CHAPTER 1

INTRODUCTION

1.1 Background of Study

The oil and gas industry is looking into ways to develop smaller and more cost effective production platforms. In addressing the need to achieve the smaller production platform, minimum facilities have to be designed only fit for purpose. In a typical oil and gas production facility, separation is the heart of the process. Separation is a process to separate the gas from the liquid and the water from oil. This is usually done in a separator which is an unfired pressure vessel. The well stream flows into the separator and allows the gas, oil and water to separate because of the gravity. The separation process is crucial to produce saleable oil and gas and to protect downstream equipments. A two-phase separator is commonly used on the gas platform to separate liquids from gas. The existing separator design is most suitable for processing crude oil and gas on large platforms. Hence there is a need to optimize separator design suitable for usage on smaller platforms which will ultimately allow the field to develop economically.

1.2   Problem Statement

Field development plans always aim to arrive at optimum project and maintenance cost hence minimum project life cycle cost in order to develop the field in an economical and cost-effective manner. Hence, the oil and gas industry is developing smaller production platforms to achieve this. Separators are the main equipment on the production platform. Separator size should be designed only fit for purpose. Existing separator designs are normally large, bulky and expensive to purchase. This constraint affects the limited space and load requirements on the supporting platform. It will also increase the material and installation costs of offshore structures. In order to optimize the costs and maximize the effectiveness of separation equipment, better designs for separator are proposed. Therefore, this project aims to optimize the design that is suitable for gas/liquid separator

1.3   Significance of the Project

This project was to develop an optimized separator design fit for purpose. The proposed design would be able to produce separator that will reduce space and provide cost saving for the offshore platform. This might translate to lower overall field development costs and increase project economics.

1.4   Objectives

The main objectives of the project are:

a. To study on the current two phase separator design and its working principle based on standard codes.
b. To propose for design improvement using Baram Field data as case study.
c. To carry out a simulation to propose the optimal horizontal separator design.

1.5   Scope of Study

The scope of study as follows:

a. Study on the technical part of the separator design, familiarizing with separator working principle and the design available in the market and the criteria used in the design.
b. Case study will be carried out on a specific separator using typical reservoir data (crude oil assay) and identify the area for improvement.
c. Simulate improved separator design using computer software (Excel Solver).
d. Determine areas for improvement and design consideration for function improvement.

CHAPTER 2

LITERATURE REVIEW

2.1   Natural Gas Separation

An oil reservoir always has some amount of natural gas associated with it and some reservoirs may be completely gas reservoirs. Each well in the reservoir may produce gas with a different composition, and the composition of the gas stream from each individual well may change as the reservoir is depleted. Natural gas is frequently characterized in terms of its nature of occurrence underground, as follows:

a. Non-associated = Found in reservoirs with no or minimal amounts of crude oil, non-associated gas is typically richer in CH4, poorer in heavier components.

b. Dissolved or associated = Gas in solution with crude oil is termed dissolved gas, whereas the gas found in contact with the crude oil as gas cap gas is termed associated gas. Associated gas is poorer in CH4, but richer in heavier components.

c. Gas Condensates = Gas condensates have high amount of hydrocarbon liquids and may occur as gas in the reservoir.

Natural gas associated with oil production and produced from gas field generally contains components such as C_1,C_2,C_3, and water vapor. Field processing of natural gas implies the separation of gas, oil and water before the gas can be sold in the market.

2.2 Gas Production Facility

Objective of gas facility is to separate natural gas, condensate or oil and water from a gas producing well and condition these fluids for sales and disposal. Below is the diagram for the gas production facility.

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Gas Treating → Dehydration → Gas → Gas Sales

Wells          Cooling                    Gas Compression

Heating → HP Separation → Stabilization → Oil Sales

                    Oil and water handling
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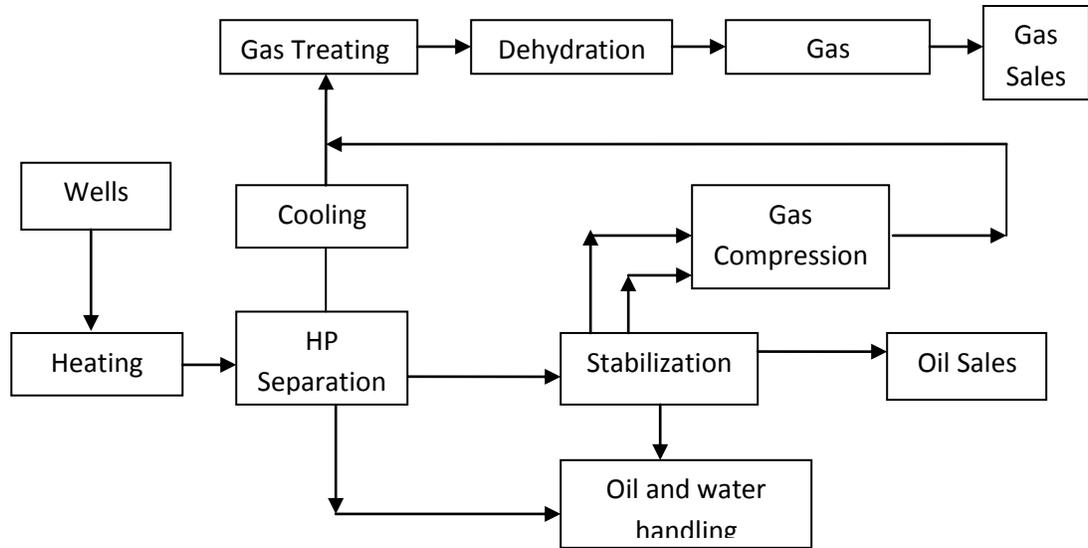
Figure 2.1: Block Diagram for Gas Facility

Figure 2.1, shows the typical flow of gas production system to handle gas wells. Gas processing is different to oil processing essentially because the pressure at the surface facilities will be higher than for normal oilfield operation. The well flow stream may require heating to initial separation. Since most gas wells flow at high pressure, a choke is installed to control the flow. When the flow stream is choked, the gas expands and its temperature decreases. Low temperature exchange (LTX) units and indirect fired heaters are commonly used to keep the well stream from plugging with hydrates [1]. It also possible that cooling may be necessary. It used when the gas flowing temperature is high, the temperature downstream of the choke may be high enough so that it will not be necessary to install a line heater upstream of the HP separator.

On the separation, separator provides a place for any liquid to settle out from the gas. The separator pressure is set higher than the pipeline pressure so that the gas can go through the required cooling, treating, and dehydration each with some pressure drop and arrive at the required pipeline pressure [2]. If the flowing tubing temperature is higher, the hot gas leaving the HP separator can cause process and corrosion problems. Heat exchangers are used to cool the gas and also to cool or heat fluids for treating water from oil.

Stabilization removes the light hydrocarbons from the liquid stream either by reducing the pressure and letting the lighter components flash or combine pressure reduction and heating. Most of water will be removed during separation. The resulting stable condensate has a low vapor pressure so it can be stored in tanks. As for the compression part, the lighter components removed in the gas phase during the stabilization process will be at a lower pressure than the main gas stream. These components must be compressed to the HP separator pressure so they can be processed with the rest of the gas

2.3   Stage of Separation
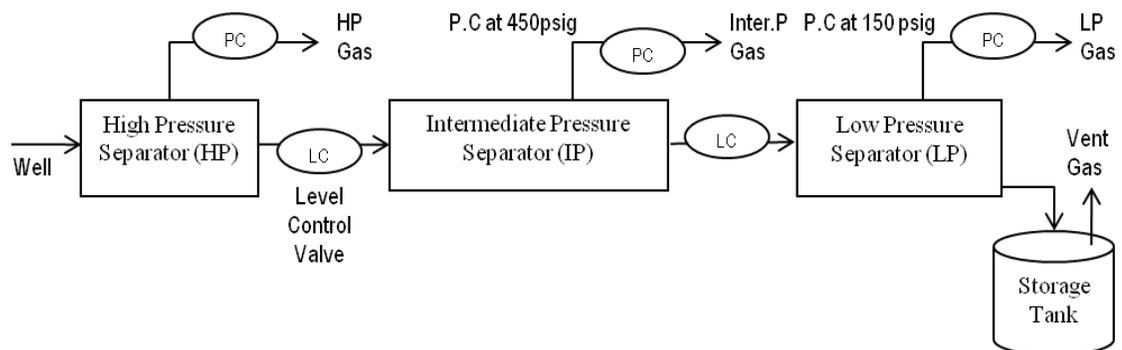
Figure 2.2: Simplified 3 stage, two phase (gas/liquid) separation.

Figure 2.2 shows a typical separation train might have a well producing into an HP separator at 1100psig, with the oil to an IP separator at 450psig, and LP separator at 150 psig. If the production is high pressure and if the oil from the separator is put directly in pipeline, gas will flash as the pressure decreases due to friction losses in the pipeline.

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Gas takes up much larger volume than its equivalent mass of oil, so a pipeline sized for liquid flow will be undersized if some of the liquid flashes into gas resulting in excessive velocities and pressure drop [3]. For this reason, oil pipeline owners generally specify a maximum vapor pressure allowed to prevent the lighter components in the oil from flashing into gas. Separator pressure is chosen so that the flash gas from each stage of separation feeds into a stage of compression with reasonable compression ratios for each stage of the compressor.

2.4 Phase Equilibrium

Equilibrium is a theoretical condition that describes an operating system that has reached a "steady-state" condition

Figure 2.3: Phase envelope of a multi-component mixture

Figure 2.3 shows a mixture phase envelope. The phase envelope curve separates the liquid and gas phases. The area within this envelope is called the two-phase region and represents the pressure and temperature ranges at which liquid and gas exist equilibrium. The left most line of the two phase region is the bubble point indicate where first bubble of vapor appears when pressure is lowered at constant temperature or when the temperature increases at constant pressure [4]. The right most line section of

the phase envelope is the dew-point line where the first drop of liquid forms on this line for certain temperature at reducing pressure or for certain pressure at reducing temperature on this particular envelope.

2.5   Separator

Based on the mixture phase envelope, separation process using separators can only be applied and be effective if the separation condition (pressure and temperature) are done within the two phase region. For conditions outside the two phase, either single phase liquid or single phase gas, putting a separator will serve no purpose.Separators are used to separate a mixture of liquid and gas. Their separation is based on the difference in specific mass between the two components. The greater this differences the quicker and easier the separation is achieved and vices versa. A separator is primarily to separate a combined liquid-gas stream into components that are relatively free of each other. The name separator usually is applied to the vessel used in the field to separate oil and gas coming directly from oil or gas well, or group of wells [5]. Separators can be classified as follows:

2.5.1   Class by configuration

a. **Vertical separator:** Has a definite advantage when well streams containing large quantities of mud and sand are to be processed. This is because the vessel has good bottom drain and clean out features. Refer to Appendix A for the vertical separator picture.

b. **Horizontal separator:** Are most efficient where larger amounts of solution gas are present in the oil. The greater area of oil surface in this vessel configuration provides optimum conditions for entrapped gas to be freed from the liquid. Horizontal separators are recommended for use with high gas oil ratio fluid streams unless additional factors dictate otherwise. Refer to Appendix A for the

horizontal separator picture. Also good for service with fluctuating liquid loading. Can handle slug flow well.

c. **Spherical separators:** Previously, spherical separators were popular due to their low price. While the spherical separator has some merit where foaming is a problem, their use has been completely discontinued by industry. Refer to Appendix A for the spherical separator picture.

