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“I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in term of scope and quality for the award of the degree of Bachelor of Chemical Engineering”.

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Date : ----------------------------------

STUDENT’S DECLARATION

I declare that this report is the result of my own work except as cited in the references and summaries which have been duly acknowledge.

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DYNAMIC MODELLING OF CRUDE DISTILLATION UNIT

by

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A thesis submitted to the Faculty of Chemical and Natural Resource Engineering in partial fulfilment of the requirement for the Degree of Bachelor of Engineering in Chemical Engineering

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Special Dedication to:

My father, Tan Kiah Ewe,

My mother, Ng Geik Keow

My beloved siblings,

My fellow Lecturers,

My friends

For all your concern, support and faith in me.

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LIST OF ABBREVIATIONS

ADU	Atmospheric Distillation Unit
API	American Petroleum Institute
BK10	Braun K10
CDU	Crude Distillation Unit
CS	Chao-Seader
GS	Grayson-Streed
HC	Hydrocarbon Component
HVGO	Heavy Vacuum Gas Oil
LPG	Light Petroleum Gas
LVGO	Light Vacuum Gas Oil
MBWR	Modified Benedict Webb Rubin
NRTL	Non Random Two Liquid Model
PR	Peng-Robinson
PRSV	Modified Peng Robinson
SRK	Redlich-Kwong-Soave
TEG	Tri-Ethylene Glycol
VDU	Vacuum Distillation Unit
ZJ	Zudkevitch Joffee

PEMODELAN DINAMIK UNIT PENYULINGAN MINYAK MENTAH

ABSTRAK

Pada masa kini, penggunaan dan permintaan minyak mentah terdapat pertumbuhan yang pesat bagi pelbagai bidang industri. Oleh sebab demikian, harga petrol semakin meningkat kerana permintaan yang jauh lebih tiggit berbanding dengan penghasilan produk petroleum. Dengan maklumat yang sedia ada, kebanyakan model CDU yang digunakan adalah model dalam keadaan mantap.Pertamanya, prosedur untuk kerja ini adalah membentuk model matematik bagi peringkat teori. Kemudian berdasarkan persamaan separa yang diperolehi, hubungan antara pembolehubah input dan pembolehubah output CDU dikajikan. Selepas itu, Aspen Plus Simulasi CDU telah dijalankan dalam mod keadaan mantap dan keputusan yang diperolehi dikajikan. Seterusnya, simulasi dinamik CDU dijalankan di Aspen Plus Dynamic dan berdasarkan keputusan yang diperolehi perubahan CDU berkenaan dengan masa dikajikan. Sebagai kesimpulan, keputusan yang diperolehi daripada simulasi keadaan mantap telah membukti bahawa perubahan keseimbangan tenaga dalam CDU membawa kepada perubahan dalam imbangan jisim CDU. Dari keputusan simulasi dinamik, ia telah menunjukkan perubahan semua pembolehubah proses berkenaan masa sehingga kestabilan sistem dicapai. Satu model dinamik yang baik perlukan untuk menghasilkan satu strategi kawalan yang baik. Oleh itu, kerja ini banyak memanfaatkan dalam memahami perubahan CDU dan boleh digunakan untuk meningkatkan kecekapan proses penapisan dan juga dapat diguankan meningkatkan hasil produk.

DYNAMIC MODELLING OF CRUDE DISTILLATION UNIT

ABSTRACT

There is rapid growth in the usage and demand of crude oil in various industrial fields. Thus, the price of the petrol is rising due to the stronger-than-expected demand for petroleum products. With the available information, most of the modeling models used today is only steady state models. The procedure for this work was firstly forming a mathematical model for the theoretical stage of the column. Then based on the partial equation obtained, the relationship between input variable and output variable was studied. After that, Aspen Plus simulation of CDU was run in steady state mode and the results obtained was studied. Next, a dynamic simulation of CDU in Aspen Plus Dynamic was run and the dynamic behavior of CDU model was studied based on the results obtained. Based on the result obtained from steady state simulation, it was proven that the change of energy balance of the column lead to a change in the mass balance of the column. As the conclusion the dynamic simulation results shown on all the changes of process variable with respect to time until the system stability achieved. A good dynamic model is necessary to develop a proper control strategy. Thus, this work was very helpful in understanding dynamic behaviour of CDU and used to increase the efficiency of refining process which also increases the yield of the product.

CHAPTER 1

INTRODUCTION

1.1 Background of the Proposed Study

Crude oil or known as petroleum is an extremely versatile substance. Crude oil is the formation of different type of hydrocarbon components which need to be passing thought a separation process in order to obtain the desire product. From the refining process of crude oil, it creates everything from asphalt and gasoline to lighter fluids and natural gas which containing a variety of essential elements such as sulfur and nitrogen. A part from that, Crude oil products are also vital feedstock for the purpose of manufacture medicines, chemicals and plastics.

Crude distillation is the first major separation process which also consider as the fundamental process in a petroleum refinery. A Crude distillation unit (CDU) consists of an optional pre-flash distillation column, Atmospheric distillation column

(ADC) and a vacuum distillation column (VDU). The petroleum products obtained as Chang (2006) reported from the distillation process are light, medium and heavy naphtha, kerosene, diesel, atmospheric gas oil (AGO), light vacuum gas oil (LVGO), heavy vacuum gas oil (HVGO) and oil residue. To date, there are various academic contributions on the analysis of crude distillation system. Those research of analysis can be dovetailed into three major area which are heat exchanger networks associated to CDU (Plesu et al., 2003; Gadalla et al., 2003), refinery planning and scheduling (Cao et al., 2009; Rivero et al., 2004) and crude distillation modelling, simulation and optimization (Inamdar et al., 2004; Liau et al., 2004; Dave et al., 2003; Kumar et al., 2001; Seo et al., 2008). Study and analyze the actual performance of the crude distillation column is beneficial in order the industrial to achieve the highest efficiency which can help to lower down the cost of operating of the product thus may help reduce the price of the petroleum products.

In this research the model of CDU used consist of a pre-flash column followed by atmospheric distillation column and vacuum distillation column. The basic model schematic diagram of CDU is shown in Figure 1.1.

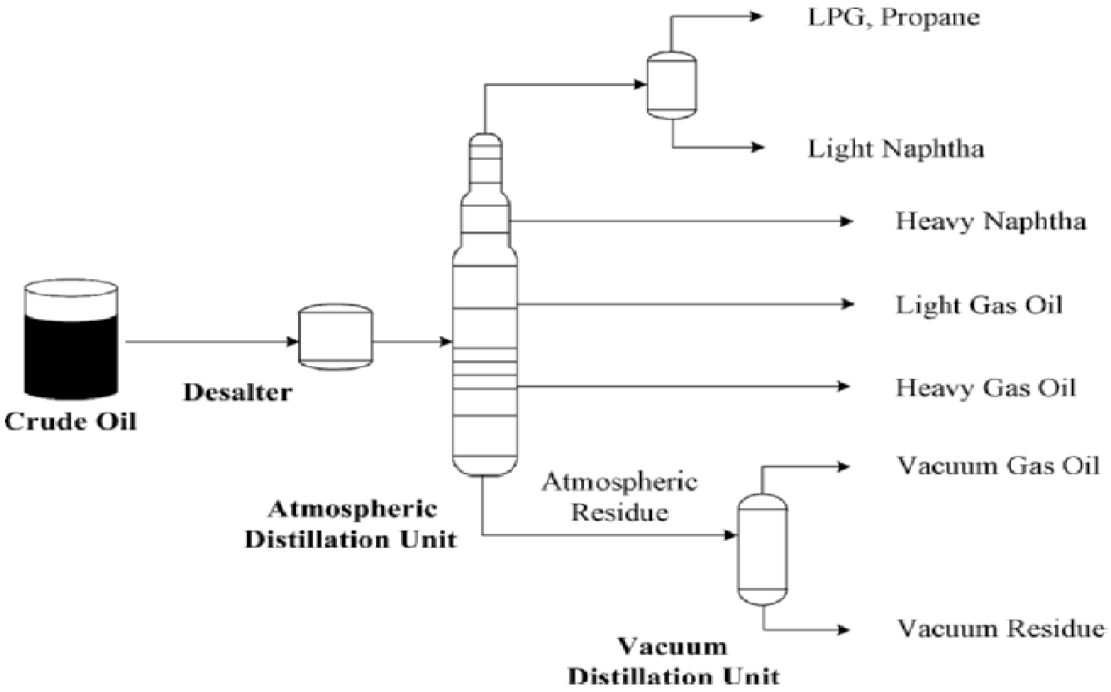


Figure 1.1 Schematic Diagram of Crude Distillation Unit

(**Source:** Chang, 2006)

1.2 Problem Statement

There are rapidly growth in the usage, and demand of crude oil in industries field such as medicines, chemicals, plastics and as fuel for vehicle. However, there is a limited supply available the worldwide market. Therefore, the price of the petrol gave rise due to the stronger-than-expected demand for petroleum products.

Other than that, the dynamic model of crude distillation unit need to be study clearly and known in order to obtain a high efficiency refining process which can increase the yield of the petroleum product. A proper control system can be develop by understand the dynamic behavior of CDU.

However as what information available nowadays, most of the other researchers are only focus on steady state modeling. Hence, the research on dynamic modeling for CDU is required so that it can be the atom to initiate the other researcher to explore and study more in this section.

1.3 Research Objectives

There are two main objectives of conducting this study

1.3.1 To develop a dynamic model of CDU based on the steady states CDU model.

1.3.2 To study the effect of different operating conditions of petroleum refining toward the yield and composition of petroleum products by solving model equations.

1.4 Scope of the Proposed Study

The scope of this study is to study the interaction between the mass balance, component material balance and heat balance. The formula of mass balance, component material balance and heat balance is used to build up a mathematical model for the petroleum refining process. The mathematical model can be described the relationship between input variable and output variable by an ordinary or partial differential equation.

A part from that, the scope of this proposed study also include the study on the effect of different operating condition of petroleum refining toward the yield and composition of petroleum product. A mathematical equation that form from mathematical model is needed to find an appropriate method to solve the effect of different operating condition of petroleum refining toward the yield and composition of petroleum product.

Thus, a dynamic model of CDU will be developed based on the steady states CDU model. The steady state CDU model is used on the study of dynamic behaviour of CDU thus to find the simulation result under dynamic condition. The simulation result obtained will be compare with the plant data available in literature.

1.5 Significance of the Proposed Study

The significance of this study is the study of dynamic behaviour of the CDU model. A good dynamic model is necessary to develop a proper control strategy. A part from that, this study is very helpful for the understanding of dynamic behaviour of CDU and this study can act as an atom which will initiate the development of CDU. It is because this study involves the study of interaction between the mass balance, component material balance and heat balance which will show the relationship between the input variable and the output variable.

1.6 Conclusion

The main aim of this study is study about the dynamic behaviour of the CDU model. Therefore, this proposed study is very helpful in understanding dynamic behaviour of CDU. Thus, this proposed study also can be an atom to initiate the development of CDU in order to find a proper control strategy. Furthermore, this study also aims on the effect of different operating condition of petroleum refining toward the yield and composition of petroleum product through the study of the interaction between the mass balance, component material balance and heat balance which is helpful to understand clearly the relationship between the balance law, input and output variable. As conclusion, this study can act as an atom to the development of dynamic model of CDU.

CHAPTER 2

LITERATURE REVIEW

In recent years, the demand for petroleum products is rapidly rise. For example, in 2005, each of the estimated 296 million people in the U.S. used an average of almost three gallons of petroleum every day. In 1978, the average American used 3.5 gallons per day mixture. (U.S Energy Information Administration, 1979)

Distillation is a method used for separate component from a liquid mixture based on their relative volatilities. Unlike purely mechanical separations, distillation methods utilize the differences in vapour pressure or boiling point of each component but not density or particle size. The distillation column provides an environment where the liquid and the vapour phase can achieve equilibrium within the column. When the mixture is heat up, the higher volatility component will be evaporated first. The appearance of gas phase is due to the vaporization process of a component at its boiling temperature. (McCabe, 1967)

2.1 Process Mathematical Modelling and Dynamic Modelling

Mathematical Modelling is an important part of process design economically. It is because, modelling involve the conceptual synthesis of the process flows sheet, detailed design of specialized processing equipment and the design of the process control systems. Other than that, Mathematical model is also used to investigate the source of problem. Then important factors will be determined and those factors will be interplay as in a mathematical way. Then the mathematical relationships will be analyzed. After all, mathematical model is an evaluation of how to applicable the results obtained into the real-world situation. **(**Rick, 2003).

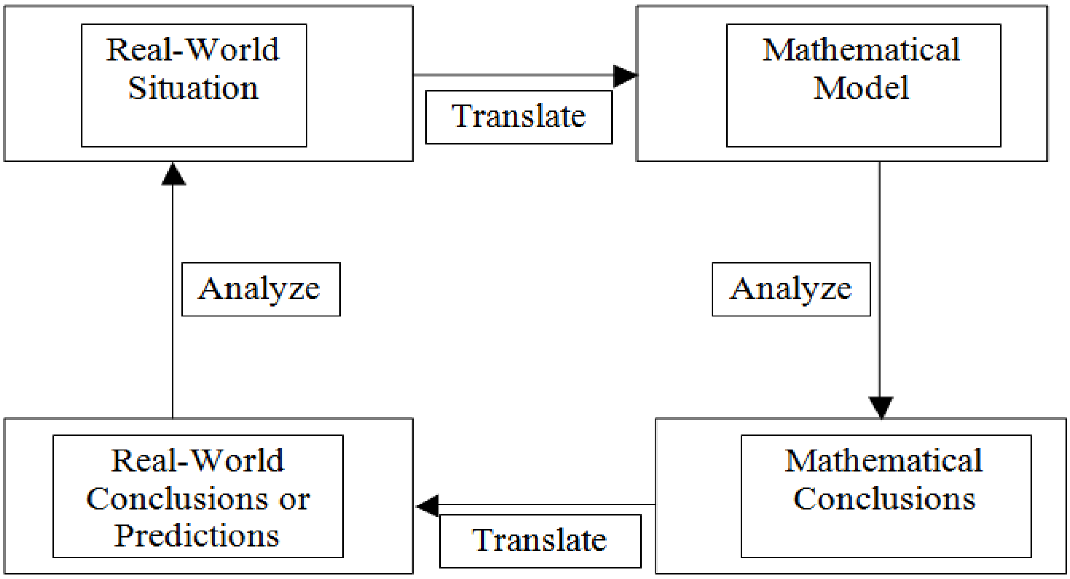


Figure 2.1 Mathematical Modelling Process

(**Source:** Rick, 2003)

The core study of dynamic modelling is the study on the dynamic behaviour. Ddynamic behavior is the behavior describes of a distributed parameter in a system. The behavior describe is in terms of how one qualitative state affect another. A qualitative state is described by a static model. For example, it describes the distributions and intersections of the qualitative fields at a particular time instant or interval. (Monika, 1997)

2.2 Industrial Characteristic

As mentioned before, Crude distillation is the first major separation process which also consider as the fundamental process in a petroleum refinery. The petroleum obtained from different oil farm consists of different hydrocarbon composition combination. Chang, (2006) stated that petroleum was form from the bodies of ancient organisms such as died animals and plants and over time those body was transformed into simple chemicals compound. Therefore, each petroleum fields have their unique operating condition due to different combination of composition inside the crude.

As stated by ICCT at 2011, there was more than 660 refineries, in 116 countries, are currently in operation and producing more than 85 million barrels ofrefined products per day.Thus, each refinery have its own unique processing method, configuration and performance which based on the crude oil characteristics, process equipment available, operation costs, refinery's location, vintage, availability of funds and product characteristic demand.

2.3 Refinery Flow Scheme of Crude Distillation Unit

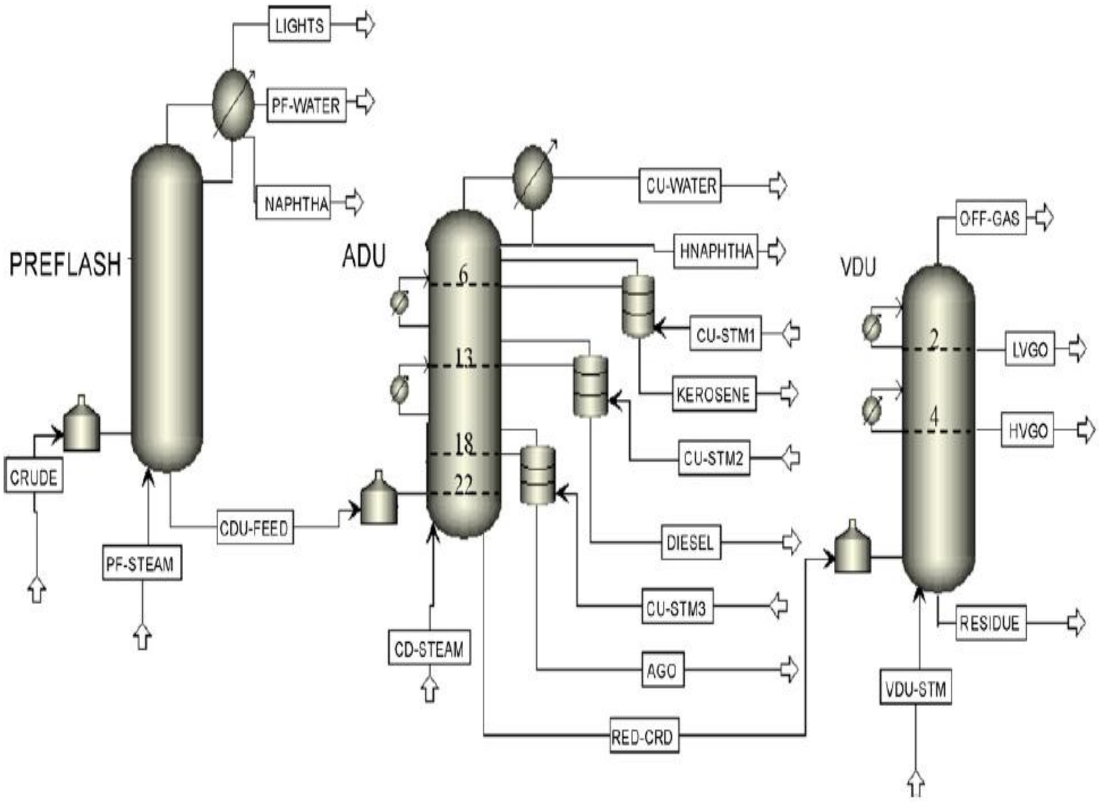


Figure 2.2 Schematic Diagram of a Crude Distillation Unit

(**Source:** Raja et al, 2010)

Table 2.1 Parameter for CDU

Parameters	Value
1) Preflash Unit	
No of Stages	10
Pressure	273.7 kPa (top stage)
	308.2 kPa (bottom stage)
Temperature	232^{o}C
Condenser Temperature	$77\,^{o}$C
Condenser Pressure	274 kPa
Condenser Pressure drop	14 kPa
2) ADU	
No of Stage	25
	22 (feed stage)
Pressure	108.2 kPa (top stage)
	170.3 kPa (bottom stage)
	28 kPa (pressure deop)
Pump Around	
Pump Around 1	Stage 8 – Stage 6
Heat Duty	-11.7 MW
Pump Around 2	Stage 14 – Stage 13
Heat Duty	-4.4 MW
Side Stripper	
Kerosine Stripper	4 Equilibrium Stages Stage 6 – Stage 5
Diesel Stripper	3 Equilibrium Stages Stage 13 – Stage 12
AGO Stripper	2 Equilibrium Stages Stage 18 – Stage 17
3) VDU	
No of Stage	6
	5 (feed stage)
Pressure	8.0 kPa (top stage)
	9.3 kPa (bottom stage)

(**Source:** Raja et al, 2010)

2.4 Physical and Chemical Properties of Crude Oil in Malaysia

Crude oil can be classified into light crude and heavy crude. Those “light” or “heavy” is a characteristic representative of crude oil’s density which based on the American Petroleum Institute (API) gravity. This API gravity value is the comparison of oil with water which reflects the “Light” or “heavy” of crude.

