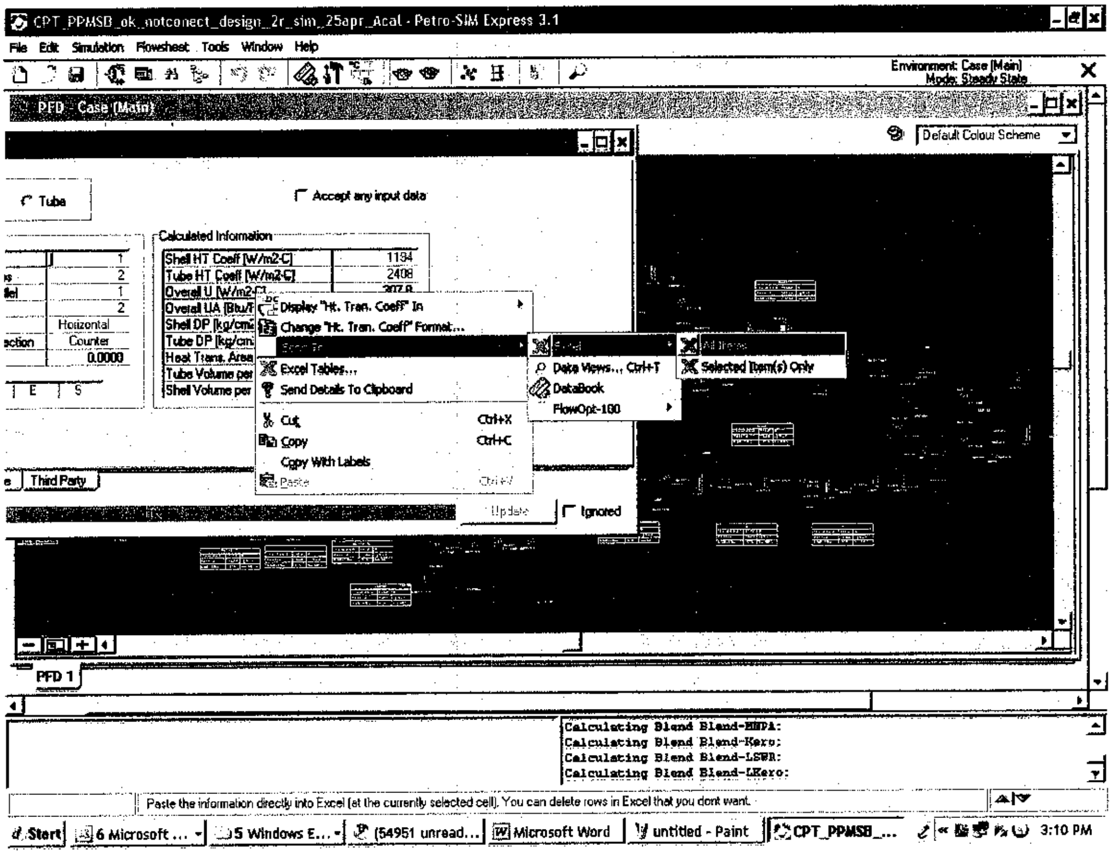

Figure 4.4: Exporting the data from PETROSIM to Microsoft Excel

4.3 ANALYSIS OF HEAT EXCHANGER PERFORMANCE

The performances of heat exchangers are evaluated through the calculation of overall heat transfer coefficient based on the daily average data [12].

The rate of heat transfer across the tube metal wall between the crude and the product stream is given by

$$Q = U_a A F \Delta T_{LM}$$

where

Q = Heat transferred in W

U_a = Overall heat transfer coefficient in W/m^2.°C

A = Heat transfer surface area in m^2

$LMTD$ = ΔT_{LM} = Log Mean Temperature Difference in °C = $\dfrac{(T_1 - t_2) - (T_2 - t_1)}{\ln\left(\dfrac{(T_1 - t_2)}{(T_2 - t_1)}\right)}$

T = Hot fluid temperature

t = Cold fluid temperature

F = LMTD correction factor

1 = Inlet

2 = Outlet

The heat transfer rate can also be calculated using the energy balance on the cold or hot stream and is given by [12]

$$Q = m_c Cp_c \Delta T_c = m_h Cp_h \Delta T_h$$

where

m = mass flow rate in kg/h

C_p = Specific heat capacity in W/kg.°C

ΔT = Temperature difference in °C

c = Cold fluid

h = Hot fluid

Tube-side film heat transfer coefficient

The film heat transfer coefficient on the tube side under turbulent conditions is given by the Colburn Equation [12]

$$Nu_t = 0.023 \mathrm{Re}_t^{0.8} \mathrm{Pr}_t^{0.4} \left(\frac{\mu_s}{\mu_{s\partial}} \right)^{0.14}$$

where N_{ut} is the Nusselt number on the tube side: $N_{u_t} = \frac{h_i D_i}{k}$