2.5.2   Class by functions

a. **Scrubber:** Used for the separation of predominantly gas stream with little liquid content.
b. **Knockout:** Fall into two categories: free water and total liquid knockouts. Free water knockout is a vessel used to separate free water from a combined gas, hydrocarbon liquid and water stream. The total liquid knockout is normally used to remove liquids from a high-pressure and high volume gas stream [6].
c. **Flash chamber:** This vessel used as a subsequent stage of separation to reduce the liquid hydrocarbons flashed from a primary separator.
d. **Expansion vessel:** This name applied to the vessel into which gas is expanded for a cold separation application. It is also referred to as a cold separator or normally used as a degassing vessel.

2.5.3   Class by number of phases separated

a. **Two phase:** A commonly used separator which is used to separate gas from liquid.
b. **Three phase:** Typical of the type found on offshore platforms and used to separate gas from the liquid and the water from the oil.
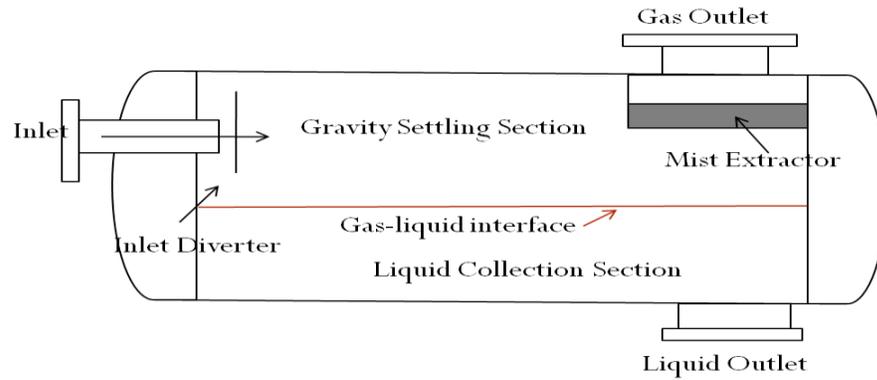
Figure 2.4: Two-Phase Separator Schematic
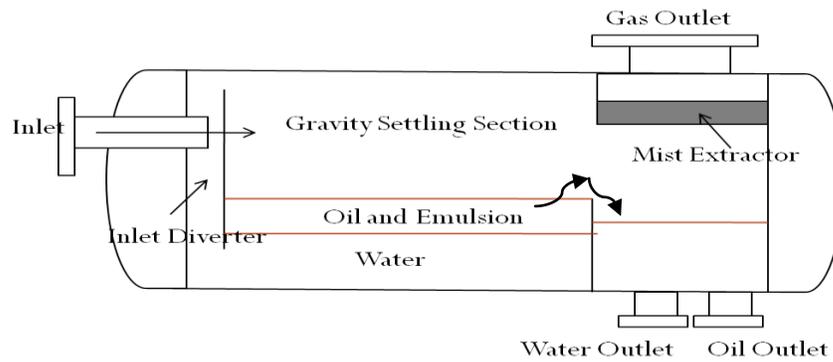
Figure 2.5: Three-Phase Separator Schematic

Figure 2.4 and 2.5 shows the comparison schematic diagram of two phase separator and three phase separator. Three phase separator is designed to separate oil, water and gas and has two liquid outlets. They are identical to two phase vessels except for the water compartment and an extra level control and dump valve.

2.6   Principle of Separation

Four principles used to achieve physical separation of gas and liquids or solids are momentum, gravity settling ,coalescing and equilibirium.Any separator may employ one or more of these principles, but the fluid phases must be immiscible and have different densities for separation to occur. Regardless of shape, the principles used are the same.The four principles are can be shown from the figure 2.7:
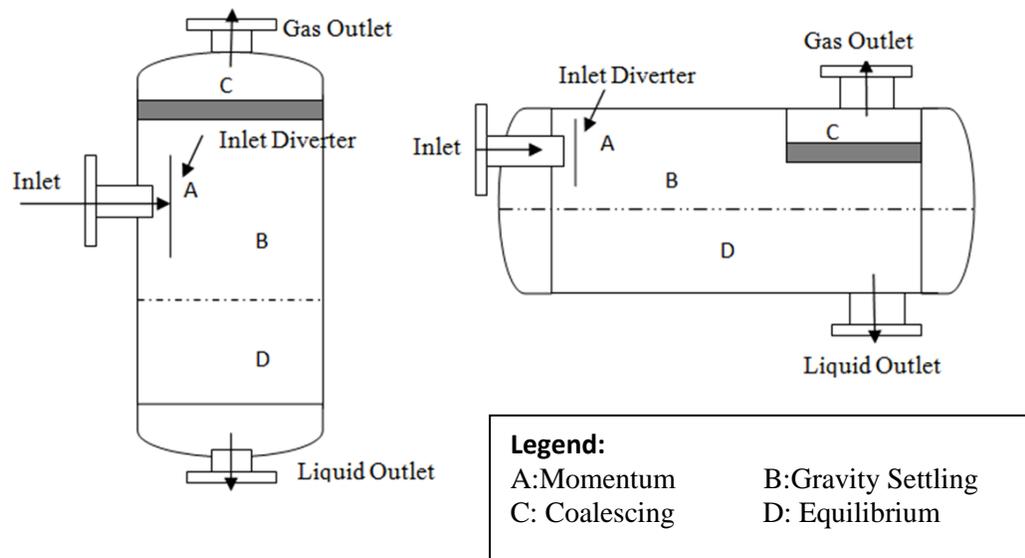
Figure 2.6: Separator Principles

a. Momentum

Fluid phases with different densities will have different momentum. If a two phase stream changes direction sharply, greater momentum will not allow the particles of the heavier phase to turn as rapidly as the lighter fluid, so separation occurs.Momentum is usually emplyed for bulk separation of the two phases in a stream. The momentum principle happen in primary separation section A where used to separate the main portion of free liquid in the inlet streams.It contains the inlet nozzle which may be tangential, or diverter baffle to take advantage of the inertial effects of centrifugal force or an abrupt change of direction to separate the major portion of liquid from the gas stream [7].

b. Gravity Settling

Drag Force of Gas on Droplet

Liquid
Droplet
D_p

Gravitational Force on Droplet
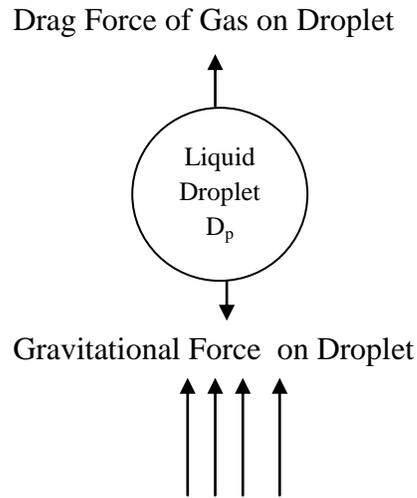
Figure 2.7: Forces on liquid droplet in gas stream.

Liquid droplets will settle out of a gas phase if the gravitational force acting on the droplet is greater than the drag force of the gas flowing around the droplet.These forces can be described mathematically using the terminal or free settling velocity.The drag coefficient has been found to be a function of the shape of the particle and the Reynolds number of the flowing gas. For the purpose of this equation particle shape is considered to be a solid, a rigid sphere.The secondary separation section, where the gravity settling of liquid from the gas stream after its velocity has been reduced[6,8].Small liquid droplets that were entrained in the gas and not separated by the inlet diverter are separated out by gravity and fall to the gas liquid interface.The efficiency of this section depends on the gas and liquid properties, particle size and degree of gas turbulence.

c. **Coalescing**

Very small droplets such as fog or mist cannot be separated practically by gravity.These droplets can be coalesced to form larger droplets that will settle by gravity.The coalescing part is in the section C shown in the figure 2.6.Coalescing devices in separators force gas to follow a tortuous path.The momentum of the the droplets causes them to collide with other droplets or the coelescing device forming larger droplets.

These larger droplets can then settle out of the gas phase by gravity.Wire mesh screens,vane elements, and filter cartridges are typical examples of coalescing devices.Figure 2.8 below shows the process of coelecsing inside the coeslescing device.
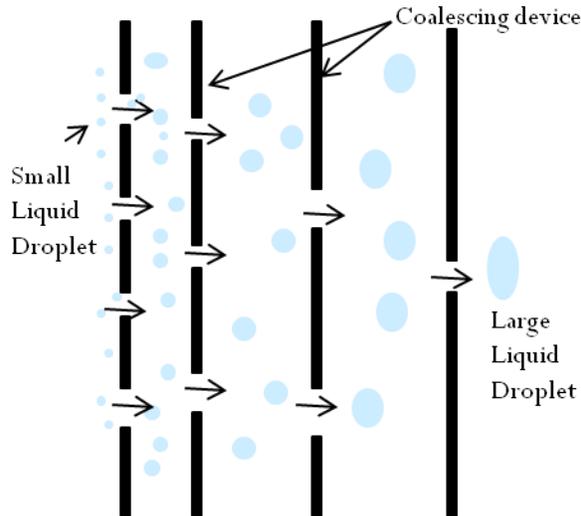
Figure 2.8 :Coeslecsing process inside the coalescing device.

d. **Equilibrium**

This stage occur at liquid collection in D section as shown in the Figure 2.6.It is provide retention time required to allow entrained gas to evolve out from the liquid phase and rise to the vapour space.After a certain period of retention time,phases become equilibirium with each other and separated naturally due to density difference.