As addressed in an Introduction to Petroleum Refining and The Production of Ultra Low Sulphur Gasoline and Diesel Fuel by ICCT in 2011, the value of API gravity 10 is the base of water. The crude with API more than 10 than the crude will float on the water, if the crude with API less than 10 than the crude will sink. The lighter the crudes, the easier and less processing cost. It is because the lower API gravity value represent that higher percentage of light hydrocarbon is contained in the crude which will require more simple distillation process at a petroleum refinery. Figure 2.3 below show the quality of a light and heavy crude, in term of the natural yield of light gas, gasoline, distillate (kerosene, diesel) and heavy oil and the average demand for these product categories in a developed countries.

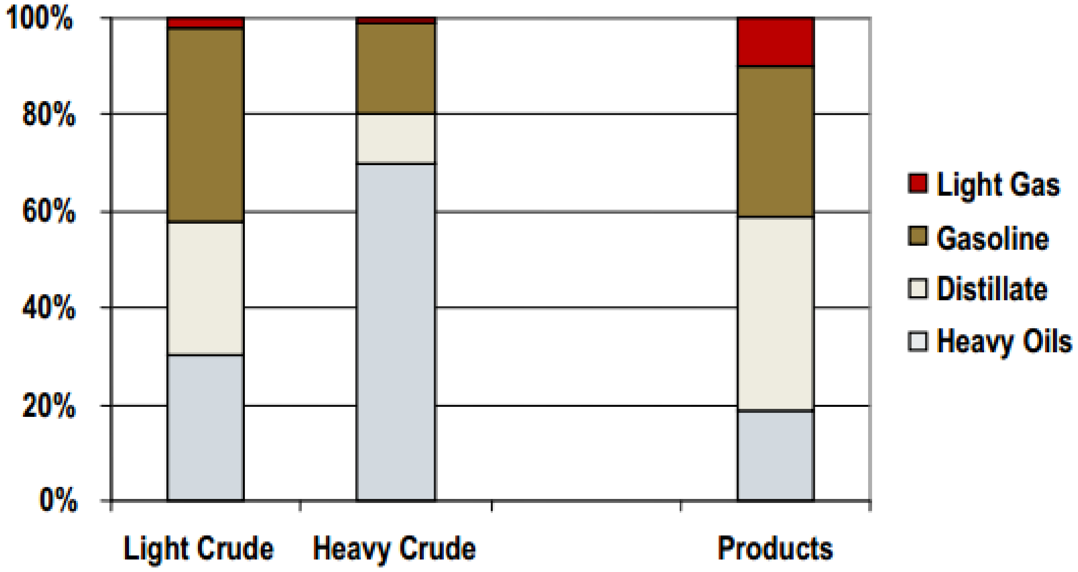


Figure 2.3 Typical yield of light and heavy crude oils

(**Source:** ICCT, 2011)

In general, the densities of Malaysia crude oil field have almost the same density to some of the crude oils in Norwegian Continental Shelf which the densities vary in between 0.79 to 0.98 g/cm^3 at 15^{o}C ± 5^{o}C from thesis of Formation and Stability Study of Some Malaysian Crude Oil Emulsions which the authors are Ariany in year 2004.

In this research, the methodology involves changing the operating crude oil inlet flow rate and composition of the crude feed by change type of crude oil. For running the Aspen Plus software, the requirement of changing the crude composition is API, distillate percentage and crude density. The API is difference for each source of crude. Therefore, difference type of Malaysian crude properties of Malaysia oil field is obtained. For example, the crude oil for Bekok, Labuan Sarawak, Tapis and Miri Sarawak. Table 2.2 and Table 2.3 below are identifies API, distillate percentage and mid percentage API of crude oil field Malaysia from Aspen Plus Data Storage.

Table 2.2 Crude Property of Bekok and Labuan Crude Oil

Types of Malaysian Crude	Bekok		Labuan Sabah	
API	49.07		33.2	
	Percentage distillate	Temperature (F)	Percentage distillate	Temperature (F)
	2.7	68	0.97	68
	9.75	145	2.97	145
	36.51	330	21.77	330
	52.25	450	39.77	450
	78.38	650	78.04	650
	80.38	680	81.04	680
	96.23	975	97.87	975
	Mid Percentage	API gravity	Mid Percentage	API gravity
	65.32	41.65	30.77	38.7
	72.98	38.71	40.15	35.56
	88.3	32.84	58.9	29.27
	89.19	31.54	89.45	15.79

(**Source:** Aspen Technology, 2009)

Table 2.3 Crude Property of Tapis and Miri Crude Oil

Types of Malaysian Crude	Tapis		Miri Light Sarawak	
API	45.9		36.27	
	Percentage distillate	Temperature (F)	Percentage distillate	Temperature (F)
	1.91	68	1.15	68
	34.49	347	2.75	145
	67.53	563	25.85	330
	77.82	650	41.65	450
	87.85	761	74.74	650
	93.66	878	77.74	680
	97.27	1049	98	975
	100	1500		
	Mid Percentage	API gravity	Mid Percentage	API gravity
	51.01	43.73	33.75	40.65
	72.68	40.12	58.2	30.99
	87.54	31.86	87.37	21.01
	88.91	28.33	87.87	20.71
	93.93	23.67		
	96.83	17.37		
	98.64	6.99		

(**Source:** Aspen Technology, 2009)

2.5 Choosing a Model for Modelling

During the design process, the selection of the right type of model was very important. Martin. (2007) addressed that there are three types of model which was white box model, black box model and gray box model. If a wrong type of model was selected, it will lead a waste of computing power, time and either providing too little detail or far too much information.

2.5.1 White Box Model

White box model was the most detailed model type. It is because white box model was contains a full description of the simulation model and only used in the situations where the simulation results must closely match to those plant production in reality. According to Martin (2007) a pure white box model cannot exist as it was essentially a copy of industrial operation scheme and often white box model consume large amounts of computing power.

The advantages of using white box models were because of its extremely flexible and realistic. Under white box model, everything was modeled on a low level of physical processes and it provides the closest match to the real plant.

However white box models were complexity and large computing overheads. A white box model was modeled based on a low level physical process which contains either no or few approximations, thus white box are the most complex types of model to set up and implement. This also renders them the slowest running type of model and requires fast computers and large amounts of memory.

2.5.2 Black Box Model

A pure black box model or known as empirical model was only used when the response of a system was not detail descript or only represented by an empirical description or a set of transfer parameters that do not describe any internal physics. Thus the model was just simply solves by a numerical problem without reference to any underlying physics. Martin (2007) report that in black box model, there was no process fundamental physical understanding required. It is because this model was fully run based on input/output data and only describes the relationship between the measured input and output data of the process. Block box model were useful when the condition of limited time and there is insufficient physical understanding of the process. The advantages of using black box model were fast running and minimal required computing power. For black box model usually consist of a set of rules and equations which were easy to optimize, relatively simple and does not required large computing power.

The disadvantages of using black box model were lack of flexibility and non-physical. The black box model was no process understanding required. Therefore, once there was any change on the description of physically, it required a lot of work to determine a new rule or bulk parameter for black box model. A black box model is not appropriate for any form of sensitivity analysis. It can conclude that black box model is not suitable for sensitive analysis.

2.5.3 Gray Box Model

Gray box model was the model box which used for this research. In a grey box model, some or all of the mechanisms describing the behavior of a device were known, but not all fully represented in the model. Other than that, certain elements within the grey box model can be approximated by rules. As stated by Martin at year 2007, he state that majority of simulation models used were grey box models. A grey box model provides a physical representation, but some of the physics was approximated.

Other typical approximations that are made in a grey box thermal model:

i. Non-linear parameters or processes are often approximated by linear ones.
ii. Areas of physical detail are often simplified by averaging the localized properties. For example, multi-layer structures can be approximated by a single layer, the single layer having the average properties of all of the layers involved.
iii. Contact between one part of a model and another is sometimes considered perfect, when in reality it is not. For example, the thermal contact between a surface-mount component and a PCB.

Therefore, there was some assumption made in order to run the simulation of this work. Those assumption and simplification was the crude is breaking into pseudo-components, the fluid on column tray is perfectly mixed and incompressible, and the equilibrium tray where trays vapour hold up is negligible and so on. The assumption and simplification is stated in detail in section 2.7 below.

2.6 Selection of a Thermodynamic Method

Other that then steps of selecting type of model, the step of selecting a thermodynamic method was also another important step for obtaining an accurate simulation. In Aspen Plus programme, it provides several type of thermodynamic method. For the method suitable for petroleum refinery, it can be divided into two groups where one group was base on the state equation of gases and the other group was specially developed for hydrocarbon mixture.

For the first group which base on the state equation of gases was the best choice for the real components. For example, Peng-Robinson (PR) state equation and Redlich-Kwong-Soave (RKS) state equation.

For the second group that specially developed for hydrocarbon mixture was suitable for pseudo-component. For example, Braun K10 (BK10), Chao-Seader (CS) and Grayson-Streed (GS).

In detail for the second group, BK10 was a model suitable for mixtures of heavier hydrocarbons at pressures under 700 kPa and temperatures from 170 ^{o}C to

430 ^{o}C. The values of BK10 were obtained from the Braun convergence pressure method using tabulated parameters for 70 hydrocarbons and light gases. (Juma, 2009)

The Chao-Seader model in Aspen-Plus is the method for heavy hydrocarbons, where the pressure was less than 10342 kPa (1500 psia), and temperatures range from -17.78℃ to 260℃. However, the CS property package was only can be used for the steam systems and three-phase flashes, but only restricted to the use of pure H_2O as the second liquid phase. (HYSYS-Basics, 2008)

The Grayson-Streed correlation was an extension of the Chao-Seader method which only special emphasis on H_2. Therefore, GS correlation was recommended only used with systems having a high concentration of H_2 because of the special development of this model based on H_2. The GS correlation can also be used for simulating topping units and heavy ends vacuum applications. This correlation may also be slightly more accurate in the simulation of vacuum towers. (HYSYS-Basics, 2008)

As the summary from Aspen Technology Aspen Plus user guide, the recommended property methods for difference type of system are shown in Table 2.6 below. The decision of property method used for this dynamic simulation was PR which is the most recommended obtained from the literature review.

Table 2.4 Recommended Property Methods for Difference Type of System

Type of System	Recommended Property Method
TEG Dehydration	PR
Sour Water	PR, Sour PR
Cryogenic Gas Processing	PR,PRSV
Air Separation	PR,PRSV
Atmospheric Crude Towers	PR, PR Optional, GS
Vacuum Towers	PR,PR Optional, GS(<10mmHg), BK10, Essok
Ethylene Towers	Lee Kesler Plocker
High H2 Systems	PR, ZJ or GS (see T/P limits)
Reservoir Systems	PR, PR Optional
Steam System	Steam Package, CS or GS
Hydrate Inhibition	PR
Chemical Systems	Activity Moduls, PRSV
HF Alkylation	PRSV, NRTL (contact Hyprotech)
TEG Dehydration wit Aromatics	PR (contact Hyprotech)
Hydrocarbon Systems where H2O solubility in HC is important	Kabadi Danner
System with select gases and light hydrocarbons	MBWR

(**Source:** HYSYS-Basics, 2008)

2.7 Assumption and Simplification

The most vital play by a chemical engineer in modelling was the professional engineering judgment and decision as what were the assumptions which can be utilize in the mathematical model. In the real world, each model was extremely rigorous which the entire phenomenon from macro down to microscopic detail should be including during modelling. Therefore, the duty of an engineer was compromise between rigorous descriptions and finds a best solution method which is good enough.

The Simplification and assumption have to be made based on the literature (Luyben, 1990; Gabriel, 2007; Raja et al, 2010) are:

i. The crude is breaking into pseudo-components.

ii. Fluid on column tray is perfectly mixed and incompressible.

iii. Equilibrium tray where trays vapour hold up is negligible.

iv. Component dynamic of condenser and reboiler negligible.

v. Fluids are in thermal equilibrium but not phase equilibrium which means the fluids at a tray are uniform, coexisting at the same temperature and pressure, and having a certain interrelated composition.

CHAPTER 3

RESEARCH METHODOLOGY

In this work, the main aim was to study of dynamic behaviour of the CDU model. In the other hand, this work also involve the study of the interaction between the mass balance, component material balance and heat balance which is helpful to understand clearly the relationship between mass balance, component material balance and heat balance toward the product composition. Furthermore, this work also aims to explore the effect of different operating condition of petroleum refining toward the yield and composition of petroleum product. Thus, another aim was to develop a dynamic model of Crude Distillation Unit based on the steady states CDU model.

This report was a qualitative research which seeks out the ‘why’ through the analysis experiment conducted by computing software Aspen Plus in the condition of steady state. Once the model is valid, a dynamic model of CDU was developed based on the steady states CDU model.

3.1 Experiment Design

3.1.1 Instrumentation

The instrument need for this experiment was only the computer software Aspen Plus User Interface and Aspen Plus Dynamic. For construct Mathematical model, all the equation involved was listed out and combined together. For Steady state simulation, all the crude oil data such as API, percentage distillate of difference temperature and mid percentage distillate keyed into Aspen Plus Use interface.

Once the steady state model is valid, a dynamic model of CDU was developed based on the steady states CDU model. The methods and procedure for developing the dynamic model was exporting the steady state model into dynamic format.

After that, all the simulation result was summarized into table form and graph so that easy to compare with the result.

3.2 Procedure

3.2.1 Procedure of Forming Mathematical Model

For main step of performing the study on dynamic modelling of CDU was forming a mathematical model of CDU. Therefore the first procedure was to form a mathematical model for the CDU. The first step of forming a mathematical model was gathering the entire relevance information base on the system boundary of the study which was the CDU. The relevance information was the assumption made for CDU as stated in Chapter 2.7, the inlet variable and outlet variable for the CDU. After that, a simple overall diagram that outlines the CDU is sketched as Figure 3.1. The simple overall diagrams are the theoretical stage of the column.

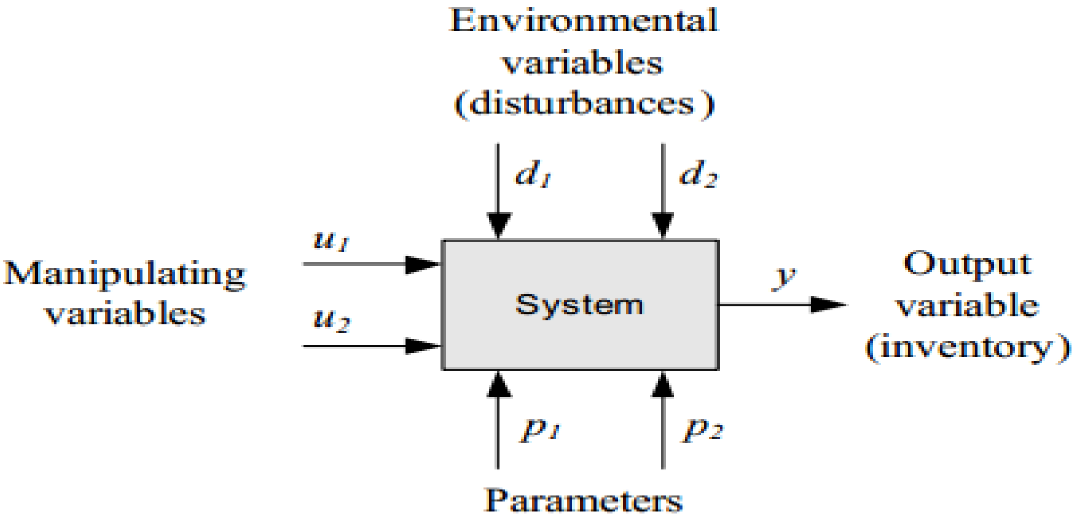
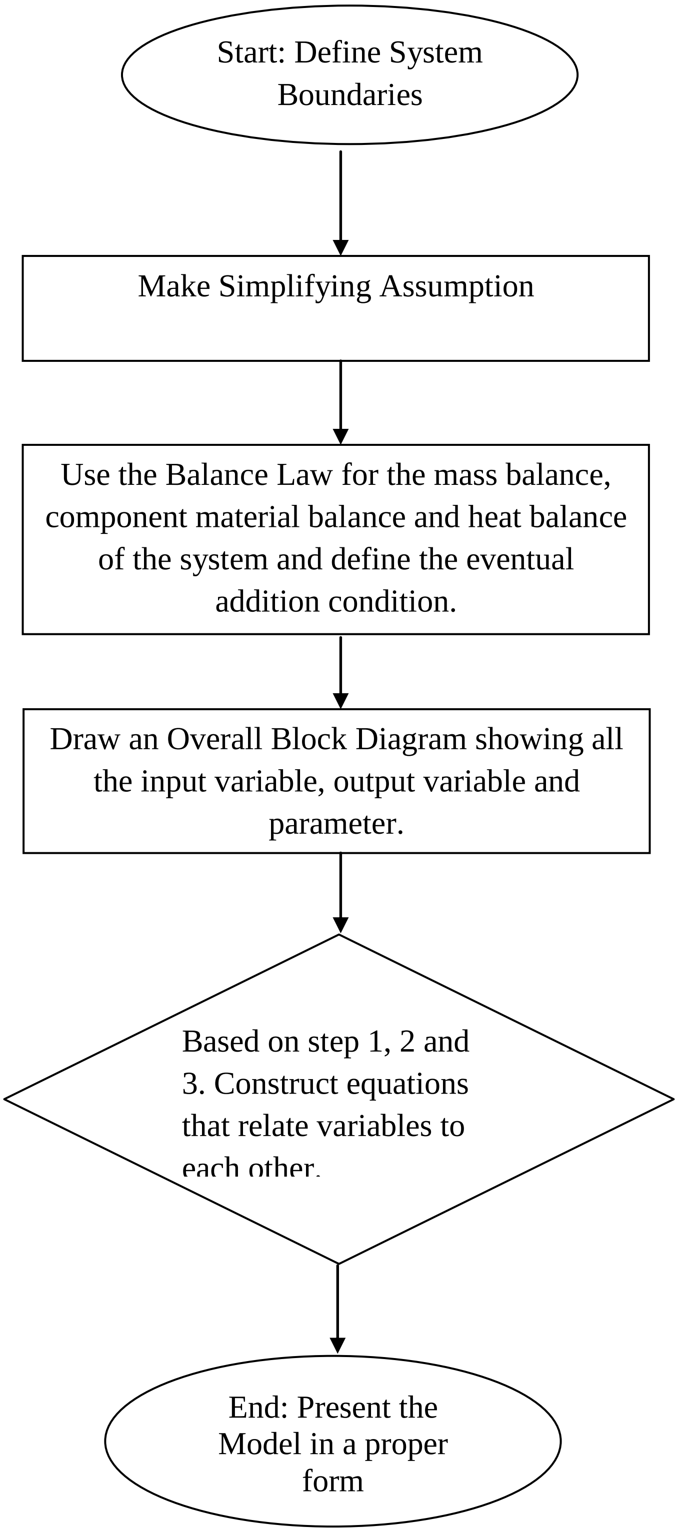


Figure 3.1 Overall Block Diagram

(**Source:** Haugen, 2010)

Since the mathematical model for the pre-flash tower, main column and the side-stripers was qualitatively the same, the only different of those three are the number of tray inside. Therefore, all of them are consider as a structural parameter. All of them having the same total mass balance, component balance and heat balance. Thus only the main column diagram is sketched. The diagram sketched was used to identify the important variable and constant thus a mathematical equation was constructed based on the diagram sketched.