Re_t is the Reynold's number on the tube side: $\mathrm{Re}_t = \frac{D_i V \rho}{\mu}$

Pr_t is the Prandtl number on the tube side: $\mathrm{Pr}_t = \frac{c_p \mu}{k}$

The heat transfer coefficient under different operating conditions is calculated as a correction from the heat transfer coefficient at design conditions as given by [12]

$$\frac{h_{ta}}{h_{td}} = \left(\frac{\dot{V}_a \rho_a}{\dot{V}_d \rho_d} \right)^{0.8} \left(\frac{\mu_a}{\mu_d} \right)^{-0.4} \left(\frac{C_{pa}}{C_{pd}} \right)^{0.4} \left(\frac{k_a}{k_d} \right)^{0.6}$$

Shell-side film heat transfer coefficient

Calculation of shell-side film heat transfer coefficient is more involved and subjective compared to the tube-side film heat transfer coefficient. One of the widely used methods for the estimation of shell-side heat transfer coefficient for the vertical segmental baffle shells is the Bell-Delaware method. The step-by-step procedure is explained in the individual researcher report in Appendix B. The heat transfer coefficient under different operating conditions is calculated as the correction from the design conditions and is given by [12]:

$$\frac{h_{sa}}{h_{sd}} = \left(\frac{\dot{V}_a \rho_a}{\dot{V}_d \rho_d}\right)^{0.7} \left(\frac{\mu_a}{\mu_d}\right)^{-0.32} \left(\frac{C_{Pa}}{C_{Pd}}\right)^{1/3} \left(\frac{k_a}{k_d}\right)^{2/3}$$

Heat exchangers except E1108 and E-1111 in the CPT use segmental baffles whereas E1108 and E1111 use the helical baffles. The heat transfer coefficients for the helical baffles are estimated using the B Peng equation. The correction for changes in operating conditions for the helical baffle heat exchangers are given by [12]

$$\frac{h_{sa}}{h_{sd}} = \left(\frac{\dot{V}_a \rho_a}{\dot{V}_d \rho_d}\right)^{0.7} \left(\frac{\mu_a}{\mu_d}\right)^{-0.4} \left(\frac{C_{Pa}}{C_{Pd}}\right)^{1/3} \left(\frac{k_a}{k_d}\right)^{2/3}$$

Overall heat transfer coefficient

The overall heat transfer coefficient, U, may be defined optionally in terms of either hot fluid surface area or cold fluid surface area. Thus, the option of A_o or A_i must be specified in evaluating U from the product, UA. For plain tubular exchangers, U based on tube outside surface A_o, then, the overall heat transfer coefficient is given by [12]

$$\frac{1}{U} = \frac{d_o}{d_i h_i} + \frac{d_o . Rf_i}{d_i} + \frac{d_o Ln\left(\frac{d_o}{d_i}\right)}{2k_w} + Rf_o + \frac{1}{h_o}$$

Overall heat transfer coefficient under clean conditions is given by subtract the fouling effects from Equation above. [12]

Fouling Resistance

The fouling resistance is calculated by the difference between the actual (fouled) and clean heat transfer resistances and is given by [12]

$$R_f = \frac{1}{U_a} - \frac{1}{U_{clean}}$$

4.4 SIMULATION INTERFACE

For the simulation interface, the GUI had been developed in Microsoft Excel using visual basic application (VBA). There are three main simulation interfaces for the user to interact with the fouling prediction model:

a. GUI- General:

   - This interface will guide users to proceed to the data collection from PI, crude blend data insertion and as well as the simulation for the constant data keyed in.

