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DESIGN OF A THREE PHASE SEPARATOR USED IN OIL AND GAS INDUSTRY

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Abstract

Crude oil is available in Oman through the major Oil and Gas industries. Oman is a major oil producer in the Middle East, with proven oil reserves of over five billion barrels. The government of Oman holds a majority stake in the company, and its principal activity is the production, refining, storage, and distribution of crude oil and natural gas. These companies are also producing a range of refined products, including gasoline, diesel, and aviation fuel. Once the reservoir is separated, the gas and oil must be managed carefully to prevent phase separation. This can be done by controlling the temperature, pressure, and phase compositions of the reservoir. The aim of this research is to design a three phase separator used in the oil and gas industry to reduce the time and cost of oil separation. The three-phase separator is designed and fabricated for laboratory scale. The design is validated by Aspen-Hysys software. The results obtained for oil and water separation at different temperatures are analyzed by graphs.

Keywords: Three Phase Separator, Crude Oil, Aspen-Hysys Simulation, Multi Phase Flow, Phase Separation

INTRODUCTION

Oman is a major oil and gas producer in the Middle East. It is one of the ten members of the Organization of Petroleum Exporting Countries (OPEC) and holds the fifth-largest proven crude oil reserves in the world. Oman's oil and gas industry is a major contributor to the country's economy and currently accounts for more than half of its GDP and 86% of its export earnings.

Oman's oil and gas resources are mainly located in the northern part of the country and are mainly offshore. This is why the offshore sector is the main driver of the industry in Oman. The majority of Oman's oil production is split between Petroleum Development Oman (PDO) and Occidental Petroleum. The country's total oil production capacity is estimated at around 1.2 million barrels of oil per day (BOPD) [1],[2].

Oil and gas industry in Oman is affected by phase separation issues due to the presence of water in the oil. This is a major issue due to the fact that the presence of water can lead to corrosion, blockage of pipelines, and decreased production. The most common cause of phase separation is due to the difference in temperature, which can cause the oil and water to separate. Other causes of phase separation include changes in pressure, turbulence, and chemical reaction [3]. To address phase separation issues in the oil and gas industry in Oman, operators should make sure that all pipelines are properly maintained and monitored. This includes regular inspections,

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testing, and cleaning of the pipelines. Additionally, operators should ensure that the temperature, pressure, and other conditions are properly controlled to avoid phase separation [4].

Furthermore, operators should also use oil-water separators in their production systems to separate the oil and water. These separators can help reduce the amount of water in the oil and increase the efficiency of the production process. Finally, operators should also utilize advanced technologies such as artificial intelligence and machine learning to better predict and prevent phase separation [5].

Three-phase separators are used to separate and collect a variety of fluids from a process stream. They are most commonly used in oil and gas production and refining, as well as other industrial processes. There are several different types of three-phase separators, each with its own unique features and benefits [6].

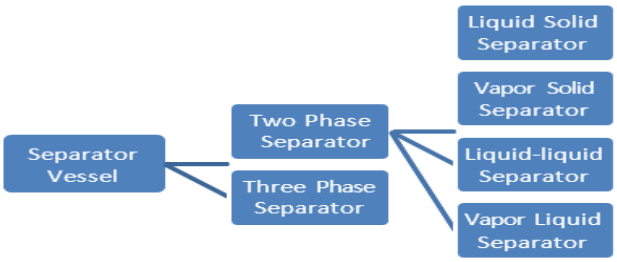

Figure 1: Different types of phase separators

There are several phase separators used in the oil and gas industries such as Gravity separators use the force of gravity to separate the different phases of a process stream. This type of separator is most commonly used in oil and gas production, where it is used to separate oil, gas, and water. Gravity separators are typically cylindrical in shape and are typically installed vertically. Centrifugal separators use centrifugal force to separate the different phases of a process stream. This type of separator is most commonly used in oil and gas production, where it is used to separate oil, gas, and water. Centrifugal separators are typically cylindrical in shape and are typically installed horizontally. Cyclonic separators use centrifugal force to separate the different phases of a process stream. This type of separator is most used in oil and gas [7].