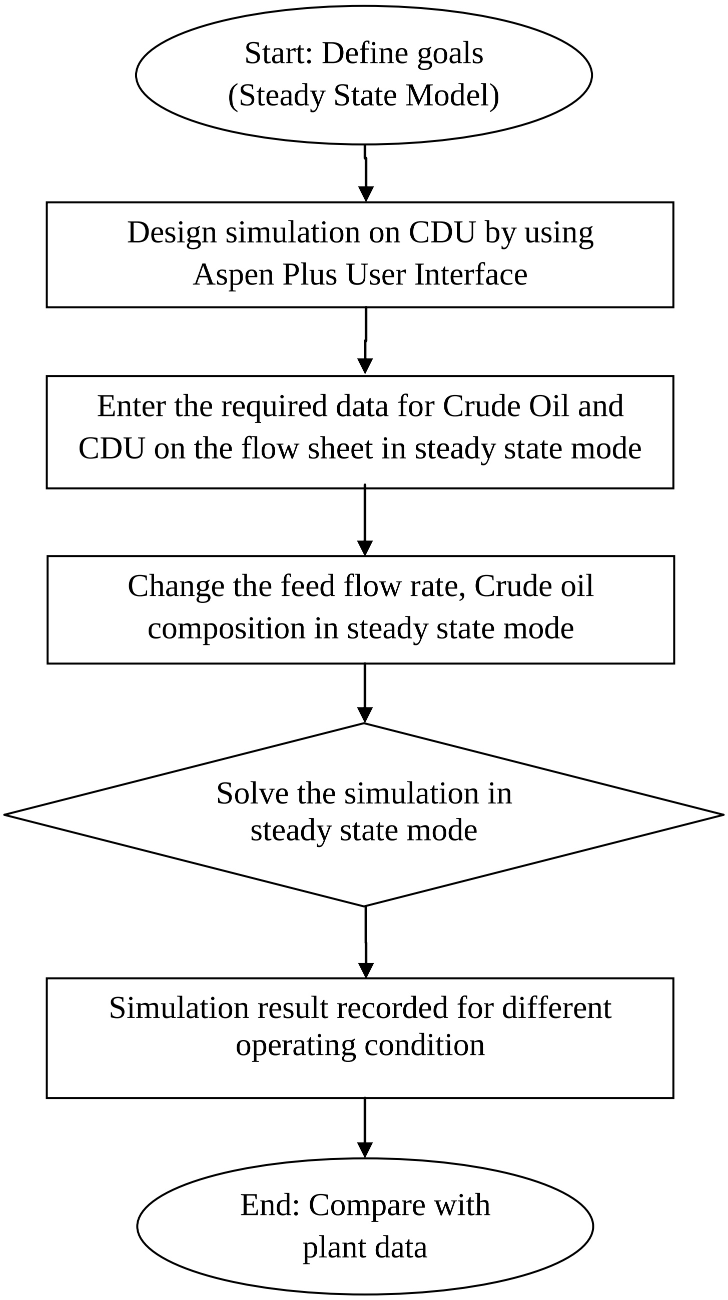
The equation for the main column and equation at feed tray, N are formed based on Figure 3.1. From the mathematical equation which represent in the form of differential equation or partial differential equation, the relationship of the inlet variable toward the outlet variable was determined. After all, the mathematical conclusion and real world conclusion was been made base on the mathematical equation obtained. The procedure for forming a mathematical model was shown in Flow Chart 3.1:



Flow Chart 3.1 Routes to form a Mathematical Model

3.2.2 Procedure of Steady State Simulation in Aspen Plus

Flow Chart 3.2 below has shown the basic steady state model simulation step. The steady state simulation model was form in Aspen Plus User Interface as the step shown in the following part.

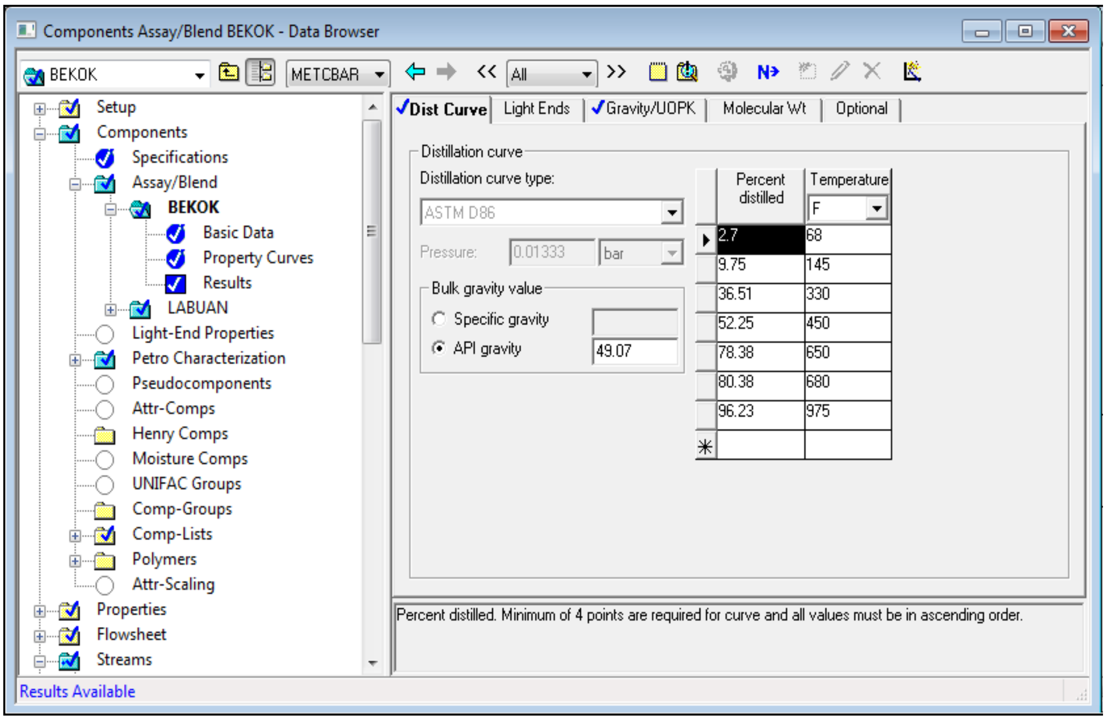


Flow Chart 3.2 Steady state model process flow chart for Aspen Plus environment

CDU processes are highly complex and integrated. Aspen Plus was a powerful tool that helps easily model CDU processes. Therefore, the CDU unit was run using Aspen Plus software. Before running the CDU process simulation, the components of crude oil need to be defined and analyzed. The steps of defining crude oil component are as below:

i. Define components
ii. Enter assay data for two crude oils
iii. Blend the crude oils to produce the crude feed
iv. Generate pseudo-components for the blend
v. Run the Assay Data Analysis calculations
vi. Examine results

The component specification sheet to specify crude oil component for simulation are as Figure 3.2 below:



Distillation curve

Distillation curve type: ASTM D86

Pressure: 0.01333 bar

Bulk gravity value
○ Specific gravity
● API gravity 49.07

Percent distilled	Temperature F
2.7	68
9.75	145
36.51	330
52.25	450
78.38	650
80.38	680
96.23	975

Percent distilled. Minimum of 4 points are required for curve and all values must be in ascending order.

Results Available

Figure 3.2: Crude oil component specification sheet

After defined the crude oil component, the following step of flow sheet generation was to as below:

i. Define the flow sheet graphically
ii. Specify properties, feed streams, and pre-flash tower
iii. Modify cuts specifications for pseudo-components generation
iv. Run the simulation
v. Examine simulation results

The Figure 3.3 below has shown the process flow sheet of the CDU steady state simulation.

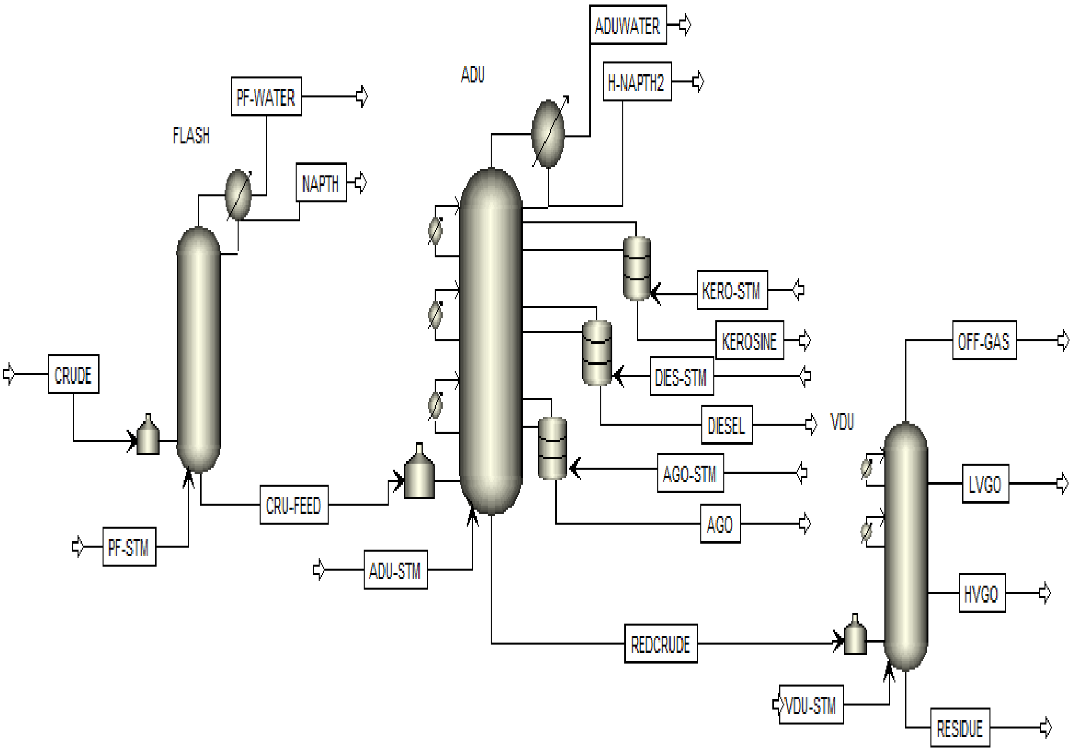
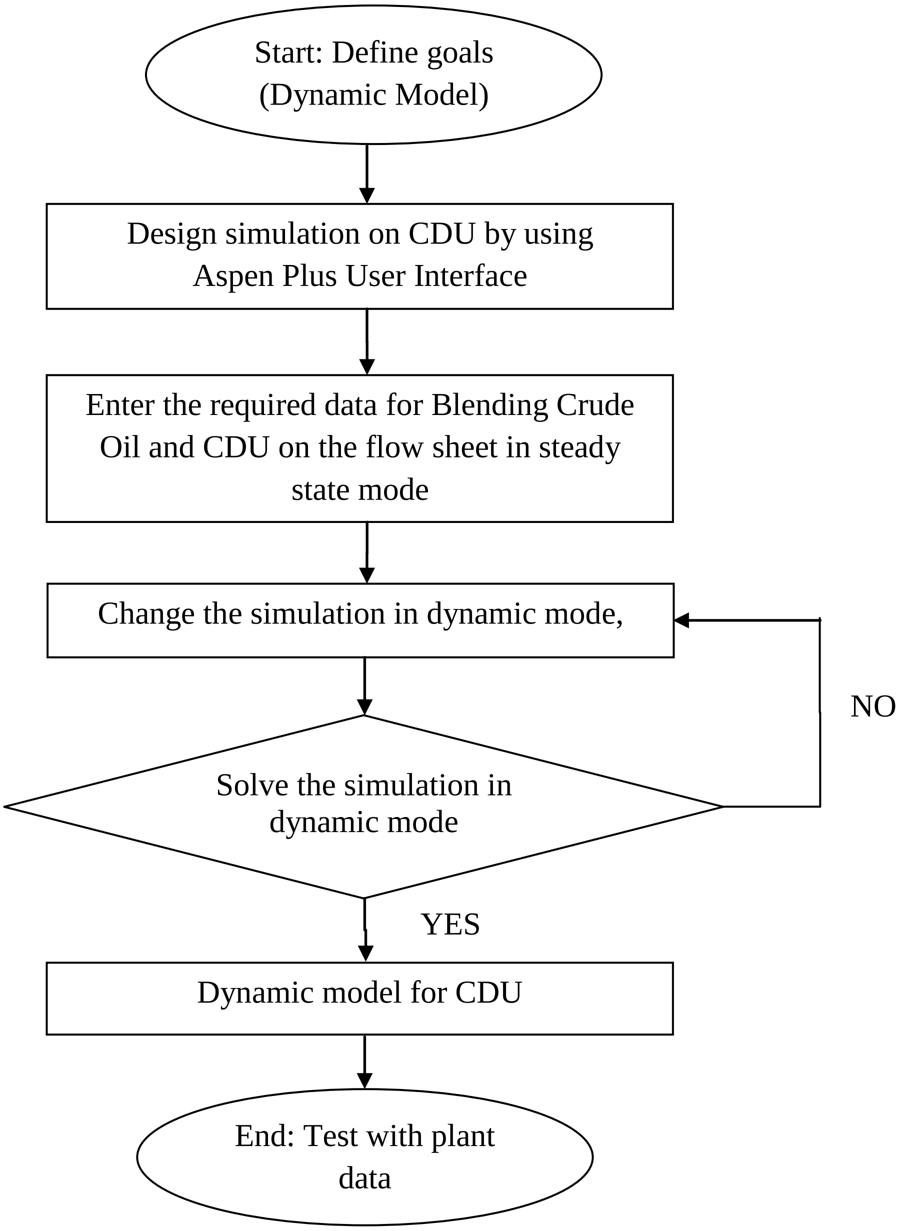


Figure 3.3: Process flow sheet of CDU

The process flow sheet of CDU consists of a pre-flash tower, atmospheric distillation unit and a vacuum distillation unit. The feed stream consisting of the crude oil first goes to the pre-flash tower where it was partially vaporized. The product stream then enters a single Petro-Frac block which name as atmospheric distillation unit. The product from ADU was then entering a vacuum distillation. Steams were fed to the bottom of all towers.

3.2.3 Procedure of Dynamic Simulation in Aspen Plus

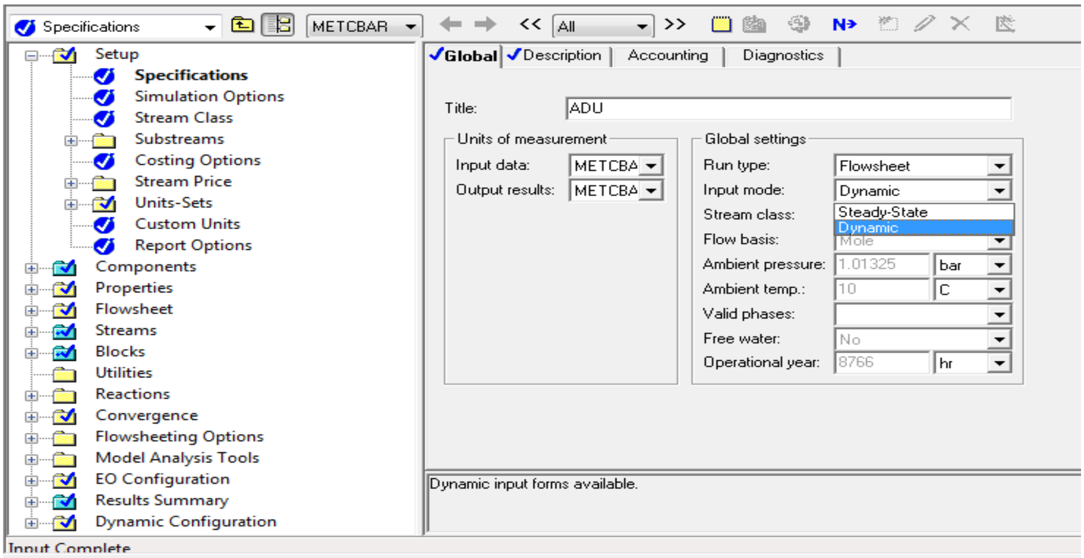
Flow Chart 3.3 below has shown the basic dynamic model simulation step. The dynamic simulation model was imported from the steady state model which completed in Aspen Plus User Interface.



Flow Chart 3.3 Dynamic model process flow chart for Aspen Plus environment

The steps of changing steady state into dynamic step are as below:

i. Change the setting from steady state to dynamic in Aspen user interface



Title: ADU

Input data: METCBA

Output results: METCBA

Run type: Flowsheet

Input mode: Dynamic

Stream class: Steady-State / Dynamic

Flow basis: Mole

Ambient pressure: 1.01325 bar

Ambient temp.: 10 C

Valid phases:

Free water: No

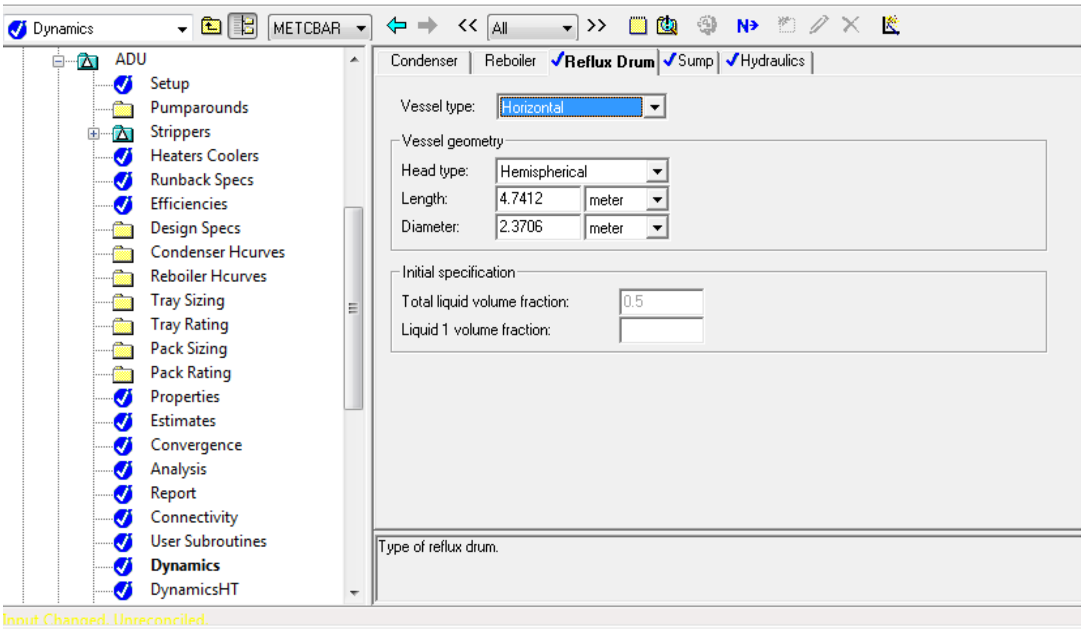
Operational year: 8766 hr

Dynamic input forms available.