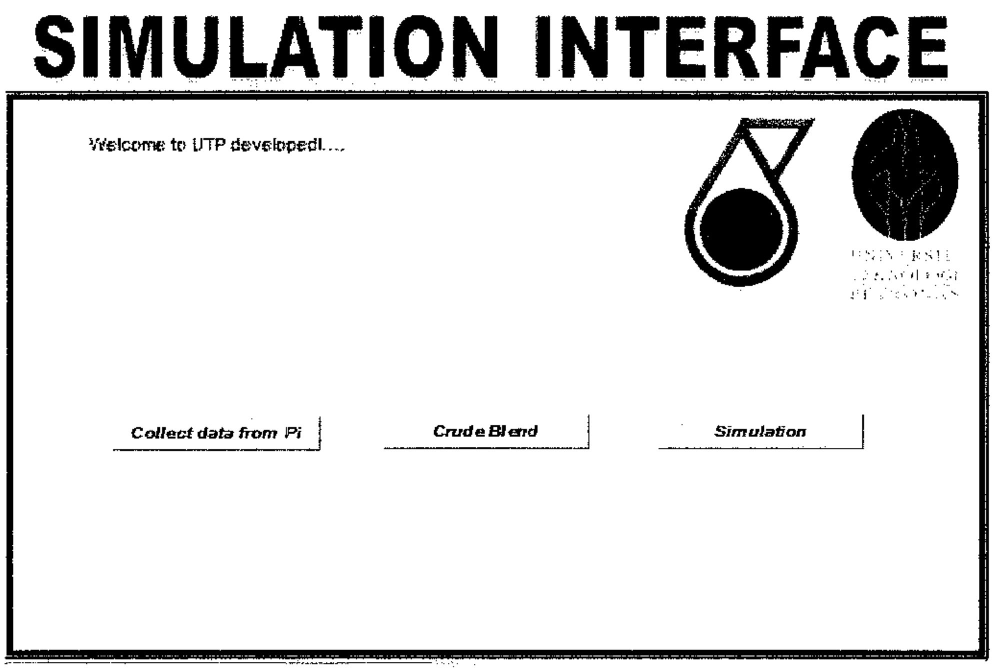

Figure 4.5: GUI-General interface.

   - By clicking the buttons above, users can interact will the suite. Next figure will show page that will appear once the button was clicked.
   - This interface will act as a main interface/page.

b. GUI-Pi

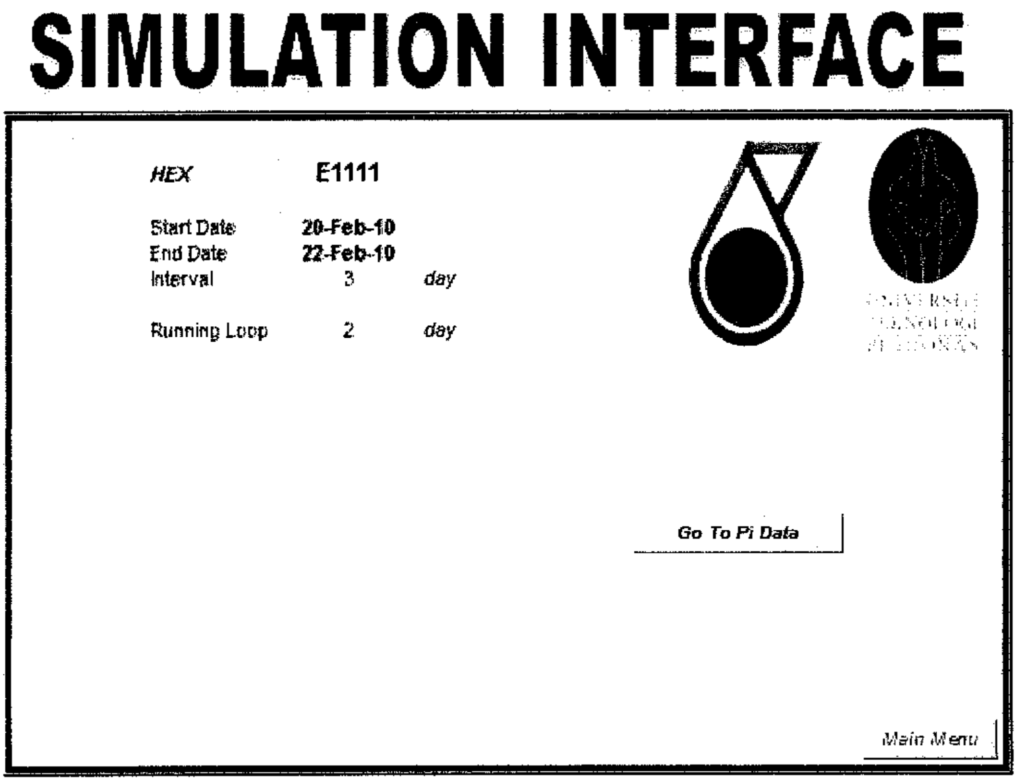

Figure 4.6: GUI-Pi interface.

- Once the 'collect data from Pi' button from main page clicked, this interface will automatically appear. Pi is an application at PPM that can collect process data from plant directly. Pi data can be obtained by putting the start date and the end data. All the other needed data had been reside into the Pi data page that will appear once the 'Go To Pi Data' button clicked.