Three Phase Separator

A three phase separator is a type of vessel used in the oil and gas industry to separate oil, gas, and water from the produced fluid stream. It is used to separate the three phases from the produced fluid stream in order to allow for further processing and production [8]. The design of a three phase separator is typically dictated by the operating conditions, fluid properties, and desired outcomes of the separation process. Generally, three phase separators are designed to be of a horizontal or vertical orientation, with the horizontal orientation being preferred for smaller separators. The size and configuration of the separator is also based on the flow rate and desired separation results. The interior of the separator is typically divided into two or three compartments, each designed to treat a specific phase of the produced fluid [9]. The design of

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the interior of the separator is intended to create sufficient turbulence to ensure an efficient separation of the different phases. This is typically accomplished by the introduction of baffles, weirs, or other types of flow control devices. Additionally, the separator may also be fitted with a coalesce or other filtration device to remove any suspended solids from the produced fluid [10].

DESIGN OF THREE PHASE SEPARATOR

Three phase separators are used to separate gas, oil, and water from the production stream. The design of a multi-phase separator should take into consideration the desired performance, space requirements, and cost. Shehi et.al. has conducted the research on selection of the primary components of a multi-phase separator are the inlet, separator body, and outlet.

1. Inlet: The inlet to the separator should be designed to allow for a smooth, efficient flow of the production stream while minimizing turbulence. It should also be designed to minimize the chance of entrainment of water droplets or gas bubbles in the oil phase.
2. Separator Body: The separator body should be designed to facilitate the separation of the different phases of the production stream. This can be accomplished by selecting a design that facilitates the settling of the water droplets and/or gas bubbles from the oil phase. This can be accomplished by using baffles or other designs that create a swirling or vortexing flow in the separator body.
3. Outlet: The outlet of the separator should be designed to ensure the efficient exit of the separated phases. The design should also take into consideration the pressure differential between the inlet and outlet.

The separator works by using a combination of gravity, pressure, and centrifugal force to separate the three phases. The oil and gas is separated from the solids as they pass through the separator. The separated oil and gas is then further processed to remove impurities and other unwanted materials. The oil and gas mixture is first fed into the separator at the inlet. The mixture is then subjected to a centrifugal force which separates the heavier particles from the lighter ones. The heavier particles sink to the bottom of the separator and the lighter particles rise to the top. At the same time, pressure is applied to the mixture to further separate the phases. This pressure is usually generated by the use of pumps or compressors. Once the phases have been separated, the oil is sent to the outlet of the separator. The solids are then sent to a settling tank for further separation and removal. The gas is then sent to a gas scrubber for purification and removal of any.

General Design Consideration

Following are major design consideration for three phase separator used in separation of different phases of crude oil during refining process.

1. Maximum Pressure: The design of a multi-phase separator must consider the maximum pressure it will encounter. This should be based on the maximum operating pressure of the system and any potential surge pressures.

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2. Flow Rate: The design should consider the expected flow rate of the system in order to ensure that it is capable of adequately separating the phases.
3. Temperature: The design should consider the expected temperature of the system and ensure that the separator is able to handle the temperatures it will encounter.
4. Materials of Construction: The materials of construction should be selected based on temperature, pressure, and other design considerations.
5. Space Requirements: The space requirements should be considered to ensure that the separator will fit into the desired location.
6. Corrosion: The design should consider the potential for corrosion, and any potential measures should be taken to minimize the potential for corrosion.
7. Contaminants: The design should consider any potential contaminants that may be present in the system and ensure that they are adequately removed.
8. Safety Features: The design should consider any safety features that may be necessary, such as pressure relief valves and other safety devices.

Vessel Orientation

A vessel orientation in a multi-phase separator is the way the vessel is positioned in relation to the incoming flow. This includes the angle of the vessel, the direction of flow, and the location of the inlet and outlet connections. The orientation of the vessel will affect the efficiency of the separation process.