Input Complete

Figure 3.4 Step of changing from steady state to dynamic

ii. After that key in all the data require such as Reflux drum geometry, sump geometry and tray geometry for PF, ADU, VDU and all stripper.



Vessel type: Horizontal

Head type: Hemispherical

Length: 4.7412 meter

Diameter: 2.3706 meter

Total liquid volume fraction: 0.5

Liquid 1 volume fraction:

Type of reflux drum.

Input Changed, Unreconciled

Figure 3.5 Data require for dynamic state simulation

iii. Finally, export the steady state simulation into dynamic simulation format.

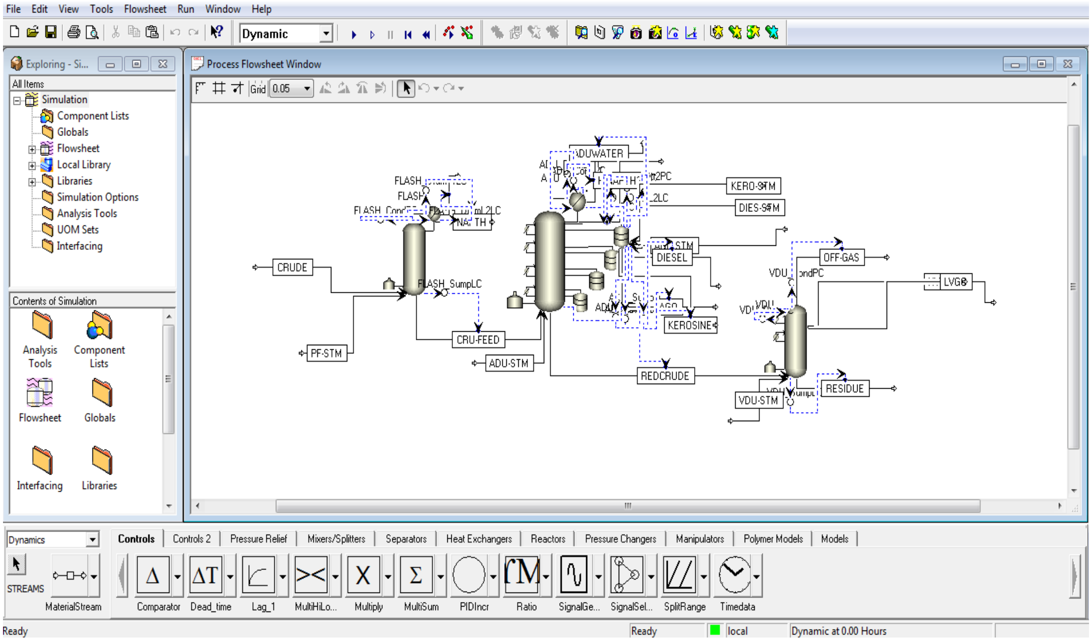


Figure 3.6 Export to Aspen Plus Dynamics

CHAPTER 4

RESULT AND DISCUSSION

This chapter mainly discussed on the result of experiment conducted for this work. The chapter begins with the mathematical model for CDU. Then a steady state simulation conducted in Aspen Plus User Interface. After the model was valid, a dynamic simulation was conducted. The result obtained was illustrated in form of table and graphs. Comparison and discussion was presented in this chapter while the experimental data are tabulated and inserted in as appendices. The CDU model was used to study the following:

i. The effect of different operating conditions flow rate of petroleum refining and composition of petroleum products toward the yield
ii. To develop a dynamic model of CDU based on the steady states CDU model. Thus obtain the evolution of the system behaviour with respect to time. Dynamic simulation results are typically presented as time trajectories of a system.

4.1 Mathematical Model

Tray N (feed stage)

Figure 4.1 represents the general scheme of a column's stage.

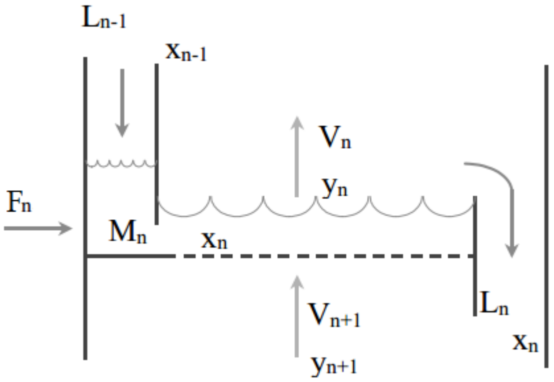


Figure 4.1 Scheme of a column stage

Overall Mass Balance,

Steady State mass balance for stage N:

$$L_{n-1}x_{n-1,j} + V_{n+1}y_{n+1,j} + F_n x_{n,j} - L_n x_{n,j} - V_n y_{n,j} = 0 \tag{4.1}$$

Where V_n is the molar flow of vapour from stage n

V_{n+1} is the molar flow of the vapour entering stage n

L_n is the molar flow of liquid from stage n

L_{n-1} is the molar flow of liquid entering stage n

x, y is the mole fraction in liquid, vapour

Dynamic State:

In dynamic state, the right hand side of the equation does not equal to zero due to accumulation of mass on the stage.

$$L_{n-1}x_{n-1} + V_{n+1}y_{n+1} + F_n x_n - L_n x_n - V_n y_n = \frac{d(M_n x_n)}{dt} \tag{4.2}$$

Where M_n represents the liquid hold up on the stage, the vapour hold up is negligible as stated in Chapter 2.7 due to pressure below 10 atm and the liquid hold up is less than 20%.

Liquid Hold up:

The liquid hold up of a stage can use the formula below:

$$M_n = \rho_{Ln}A_{Tn}h_{Tn} + \rho_{Ln}A_{Dn}h_{Dn} \tag{4.3}$$

Where M_n represents the liquid hold up on the stage

ρ_{Ln} is the liquid density at stage n

A_T is the active area of stage

A_D is the surface area of the down corner

h_T is the liquid height of stage

h_D is the surface area in the down corner

The formula used for the calculation of the liquid mole flow from a stage is Francis Equation. The Francis Equation is as below:

$$L_n = c\sqrt{2gl_{Wn}}\rho_{Ln}(h_{Tn} - h_{Wn})^{1/2} \tag{4.4}$$

Where c = 0.42 which is a constant

l_{Wn} is the weir length

h_{Wn} is the weir height

Energy Balance

Steady State energy balance for stage N:

$$L_{n-1}h_{n-1} + V_{n+1}h_{n+1} + F_n h_{Fn} - L_n h_n - V_n h_n + Q_m - Q_s - Q_{loss} = 0 \tag{4.5}$$

Where h_n, h_{n-1}, h_{n+1} are the molar enthalpy of corresponding component

Q_m is heat of mixing

Q_s is the external heat supplied

Q_{loss} is the heat loss to environment

Dynamic State

In dynamic state case, the right hand side of the equation does not equal to zero due to accumulation of heat on the stage.

$$L_{n-1}h_{n-1} + V_{n+1}h_{n+1} + F_n h_n - L_n h_n - V_n h_n + Q_m - Q_s - Q_{loss} = \frac{d(M_n h_n)}{dt} \tag{4.6}$$

Vapour Liquid Equilibrium

In the steady state, an equilibrium state between vapour and liquid phase is assumed for a theoretical stage. The general equation for equilibrium is Henry’s Law.

$$y_i = K_i x_i \tag{4.7}$$

Where K is the equilibrium coefficient for component i.

The thermodynamic method for the calculation of the equilibrium coefficient is the most important which determine the simulation accuracy. Aspen provided several type of thermodynamic method. The suitable method selected is Peng Robinson state equation with Antoine equation.

Antoine equation

$$\log_{10}(P_n^s) = A_{i,j} - \frac{B_{i,j}}{C_{i,j}+T_n} \tag{4.8}$$

Where P^s is the saturated partial pressure

T_n is the temperature at stage n

$A_{i,j}$, $B_{i,j}$, $C_{i,j}$ is the Antoine coefficient

The CDU give an unsteady state behaviour to the process, product flow rate and product purity. Therefore, in order to clearly understand and to form a dynamic model of the CDU a mathematical model constructed with some assumptions were made as stated in the literature review Chapter 2.7. The mathematical model for pre-flash, ADU, VDU and side stripper is quantitatively the same. The different is only the number of stage and can be considering as a structural parameter. Mathematical model only involve equation for total material balance, component balance, energy balance and vapour liquid equilibrium. The combination of all equation listed created the mathematical model of a theoretical stage for a distillation column.

In a steady state condition, as the crude feed flow rate increased while the heat supplied and the heat loss is constant. The heat of mixing is assumed negligible. Then form formula below:

$$L_{n-1}h_{n-1} + V_{n+1}h_{n+1} + F_n h_{Fn} + Q_m = L_n h_n + V_n h_n + Q_s + Q_{loss} \tag{4.9}$$

As the feed flow rate increased and Q_s, Q_{loss}, Q_m is constant, the value of L_n and V_n need to be increased so that the equation is balance. This shown that the liquid product is proportional to the feed flow rate as the energy is constant and the change of energy balance of the column may lead to a change in the mass balance of the column.

4.2 Steady State Result

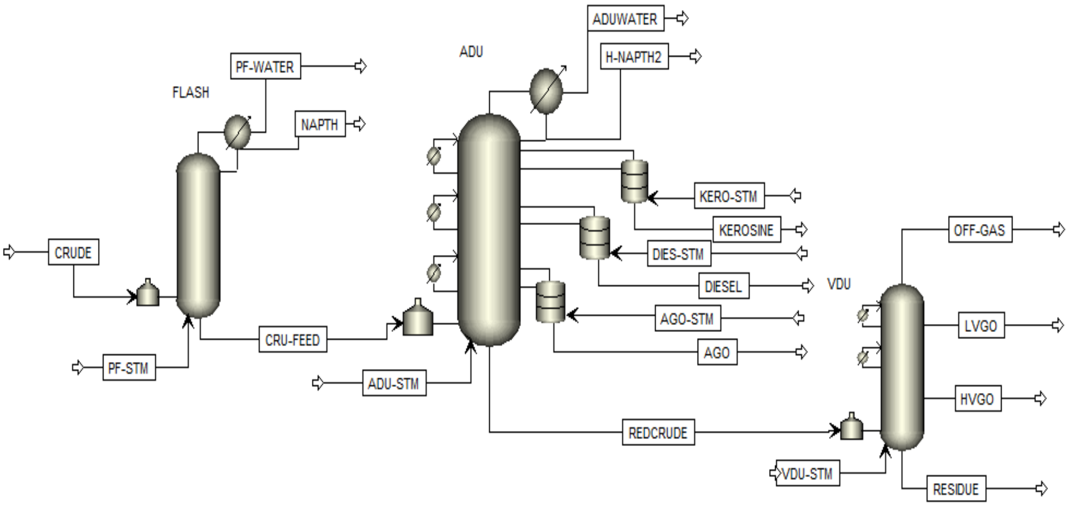


Table 4.1 Steady State Simulation Result of Various Crude Flow rate and Different Type of Crude

Crude	Product	Crude Flow rate (m^3/day)				
	Flow rate (m^3/h)	17653.6	19860.3	22067	24273.7	26480.4
Bekok	Naphtha	140.1041	139.7978	139.5371	139.328	139.1515
	Heavy Naphtha	133.4339	119.0416	136.5907	119.7055	120.3649
	Total Naphtha	273.538	258.8394	276.1278	259.0335	259.5164
	Kerosene	97.44406	102.8564	105.1721	106.5084	103.9496
	Diesel	31.38072	94.52823	2.006039	98.05913	98.97323
	AGO	60.42181	60.47855	60.34729	61.35365	61.30198
	Red Crude	421.6153	479.4417	666.9554	698.2277	808.3911
	Off Gas	3.59E+05	3.75E+05	5.32E+05	5.63E+05	7.38E+05
	LVGO	63.87504	72.31829	76.6108	77.24213	78.15937
	HVGO	71.92549	88.19403	95.4392	96.33247	97.92882
	Residue	142.488	157.9226	232.9635	235.9713	265.5292
Tapis	Naphtha	141.2376	140.9434	140.6835	140.4568	140.2633
	Heavy Naphtha	123.5355	118.8409	127.5672	123.5572	120.8763
	Total Naphtha	264.7731	259.7843	268.2507	264.014	261.1396
	Kerosene	118.5724	83.58575	106.4657	76.80646	115.0764
	Diesel	91.33528	130.3283	102.7796	125.4617	100.8747
	AGO	59.67933	60.44353	60.75149	60.35981	61.54149
	Red Crude	3.61E+02	474.1264	5.86E+02	701.7991	811.1328
	Off Gas	3.41E+05	3.85E+05	4.53E+05	5.66E+05	7.26E+05
	LVGO	54.91964	64.10082	74.73862	77.54619	78.6777
	HVGO	62.57733	118.8409	92.11691	96.88255	98.63214
	Residue	117.0731	161.8823	198.9734	234.1582	259.5011

Crude	Product	Crude Flow rate (m^3/day)				
	Flow rate (m^3/h)	17653.6	19860.3	22067	24273.7	26480.4
Miri	Naphtha	140.0224	139.6762	139.3939	139.1663	138.9767
	Heavy Naphtha	139.1719	138.1199	137.1731	136.4274	135.6607
	Total Naphtha	279.1943	277.7961	276.567	275.5937	274.6374
	Kerosene	111.5544	109.9861	108.9196	108.1055	107.4901
	Diesel	81.8525	82.7999	83.44074	84.05511	84.57015
	AGO	70.86417	69.73126	68.56473	67.56774	66.73819
	Red Crude	350.9058	465.5199	580.3409	692.546	803.0208
	Off Gas	3.12E+05	2.65E+05	3.76E+05	5.36E+05	7.03E+05
	LVGO	50.52558	78.07489	78.22775	78.49684	78.74049
	HVGO	60.98761	98.02526	88.34716	98.98062	99.64381
	Residue	143.7242	198.7177	249.7212	253.4908	265.9278
Labuan	Naphtha	141.4108	141.0419	140.7241	140.2243	140.4527
	Heavy Naphtha	141.2238	140.4575	139.6729	138.2285	138.9191
	Total Naphtha	282.6346	281.4994	280.397	278.4528	279.3718
	Kerosene	112.8441	111.3201	110.2167	109.0157	109.5159
	Diesel	79.95723	80.89577	81.5428	82.59357	82.10991
	AGO	71.19911	70.06667	69.14994	67.66918	68.37139
	Red Crude	3.57E+02	472.0448	5.87E+02	813.3957	700.6735
	Off Gas	2.66E+05	2.89E+05	3.47E+05	7.03E+05	5.23E+05
	LVGO	60.08531	69.04719	78.30722	79.30895	78.83748
	HVGO	70.29993	89.12263	98.42842	100.3743	99.51016
	Residue	146.7278	206.5938	256.2764	260.2008	258.5218