c. GUI-Constant

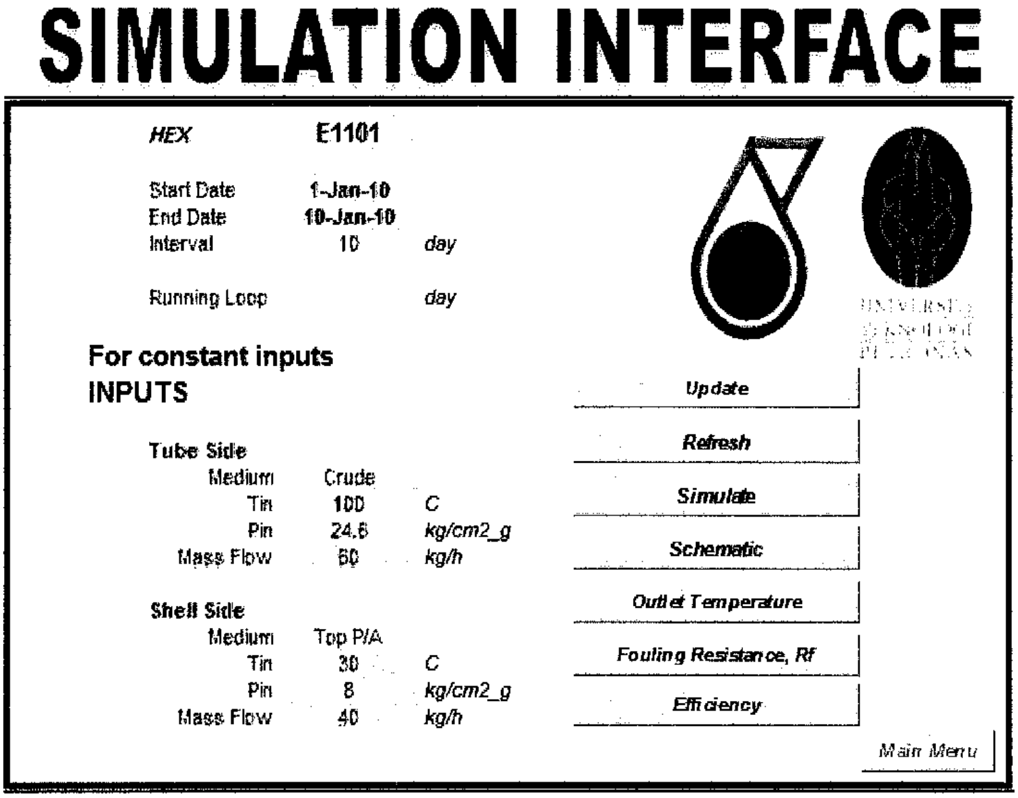

Figure 4.7: GUI-Constant interface.

- The interface above will appear once the 'simulation' button clicked. All the data entered here will go to the Neural Network for the fouling prediction and calculation.

d. Crude Blend

CRUDE BLEND DATA BACK

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
DATE	Tapis	Masa	Miri Light	Bintulu Crude	Arab Light	Cendor	Bintulu Condensate	Murban	Cossack	Kekwa	Kikeh	Angsi	Bulang	Other	TOTAL

Figure 4.8: Crude Blend sheet

- Crude blend data will be entered by user in this sheet. The crude blend data will be used in the simulation to calculate the fouling resistance of the respected heat exchanger.

CHAPTER 5

CONCLUSION & RECOMMENDATIONS

5.1 CONCLUSION

Modelling of heat exchanger fouling has been found to be a very useful technique to improve the overall performance of the systems. A fouling prediction model will determine the fouling resistance of the heat exchanger R_f. A neural network based model will predict the shell and tube outlet temperatures of a heat exchanger using the calculated R_f. The successful of prediction of the temperature allows the prediction of the decrease in heat transfer efficiency for effective preventing maintenance scheduling of the heat exchanger cleaning.

By obtaining or knowing the fouling in heat exchanger, this project can be further improved by adding the scheduling for maintenance in order to maintain the efficiency of the heat exchanger. Despite the enormous costs associated with the heat exchanger fouling, only very limited research has been done to determine accurately the economic penalties due to fouling and to attribute those costs to the various aspect of heat exchanger design and operation. However, reliable knowledge of fouling economic is desired to evaluate the cost efficiency of various mitigation strategies [9].

5.2 RECOMMENDATIONS

Here are some recommendations that can be done in the future in order to improve this model:

1. In order to obtained more accurate and faster calculation or iteration, MATLAB software is better been used compared the Microsoft Excel. MATLAB is special software that is design to do a complex mathematical calculation in easier way and faster. Plus, MATLAB has a capabilities to create graph and chart efficiently

2. User Interface (GUI) is better be done in Microsoft Visual Basic (VB) rather than using Visual Basic for Application (VBA) in Microsoft Excel. VB can create a more interactive User Interface as compared to the VBA. But VB is rather difficult to deal with especially the connection between the VB with the Excel. So the recommendation here is to have an expert from IT Department to assist in the VB matter.