Table 1: Advantages and disadvantages of Vessel Orientation

Orientation	Advantages	Disadvantages
Vertical	• High efficiency: The vertical orientation of the vessel enables the oil, gas and water to separate more efficiently as the gas rises to the top, the water settles at the bottom and the oil in the middle. • Less maintenance: Vertical orientation of vessels requires less maintenance because of its simple design.	• Possibility of oil-water emulsions: Since the oil and water are separated in vertical orientation, there is a possibility of oil-water emulsions forming which can be difficult to separate. Cheaper construction • Higher pressure drop: The vertical orientation requires higher pressure drop for the separation of oil, gas and water, as compared to horizontal orientation.
Horizontal	• Provides greater flexibility in terms of installation and maintenance. Fabrication is expensive. • Reduces the amount of space needed for the vessels and allows more efficient use of available space.	• Potentially create problems with the inlet and outlet of the vessel Necessary to maintain the level of liquid. • If the vessel is not properly sealed, the process fluid can potentially leak out of the vessel.

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Aspen Hysys Simulation

Three phase separators are used to separate a mixture of components into two or more distinct phases. Aspen Hysys is a process engineering software used for designing and simulating process systems. It can be used to design and simulate a three-phase separator. Trupti et al. has studied the Aspen Hysys software for design of separator. It can be used to determine the optimal design parameters for the separator, such as the size and shape of the separator, the material of construction, and the operating pressure. Additionally, the software can be used to simulate the performance of the separator under various operating conditions. The software is also used to analyze the results and make recommendations for process optimization. The Simulation of a three-phase separator in Aspen HYSYS environment is shown in Figure 2.

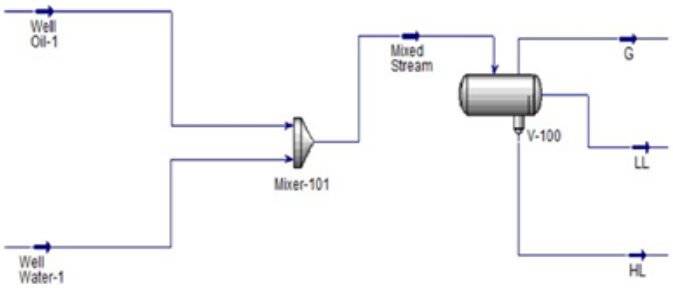

Figure 2: Hypothetical model of the Aspen HYSYS simulation

The details of the simulation are as follows:

- Molar Flow Rate of the Feed (F): 2511 kgmol/h
- Thermodynamic Package: Peng-Robinson-Stryjek-Vera 2
- Flash Algorithm: Gibbs Minimization VLLE
- Temperature of the Feed: 313 K
- Pressure of the feed: 1.013 bar

WORKING PRINCIPLE OF HORIZONTAL THREE PHASE SEPARATOR

The working principle of the horizontal three phase separator is based on the fact that different densities of two fluids (or two phases) can be separated by gravity. This separation is possible when one phase is heavier than the other and when the two phases have different specific gravities. When the two phases have the same specific gravity, separation is impossible. The horizontal three phase separator is basically a large vessel with a horizontal cylindrical body and a conical bottom. It is designed in such a way that the heavier phase will settle at the bottom of the vessel while the lighter phase will remain at the top. The separator also has a number of baffles and other features to ensure effective separation. At the inlet of the separator, the mixture of two phases is fed into the vessel. The mixture is then allowed to settle, allowing the heavier phase to settle at the bottom of the vessel, while the lighter phase will remain at the top. The separator also contains a number of baffles to ensure that the heavier phase is

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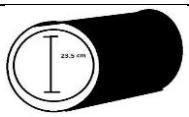
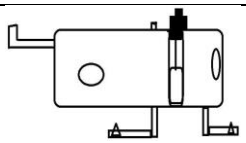
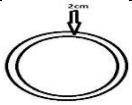
effectively separated from the lighter phase. Once the separation process is complete, the heavier phase is collected from the bottom of the vessel, while the lighter phase is collected from the top. Walke et al. investigated effect of time on layer formation of water and oil and proved that it is based on the density of phases.

