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Several Studies Proceed For the HTPS: Challenges and Optimization

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ABSTRACT

The rapid expansion of oil production has increased the demand for effective separation systems, with oil separators playing a vital role as the first stage in oil production due to their fast response. The horizontal three-phase separator (HTPS) is the most commonly used type, valued for its effectiveness and low maintenance requirements. HTPS is an essential component in oil and gas production systems, efficiently separating crude oil into oil, water, and gas phases. This paper examines the limitations of current research and the challenges associated with a comprehensive review of HTPS components and optimization methods. It outlines the design fundamentals, internal configurations, and operational challenges, while also analysing mitigation techniques. This study provides a comparison between different optimization approaches in the oil recovery (OR) separator. This study contributes to ongoing research and serves as a practical guide for enhancing the design, efficiency, and reliability of TPSHs in diverse operational environments.

1. Introduction

The oil production is categorized by its purity, with higher quality associated with lower levels of impurities. At extraction, oil from the wellhead contains some water, solid contaminants, and associated gas. However, before exportation or refining, it should be treated in a series of processing stages to remove water, sand, and even the salt components. one of the most important pieces of equipment in the degassing field of oil production is the separator, which plays a main part in separating crude oil into its three phases: oil, water, and gas [1]. There are various types of oil separator configurations in multi-flow, such as two-phase or three-phase, but geometrically, such as vertical, horizontal, and spherical separators. among the most widely used, related to their efficiency in handling multiphase flow and their capability to remove salts, sand, and other solid impurities through specialized internal components at complex oilfield flow, which has a higher water cut [2]. Regarding the essential function of improving product quality and reducing operational problems, the separators have been the focus of many studies, which focus on both

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design and operational parameter development [3-5]. The horizontal design is important due to Accommodates high flow rates, offer a large surface area and longer retention time, improving phase separation, and being more efficient at handling high water-content streams compared to vertical separators[6, 7]. Also, it’s more efficient at handling high water-content streams compared to vertical separators [8]. The study aims to provide a comprehensive overview of oil separators, particularly horizontal three-phase-separator units, by discussing their types, internal components, common operational challenges, and the latest studies focused on enhancing their performance [9]. Special attention is given to experimental investigations, numerical simulations, and optimization techniques that improve both the production efficiency and structural design of these units. In the end, this review is required to highlight the importance of oil separators as a kind of support for future research and serve as a practical guide for enhancing the design, efficiency, and reliability of HTPS in diverse operational environments, also offering a solid foundation for continued research and innovation in this vital area of oil and gas processing.

2. Horizontal Three-Phase Separator(HTPS)

HTPS 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 HTPS is typically dictated by the operating conditions, fluid properties, and desired outcomes of the separation process. Generally, HTPSs are designed to be of a horizontal or vertical orientation, with the horizontal orientation being preferred for smaller separators [10]. The size configuration of HTPS is also based on the flow rate and desired separation results. The HTPS is internally divided into two or three compartments, each designed to treat a specific phase of the produced fluid. The design of 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 ([1, 11, 12].

3. Separation Principles

The goal of ideal separation is to divide the hydrocarbon stream into liquid-free gas and gas-free liquid. In order to achieve this, the gas and liquid must reach a state of equilibrium under the existing conditions of pressure and temperature within the vessel (The fluids to be separated must be insoluble in each other, and one fluid must be lighter than the other). Furthermore, separations rely on the effect of gravity to separate fluids[13]. However, if the fluids are soluble in each other, gravity alone cannot facilitate separation. For instance, a mixture of distillate and crude oil will not separate in a vessel because they dissolve in each other. In such cases, they must be segregated through the distillation process [14]. The well flow is fed into a horizontal vessel. The retention period is typically five minutes, allowing gas to bubble out, water to settle at the bottom, and oil to be taken out in the middle. The pressure is often reduced in several stages (high-pressure separator, low-pressure separator, etc.) to allow controlled separation of volatile components [15].

4. Separation Process in Oil and Gas

The physical and chemical characteristics of the oil and its pressure and temperature conditions determine the quantity of gas it will contain in solution. The rate at which the gas will be liberated from any given oil is a function of its change in pressure and temperature. **Figure 1** shows that the quantity of the separated gas from crude oil by an oil and gas separator depends on many variables [16]. Moreover, these are the agitation, heat, special baffling, coalescing packs, and filtering materials that assist in eliminating gas that otherwise may be retained in the oil because of the viscosity and surface tension of the oil [15]. Gas can be removed from the top of the drum by virtue of being gas. A baffle at the end of the separator, set at a height near the oil-water contact, allows oil to spill over onto the other side, but traps water on the near side. The two fluids can then be piped out of the separator from their respective sides of the baffle. The generated water is either reinjected into the oil reservoir, disposed of, or treated. **Figure 4** shows the main separator components.

Instrumentation fixed to the vessel measures the bulk level/gas-liquid interface and the oil-water interface. Valves on the oil and water outlets are manipulated to maintain the interfaces at their optimum levels so separation can take place. The separator will only accomplish bulk separation. The finer water droplets will not settle out by gravity and remain within the oil stream. Typically, the oil from the separator is routed to a coalescer to further reduce the water content of the oil.