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2.7   Separator Internal Design

There are varies type of separator internal design for the two-phase separator. The designs are based on the application. Figure 2.10 below shows the basic internal design for the two-phase separator.
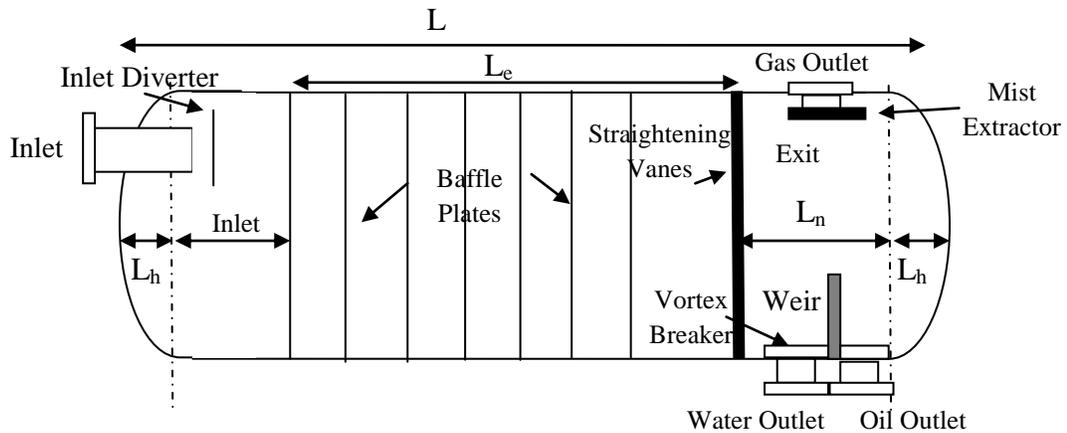
Figure 2.9: Internal Parts of a horizontal separator

Figure 2.9 above shows separator mechanical devices used inside the separator to improve their efficiency and simplify their operation .It shows the separator consists of three sections which are inlet or initial separation section, gravity settling section and the end of the section Details of internal part of separator are shown in the Appendix B. The most commonly used internals design are listed below:

a. **Inlet Diverter** is just downstream of the separator inlet. It will divert the fluid momentum and directs the gas to the top and the liquid to the bottom of the separator.

b. **Baffle Plate** covers the whole cross section of the cylindrical shell and enhances the linear momentum of the fluid along the longitudinal axis of separator.

c. **Straightening vanes** are positioned in the gas section of the vessel to produce smooth laminar flow of the gas stream.

d. **Mist extractor** is positioned after the straightening vanes to remove liquid mist from the gas stream. The mist extractor provides a large surface area for the mist droplets to coalesce [9]. Mist extractors are usually made of closely woven wire mesh.

e. **Vortex breakers** are positioned just above all liquid outlets. They prevent vortexes from forming and so stop other phases leaving with the liquid.

2.8   Foundations in Separator Design Theory

2.8.1 Settling Theory

Separator sizing based on settling theory considers that the phase change is nearly complete as the fluid enters the separator. To apply settling theory in separator design, it is assumed that the droplets act as spherical particles and that they will settle in a continuous phase due to gravity forces [6,8,10]. Whenever relative motion exists between a particle and a surrounding fluid, the fluid will exert s drag force upon the particle. The motion mechanism to separate the droplets assumed that a liquid in a gas or vapor flow is acted by three main forces:

a) Gravity (directed downward),

$$F_G = \rho_l V_p g \tag{2.1}$$

b) Buoyancy (opposite to the gravity),

$$F_B = \rho_v V_p g \tag{2.2}$$

c) Drag (opposite to the direction of droplet velocity)

$$F_D = C_D A \rho \left[\frac{v_t^2}{2g} \right] \tag{2.3}$$

Where F_D = drag force, N

C_D = drag coefficient

A = cross-sectional area of the droplet, m^2

p = density of the continuous phase, kg/m^3

U_c= terminal settling velocity of the droplet, m/s

g = gravitational constant, 32.2 m/s^2

An objective of design separator is to size such that the drag and buoyancy forces succumb to the gravity force, causing the droplet to disengage. The force balance on an average liquid droplet can be established by the application of Newton's Law.

2.8.2 Terminal Velocity

Defined as the velocity at which the vertical component of the drag force exactly counteracts the net gravity force. The motion mechanism for separating oil droplets in continuous gas phase, force balance, and acceleration on the body are zero (constant).The dropout velocity of a spherical particle diameter dp in a stream, relative to the vapor flow in the vertical direction, is given by [10]:

$$Uc = 0.0036 \, ((\rho_L - \rho_g / \rho_g) / d_m \, C_D)^{\wedge 0.5} \tag{2.4}$$

Where U_c = Liquid Settling Velocity

d_m = Droplet Diameter (micron)

ρ_L = Liquid Density (kg/m^3)

ρ_g = Gas Density (kg/m^3)

C_D = Drag Coefficient

$$C_D = \left[\frac{24}{Re} + \frac{3}{Re^{0.5}} + 0.34 \right] \tag{2.5}$$

where, Re = Reynolds number, dimensionless

$$Re = 0.001 \, d_m \, V_t \, \rho_g / \mu \tag{2.6}$$

where, μ = viscosity of the gas, cp

2.8.3　Droplet Size

To apply settling equations to separator sizing, a liquid droplet size to be removed must be selected.

Table 2.1: Typical drop removal size

Service	Drop/ Bubble Size,μm
Removal of liquid drops from gas	Bulk : 100-300
Removal of water from oil	Bulk : 500
Removal of oil from water	Bulk : 100
Removal of gas from oil	Bulk : 200

Table 2.1 shows for the two-phase separator it appears that range 100-300 micron droplets are removed. From field experience, 140 micron droplets are removed, the mist extractor will not become blooded and will able to perform its job of removing those droplets between 10- and 140 micron diameter [9].

2.8.4　Retention Time

To assure that the liquid and gas reach equilibrium at separator pressure a certain liquid storage is required. This is defined as "retention time" or the average time a molecule of liquid is retained in the vessel assuming plug flow. The retention time is thus the volume of the liquid storage in the vessel divided by the liquid flow rate. For most applications retention times of between 30 seconds and 3 minutes have been found to be sufficient [2,10,11]. Where foaming crude is present retention times up to four times this amount may be needed.

2.8.5 Phase Levels

Stable level of gas/oil interfaces is important for good separation. The typical two-phase separator level settings are shown in the Figure 2.11
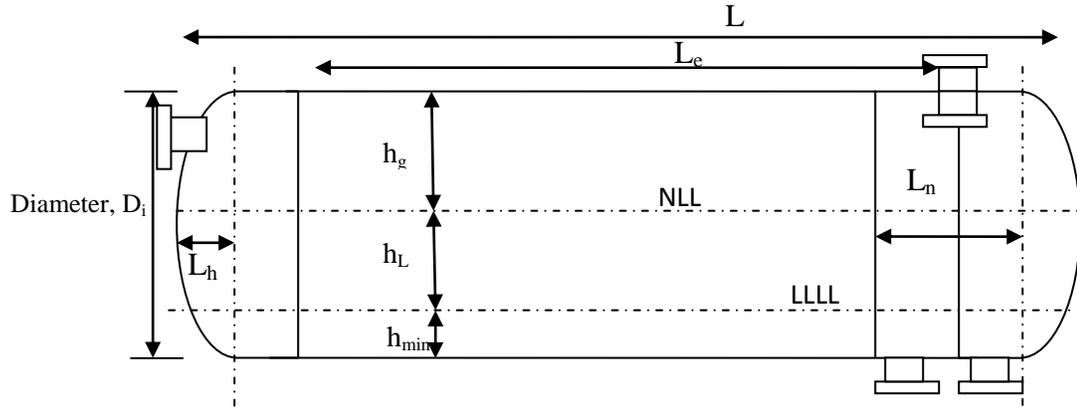
Figure 2.10: Phase Levels

Below Table 2.2, shows the typical separator level settings. The space between the different levels is at least 4 to 6 in. or minimum of 10 to 20 seconds of retention time. The location of the lowest levels must consider sand/solids settling. These levels are typically 150mm from bottom.

Table 2.2: Typical Separator Level Settings

Designation	Description	Comments
LLLL	Low-Low Liquid Level	This level ensures that gas will not exit with liquid. Shutdown of operation occurs.
LLL	Low Liquid Level	LLL and HLL typically alarm for control room.
NLL	Normal Liquid Level	Liquid level can vary between LLL and HLL under normal operating conditions with NLL as desired targeted level.
HLL	High Liquid Level	Surge volume between NLL and HLL.
HHLL	High-High Liquid level	This level ensures that liquid will not exit with the liquid. Shutdown of operation occurs

2.9   Mechanical Design

Vessel shells must be designed for the most severe conditions of coincident pressure and temperature expected in normal operation. Vessel or their parts subject to thinning by corrosion, erosion, or mechanical abrasion have a provision made for the desired vessel life with a suitable increase in the thickness of the material determined by the design formulas [12,13,14]. The design equation for vessel shells under an internal pressure greater of 150 psig or grater, subject to circumferential stress is

$$t_{cs} = \frac{P_D D_i}{2SE\text{-}1.2P_D} + t_c \qquad (2.7)$$

where t_{cs} = Minimum wall thickness of the cylindrical section.

P_D = Design Pressure

S = Maximum Allowable Stress Value in tension

E = Joint Efficiency   (range from 0.6 to 1 for 1005 of X-rayed joints)

t_c = Corrosion Allowance (range from 1.5 to 3.2 mm
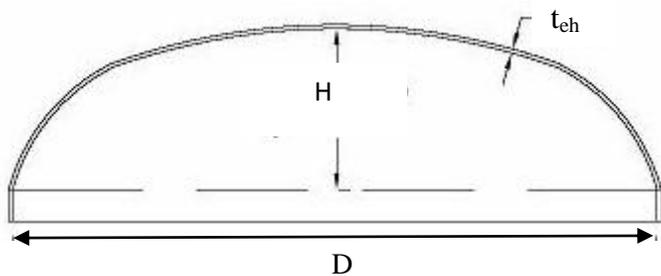
Figure 2.11 : Ellipsoidal Head

Figure 2.11 shows the 2:1 elliptical heads used for the design separator. The ASME [14] code approves the use of many different design of heads exist. Elliptical heads (2:1) provides an economic design with respect to material consumption because the code states that overall vessel wall thickness should be the larger of the cylindrical section

and head. The elliptical head wall thickness is less than wall thickness of the cylindrical section. The thicknesses of ellipsoidal heads are obtained with

$$t_{eh} = \frac{P_D D_i}{2SE - 0.2\ PD} + t_c \qquad (2.8)$$

2.10   Manufacturing Cost

The manufacturing cost of separator depends on the dimensions, diameter and length. The cost internals are only weak function of the chosen design variables as the design and size largely determined based on the various constant rates. Thus, the cost internal has not been considered. This means that the internals are not directly subject to optimization. It will merely adjust the its shaper according to what will obtained the less costly separator vessel. However the rectangular shape of length separator end section (L_n) and inner diameter (D_i) is in the objective function. Assumption made that it si the demister area that bears cost and not the shape of the area. Companies are likely to have different cost formula. The objective cost formula denoted as C, can be formula as [15]

$$C = t_{cs}\ F_c\ \rho_s\ [\pi\ D_m\ L + 2\ F_a\ F_h\ D_m] \qquad (2.9)$$

where F_a = Factor for determining surface area of a vessel head from vessel diameter squared   (2:1) elliptical heads

F_c = Cost factor per unit mass to manufacture a vessel shell

F_h= Ratio of cost per unit mass to manufacture a vessel head compared with that of a vessel shell

ρ_s = Steel Density

$$D_{m`} = \sqrt{\frac{D_i^2 + (D_i + 2t_{cs})^2}{2}}$$
(2.10)

where D_m = Mean separator diameter which is defines as

2.11 Flash Calculation

The amount of hydrocarbon fluid that exists in the gaseous phase or the liquid phase at any points at the process is determined by a flash calculation. For a given pressure and temperature each component in the gas phase will depend not only on pressure and temperature, but also on the partial pressure of the component [16,17]. Therefore the amount of gas depends upon the total composition of the fluids as the mole fraction of any one component in the gas phase is the function of the mole fraction of every other component in this phase. This is best understood by assigning an equilibrium "K" value to each component. The K value is a strong function of a temperature and pressure and of the composition of the vapor and liquid phase. It is defined as

$$K_N = V_N/V \,/\, L_N/L$$
(2.11)

where K_N =Constant for component N at a given T and P

V_N =Moles of component N in the vapor phase

V = Total moles in the vapor phase

L_N =Moles of component N in the liquid phase

L =Total mole on the liquid phase

If K_N for each component and the ratio of total moles of vapor to total moles of liquid (V/L) are known, then the moles of the component N in the vapor phase (V_N) and the moles in the liquid phase (L_N) can be calculated from

$$V_N = \frac{K_N\, F_N}{\frac{1}{(V/L)} + K_N} \qquad (2.12)$$

$$L_N = \frac{F_N}{K_N\left(\frac{V}{L}\right) + 1} \qquad (2.13)$$

where F_N = total moles of component N in the fluid.