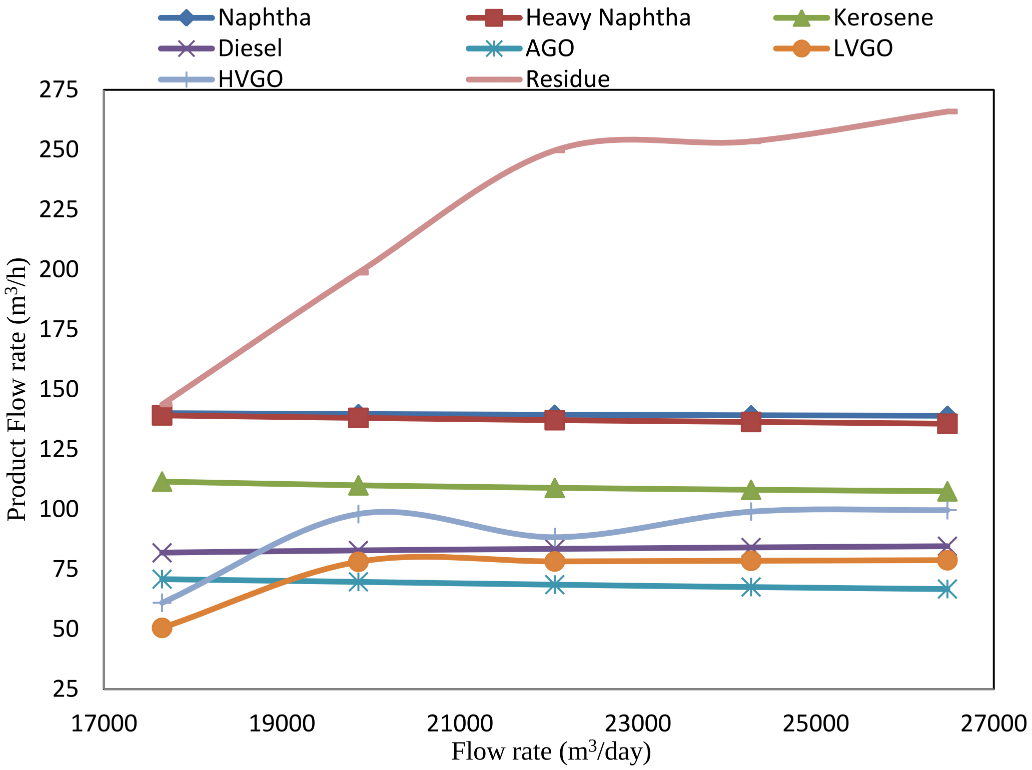


Figure 4.2(a) Product Flow Rate versus Bekok Crude Input Flow rate

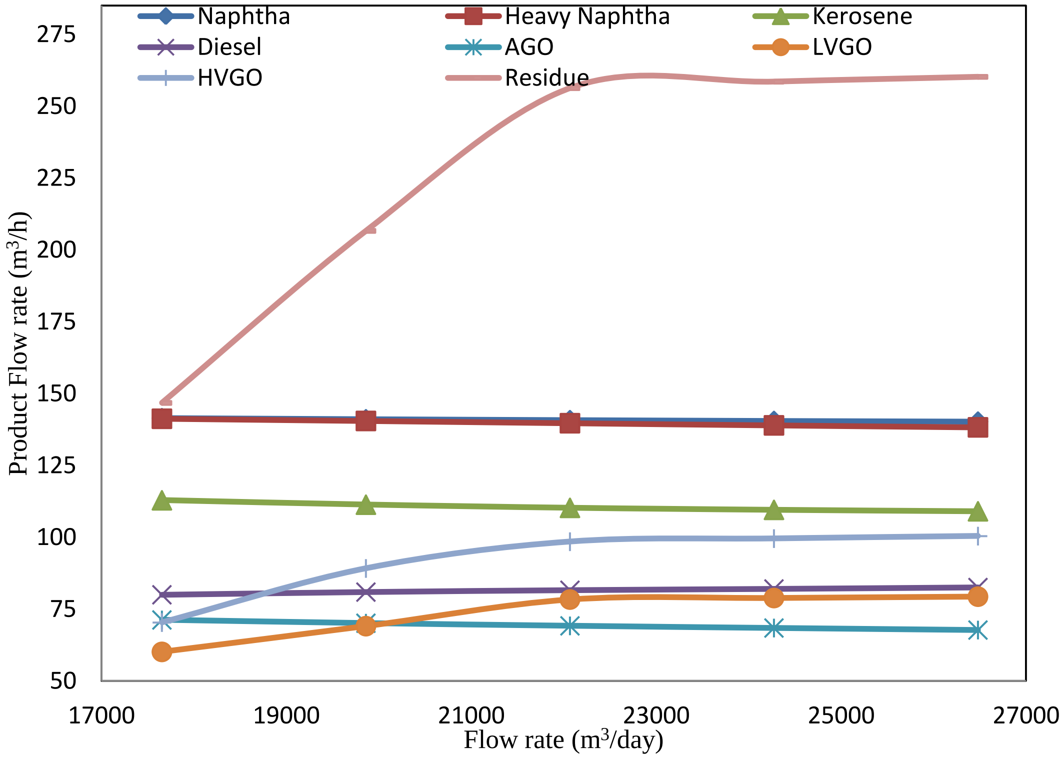


Figure 4.2(b) Product Flow Rate versus Tapis Crude Input Flow rate

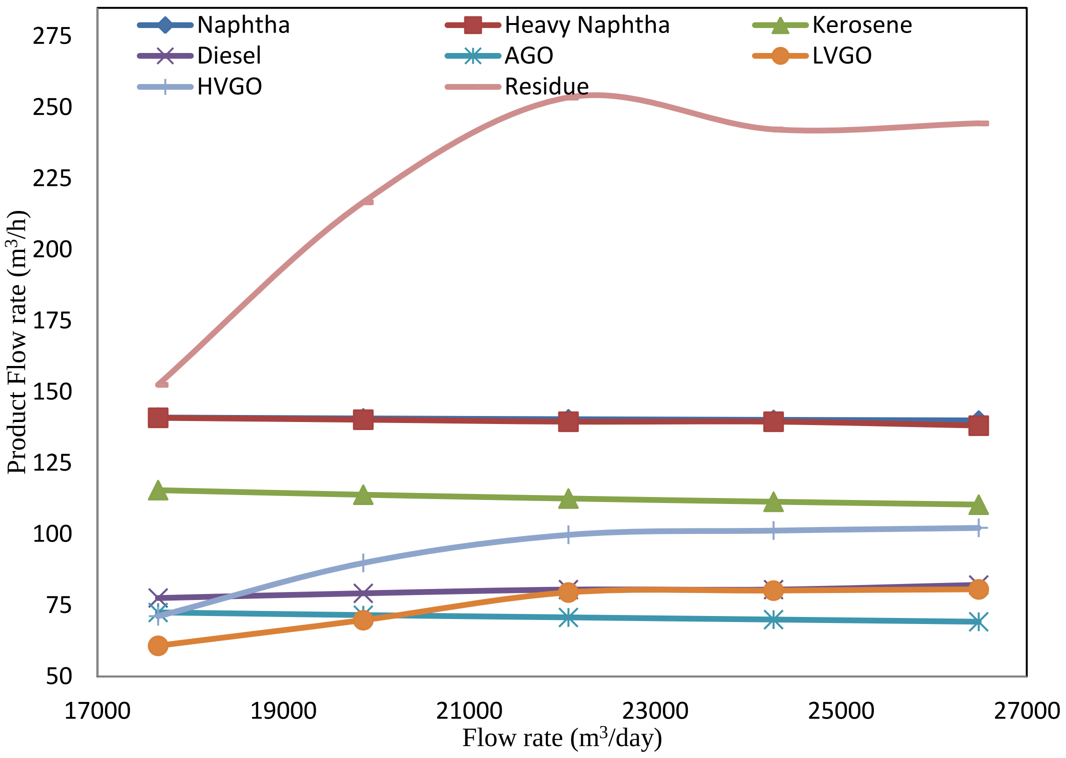


Figure 4.2(c) Product Flow Rate versus Miri Crude Input Flow rate

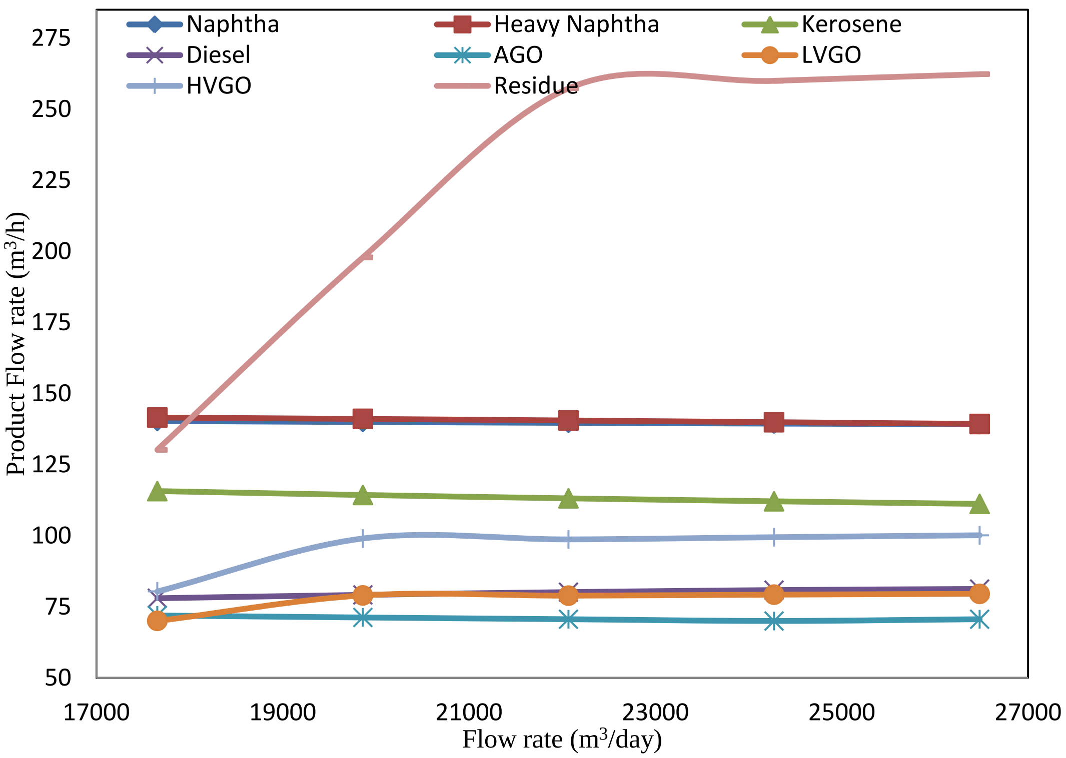


Figure 4.2(d) Product Flow Rate versus Labuan Crude Input Flow rate

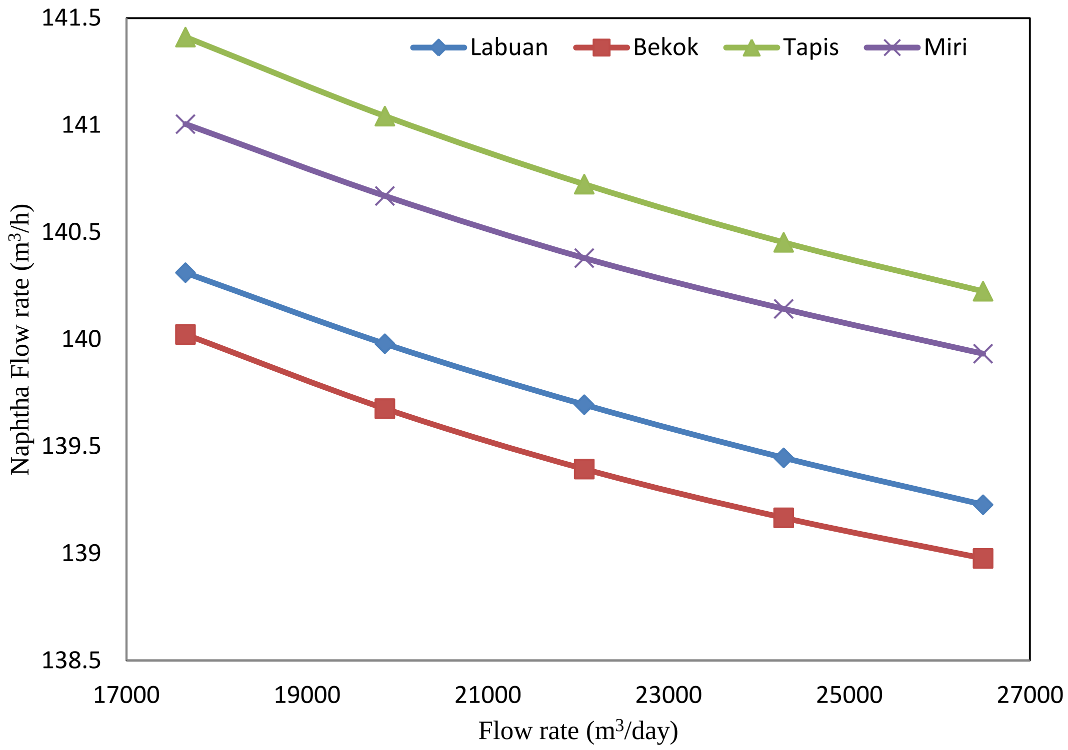


Figure 4.2(e) Naphtha Flow Rate versus Crude Input Flow rate of Different Crude

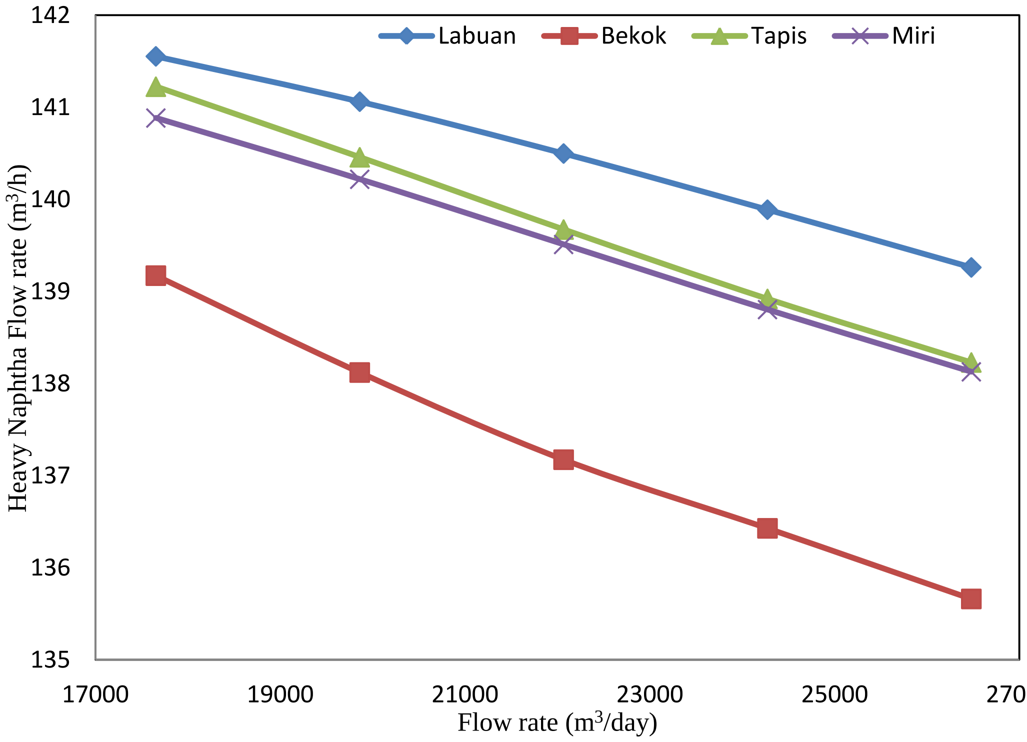


Figure 4.2(f) Heavy Naphtha Flow Rate versus Crude Input Flow rate of Different Crude