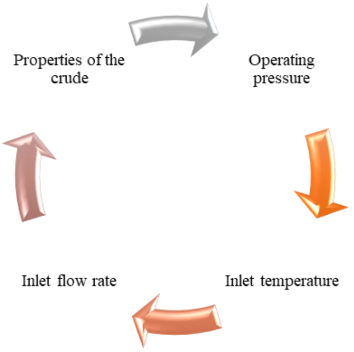


Figure 1: The variables' effect on the separation process of the separator

5. Separator Main Regions

For efficient and stable operation over a wide range of conditions, a gas-liquid separator must have the features described:

- **Primary separation section**

Removing the bulk of liquid from the inlet stream. It is desirable to quickly slugs and large droplets of liquid from the gas stream to minimize gas turbulence and re-entrainment of liquid particles in preparation for a second step of separation. This is usually accomplished by a change in the direction of fluid flow. Centrifugal force from a tangential inlet on a vertical vessel quickly removes large volumes of liquid and allows redistribution of gas velocity. Properly shaped and positioned deflection plates are usually used in horizontal and spherical vessels to accomplish this effect with a minimum of re-entrainment [10, 17, 18].

- Secondary separation section:

For removing a maximum of smaller liquid droplets without an elaborate design. The major separation principle in this section is gravity settling from the gas stream after the velocity has been drastically reduced. The efficiency of this section primarily depends upon the gas and liquid properties, the liquid drop size, and the degree of gas turbulence. The turbulence factor is often minimized by inlet arrangement and properly designed and positioned straightening vanes [12, 19, 20].

- Removing section:

A maximum of the tiny liquid droplets remains in the gas stream after passing through the primary and secondary separation sections. The usual oilfield separator employs either the impingement principle or the centrifugal force principle as the primary mechanism of mist extraction. In either case, tiny liquid droplets are collected on a surface where they are drained away from the gas stream or form large droplets that can fall back into the primary separation section [21-23].

- Liquid accumulation section:

For receiving and disposing of the liquids collected. This section should be arranged so that the separated liquid has a minimum disturbance from the flowing gas stream. It should also be of sufficient volume and have the proper liquid level control equipment to handle liquid surges that may occur in normal operation for the particular installation [17, 20, 24].

- The separator mechanical part:

The physical structure and internal components of oil and gas separators are specifically designed to regulate fluid dynamics and enhance the efficient separation of oil, water, and gas phases. According to these, internal mechanical elements are essential for controlling flow distribution, minimizing turbulence, and promoting gravity-driven settling, thereby directly influencing overall separation efficiency [9, 25]. The main components of a separator typically include (a slot entry for inlet production positioned at the top of the separator, an oil outlet slot located at the lower section, a gas exit slot at the upper section, a water outlet slot at the bottom, and a discharge slot at the base for maintenance operations. Additionally, two safety valves are positioned at the top and connected to a flare line, ensuring safe pressure relief. Instrumentation features include a pressure gauge, level measurement and control devices, and a temperature gauge for operational monitoring. Maintenance and protective barriers surround the separator slots to ensure reliability and safety [7, 8, 18, 26]. The separator functions according to the principle of natural phase separation, relying on differences in density and physical properties among gas, oil, and water. Its operation can be summarized as a systematic process where gas rises to the top, oil accumulates in the middle layer, and water settles at the bottom, enabling efficient HTPS separation under controlled conditions, see **Figure 3,** and the work principle pointed out in **Figure 2.** Flowchart of the Separation Stages in HTPS.

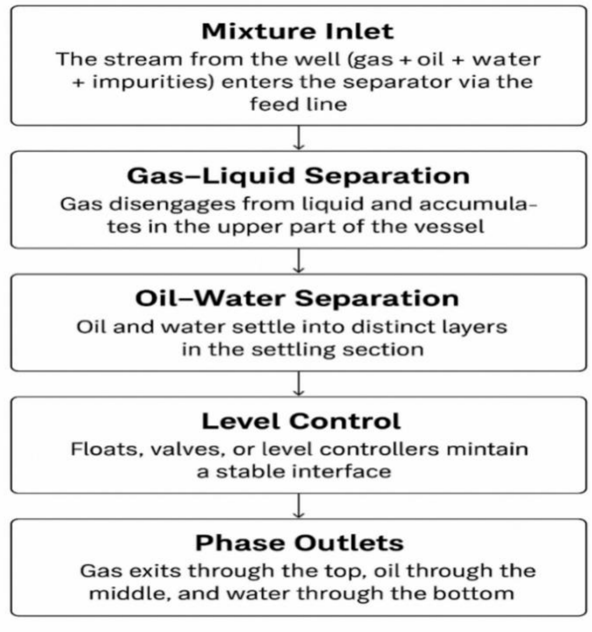


Figure 2: The Separation Stages Flowchart in HTPS.