Table 2: Parameters Affecting the Orientation

Component	Design Parts
Separator Diameter	
Inlet and Outlet Connections	
Thickness of the Metal Sheet	

Valuation of Design Aspects of Three-Phase Separator.

The design aspects of a three-phase separator can have a significant impact on the performance of a plant, as well as its overall efficiency and safety. The design of a three-phase separator must be carefully considered to ensure that it is able to safely and effectively separate oil, gas, and water, while also minimizing energy losses that can occur during the separation process. Furthermore, the design must also be able to withstand the environmental conditions that it may be exposed to. When evaluating the design aspects of a three-phase separator, it is important to consider factors such as the size of the separator, the materials used in construction, the number of stages, the type of design, and the flow control devices. All of these factors should be taken into account when determining the overall value of the design.

The most suitable materials for fabrication of a Three-Phase Separator are stainless steel, carbon steel, and aluminum, depending on the application and environment. Stainless steel is the most durable and corrosion-resistant option, while carbon steel and aluminum are more cost-effective. Other materials, such as polymers, may also be used in some cases. Thus, there are numbers of suitable material use for this purpose including:

1. Stainless Steel (Grade 304)
2. Stainless Steel (Grade 316)

Stainless steel is an ideal material for the fabrication of a three-phase separator because of its excellent corrosion resistance and strength. This is important because the separator is often exposed to harsh chemicals, high temperatures, and pressure extremes. Additionally, stainless steel's high thermal conductivity ensures that the temperature of the separator remains consistent, which is essential for the efficient functioning of the equipment. Stainless steel having a film layer which can be described as a passive layer which can't react with other metal

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of materials. Also can be described as self-renewing if the layer damaged [14]. Furthermore, the Table-3 shows two types of Stainless Steel. However, in this research work the first type was chosen because of the following reasons in the table below;

Table 3: Features of Stainless Steel

Stainless Steel (Grade 304)	Stainless Steel (Grade 316)
Grade 304 stainless steel is strong and has excellent tensile strength.	Grade 316 stainless steel offers excellent corrosion resistance due to the presence of molybdenum in its chemical composition
Grade 304 stainless steel can be formed and welded easily.	High temperature strength and is able to withstand temperatures up to 1500°F (816°C)
Grade 304 stainless steel is non-magnetic, making it suitable for applications where magnetic properties are undesirable.	Higher tensile strength than other grades, making it suitable for a variety of applications.

DESIGN EQUATIONS

The primary separator is designed with a number of baffles that create various flow paths for the oil and gas. A weir plate is placed at the inlet of the separator, which allows the liquids to flow into the vessel at a controlled rate. The oil and gas then flow through the baffles and are separated based on their respective densities. The oil and gas then flow out of the separator at the outlet. The secondary separator is designed with a series of mesh screens and coalescing plates that are designed to remove any remaining oil droplets from the gas stream[15]. The gas then flows out of the separator at the outlet.

Settling Theory

This theory is based on the fact that when two different densities of liquid are placed into a container, the heavier liquid will settle to the bottom while the lighter liquid will rise to the top. This is due to the fact that gravity pulls on the heavier liquid more than it does on the lighter liquid. This same principle applies to a three-phase separator, where the heavier phase will settle to the bottom while the lighter phase will rise to the top. The settling velocity of particles is calculated by using following equation

$$V = \frac{2G\rho_g(d_1 - d_2)}{(\rho_l - \rho_g)} \qquad (1)$$

Retention Time

A retention time in a three-phase separator is the amount of time it takes for a given volume of liquid to pass through the separator. It is usually expressed in minutes. [16] Al Hinai et al. studied the importance of retention and its effect on the efficiency of the separation process and the quality of the separated liquids

$$\text{Retention Time} = \frac{\text{Volume of Separator}}{\text{Flow rate of Inlet Stream}} \quad (2)$$

But Volume of Separator is calculated by following equation.