2.11.1 Molecular Weight

The molecular weight of a stream calculated from the weighted average gas molecular weight given by [4,17,18]:

    a. Gas Molecular Weight:

$$MW = \Sigma[V_N \times (MW)_N] / V_N \qquad (2.14)$$

    b. Liquid Molecular Weight:

$$MW = \Sigma[L_N \times (MW)_N] / L_N \qquad (2.15)$$

2.11.2 Density

    a. Gas Density:

$$\rho_V = \frac{(MW)\,P}{ZRT} \qquad (2.16)$$

Where ρ_V = Density of gas, lb/ft^3

    T = Temperature, R

    Z = Gas Compressibility Factor

    R = Universal Gas Constant

    b. Liquid Density:

The liquid phase density can be estimated by the Standing method (1981),that is [4],

$$\rho_l = \frac{62.4\gamma_{oST} + 0.0136 R_S \gamma_g}{0.972 + 0.000147\left[R_S\sqrt{\frac{\gamma_g}{\gamma_o}} + 1.25\,(T-460)\right]^{1.175}} \qquad (2.17)$$

Where γ_{oST} = specific gravity of stock tank oil,water

γ_g = specific gravity of solution gas,air = 1

Rs = gas solubility of the oil,scf/stb

2.11.3 Flow Rate

a. Gas Flow Rate

If the flow rate of the inlet stream is known in moles per day, then the number of moles per day of gas flow is

$$V = F./\ 1+ 1/(V/L) \tag{2.18}$$

where V = gas flow rate (moles/day)

The flow rate in standard cubic feet can be determined by:

$$Q_g = 380V/1000000 \tag{2.19}$$

where Q_g = Gas Flow Rate,MMscfd

c. Liquid Flow Rate

$$Q_l = L \times (MW) / 350\ (SG) \tag{2.20}$$

where Q_L = Liquid Flow Rate,bpd

2.12   Optimization Model

Algorithm mathematical optimization techniques have been used widely in design optimization. Mathematical programming formulas are used for the design units, systems and are even used at the conceptual level [12,19].

To cast the separator problem into a mathematical program it must be formulated in the general form:

max or min $z = f(x_1, x_2, \ldots\ldots\ldots x_n)$

subject to $g_1(x_1, x_2 \ldots\ldots x_n) (\leq,=,\geq) b_1$

$g_m(x_1, x_2 \ldots\ldots x_n) (\leq,=,\geq) b_m$

The objective function (z), which is a function of the design variables (xi) is to be maximized or minimized subject to a set of constraint (gi).The constraints are functions of the design variables and describe physical design relationship expressed as inequalities or equalities. A feasible solution of a mathematical program satisfies all the constraint. A subset of the inequality constraints will be active, that is satisfied at equality. The active constraint will inform which physical relationships are constraining the design. The status of the inactive constraints can be used to quantify the flexibility of the design. An optimal design is one for which no other design have higher or lower objective function value.

Many algorithms exist to solve mathematical programs [20].Because of nonlinearity in the separator design problem both in objective function and in constraints, chose the Generalized Reduce Gradient (GRG2) to find the optimal separator design. This code most widely used in the industry. It is a stand-alone system, it is the optimizer employed by the "Solver" optimization options within the spreadsheet programs such as Microsoft Excel.

2.13 Baram Field Background
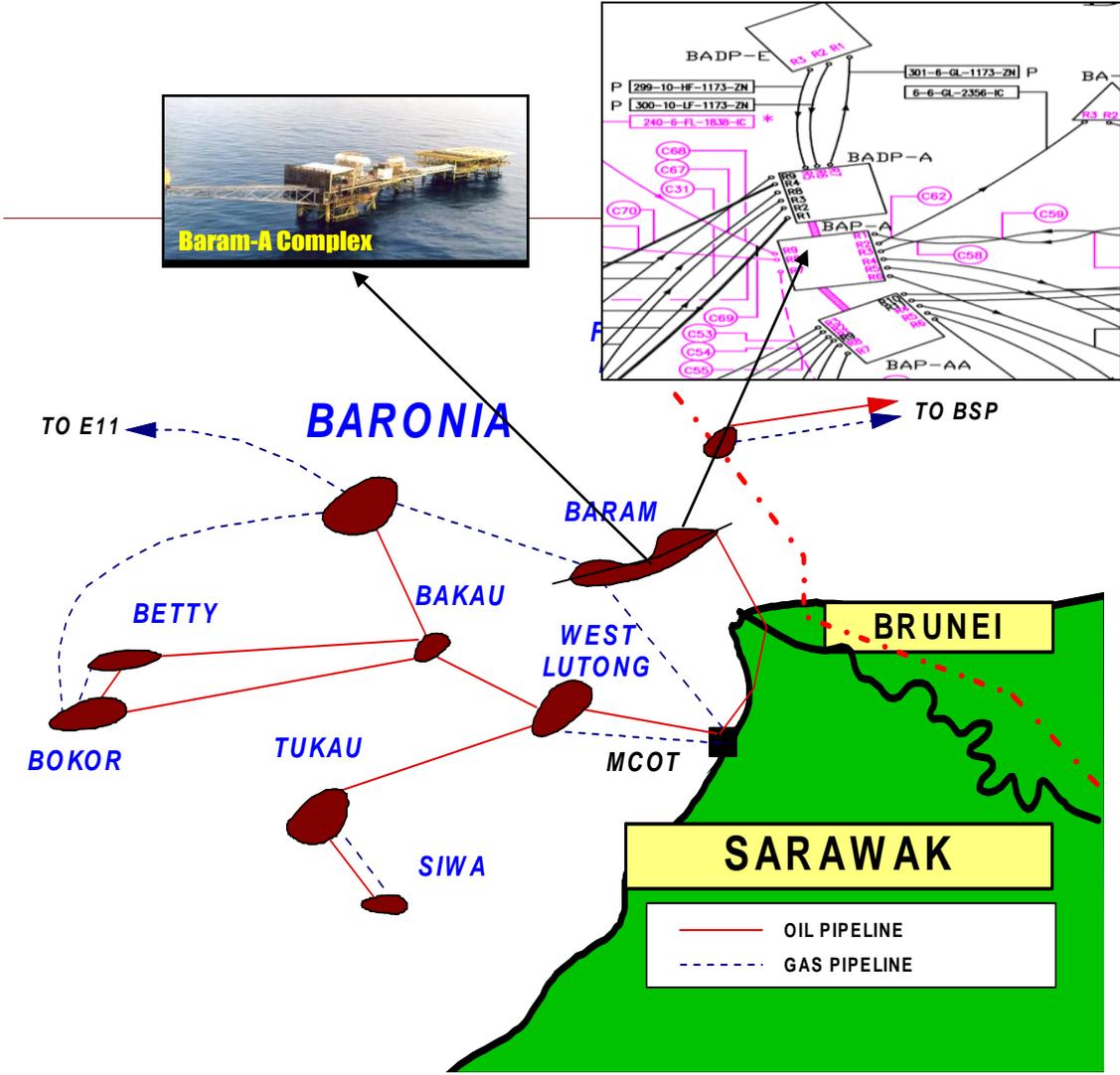
Figure 2.12: Location of BAP-A Platform

Baram field complex comprises of the drilling platform, production platform, and compression platform. The Baram platform located in Baram Delta area, offshore Sarawak, east Malaysia about 32 km from Miri. As shown in the Figure 2.12, the figure shows the exact location of BAP-A which are between the BADP-A and BAP-AA. The BAP-A is a production platform receives fluid from drilling platform BADP-A and from remote BADP-C platform[21].
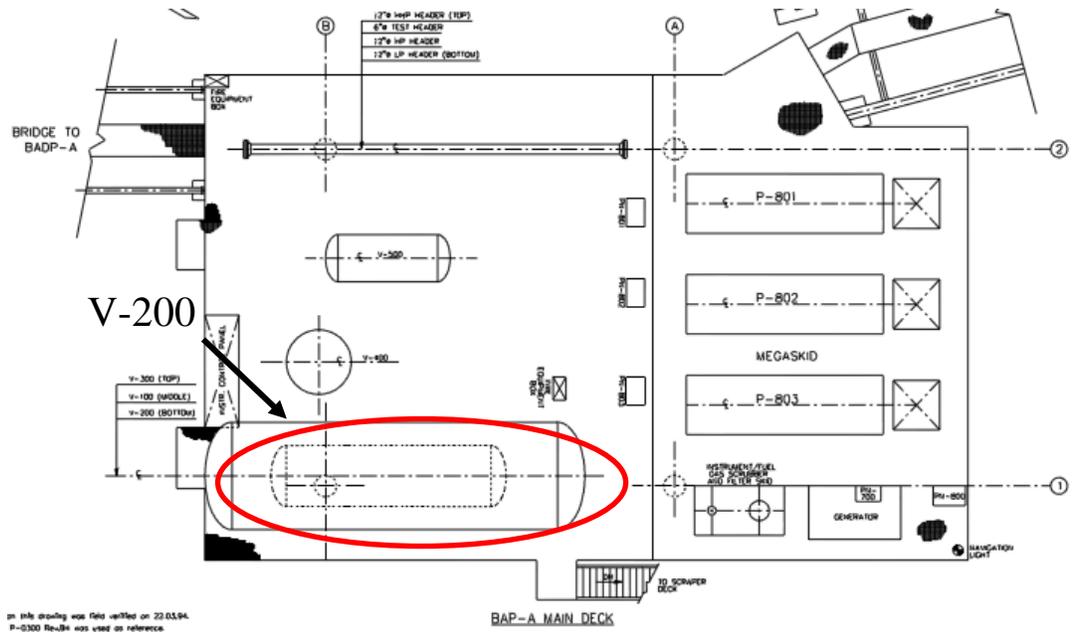
Figure 2.13: BAP-A Equipment Layout

Figure 2.13 shown the location of the V-200 on the platform.V-200 is a low pressure separator which connected with HP separator (V-100) and a surge vessel (V-300) operating in series. Each separator is designed for two-phase operation, separating gas from liquid. Baram (BAP-A) has been chosen as the case study as it is one of the earliest area developed and the production is decreasing. Thus, V-200 is selected for the case study to review the design base on the current production. Refer to the Appendix C for the mechanical equipment drawing.