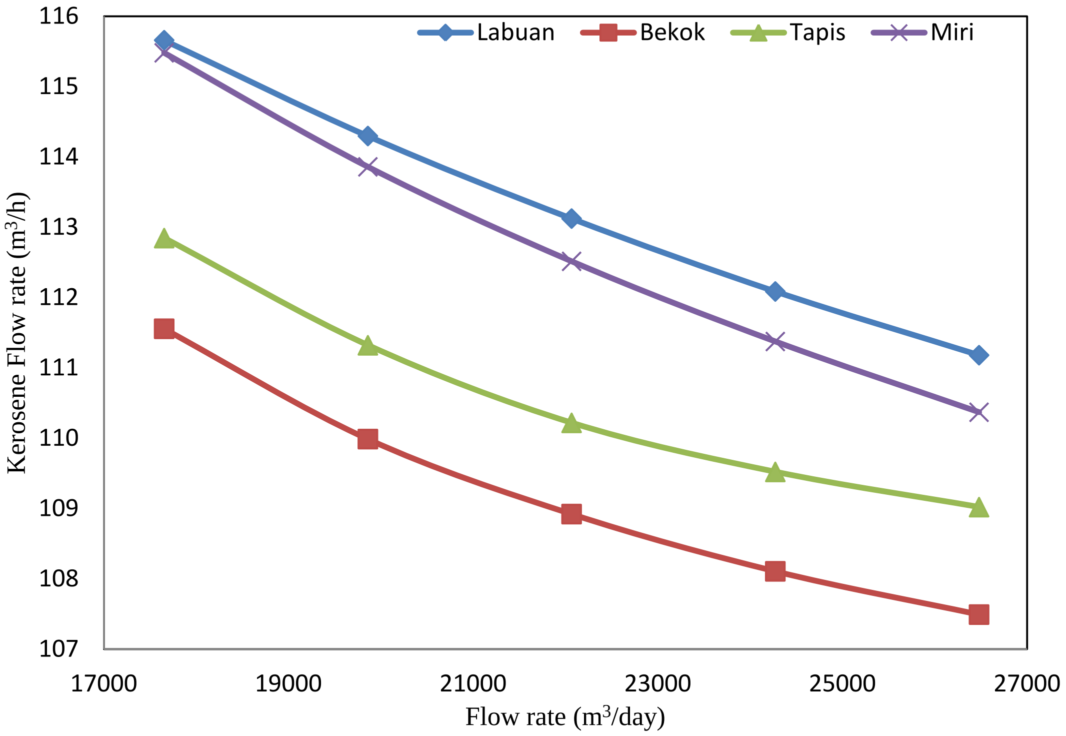


Figure 4.2(g) Kerosene Flow Rate versus Crude Input Flow rate of Different Crude

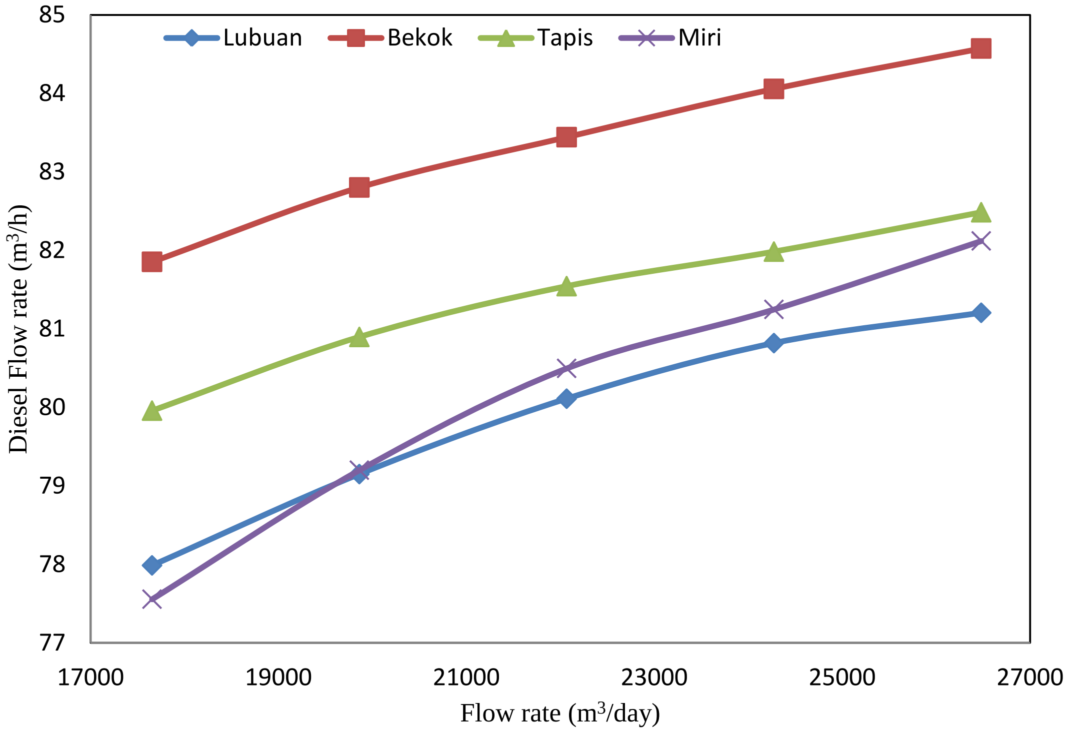


Figure 4.2(h) Diesel Flow Rate versus Crude Input Flow rate of Different Crude

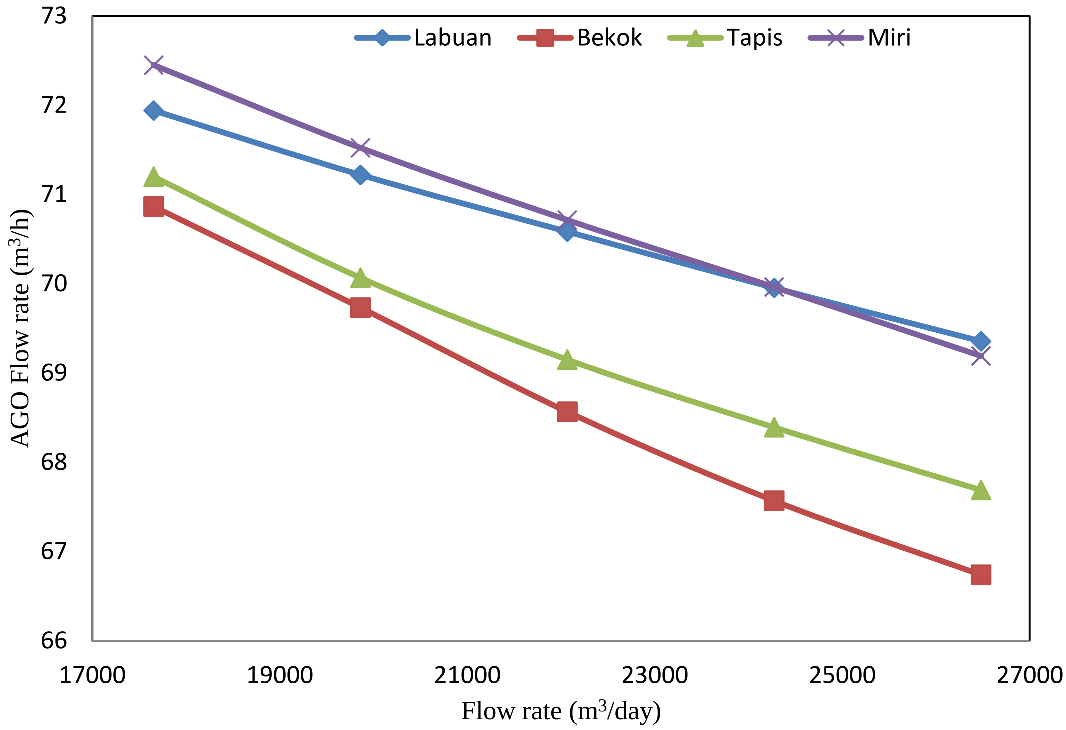


Figure 4.2(i) AGO Flow Rate versus Crude Input Flow rate of Different Crude

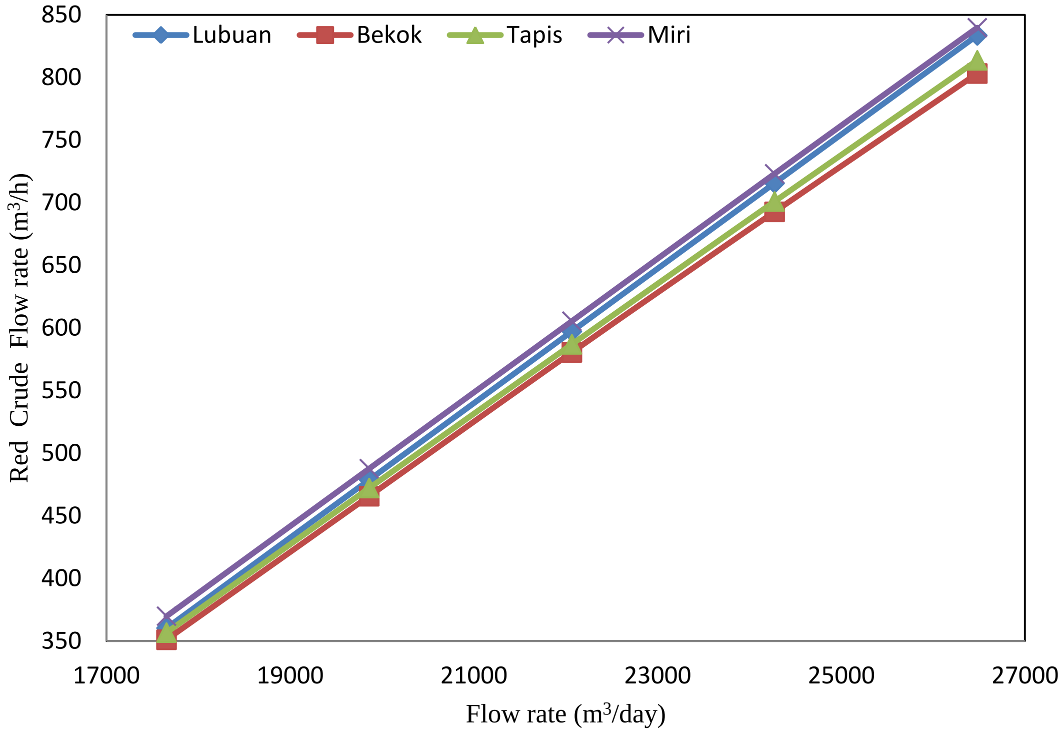


Figure 4.2(j) Red Crude Flow Rate versus Crude Input Flow rate of Different Crude

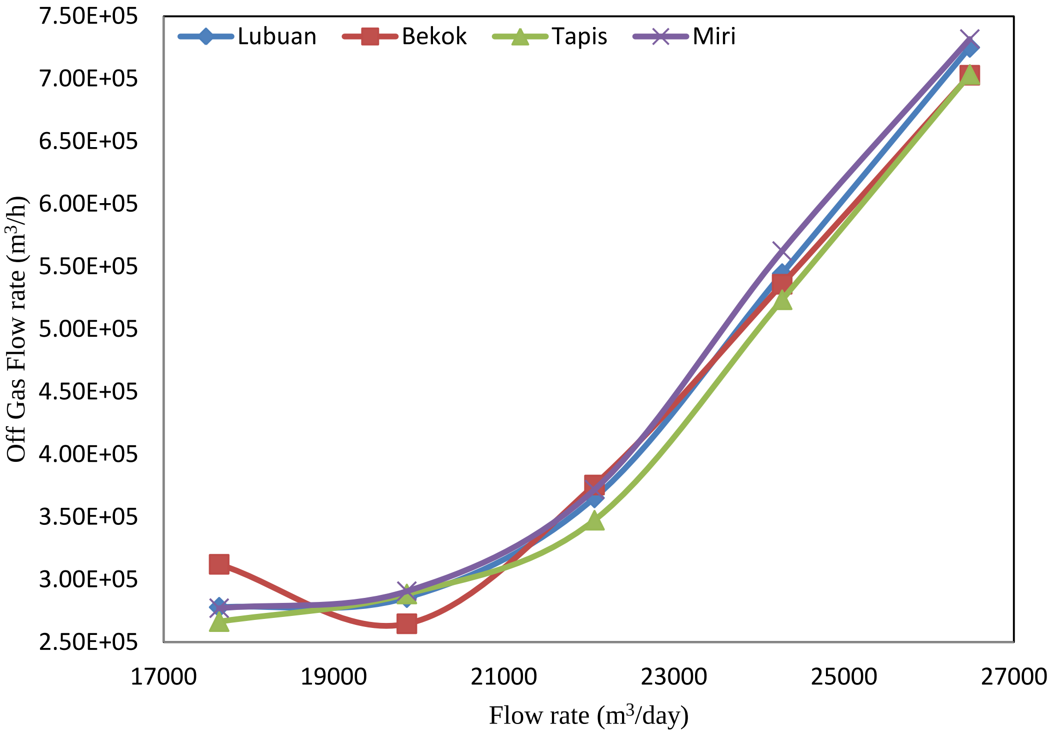


Figure 4.2(k) Off Gas Flow Rate versus Crude Input Flow rate of Different Crude

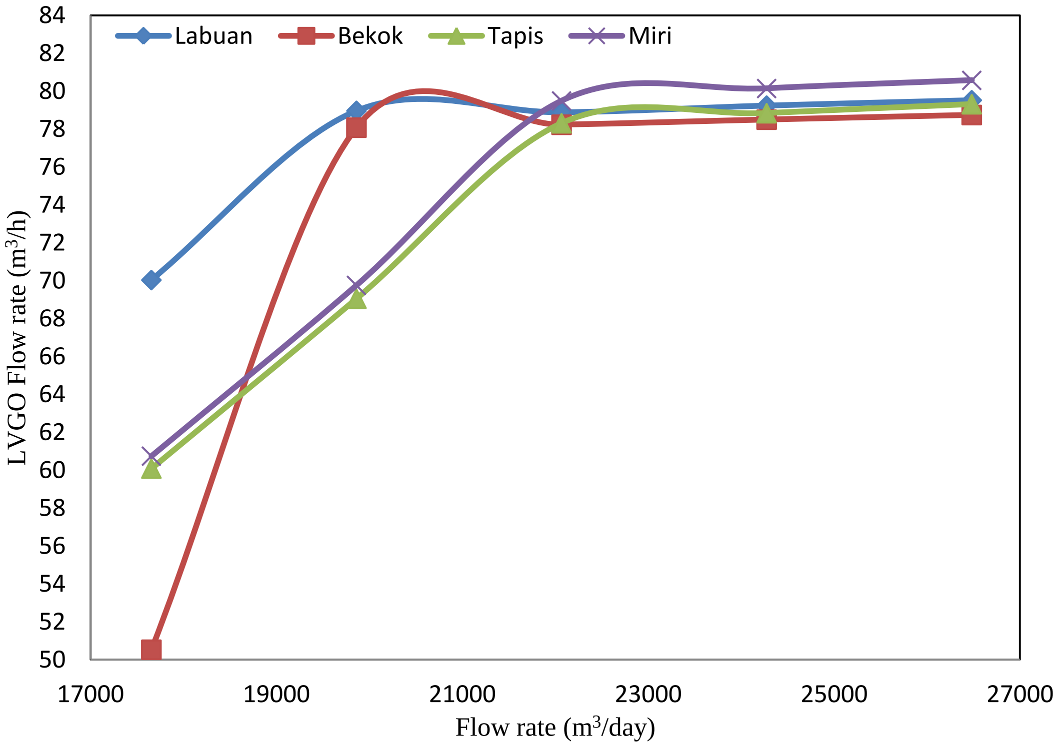


Figure 4.2(l) LVGO Flow Rate versus Crude Input Flow rate of Different Crude

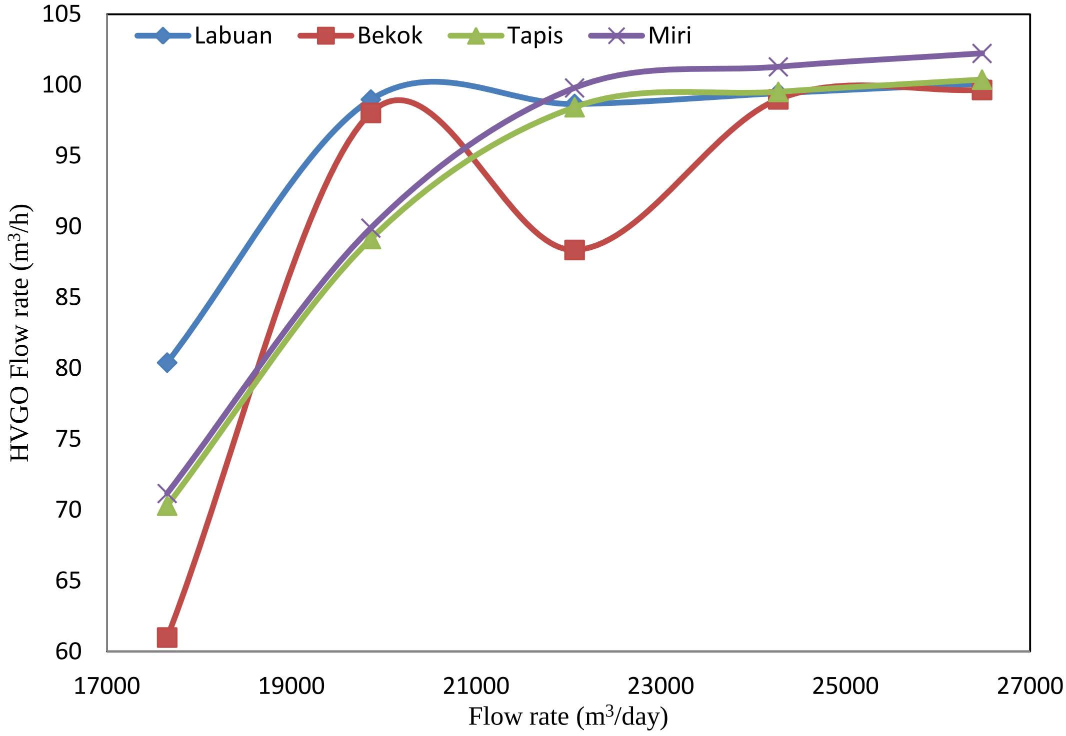


Figure 4.2(m) HVGO Flow Rate versus Crude Input Flow rate of Different Crude

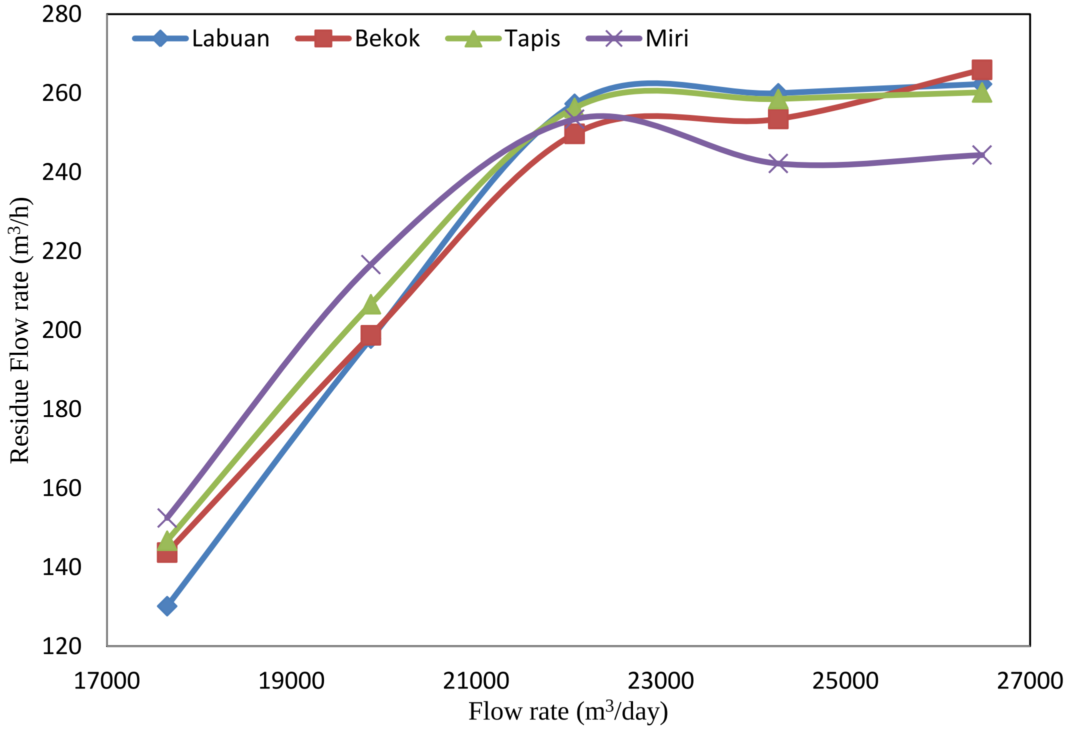


Figure 4.2(n) Residue Flow Rate versus Crude Input Flow rate of Different Crude

Steady state simulations start with a ‘‘base case’’ in which all the assumptions are used as preliminary project specifications. The CDU specification is based on the literature review CDU specification. Base case input specifications and simulation results are reported in Table 2.1 and Table 4.1(a) respectively

The Figure 4.2(a) until Figure 4.2(d) show the product output flow rate of difference type of crude (Bekok, Labuan, Tapis, Miri) with the change of crude input flow rate for 17653.6 m^3/day, 19860.3 m^3/day, 22067 m^3/day, 24273.7 m^3/day and 26480.4 m^3/day. Based on the literature review the crude inlet flow rate is 22067m^3/day while the other input flow rate was obtained by -20%, -10%, +10% and +20% of the literature crude flow rate.

From the Figure 4.1(a) until Figure 4.1(d), as the crude input flow rate decreases the residue flow rate decreases while as the crude input flow rate increased, the residue flow rate dramatically increased. It is because the steam flow to the column and the reboiler duty is keep constant while the crude input flow rate changed. The heat energy input to the CDU keep constant which supposedly less heat energy or more heat energy is required as the crude input flow rate changed. The amount of heat energy required is used to vaporise the bottom crude in CDU. As the crude input flow rate increased, the liquid in the bottom of the column was increased due to the input heat energy is not sufficient enough and the bottom liquid was not boiled-off thus the residue flow rate increased. Hence, this proven that the change of energy balance of the column may lead to a change in the mass balance of the column.

In actual, the product flow rate should be increased as the crude input flow rate increased. However, the Figure 4.2(a) until Figure 4.2(b) shown that the other product such as naphtha, heavy naphtha, kerosene, diesel, AGO, off gas, LVGO and HVGO does not have a big fluctuation due to the constant of column specification. For example, the pump around duty, stripper draw rate and the condenser duty are kept constant throughout the crude input flow rate change so the amount of heat energy to vaporise the product is constant and the amount of product flow rate is almost constant.

A part from that, Figure 4.1(e) until Figure 4.1(j) is the comparison of difference type of crude and each product flow rate of ADU by changing crude input flow rate. The crude API value descending from Bekok, Tapis, Miri to Labuan, the API values are 49.07, 45.9, 36.27 to 33.2 respectively.

Based on the literature review Chapter 2.4 and compare with result of Figure 4.1(e) and Figure 4.2(f), the result obtain is feasible because the figure shown that the crude of Bekok which is higher in API value contain more light hydrocarbon (naphtha and heavy naphtha) compare to the other crude. However, as in the Figure 4.2(e) the naphtha product flow rate decreased as the flow rate of crude input increased. This is because the heat energy supply to the column is constant and the energy is evenly distributed to the input crude. Thus, less amount of naphtha gain the sufficient energy to vaporise in the column.

Figure 4.2(g) show the changes of crude input flow rate toward kerosene flow rate with different type of crude. As the crude input flow rate increased, the kerosene product flow rate nearly constant with small fluctuation. It is because the kerosene product has the same energy problem like the distillate product of the column. The energy provided to the column does not sufficient enough to vaporise all light hydrocarbon in the crude as the crude input flow rate increased.

As for the diesel product, product flow rate increased as the crude input flow rate increased. This can be seen from Figure 4.2(h). This phenomenon occur because there are more light key product in the diesel which does not obtain sufficient energy to vaporise from liquid phase into vapour phase as the crude input flow rate increased.

As for the AGO product, the product flow rate does not has big fluctuation as the crude input flow rate increased based on Figure 4.2(i). It is because the heat energy effect does not deal big effect as the top of the column.

For the Red Crude which is the residue from the ADU, the output flow rate increased as the crude input flow rate increased. It is because heat energy was not sufficient for the bottom liquid to be boiled-off and more medium hydrocarbon which do not have sufficient energy still in liquid form. This statement is proven by Figure 4.2(j).

Figure 4.2(k) until Figure 4.2(n) was shown the comparison of difference crude and each product flow rate of ADU by changing crude input flow rate. For the off gas which shown by Figure 4.2(k). Under vacuum condition, the energy require for changing phase from liquid to vapour was lower compared to normal condition. Therefore, the off gas product flow rate increased as the crude input flow rate increased due to the light and medium hydrocarbon which does not boiled-off in ADU was vaporised in the VDU.

The statement of “The energy require for changing phase from liquid to vapour was lower compared to normal condition and the light and medium hydrocarbon which does not boiled-off in ADU was vaporised in the VDU” was also can be use to explain the phenomena of increased product flow rate of LVGO, HVGO and residue.

4.3 Dynamic State Result

The dynamic response of CDU depends on the flow rate and the volume. The lower the crude inlet flow rate, the smaller the volume of all column, the faster the transient response. The procedure for sizing PF, ADU and VDU has already been discussed in Chapter 3. The only remaining issues are the sizes of the reflux drum geometry, the sump geometry and the tray geometry. A commonly used heuristic was to set these holdups to allow for 6 min of liquid holdup when the vessel is 50% full, based on the total liquid entering or leaving the vessel.