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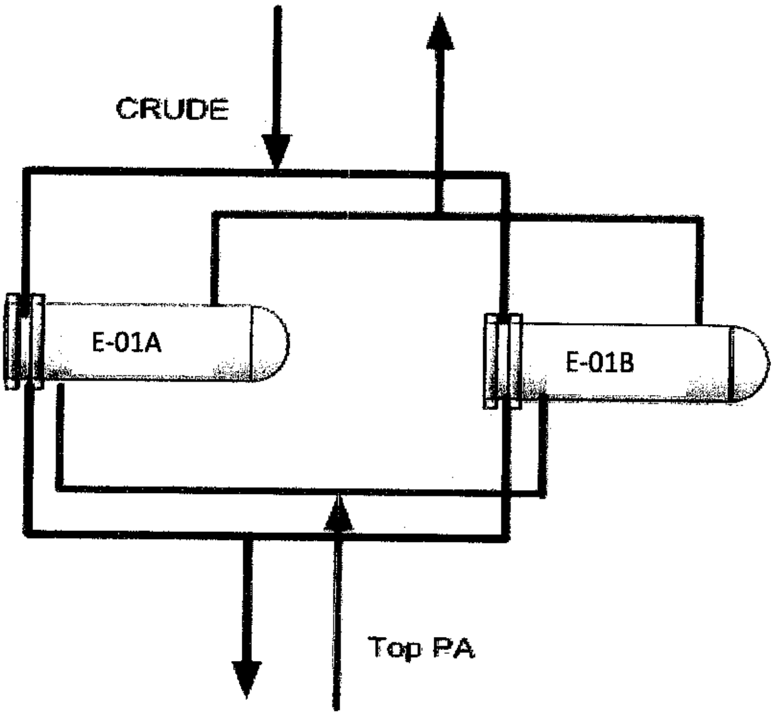
[15] http://vb.net-informations.com/excel-2007/vb.net_excel_oledb.htm