Figure 2.14: V-200 LP Separator.

2.13.1 Design Specification of V-200

Table 2.3: Design Specification of V-200

DATA	VALUES
Size	1829mm OD x 6096mm T.L to T.L
Design Pressure	125 psig
Design Temperature	150 ^{o}F
Type of Heads	Semi-Elliptical
Material Of Construction	SA 516, Grade 70
Weld Joint Efficiency, E	1.0
Corrosion Allowance, t_c	3.0 mm

CHAPTER 3

METHODOLOGY/SCOPE OF WORK

```
┌─────────┐
│  START  │
└─────────┘
     │
     ▼
┌──────────────────────────────┐
│  Natural Gas and Separator    │
│  Design Literature Review     │
└──────────────────────────────┘
     │
     ▼
┌──────────────────────────────┐
│  Critical review for various  │
│  types of gas/liquid          │
│  separation law and equation  │
└──────────────────────────────┘
     │
     ▼
┌──────────────────────────────┐
│  Used Flash Calculation to    │
│  find properties and flow     │
│  rates of both gas and liquid │
│  stream                       │
└──────────────────────────────┘
     │
     ▼
┌──────────────────────────────┐
│  Propose Mathematical Model   │
│  for Optimize Separator       │
│  Design                       │
└──────────────────────────────┘
     │
     ▼
┌──────────────────────────────┐
│  Simulation Mathematical      │
│  Model using production       │
│  forecast of Baram Data       │
│  (EXCEL Solver)               │
└──────────────────────────────┘
     │
     ▼
┌──────────────────────────────┐
│  Analysis effect on           │
│  constraint design and        │
│  separator dimension          │
└──────────────────────────────┘
     │
     ▼
┌──────────────────────────────┐
│  Optimized Separator Design   │
│  Model Completed              │
└──────────────────────────────┘
     │
     ▼
┌─────────┐
│   END   │
└─────────┘
```

Figure 3.1: Process flow of optimized design

28

3.1   Literature Review

During the literature review, research and study was done on the separator types, working principle, sizing capacity, stages of separation, design specification,design drawing and characteristic based on crude properties. This was important which gave direction to understand the concept and principles applied in the field.The information gathered referring to Code API 12J specification,ASME standard, ASME VII DIV. 1, respective books, journals and thesis develops by external and internal parties.

3.2   Critical review of separator's law and equation.

In the research, few separation principles is studied and model like Stoke' Law and Newton's Law has draw attention to know more about the theory and the application. Every model or equation founded is related to the basic concept of separator design. All the parameters are investigated and related all together the laws and the equation to the basic concept of separator principles. The specific mathematical model is then derived in terms of separator sizing and determine optimize design for the separator design.

3.3   Mathematical Model use in Optimize Separator Design

For the optimization of the separator design, the constraints had been classified into four categories which are capacity, geometrical, and mechanical design constraint.

   a. Gas Capacity Constraint
      The design of flow rate gas capacity in a gas/liquid separator is based on oil droplet gravity settling in vertical height.

$$Q_g = \alpha U_g A_t \qquad (3.1)$$

   Where Q_g= Gas Flowrate (m^3/s)

   A_t =Total Cross Sectional Area (m^2)

   U_v = Gas Velocity (m/s)

   α = Gas Area Fraction

The travel time for the gas through the settling section and the settling time for an oil droplet are as below:

$$t_v = \frac{L_e}{U_g} \qquad (3.2) \qquad t_d = \frac{h_g}{U_c} \qquad (3.3)$$

where t_v = Residence Time of Gas (s)

t_d = Liquid dropout time particle (s)

h_g = Vertical space for vapor flow (m)

U_c = Settling velocity of Liquid dropout

L_e = Length of gravity separation section (m)

In order for droplet separation occurs, the condition required to complete the settling of an oil droplet of a certain size :

$$t_v \geq t_d \qquad (3.4)$$

Subsituting Eqs. 3.2 and 3.3 into 3.4 and rearranging lead to

$$Le \geq \frac{h_g g}{\alpha A_t U_c} \qquad (3.5)$$

b. Liquid Capacity Constraint

The design of liquid capacity in the separator is based on the gravity settling of liquid droplets. A horizontal vessel with an inside diameter, Di will be assumed. This gives the following total cross sectional area, At :

$$At = \pi Di^2/4 \qquad (3.6)$$

From the typical dimension of horizontal-oriented separator shown in figure 2.11 the following relationship lead to

$$V_L = L_e \, (A_t \, (1\text{-}\alpha) - A_{hmin}) \qquad (3.7)$$

$$V_{hmin} = L_e A_{hmin} \qquad (3.8)$$

where V_L = Volume for accumulated liquid

A_{hmin} = Cross sectional area for vapor flow (m^2)

$$A_{hmin} = \frac{D_i^2}{4}\left(tan^{-1}\frac{X}{[1-X^2]^{0.5}} + 1.573\right) - \left(\frac{D_i}{2} - h_{min}\right)\left(D_i h_{min} - h_{min}^2\right)^{0.5}$$
$$(3.9)$$

$$X = \frac{D_i/2 - h_{min}}{D_i/2} \qquad (3.10)$$

The cross sectional area for vapor flow, A_g is given by

$$A_g = A_t - A_L - A_{hmin} \qquad (3.11)$$

Where A_L = cross sectional area for liquid (m^2)

The inside separator diameter is calculated with following equation:

$$Di = h_g + h_L + h_{min} \qquad (3.12)$$

Where h_g = vertical space for vapor flow (m)

h_L = depth for level of liquid (m)

h_{min} = minimum height from bottom of separator (m)

c. Slenderness (L/D) Ratio

Defined as the relation of the ratio of the length to the diameter of the separator. It is common based on plot restrictions, experience, and economic considerations [8]. The common used in practice L/D ratios is 3-5 [10,22].

d. Inlet and End Sections Design

The end section and its internal are shown in figures 2.7 and 2,8. The minimum length of the end section can be formulated as [23,24]

$$L_n = (2d_{n,w} + 2\ d_{n,o} + d_{n,g}) \qquad (3.13)$$

where L_n = Length of separator end section (m)

$\quad d_{n,w} =$ Minimum nozzle diameter for water (m)

$\quad d_{n,o} =$ Minimum nozzle diameter for oil (m)

$\quad d_{n,g} =$ Minimum nozzle diameter for gas (m)

$$dn = 0.161\ (Q\rho^{0.5})^{0.5} \qquad (3.14)$$

e. Transportation Constraint

Because of handling and transportation separators have some practical upper overall size limits [23,24]

$$L = L_e + L_n + 2L_h + 2t_c$$
$$(3.15)$$
$$D = D_i + 2t_c \qquad (3.16)$$
$$L_h = D_i/4 \qquad (3.17)$$

Where L = Length of separator (m)

$\quad L_h$ = Separator head section length (m)

$\quad t_c$ = Corrosion Allowance (m)

$\quad D$ = Total Separator Diameter (m)

$\quad D_i$= Inner Diameter (m)

f. Mechanical Design Constraint

The oil industry is very safety conscious and approaches mechanical design of separators using codified design rules. Using the ASME [14] code the wall thickness in the cylindrical section is as Eqn. 2.4.

g. Objective Function

The objective function is the minimization of the manufacturing cost of separator, which depends on the dimension, diameter, and length. The objective cost function can be formulated as [15]:

$$C = t_{cs} \, F_c \, \rho_s \, [\pi D_m \, L + 2 \, F_a \, F_h \, D_m{}^2]$$ (2.6)

h. Bounds

In addition to constraints, the system also contains some nonnegative bounds for which optimization model must satisfy. The bound are given as below:

$0 \leq A_t \leq (\pi/4)D^2$	(3.18)	$0 \leq A_{hmin} \leq A_g, \, A_L \leq A_t$	(3.19)
$0 \leq h_g, \, h_L \leq D_i$	(3.20)	$0 \leq D \leq 4.5$	(3.21)
$0 \leq D_i \leq D_m \leq D$	(3.22)	$0 \leq L_e \leq L \leq 20$	(3.23)
$0 \leq \alpha \leq 1.0$	(3.24)		

3.4   Simulate Mathematical Model

The optimize separator design is derived in terms of length and separation factor by incorporating the case study data into EXCEL Solver for data manipulation. The investigation of controlling parameters is then performed by manipulating the parameters in the equation[20]. The optimum condition is selected based on the result obtained. Proper analysis has been done as to find the effect of constraint and parameters to the separator dimension. Relative cost analysis on the separator design also is done as to evaluate the desirability of the design in the market.

3.4.1 Solution Algorithm for Separator Model

After the mathematical model has been developed, an algorithm is constructed to prepare an organize way to key in the data into the mathematical model so that simulation system is well operated. In figure 3.2, shows the algorithm for the two phase separator.

From the figure, the input algorithm has been divided into three groups. The design parameters consist of the case specific data calculated using the flash calculation such as flow rates, and physical properties. The physical constants and fixed variables consist of material, construction and constant from chosen standard. The final group of inputs is the initial guesses of the two design variables.

After putting in the inputs, then proceed to determine the design variables which are the mounting point of the vane demister relative to the gas outlet, the wall thickness in the ellipsoidal head and separator head section length. Then, the gravity settling, gas capacity constraint and liquid capacity constraint can be calculated by using equation derived The objective function is the minimization of the manufacturing cost which depends on the separator dimensions, diameter and length. The function is subject to gas capacity constraint, liquid capacity constraint and maximum separator of diameter and length of separator.

In addition to the constraint, the system also contains some bounds for which the optimization model must consider. Lastly, the result is discussed to have further understanding for the simulation model and also to find the optimum condition for the separator design. Refer to Appendix E for the Gantt chart for the project.