These volumetric liquid flow rates for PF, ADU, stripper column and VDU were found in the Profiles under each block. The volumetric liquid flow rate for the reflux drum (stage 1) bottom tray of PF, ADU, stripper and VDU were show in the Table 4.1 below. The total volumes of the reflux drum and sump geometry were calculated using equation below by assuming a length to diameter ratio of 2.2, weir height 0.05 and tray spacing 0.6096. (William, 2006)

$$Volume, v = \frac{\pi D^2}{4}(2.5D) \quad (4.10)$$

$$Volume, v = Q \times t \quad (4.11)$$

Where Q is the flow rate of product

t is the resident time 6 min

Table 4.2 Dynamic State Simulation Result of Various Crude Flow rate and Different Type of Crude

System	Flow rate (m^3/h)	Volume (m^3)	Diameter (m)	Length (m)
Pre-Flash				
Reflux drum	140.7241	14.0724	1.9280	4.8201
Sump	914.1219	91.4122	3.5974	8.9936
ADU				
Reflux drum	140.4984	14.0498	1.9270	4.8175
Sump	605.3153	60.5315	3.1356	7.8389
Kerosene Stripper				
Sump	113.1214	11.3121	1.7927	4.4817
Diesel Stripper				
Sump	83.4407	8.3441	1.6198	4.0494
AGO Stripper				
Sump	70.7128	7.0713	1.5328	3.8320
VDU				
Reflux drum	3.65e5	37600	26.7538	66.8846
Sump	249.7212	25.7	2.3567	5.8917

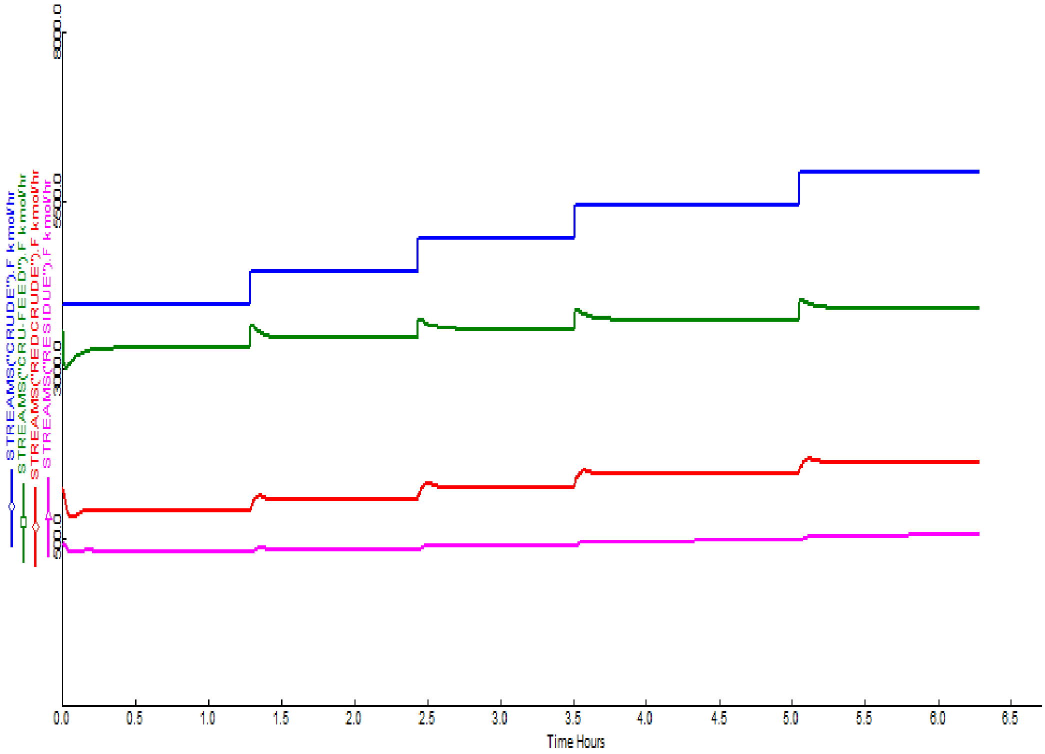


Figure 4.3(a) Respond of Bekok Crude input flow rate change on ADU feed, VDU feed and residue

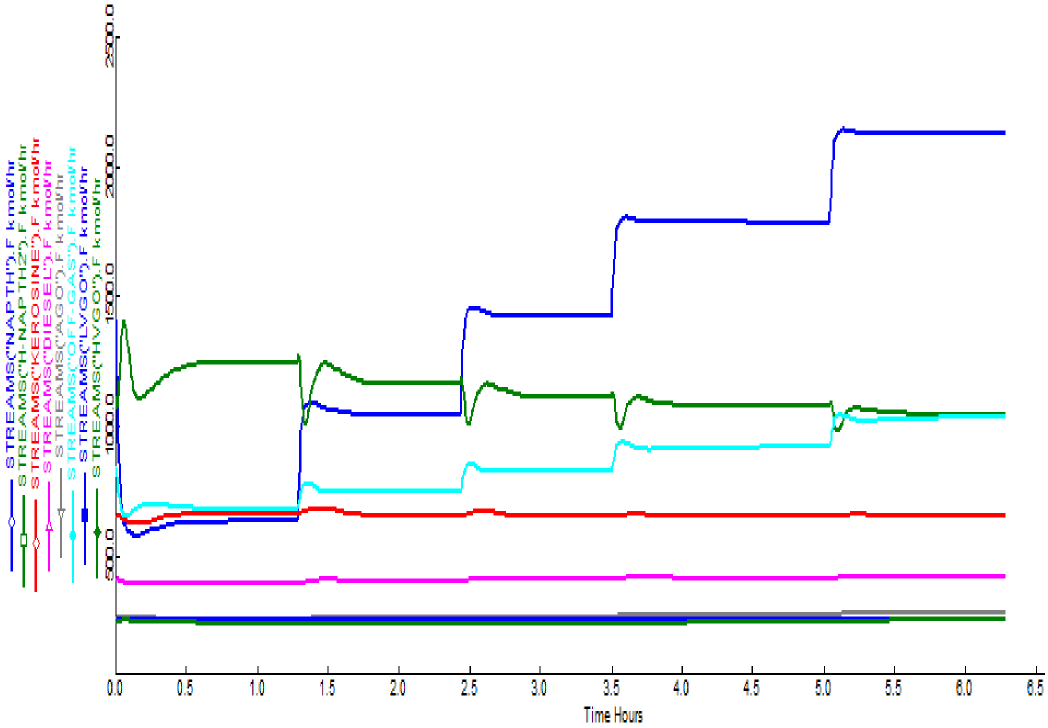


Figure 4.3(b) Product flow respond on Crude input flow change

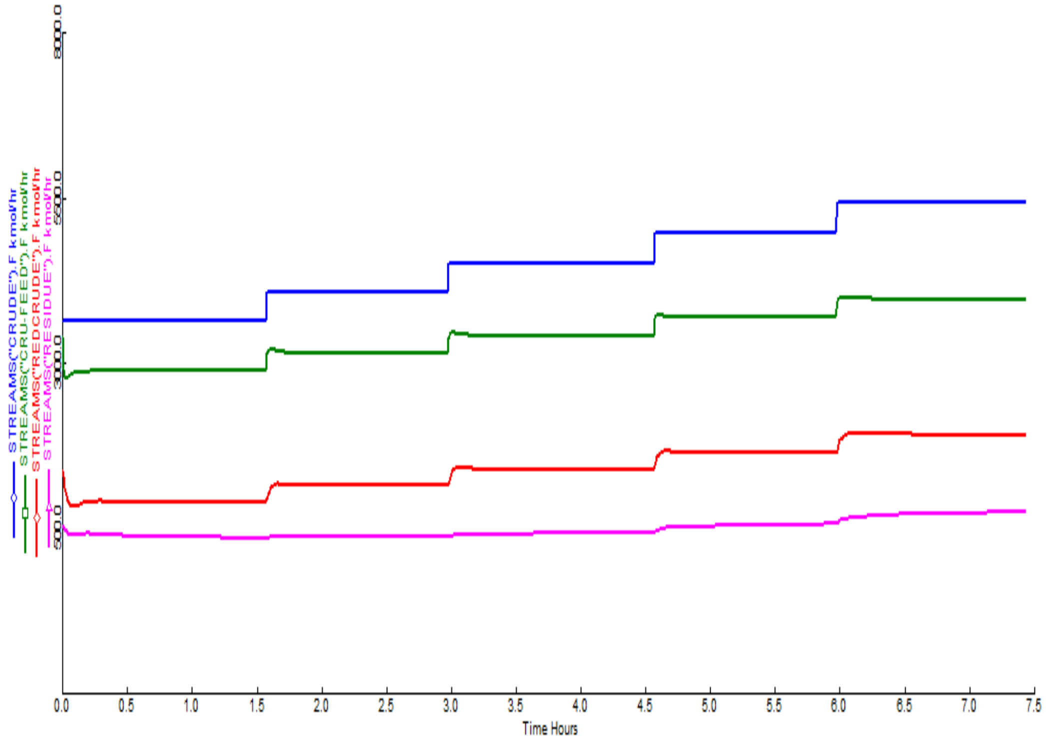


Figure 4.3(c) Respond of Tapis Crude input flow rate change on ADU feed, VDU feed and residue

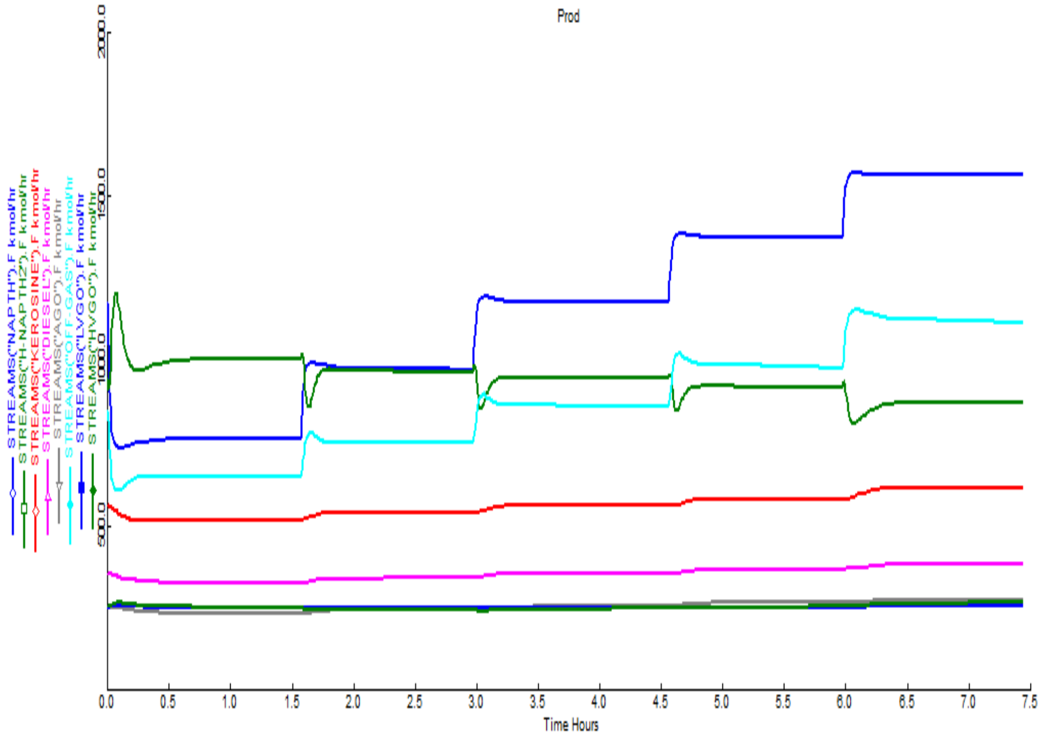


Figure 4.3(d) Product flow respond on Crude input flow change

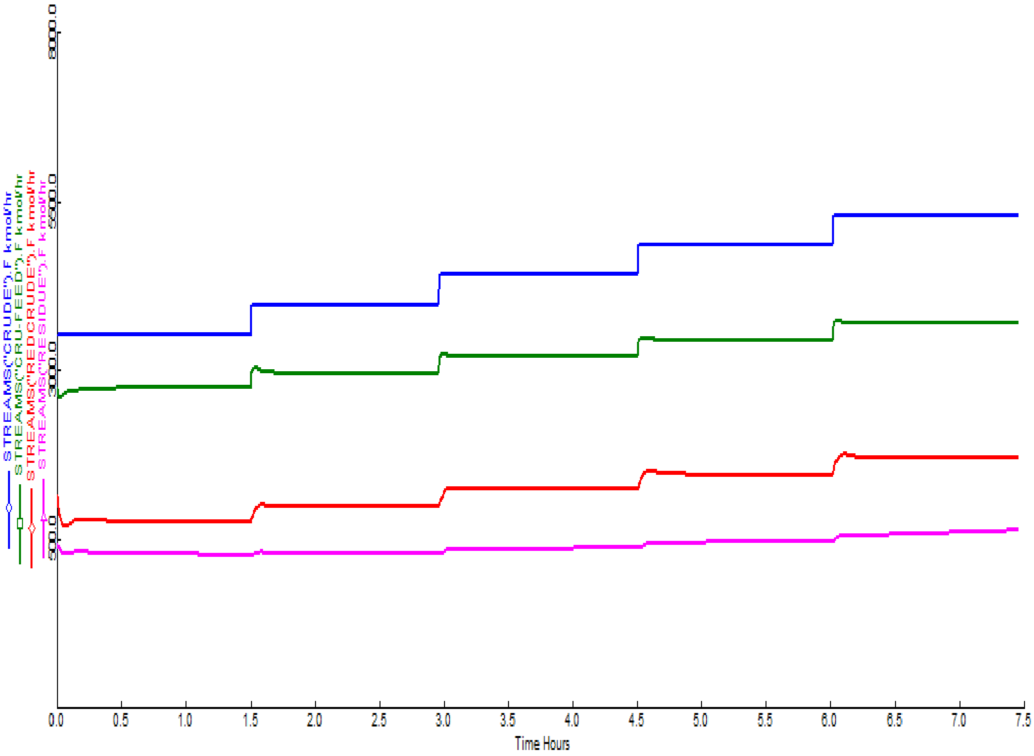


Figure 4.3(e) Respond of Miri Crude input flow rate change on ADU feed, VDU feed and residue

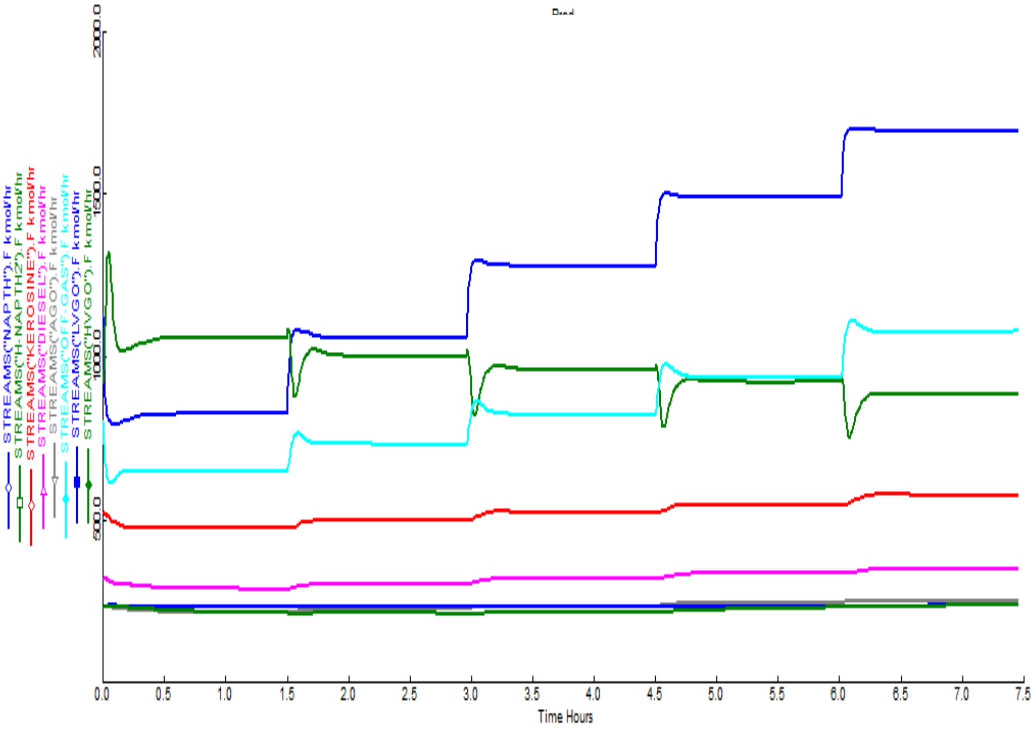


Figure 4.3(f) Product flow respond on Crude input flow change

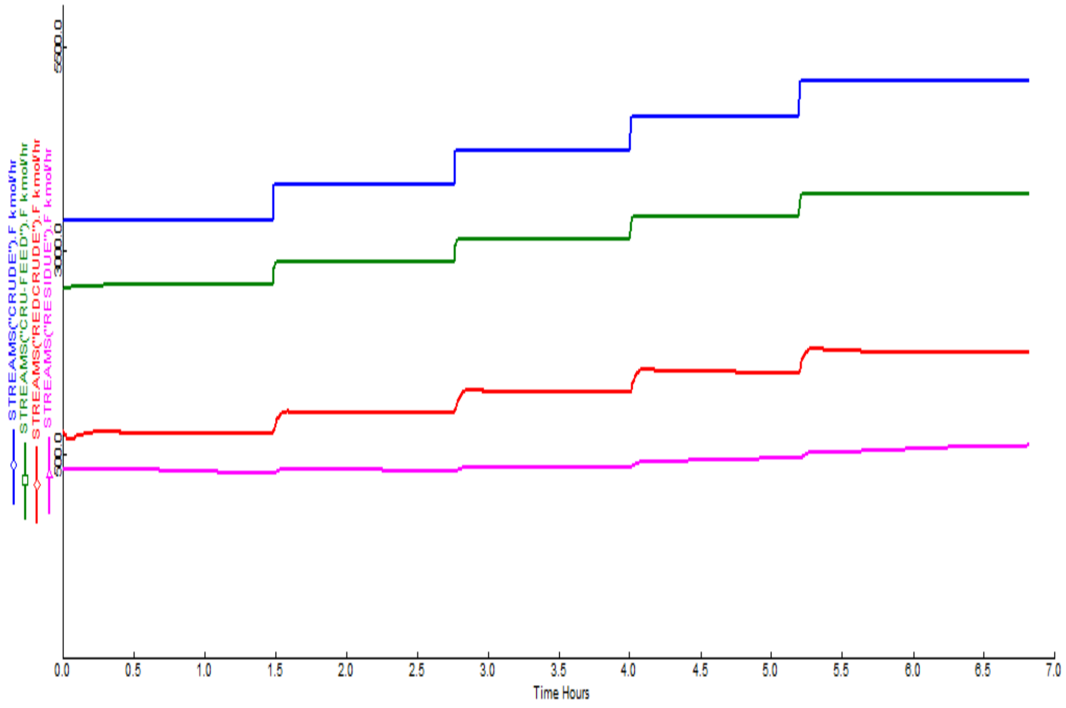


Figure 4.3(g) Respond of Labuan Crude input flow rate change on ADU feed, VDU feed and residue