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$$\text{Volume of Separator} = \frac{(\pi \text{ x } D^2 \text{x } H)}{4} \qquad (3)$$

Sizing of the demister

A demister is a device used to reduce or eliminate the condensation of moisture on the surfaces of car windows and mirrors. It works by using a small electric current to heat a wire mesh, which causes the moisture to evaporate. The mesh is designed to create a tortuous path for the droplets, thus allowing them to coalesce and drop out of the gas stream. The demister is typically located at the separator's outlet, where it can catch any remaining droplets before they are expelled into the atmosphere. Following equation is used to design demister

$$K = \frac{(\rho V)^2}{2gh} \qquad (4)$$

RESULT ANALYSIS

For the experimental investigation for separation of a mixture of suspended particles, crude oil and water, the ratio of 1:1:1 is maintained. The volume of oil separated in a three phase separator is affected by temperature. As temperature increases, the volume of oil separated decreases due to increased solubility of the oil in the other phases. Additionally, at higher temperatures, the viscosity of the oil decreases, resulting in a thinner oil that is more difficult to separate from the other phases. Figure 3 shows the effect of temperature on oil separation

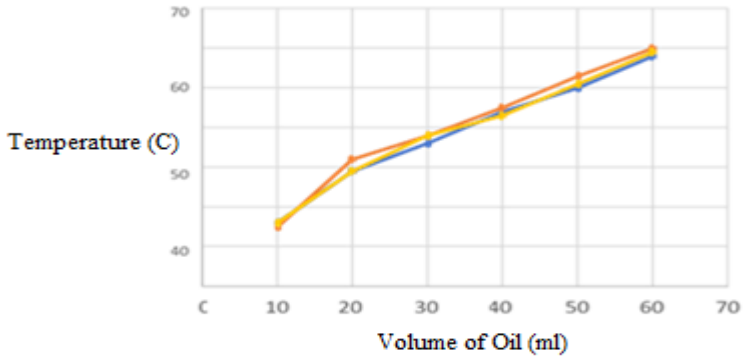

Figure 3: Effect of Temperature on oil separation

The temperature of the water in a three-phase separator affects the volume of water that can be separated. As the temperature of the water increases, the solubility of the components in the water decreases, allowing more of the components to be separated, resulting in a larger volume of separated water. Conversely, as the temperature decreases, the solubility of the components increases, allowing fewer components to be separated, resulting in a smaller volume of separated water. Figure 4 shows the effect of temperatures on water separation

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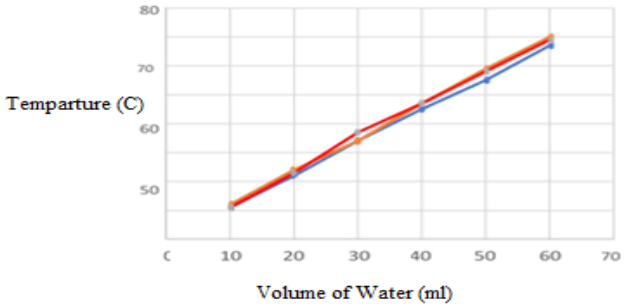

Figure 4: Effect of Temperature on water separation

CONCLUSION

The three phase separator is a critical piece of equipment in the oil and gas industry. It is used to separate oil, gas, and water that is produced from a well. The separator is typically installed at the wellhead and separates the different components based on their density. The oil, gas, and water are all sent to different locations for further processing. The separator helps to reduce the cost of production, as it reduces the amount of energy needed to produce the oil and gas. Additionally, it helps to reduce the risk of environmental contamination by separating the different components. In this research work the detailed designing of the three-phase separator has been done by calculating various parameters necessary for it and also the fabrication of a three phase separator model has been done. This model has implemented with a moveable weir which can be adjusted manually or by the aid of motors.

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LIST OF ABBREVIATION (S)

V	Volume of the separator
G	Acceleration due to gravity
ρ_g	Density of the gas
d_1	Upper part of the separator
d_2	Lower part of the separator
ρ_l	Density of the liquid
D	Diameter of the separator
H	Height of the separator
K	Mass transfer coefficient
ρ_m	Density of the mixture
v	Velocity of the mixture
h	Height of the demister pad

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