START

Input the Design parameters (ρ_l, ρ_v, μ_v, d_p), Physical constant and Fixed variables (E, F_a, F_c, F_h, h_{min}, t_c, ρ_s, σ) and Initial guess (L_e, D_i)

Determine the design variables t_{cs} by Eqn. 2.7, L_n by Eqn.3.13, L_h by Eqn 3.17

Mathematical Program

Min Eqn.2.6 (cost function)

Subject to :

Eqn.3.5 (Gas Capacity), Eqn.3.6 - 3.12 (Liquid Capacity), Eqn.3.15 (max separator length), Eqn. 3.16 (max separator diameter)

$0 \leq Le \leq L \leq 20$

$0 \leq Di \leq Dm \leq D \leq 4.5$

$3 \leq L/D \leq 5$

Output: The optimum separator design

END

Figure 3.2: Solution Algorithm for 2-phase gas/liquid separator model

CHAPTER 4

RESULTS AND DISCUSSION

4.1   Flash Calculation

Properties of the feed stream (oil and gas mixture) are fundamental for designing and analyzing oil and gas production system. The amount of hydrocarbon fluid that exists in the gaseous phase is determined by a flash calculation. Heat and material balance from Baram field has been used to calculate the inlet flow properties of the separator. The pressure used is 73 psia and temperature is 37.8^{o}C.Detail calculation of flash calculation refer to Appendix F. The results are shown in table below:

Table 4.1: Gas Properties of Inlet flow

Properties	Value
Molecular Weight	22.54
Specific Gravity	0.778
Density	47.802 kg/m3
Flowrate	26.24 MMscfd

Table 4.2: Liquid Properties of Inlet flow

Properties	Value
Molecular Weight	245
Specific Gravity	0.8876
Density	873.3811 kg/m^3
Flow rate	30217.58 bpd

Table 4.3: Summary of Inlet Flow Properties

Properties	Calculated Flow		Case Study Flow	
	Gas	Liquid	Gas	Liquid
Molecular Weight, MW	22.54	245	20.66	-
Specific Gravity, SG	0.778	0.8876	0.713	0.735
Density (kg/m^3),ρ	47.802	871.779	-	913.44
API gravity of liquid phase	-	28	-	-
Flow Rate, Q	26.24 MMscfd	30217.58 bpd	23.07 MMscfd	31200.3 bpd

Table 4.1 summarized the results of the calculated flow properties using the flash calculation and flow data based on the case study. The results show that there are differences between the calculated flow and the case study flow. This is due to difference pressure used in the calculated flow which is 73 psia while from the case study data the pressure used is 68 psia with a constant temperature equal to 37.8 ^{0}C . Normally separation is done at a constant pressure since it is easier to control the pressure in a separator, temperature will settle at whatever the equilibrium value.

Normally in practice not normally operate separator at constant temperature, unless it is a heated separator. Thus, based in Figure 2.3, line A-B should be horizontal. Separation can be performed at any pressure and temperature inside the phase boundary. The resultant liquid will produce its own phase diagram to the right of the separation point and the resultant gas will produce its own phase diagram to the left of the separation point. The liquid is at bubble point and the gas is at dew point. The calculated flow is used to determine the optimize separator model.

4.2 Separator Optimization Model

Separator sizing essentially considered the gas capacity, liquid capacity, slenderness ratio and the transportation of the separator. Thus to optimize the separator design this four constraints has been discussed.

4.2.1 Gas Constraint

The flow rate of the gas is directly related to the cross sectional area of flow and the maximum allowable gas velocity at which the liquid droplets will drop down and not carried over in the gas. In the horizontal separator, the gas occupies the top half of the separator. The gas capacity constraint can be stated as [2,8,10] :

$$Q_g = \alpha\, U_g A_t \tag{3.1}$$

The gas capacity constraint equations are based on the settling the gas retention time equal to the time required for a droplet to settle to the liquid interface. The equations are given as:

$$t_v = \frac{L_e}{U_g} \tag{3.2} \qquad\qquad t_d = \frac{h_g}{U_c} \tag{3.3}$$

$$t_v \geq t_d \tag{3.4}$$

Substituting Eqn. 3.2 and 3.3 into 3.4 and rearranging lead to

$$Le \geq \frac{h_g Q_g}{\alpha A_t U_c} \tag{3.5}$$

From the Eqn. 3.5 the length of the gravity separation section can be obtained based on the gas flow rate, velocity of the liquid dropout, and the gas flow cross sectional area fraction. Thus, by varying the factors, the length can be optimized. For the case study, the gas capacity constraint has followed the standard from the PTS [9]. There is a different in the optimize model equation with the PTS standard [9] where the PTS [9] has been considered the safety margin typically between 15% and 50% for the gas

capacity constraint while for the optimize separator model only the minimum condition of separator has been considered as no safety margin considered.

4.2.2 **Liquid Capacity**

Separators must be sized to provide some liquid retention time so the liquid can reach phase equilibrium with the gas. For the optimize separator model, the 50% full of liquid has been used. It has been suggested that the maximum liquid level should not below that half-filled separator [15,28].Thus the liquid capacity constraint can be stated as [8,15]:

$$V_L = L_e (A_t (1-\alpha) - A_{hmin}) \qquad (3.7)$$

Compared with the case study using PTS [9], the standard restricted that the liquid levels high high liquid level (HHLL) is only up to 80% of the vessel diameter. The case study also considered the de-foaming and de-gassing factor. However, for the optimize model, the assumption has been made as no foaming and de-gassing takes place during the gas-oil separation. For the optimize separator model we considered the minimum separator design condition.

4.2.3 **Slenderness (L/D) Ratio**

Slenderness is a structural relationship defined as the ratio between the internal length and the internal diameter of the separator. It can be shown that the smaller the diameter, the less the vessel will weight and thus the lower its cost [25]. However there is a point when decreasing the diameter it will give high the gas velocity that may induce liquid re-entrainment. While lower slenderness ratio, will promote plug flow. Commonly, slenderness ratios on the order of 3 to 5 are common [6,10],while there are others that used their design to slenderness ratios between 1.5 and 6 [8,27]. As for the case study, the slenderness ratio used is between 2.5 to 6. For the optimize separator model 3 to 5

has been chosen for the slenderness ratio as it is commonly used in the industries. In the separator design, the slenderness criteria is checked in the final step.

4.2.4 Transportation Constraint

Separator diameter and length can be restricted by the separator size or service. For large shop-fabricated separators, diameter and length are usually limited because of the over the road, rail or ship transportation clearance restrictions. Thus, because of handling and transportations constraints, separators total length given by [23]:

$$L \geq L_e + L_n + 2L_h + 2t_c \tag{3.15}$$

The restrictions suggested by the [15, 28] length and diameter are:

$$D = D_i + 2t_c \tag{3.16}$$
$$0 \leq D \leq 4.5 \text{ m} \tag{3.21}$$
$$0 \leq L \leq 20 \text{ m} \tag{3.23}$$

Thus for the optimize separator model, it is essential to take into considerations the transportation constraint as it is important for the separator to be transported to the offshore platform using the ship.

4.2.4 Mechanical Design Constraint

A separator consists of a cylindrical shell and end caps called heads. For safety, separator design is governed by codes ASME [14]. Most separators used in the oil and gas industry are designed and inspected according to ASME code [14] stated by [8,9,10,13,29]. For the optimize separator model, the separator used is 2:1 ellipsoidal heads because they are readily available, less expensive and take up less space than hemispherical heads. These heads had also been used for the case study.

Depending on the application, for low temperature separator, the most commonly material used and based on the ASME [14], the material used for the optimum separator is SA-516 Grade 70 which is same with the case study. This material has good ductility

at low temperature due to the re-crystallized and grain refinement structure and can remove internal residual stress [12].

4.3   Optimal Two-Phase Separator and Dimension for a Half-Filled Separator

A two-phase separator is to be designed for physical properties shown in Table 4.1.The hydrocarbon composition is taken from the heat and material balance from Baram field. The inlet of the separator is operated at P = 73 psia and T = 37.78^{o}C. The input values are summarized in Table 4.2 and Table 4.3.

Table 4.4: Design Parameters 2-Phase Separator (V-200)

Parameter	Value
Particle diameter, dp	100 x 10^{-6} m
Gas Flowrate, Q$_g$	8.599 m^3/s
Liquid Flowrate, Q$_L$	0.0556 m^3/s
Gas Density, ρ_g	47.802 kg/m^3
Liquid Density, ρ_L	871.78 kg/m^3

Table 4.5: Physical Constants and Fixed Variables

Physical Constant	Value
Joint Efficiency ,E	1.0
Minimum height from bottom of a separator, h$_{min}$	0.15m
Maximum Allowable Stress Value,S	950 x 10^5 Pa
Corrosion Allowance, t$_c$	0.003m
Steel Density, ρ_s	7850 kg/m3
Factor for determining surface area of a vessel head from vessel diameter squared (2:1) elliptical heads,F$_a$	1.09
Cost factor per unit mass to manufacture a vessel shell, F$_c$	5.0 $/kg
Ratio of cost per unit mass to manufacture a vessel head compared with that of a vessel shell, F$_h$	3.0

The Excel Solver found the optimal solution for the separator design. The minimum manufacturing cost is $ 5.89 x 10^7.The minimum design diameter and length of the separator is 4.80 m and 1.60 m. The solution is summarized in Table 4.6 below.

Table 4.6: Overall Solution for 2-Phase Separator (V-200)

Data	Value	Data	Value	Data	Value
Cost ,C	5.89 x 10^7 (Eqn.2.6)	Vertical height of gas flow,h_g	0.40 m (Eqn.3.3)	Length of end section,L_n	1.48m (Eqn.3.13)
Separator Diameter, D	1.60 m (Eqn.3.16)	Depth for liquid level, h_L	1.04 m (Eqn.3.12)	Minimum wall thickness, t_{cs}	0.0031 m (Eqn.2.7)
Inner Diameter,D_i	1.59 m (Eqn.3.12)	Min. height from bottom of separator h_{min}	0.15 m (constant)	Gas Residence time, t_v	0.27 s (Eqn.3.2)
Mean Diameter,D_m	1.59 m (Eqn.2.10)	Separator Length, L	4.80 m (Eqn.3.15)	Settling velocity of liquid droplet,U_c	1.50 m/s (Eqn.2.4)
Total Area,A_t	1.99 m^2 (Eqn.3.6)	Gravity Settling Length, L_e	2.53m (Eqn.3.5)	Slenderness Ratio, L/D	3.00
Gas Flow Area, A_g	- 0.26 m^2 (Eqn.3.11)	Head Section Length,L_h	0.3975 m (Eqn.3.17)	Gas area fraction,α	0.5
Liquid Area, A_L	0.84 m^2 (Eqn.3.11)	Area for minimum level of liquid, A_{hmin}	1.40m (Eqn.3.9)	Gas Velocity,U_g	8.64 m/s (Eqn.3.1)

Table 4.7: Constraint status for optimal 2-Phase Separator Design

Constraint	Status
Gas Capacity Constraint	2.06m
Liquid Capacity Constraint	2.33m
Transportation Constraint	4.80 m (Length)
	1.59 (Diameter)

Table 4.7 shows the separator design governed by a number of constraints. There are the gas capacity constraint, liquid capacity constraint, and transportation constraint Observed from the table 4.5, the liquid capacity is the dominant parameter. The gas capacity is proportionally to length but not directly proportional. For instance, if the length of the separator is increased from 10 to 20m, the gas separating capacity will increase only 46%. This optimum separator assumed that no specials internals are used in the separators. Refer to Appendix G for mechanical drawing of optimize separator.