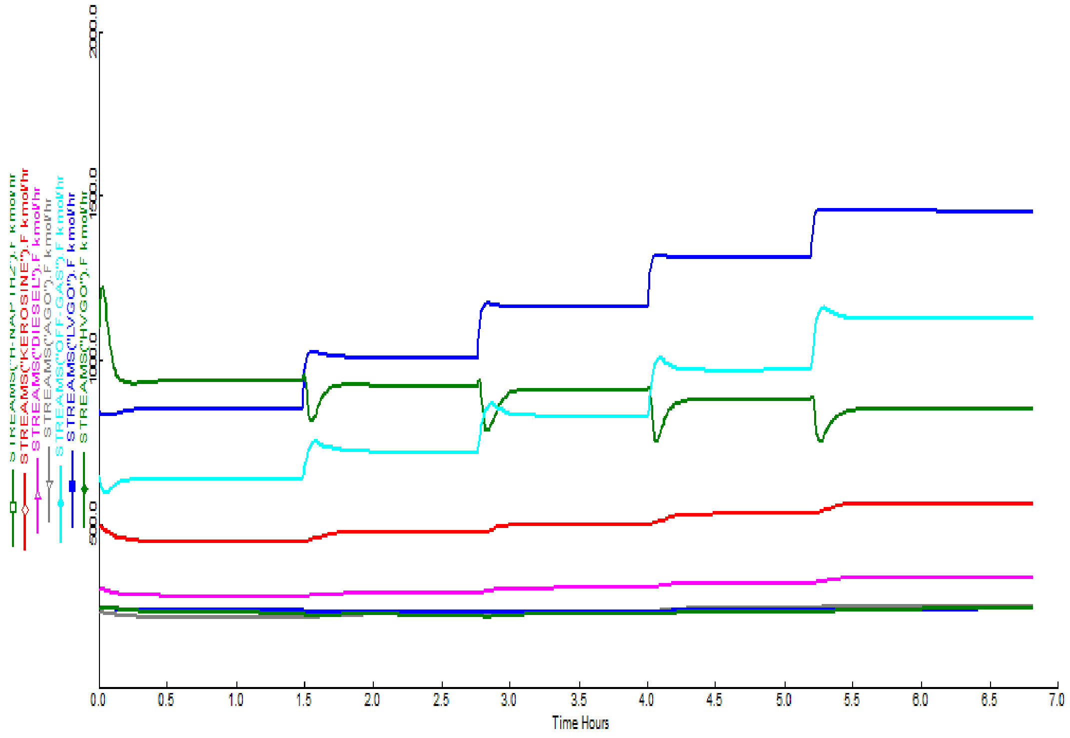


Figure 4.3(h) Product flow respond on Crude input flow change

Figure 4.3(a) until Figure 4.3(h) had shown the respond of CDU product stream toward the change of crude inlet flow rate for Bekok, Tapis, Miri and Labuan crude oil. As the crude inlet flow rate from 17653.6 m^3/day change to 19860.3 m^3/day, 22067 m^3/day, 24273.7 m^3/day and 26480.4 m^3/day, the flow rate of each distillate product also vary. The product flow rate of naphtha, kerosene, diesel, AGO, off gas, LVGO and HVGO increased as the crude inlet increased while only kerosene flow rate decreased.

Based on the dynamic simulation result, the increased phenomenon for stream crude feed, red crude and residue was having the same reason as in the steady state. The heat energy provided to the column was not sufficient enough to evaporate the entire light component in the rude as the crude inlet increased while the residue stream from VDU was only slightly increased because the vacuum condition lower down the energy require for evaporation process to occur. Therefore, most of the light component which was not evaporated in ADU was evaporated in VDU. This can be proven by the increasing outlet flow rate for the stream of off gas, LVGO and HVGO.

As illustrated in Figure 4.3(b), Figure 4.3(d), Figure 4.3(f) sand Figure 4.3(h), the product stream naphtha from pre-flash unit increased as the crude inlet increased. This increase trend was against with the result from the steady state. As in steady state simulation, process variables were assumed not vary with respect to time and the plant was assumed to start with certain set of conditions where all the process variables were assumed at a constant value for all the time. However in dynamic state simulation, all the process variables vary with respect to time until the CDU process reached a stable condition and system was not disturbed by any external factors. Therefore, the result obtained from dynamic state simulation was again the result from steady state simulation and the result from dynamic state simulation shown the dynamic behaviour of the CDU.

The product flow rate of heavy naphtha was decreased as the crude inlet increased. The decreased phenomenon was having the same reason as in the steady state. The heat energy provided to the column was not sufficient enough to evaporate the entire light component in the rude as the crude inlet increased.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This report presented the impact of changes of crude input flow rate on the CDU product flow rate. A specific journal was selected as constitutes a basic representative of CDU with 25 theoretical stages and two pumps around. A basic mathematical model represent pre-flash, ADU, VDU and side stripper was constructed with some assumptions were made as stated in the literature review Chapter 2.7 which only involve equation for total material balance, component balance, energy balance and vapour liquid equilibrium.

For Steady state simulation, the basic trend of influent of crude input flow rate toward product is shown by Figure 4.2(a) until Figure 4.2(h). The crude inlet flow rate is 22067m^3/day while the changes of input flow rate were obtained by -20%, -10%, +10% and +20% of the literature crude flow rate. As the crude input flow rate increased, the liquid in the bottom of the column increased due to the input heat energy is constant. The liquid in the column was not boiled-off and the residue flow rate increased as the crude input flow rate increased. Hence, this proven that the change of energy balance of the column may lead to a change in the mass balance of the column.

For Dynamic state simulation, as the crude input flow rate increased the product flow rate of naphtha, kerosene, diesel, AGO, off gas, LVGO and HVGO increased where only kerosene flow rate decreased. In dynamic state simulation, all the process variables vary with respect to time until the CDU process achieves a stable condition, also known as steady state condition. Once steady state is achieved, the system is not affected by any other external factors.

5.2 Recommendation

As for the better understanding on the dynamic simulation of crude distillation unit, there are some recommendations. First of all is studying on the effect of changing heat energy supplied to the CDU such as steam inlet for PF, ADU and VDU. This can help to have a further understanding of the effect of heat balance integration toward the mass balance of CDU. Besides studying on a fixed type of crude composition from available library, other crude composition also can be study such mix of two difference type of crude and study the effect of the mix crude toward the efficiency of ADU. A part from that, the study on the optimal flow rate of the crude also be suggested so that the most suitable flow rate can be determined and been applied in industry.

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APPENDIX A

Steady State Simulation Result

Bekok Crude Oil at 22067 m^3/day

Table A1 Bekok Crude Oil Steady State Simulation Result

	PF-STM	ADU-STM	VDU-STM	KERO-STM	DIES-STM	AGO-STM	CRUDE	CRU-FEED	NAPTH	H-NAPTH2	KEROSINE	DIESEL	AGO	REDCRUDE	OFF-GAS	LVGO
	FLASH	ADU	VDU	ADU	ADU	ADU	FLASH	ADU						VDU		
								FLASH	FLASH	ADU	ADU	ADU	ADU	ADU	VDU	VDU
	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	MIXED	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID	VAPOR	LIQUID
Substream: MIXED																
Mole Flow kmol/hr																
H2O	201.4246	471.462	503.5614	141.1002	69.16684	35.25174	0	7.71E-01	70.2417	44.77303	43.33678	12.72159	5.491945	5.35E-02	503.423	1.08E-01
PC3C	0	0	0	0	0	0	1162.364	280.4412	881.9226	280.4284	2.22E-03	1.99E-03	8.55E-03	6.01E-05	6.00E-05	1.29E-08
PC59C	0	0	0	0	0	0	209.9678	101.3833	108.5845	101.2014	0.127139	2.39E-02	0.030658	2.79E-04	2.79E-04	1.62E-07
PC73C	0	0	0	0	0	0	218.6058	121.7405	96.86529	121.1383	0.468548	6.75E-02	0.065567	6.65E-04	6.64E-04	5.05E-07
PC87C	0	0	0	0	0	0	230.5601	145.741	84.81903	143.7688	1.647371	0.184388	0.138828	1.61E-03	1.61E-03	1.62E-06
PC100C	0	0	0	0	0	0	234.2525	165.4041	68.84838	158.7146	5.951008	0.458659	0.276058	3.78E-03	3.77E-03	5.10E-06
PC114C	0	0	0	0	0	0	236.1811	183.4957	52.68541	156.921	24.97018	1.065675	0.529934	8.88E-03	8.85E-03	1.63E-05
PC129C	0	0	0	0	0	0	229.8793	195.2356	34.64367	97.35509	94.46375	2.402445	0.992739	0.0216	0.021512	5.59E-05
PC142C	0	0	0	0	0	0	214.2517	197.0541	17.19761	29.37284	161.0288	4.967456	1.638399	0.046657	0.046403	1.67E-04
PC156C	0	0	0	0	0	0	179.522	176.9786	2.543383	4.111136	157.8153	12.4372	2.518302	0.09665	0.095904	5.05E-04
PC170C	0	0	0	0	0	0	159.8204	159.7124	1.08E-01	3.69E-01	109.501	45.2874	4.338185	0.216608	0.214153	1.72E-03
PC184C	0	0	0	0	0	0	149.4943	149.491	3.33E-03	1.37E-02	31.41335	106.9886	10.54595	0.529366	0.520318	6.60E-03
PC198C	0	0	0	0	0	0	140.9799	140.9798	8.61E-05	1.64E-04	3.077639	107.7875	28.57989	1.534549	1.493303	0.031401
PC211C	0	0	0	0	0	0	133.8587	133.8587	1.96E-06	9.98E-07	0.1604	64.10306	63.43874	6.15652	5.88411	0.216158
PC225C	0	0	0	0	0	0	128.5941	128.5941	3.94E-08	2.60E-09	3.83E-03	19.06023	81.92117	27.6089	25.49912	1.735153
PC239C	0	0	0	0	0	0	133.9744	133.9744	7.02E-10	2.22E-12	3.33E-05	2.328825	49.07467	82.57091	71.15271	9.611326
PC253C	0	0	0	0	0	0	151.5226	151.5226	1.28E-11	8.56E-16	1.35E-07	0.136748	14.74906	136.6368	102.5166	28.70861
PC267C	0	0	0	0	0	0	154.2856	154.2856	1.86E-13	1.76E-19	3.08E-10	4.89E-03	2.845684	151.435	86.45112	52.54029
PC281C	0	0	0	0	0	0	134.66	134.66	2.15E-15	2.62E-23	5.32E-13	1.38E-04	0.447863	134.212	46.68561	63.66894
PC294C	0	0	0	0	0	0	104.5753	104.5753	1.89E-17	2.77E-27	7.12E-16	3.32E-06	0.064153	104.5111	16.17827	51.77405
PC308C	0	0	0	0	0	0	73.01661	73.01661	1.17E-19	1.82E-31	6.83E-19	6.71E-08	8.48E-03	73.00812	3.46675	27.62164
PC322C	0	0	0	0	0	0	60.04917	60.04917	7.05E-22	1.10E-35	6.73E-22	1.57E-09	1.40E-03	60.04778	0.622321	12.93235
PC336C	0	0	0	0	0	0	50.17294	50.17294	3.75E-24	5.60E-40	6.03E-25	3.67E-11	2.43E-04	50.1727	0.086313	4.839715
PC350C	0	0	0	0	0	0	42.54795	42.54795	1.66E-26	2.10E-44	4.48E-28	8.07E-13	4.28E-05	42.54791	9.44E-03	1.491446
PC364C	0	0	0	0	0	0	36.99854	36.99854	6.19E-29	5.60E-49	2.67E-31	1.63E-14	7.54E-06	36.99853	8.34E-04	0.387389
PC378C	0	0	0	0	0	0	33.34804	33.34804	2.00E-31	1.10E-53	1.32E-34	3.07E-16	1.33E-06	33.34804	6.13E-05	0.087216
PC392C	0	0	0	0	0	0	29.82549	29.82549	4.88E-34	1.23E-58	4.39E-38	4.75E-18	2.17E-07	29.82549	3.48E-06	0.016167
PC406C	0	0	0	0	0	0	26.85975	26.85975	1.49E-37	3.69E-65	1.35E-42	2.35E-20	2.26E-08	26.85975	7.81E-08	1.73E-03
PC420C	0	0	0	0	0	0	24.49173	24.49173	5.24E-40	5.34E-70	5.22E-46	3.88E-22	3.83E-09	24.49173	4.12E-09	2.90E-04
PC440C	0	0	0	0	0	0	43.5441	43.5441	2.34E-43	4.71E-77	6.77E-51	1.54E-24	5.25E-10	43.5441	9.10E-11	3.70E-05
PC468C	0	0	0	0	0	0	38.25656	38.25656	7.50E-49	2.95E-88	9.35E-59	1.32E-28	9.71E-12	38.25656	9.63E-14	5.70E-07
PC496C	0	0	0	0	0	0	34.59635	34.59635	2.58E-54	1.23E-99	9.42E-67	9.54E-33	1.69E-13	34.59635	8.81E-17	7.90E-09
PC524C	0	0	0	0	0	0	31.91661	31.91661	4.98E-60	1.32E-111	3.69E-75	4.28E-37	2.45E-15	31.91661	5.58E-20	8.72E-11
PC552C	0	0	0	0	0	0	29.96804	29.96804	4.80E-66	3.13E-124	5.05E-84	1.13E-41	2.86E-17	29.96804	2.39E-23	7.61E-13
PC579C	0	0	0	0	0	0	28.5819	28.5819	2.25E-72	1.63E-137	2.40E-93	1.75E-46	2.70E-19	28.5819	6.88E-27	5.25E-15
PC605C	0	0	0	0	0	0	26.41591	26.41591	2.02E-78	2.73E-150	2.49E-102	3.93E-51	2.92E-21	26.41591	2.58E-30	4.22E-17
PC631C	0	0	0	0	0	0	16.20554	16.20554	2.24E-84	5.50E-163	2.27E-111	6.44E-56	2.17E-23	16.20554	6.89E-34	2.37E-19
Total Flow kmol/hr	201.4246	471.462	503.5614	141.1002	69.16684	35.25174	4934.145	3586.694	1418.463	1138.168	633.9674	380.0282	267.7065	1272.43	864.3831	255.7809
Total Flow kg/hr	3628.72	8493.52	9071.8	2541.96	1246.06	635.07	7.45E+05	6.53E+05	93852.55	96681.45	75853.87	56718.1	45688.82	3.80E+05	8.24E+04	57312.53
Total Flow cum/hr	1895.068	4435.668	4737.67	1327.517	650.7441	331.6599	36507.25	914.1219	139.3939	137.1731	108.9196	83.44074	68.56473	580.3409	3.76E+05	78.22775
Temperature C	204	204	204	204	204	204	232	150.9526	47.4376	41.9168	112.2064	161.4919	198.8728	320.7305	145.9811	176.1909
Pressure bar	4.14	4.14	4.14	4.14	4.14	4.14	3.45	3.082	2.737	1.082	1.1855	1.366625	1.496	1.703	0.08	0.0826
Vapor Frac	1	1	1	1	1	1	0.632851	0	0	0	0	0	0	0	1	0
Liquid Frac	0	0	0	0	0	0	0.367149	1	1	1	1	1	1	1	0	1
Solid Frac	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

APPENDIX B

Dynamic State Simulation Result

Bekok Crude Oil and Product Stream Flow Rate

Table B1 Bekok Crude Oil Dynamic Simulation Result

Time	STREAMS ("CRUDE"). Flow	STREAMS ("CRU-FEED") Flow	STREAMS ("REDCRUDE") Flow	STREAMS ("RESIDUE").Flow
Hours	kmol/hr	kmol/hr	kmol/hr	kmol/hr
0	3947.32	3586.69	1252.74	407.323
0.5	3947.32	3320.69	880.424	288.594
1	3947.32	3322.83	870.907	277.837
1.5	4440.73	3463.69	1047.77	316.585
2	4440.73	3450.94	1067.56	320.203
2.5	4934.14	3666.41	1292.2	373.223
3	4934.14	3588.83	1252.72	370.229
3.5	4934.14	3587.73	1254.41	370.532
4	5427.56	3741.49	1434.81	431.554
4.5	5427.56	3739.98	1435.66	437.023
5	5427.56	3739.45	1434.84	443.701
5.5	5920.97	3911.64	1619.71	515.155
6	5920.97	3910.03	1620.08	526.583
6.1	5920.97	3909.89	1619.9	528.915
6.2	5920.97	3909.76	1619.72	531.278
6.25	5920.97	3909.71	1619.63	532.47
6.26	5920.97	3909.7	1619.61	532.708
6.27	5920.97	3909.68	1619.59	532.947
6.28	5920.97	3909.67	1619.58	533.186

Table B2 Product Stream Flow Rate

Time	STREAMS ("NAPTH") Flow	STREAMS ("H-NAPTH") Flow	STREAMS ("KEROSINE") Flow	STREAMS ("DIESEL") Flow	STREAMS ("AGO") Flow	STREAMS ("OFF-GAS") Flow	STREAMS ("LVGO") Flow	STREAMS ("HVGO") Flow
Hours	kmol/hr	kmol/hr	kmol/hr	kmol/hr	kmol/hr	kmol/hr	kmol/hr	kmol/hr
0	1418.49	1112.22	649.275	407.276	268.368	844.929	255.217	248.815
0.5	626.358	1231.14	661.333	395.814	255.816	686.354	255.073	244.034
1	634.701	1240.28	664.048	394.71	253.207	681.486	254.429	240.123
1.5	1065.94	1236.52	678.35	407.157	260.293	746.598	254.001	239.824
2	1043.04	1163.04	657.044	402.409	260.868	750.313	253.752	238.704
2.5	1451.5	1020.4	664.112	407.393	264.279	854.549	252.915	237.539
3	1421.03	1113.37	650.887	407.739	267.912	826.424	253.568	239.947
3.5	1420.04	1111.84	649.581	407.432	268.353	826.329	253.635	240.216
4	1783.52	1078.62	650.851	411.728	273.805	915.634	253.897	243.468
4.5	1782.42	1076.19	648.871	410.405	273.791	918.651	254.151	244.709
5	1781.64	1076.33	648.662	410.237	273.795	921.631	254.437	246.162
5.5	2126.56	1050.38	656.189	416.287	278.986	1025.06	255.017	250.145
6	2125.63	1047.67	655.043	415.329	278.871	1031.4	255.413	252.033
6.1	2125.47	1047.68	655.01	415.289	278.866	1032.52	255.494	252.417
6.2	2125.32	1047.69	654.981	415.259	278.861	1033.66	255.573	252.8
6.25	2125.24	1047.69	654.967	415.246	278.858	1034.24	255.613	252.991
6.26	2125.23	1047.69	654.965	415.244	278.858	1034.35	255.621	253.029
6.27	2125.21	1047.7	654.962	415.242	278.857	1034.47	255.629	253.067
6.28	2125.2	1047.7	654.959	415.24	278.857	1034.59	255.637	253.106