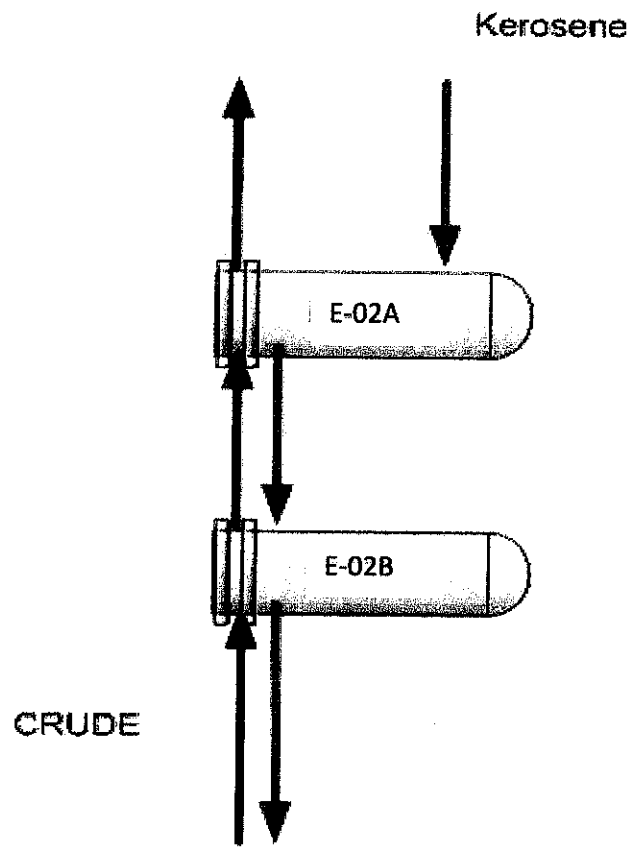
APPENDICES

APPENDIX A: Illustration of Individual Heat Exchanger

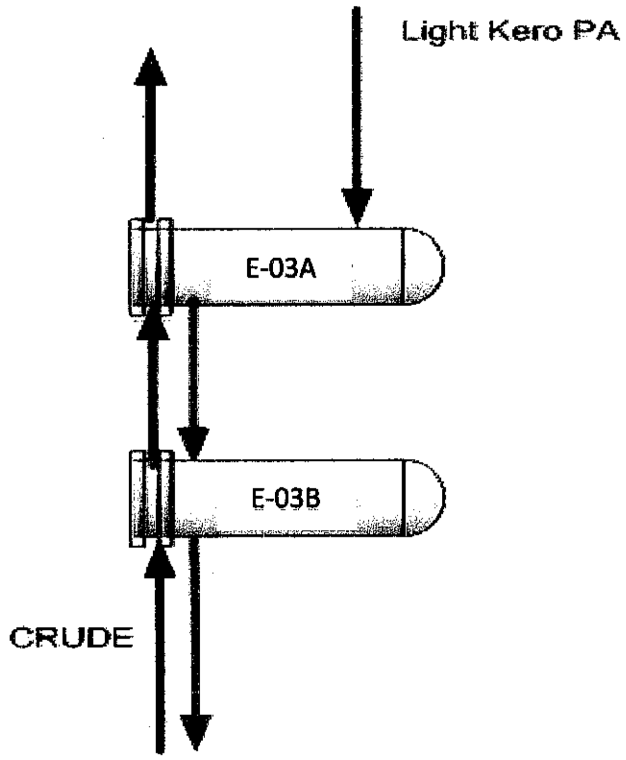
1. **E-01:**



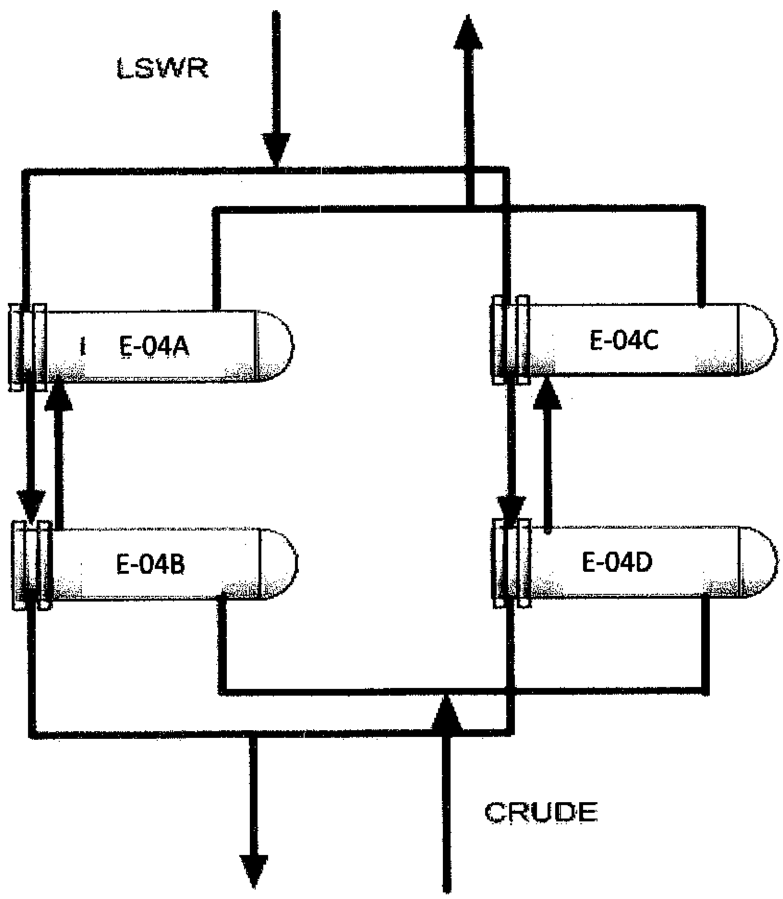
2. **E-02:**



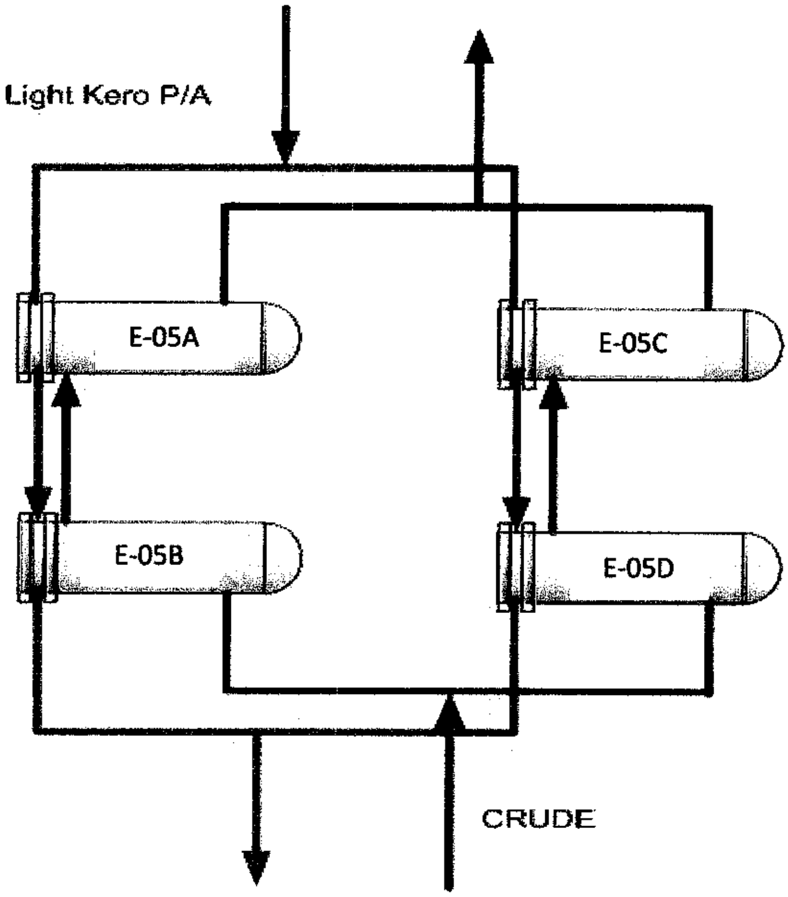
3. E-03:



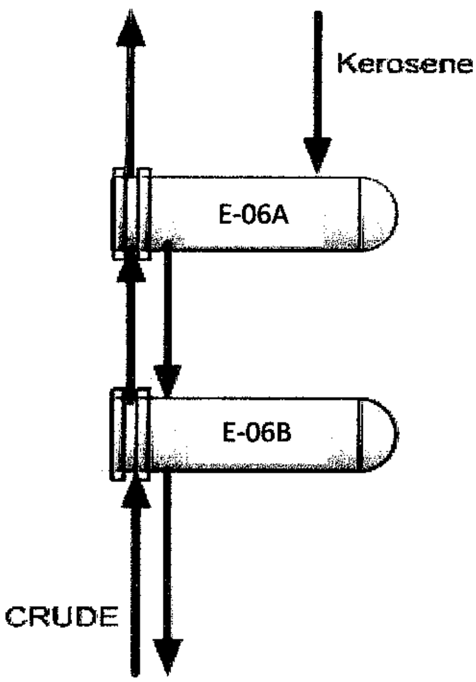
4. E-04:



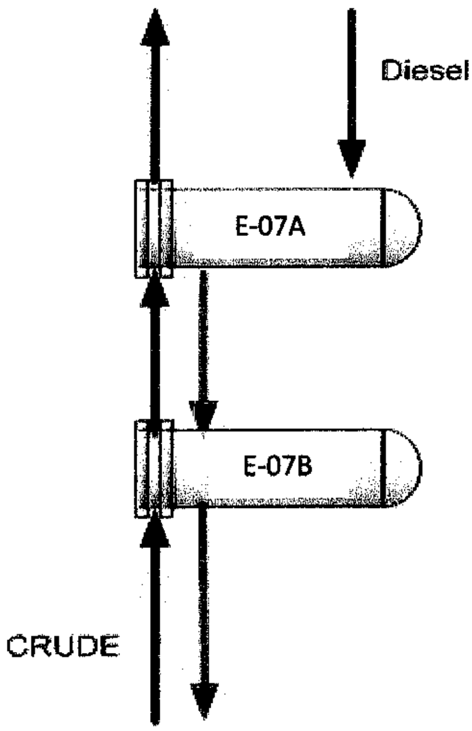
5. E-05:


Light Kero P/A
E-05A
E-05C
E-05B
E-05D
CRUDE

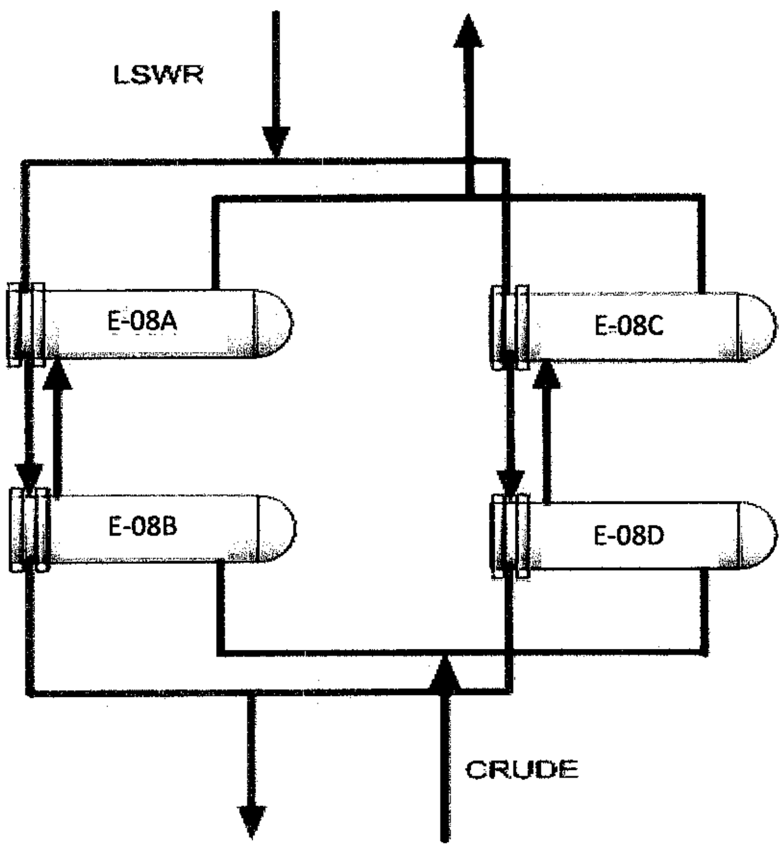
6. E-06:


Kerosene
E-06A
E-06B
CRUDE

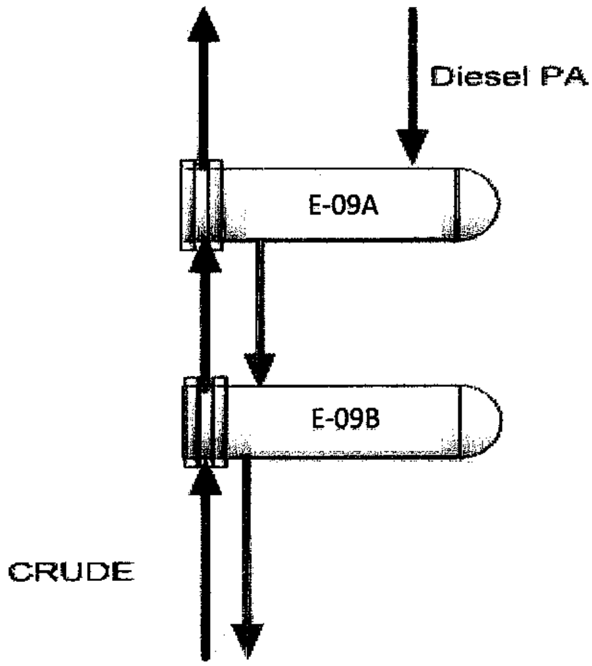
7. **E-07**



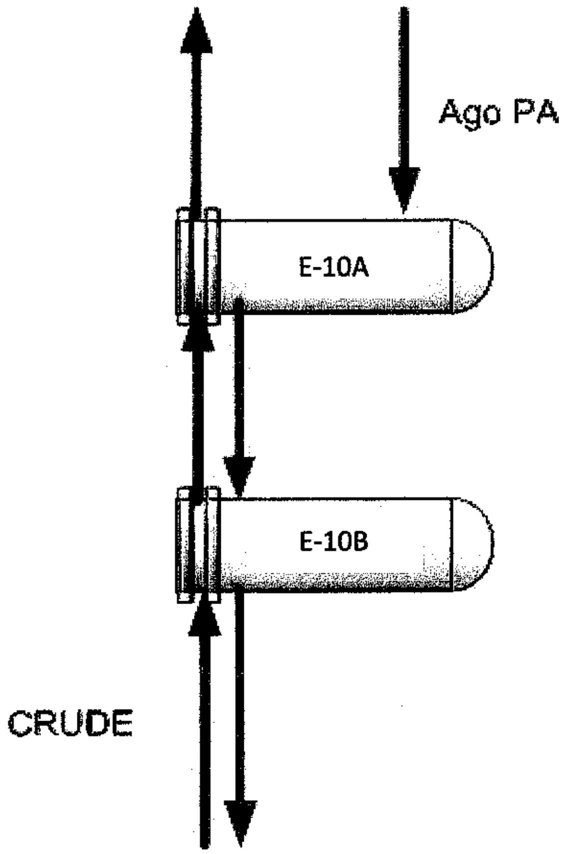
8. **E-08**



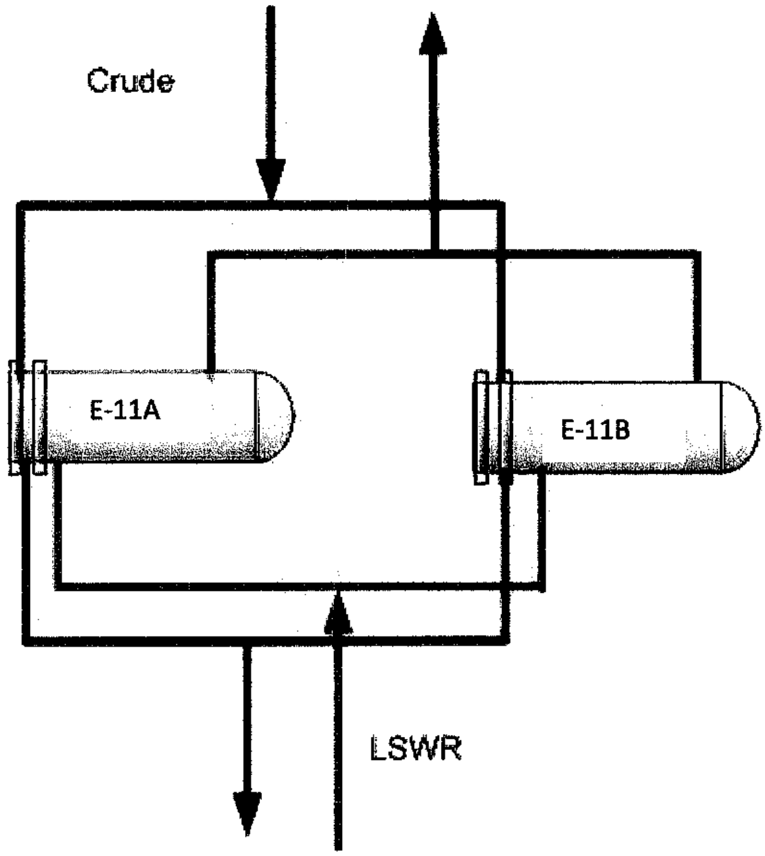
9. E-09



10. E-10



11. E-11



APPENDIX B: PETROSIM Simulation