Table 4.8: Optimize Separator Compared to Case Study

Dimension	Optimized	Case Study
Slender to slender Length	4.00 m	6.10 m
Internal Diameter	1.59 m	1.79 m

Table 4.8 shows the comparison of the optimized model and case study separator. The optimized model has reduced the slender to slender length from 6.10 m to 4.00 m and the internal diameter from 1.79 m to 1.59 m. Thus it prove the optimize model achieve to optimize the separator design as it reduce 30% from the case study separator dimension.

4.3.1 Effect on the Gravity Settling Length and Manufacturing cost as a function of Separator Inner Diameter.

Figure 4.1 shows the gravity settling length and manufacturing cost curves as a function of separator inner diameter with a constant $\alpha = 0.5$.
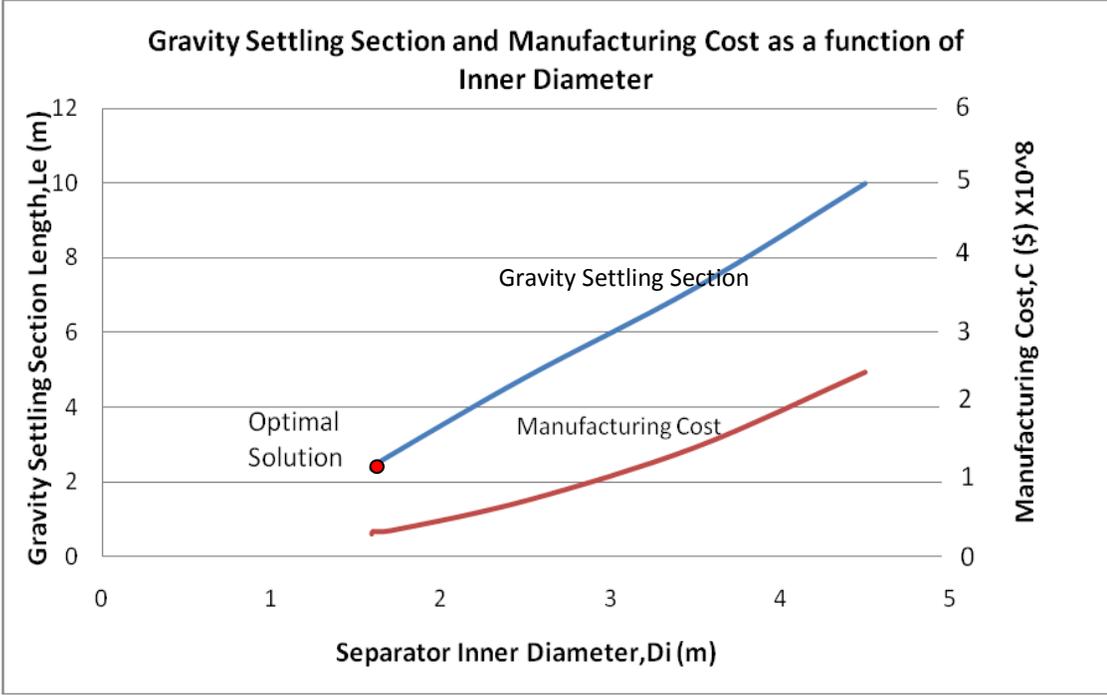
Figure 4.1: Gravity Settling Section Length curves as a function of inner diameter

As shown in the graph for the optimal separator, the separator inner diameter, Di, equal to 1.59 m and the gravity settling section, Le, equal to 2.33 m. As for the manufacturing cost it is equal to $ 0.589 x 10^8. From the graph we can observe, the manufacturing cost and the gravity settling section curves increase as the diameter increases. The curves indicated as the design with the smallest diameter is the least costly design.

4.4 Effect of Design Parameters for a Constant Droplet Diameter

In the following, analysis result of the effect of same design parameters of the separator for a constant droplet diameter (100 microns) are presented.

4.4.1 Effect of the Variation of α on the Gas Velocity and Manufacturing Cost
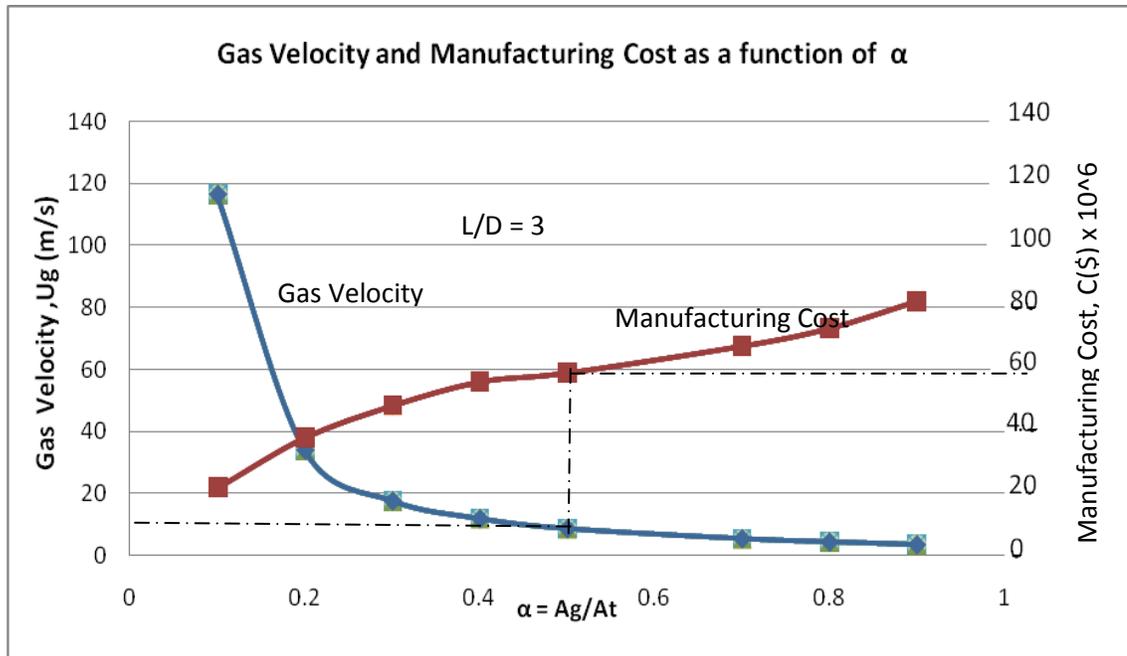
Figure 4.2: Gas Velocity and Manufacturing Cost curves as a function of α ratio.

Figure 4.2 shows the gas velocity curves and manufacturing cost as a function of gas cross sectional area fractions for liquid/gas separation, α, with L/D ratio constant of 3. The feasible design space and optimal design are depicted from the manufacturing cost curve and the gas velocity curve. As for the dotted vertical and horizontal lines touching the curves shown the optimal solution for α = 0.5, where the gas velocity is 8.64 m/s and the cost is $58.9 x 10^6.The gas velocity curve shows that a decrease in cross sectional area fractions leads to increase in the gas velocity when the diameter of the particle is constant (100 microns). The increased gas velocity reduces the residence time of the droplet as shown in the figure 4.3. Thus, the distance that droplet will fall during residence time decreases.

The manufacturing cost curve shows that feasible designs that minimize the total cost can be found between 0.1 and 0.9 values of α. The manufacturing cost curve defined the feasible design space to represent optimal designs where a set of separator sizes fulfill the design requirement. Thus, every point in this feasible region that satisfies all the constraints corresponds to an optimal design. Then, it should be noted that a point on the curves in the Figure 4.2 represents the minimum total cost and the best separator design in terms of corresponding α.

It is important to emphasize that the length of the separator and the height of the gas will determine whether the droplet is separated. As the height of the liquid is increased, the gas flow area, A_g decreases. The decreases A_g leads to an increase in the gas velocity, reducing the residence time of the droplet thus decreases the distance that droplet falls. Therefore, the selection of separator design should strongly take into consideration the gas residence time and the ratio of gas velocity to settling velocity f = Uv/Uc. Gas velocity is a function of the liquid level for a fixed volume of gas through the separator, and the critical settling velocity is a function of liquid droplet diameter.

4.4.2 Effect of the Variation of α on the Ratio of Gas Velocity to Settling Velocity and Retention Time
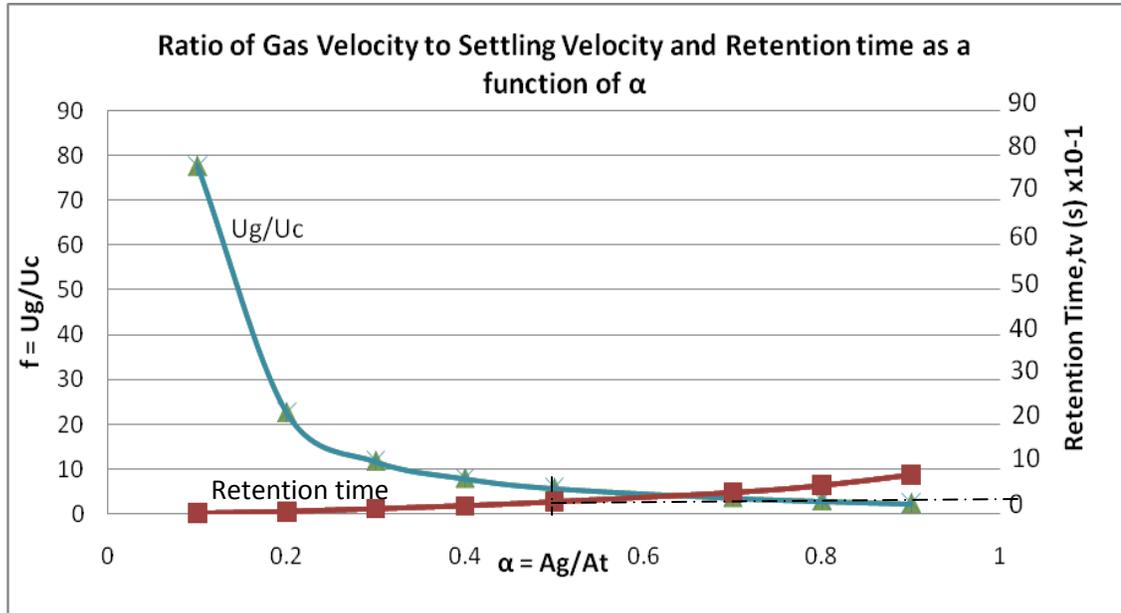
Figure 4.3: Ratio of gas velocity to settling velocity f and Retention time as a function of α

Figure 4.3 shows the ratio of gas velocity to settling velocity, f, and the retention time, t_v as a function of vapor area fractions, α. It can be seen from Figure 4.3, to minimize cost of separator design depends heavily only the ratio f and the residence time. Sufficient residence time is required to accomplish the degree of separation gas from oil [24,25]. Liquid must be held in the separator for a certain time to reach gas-liquid equilibrium under working pressure. The results in Figure 4.2, show that feasible designs that minimize the ratio f can be found at values of α = 0.1- 0.9.For instance, for α = 0.5, f is equal to 5.76 and the residence time of vapor is equal to 0.27s .To achieve good separation horizontal separators are operated half full of liquid to maximize the gas-liquid interface area. The design must provide sufficient retention time to allow liquid to reach equilibrium. Thus, because of possible practical practice, the most suitable separator size should be selected according to particular constraints, and the final selection must be made according to the lowest manufacturing cost.

4.4.3   Effect of Minimum Diameter in the Minimum Length
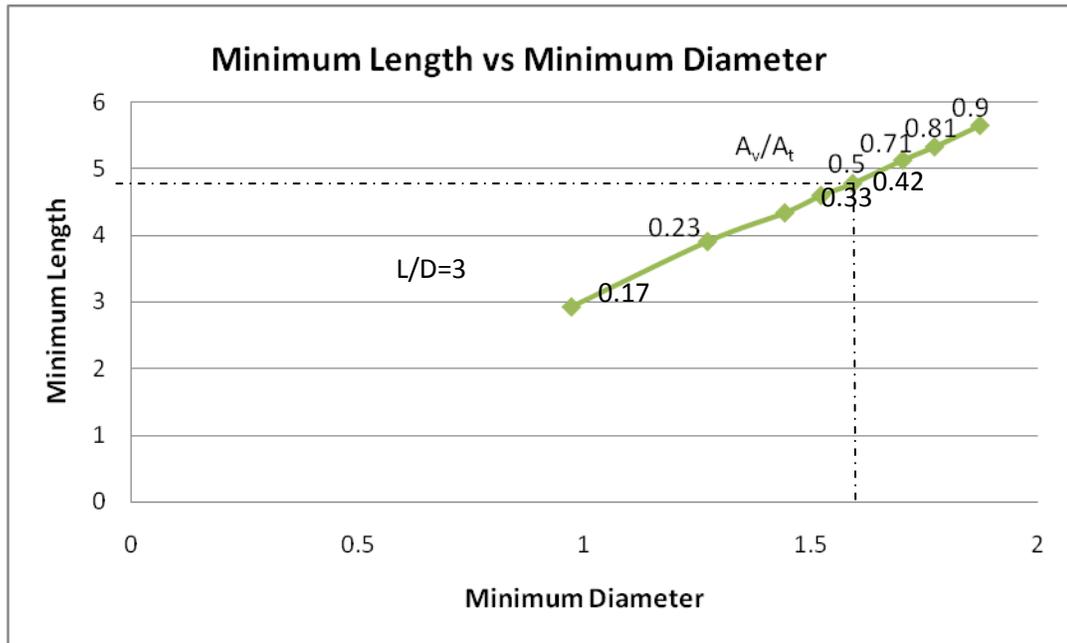
Figure 4.4: Minimum Length as a function of diameter and as a function of α

Figure 4.4 shows the minimum length for the best designs obtained for minimum inner diameter of the separator under different setting of α, keeping the diameter of the particle constant at 100 microns and slenderness ratio equal to 3. From the Figure 4.4, shows that as the height of the liquid increases,the required distance or α for separation of liquid droplet decreases. Thus, the length and diameter of the separator decrease in the same way.On the other hand, the gas velocity is increased. The distance for separation is the diameter of the vessel minus the height of the liquid.

Observed from Figure 4.4, evaluated the convenience of a cylindrical length with respect to possible changes in α.For instance, if the base case with α = 0.5, is considered as reference, it indicates that any decrease in α would place the design problem deeper into the region in which an optimal design with low cost prevails over an optimal design with a complete separator size.On the other hand, a small decrease in a α have to be consider as sudden increase gas velocity.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The following conclusions could be made from the study:

a. Optimum separation process focus on recovering more liquid by adjusting the pressure. Generally at increasing pressure more mass will escape as gas at high pressure.

b. The optimum separator design was determined by consideration of gas capacity, liquid capacity, slenderness ratio, and transportation constraint. However, the liquid capacity is the dominant parameter for the separator design.

c. The optimized separator size was 30% smaller than the case study separator.

d. Recommended liquid level for the optimum separator size was half full of diameter as it will maximize the gas-liquid interface area for Baram separator.

e. The optimum separator slenderness ratio was equal to 3 and this results the minimum length and diameter of separator that give the least manufacturing cost.

5.2 Recommendation

However, an improvement for the model to enhance its capabilities could be performed in order to obtain more efficient separator design. Instead of only considering the gravity settling principle, an extended work should include factors due to momentum and coalescence principles. Besides that, the safety constraint, and detail internal parts such as baffle plate should be considered as to improve the separator design model. The resulted model should be operated using a fully automated, systematic design method by using MATLAB or GAMS/CONOPT. Besides that, experimental work should be done based on developed model for more accuracy model validation. Student can also relate the theory with the practical work by doing the experiment and it will lead to a better understanding.

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APPENDICES

APPENDIX A

Separator Configuration

Figure 1: Horizontal Separator

Figure 2: Horizontal Separator

Figure 3 : Spherical Separator

APPENDIX B

Separator Internal Parts
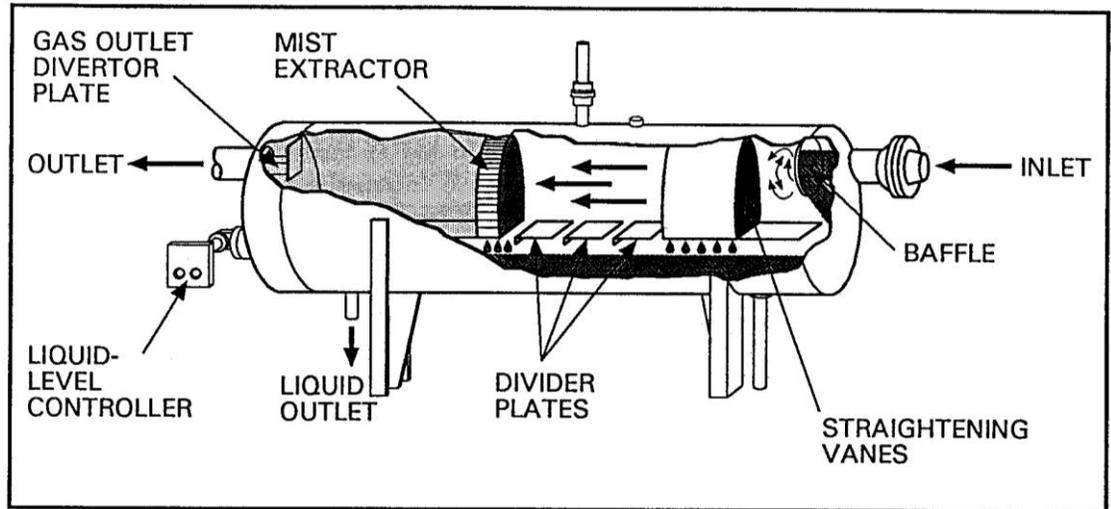
Figure 1: Separator Internal Parts

Figure 2:Vanes
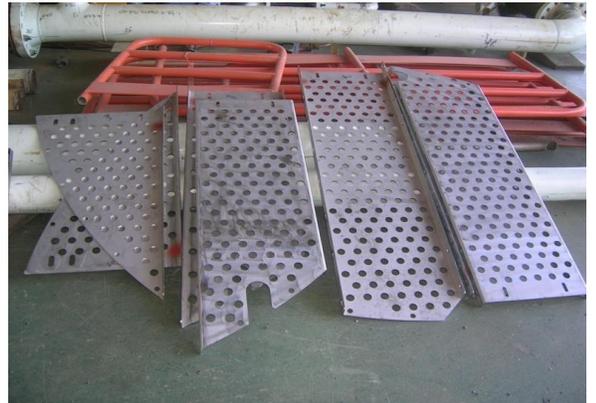
Figure 3: Baffle Plate

APPENDIX C

Mechanical Drawing (V-200)

APPENDIX D

P&ID

APPENDIX E

Baram Heat Material Balance

APPENDIX F

Final Year Project Gantt Chart

APPENDIX G

Flash Calculation Spreadsheet

Flash Calculation

i) Gas Molecular Weight

$$MW = \frac{3.437}{0.1525} = 22.54 \tag{2.14}$$

ii) Gas specific gravity

$$SG_g = (MW)_g \,/\, (MW)_{air} = 22.54 \,/\, 29 = 0.778$$

iii) Gas Density

$$\rho_g = 0.093 \frac{(MW)P}{TZ} = \frac{(22.54)(73)}{(560)(0.9846)} = 2.9842 \text{ lb/ft}^3 = 47.802 \text{ kg/m}^3 \tag{2.16}$$

iv) Gas Flowrate

$$Q_g = \left(29451.90\ \frac{kg}{hr}\right)\left(2.204\ \frac{lb}{kg}\right)\left(\frac{1}{22.53}\ \frac{lb-mol}{lb}\right)\left(379.48\ \frac{scf}{lb-mol}\right)\left(24\ \frac{hr}{day}\right)$$

$$= 26240001.12 \text{scfd} \tag{2.19}$$

$$Q_g = \frac{26240001.12}{1000000} = 26.24 \text{ MMscfd}$$

4.1.2 Properties of Liquid

i) Liquid Molecular Weight

$$MW = \frac{202.41}{0.825781} = 245 \tag{2.15}$$

ii) Liquid specific gravity

$$SG = \frac{\sum L_N \times (MW)_N}{\sum \frac{L_N \times (MW)_N}{(SG_N)}} = \frac{20.24141}{22.88045} = 0.8876$$

iii) $^\circ$API

$$^\circ API = 141.5/0.8876 - 131.5 = 27.92$$

iv) Gas Solubility

$$Rs = SGg \left(\frac{P}{18} \frac{10^{0.0125(API)}}{10^{0.00091T}} \right) = 0.778 \left(\frac{73}{18} \frac{10^{0.0125\,(27.92)}}{10^{0.00091(100)}} \right) = 0.778(7.345998)$$

$$= 5.7152 \text{ scf/stb}$$

v) Oil Density

$$\rho_o = \frac{62.4\,(SG_L) + 0.0136\,Rs(SG_g)}{0.972 + 0.000147\,(Rs\sqrt{\frac{SG_g}{SG_L}} + 1.25T)^{1.175}}$$

$$= \frac{62.4\,(0.8876) + 0.0136\,(5.7152)(0.778)}{0.972 + 0.000147\,(5.7151\sqrt{\frac{0.778}{0.8876}} + 1.25(100))^{1.175}}$$

$$= 54.5234 \text{ lb/ft}^3 \quad = 873.3811 \text{ kg/m}^3 \tag{2.17}$$

vi) Liquid Flow rate

Assume 50000 moles per day.

$$L = \frac{50000}{1 + \frac{0.251815}{0.825781}} = 38315 \text{ moles/day}$$

$Q_L = (38315)(245) / (350)(0.8876)$

$= 9387393.1 / 310.66 = 30217.58 \text{ bpd}$ (2.20)

APPENDIX H

Optimization Excel