6. Vessel Internals

Vessel internals in horizontal 3-phase separators are essential to enhance droplet coalescence processes in separators. Generally, gas-liquid separators without any enhancement internals can only remove liquid entrainment with sizes above 1oo microns. By adding efficient internals, the corresponding droplet size can be reduced to 5-10 microns ousmanou and Jordan [27]. This indicates that the gas-liquid separation efficiency can be enhanced considerably by properly designed vessel internals. It is for this reason that varieties of vessel internals have been developed, which include: inlet devices, perforated baffles, mesh pads, vane packs, and spiral flow demisters. Internals below are the major parts in the separators [6, 7], see **Figure 2**.

Inlet Diverters: serve to impart the flow direction of the entering vapor/liquid stream and provide a primary separator between the liquid and vapor. Several different inlet devices are available, with different working mechanisms. Their performances differ from each other, both in efficiency and complexity. The inlet devices have a large impact on the overall separator efficiency. Inlet devices perform the following functions:

- Primary Bulk-Liquid Separation: They remove large liquid volumes at the entry, easing the load on mist extractors or downstream separation stages and making performance more stable during feed changes.
- Momentum Reduction & Phase Distribution: Inlet devices slow and redirect the feed to ensure even gas/liquid distribution. This avoids channeling, keeps residence times uniform, and prevents local overloading of demisters or cyclones.
- Prevent Re-entrainment & Droplet Shattering: They minimize high-velocity impingement that can break droplets into smaller, harder-to-remove mist. Proper design and

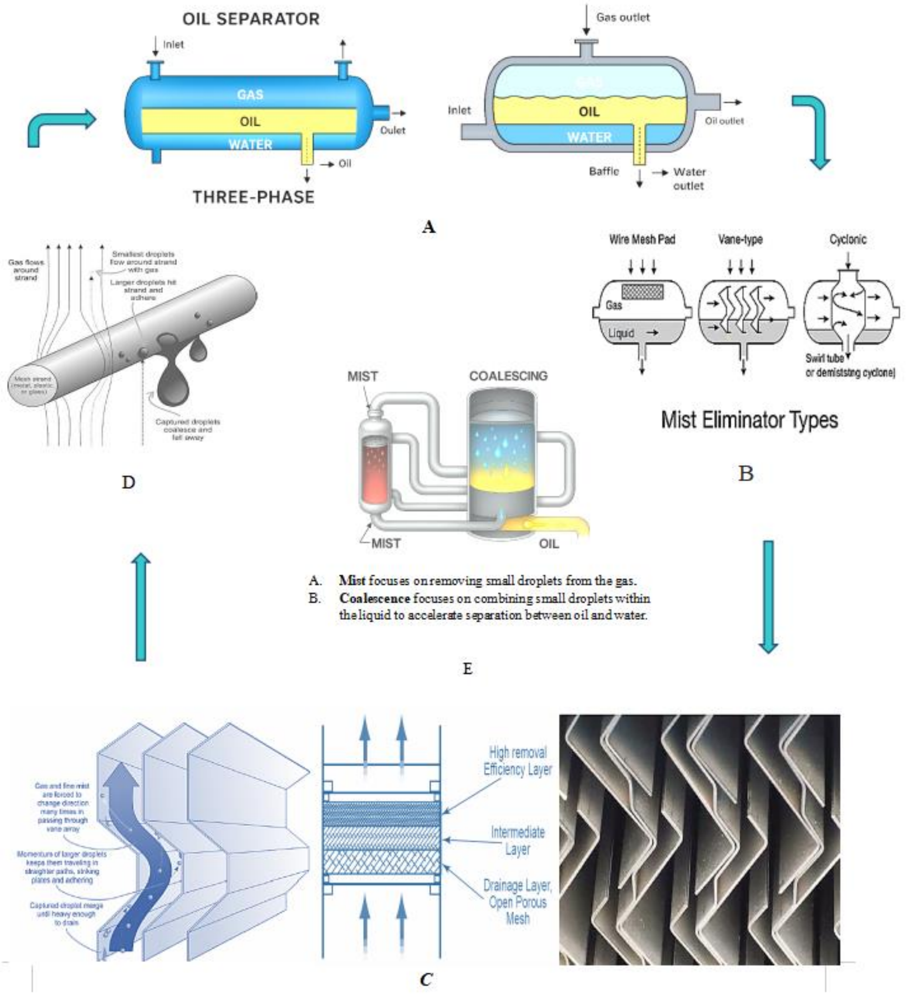
clearance also prevent the entrainment of separated liquid back into the mist

- Foam Suppression: Cyclonic or vane-type designs introduce shear and centrifugal forces that break up foam, reducing the need for demisters and chemical deformers. Common types of inlet devices include: (Diverter plate, half pipe, Slotted tee distributor, Tangential inlet with annular ring, Deflector baffle, cyclone shape, or Wave beaker) [28, 29].

Diverter or Baffle Plate: A baffle plate can be a spherical dish, flat plate, angle iron, cone, elbow, or just about anything that will accomplish a rapid change in direction and velocity of the fluids and thus disengage the gas and liquid [30, 31]. The gas will flow around the diverter while the liquid strikes the diverter and falls down in the liquid section of the vessel [32]. The design of such devices is relatively simple, it mainly needs to withstand the forces acting on it, but the geometry can vary according to fluid conditions [32-34].

Wave breaker: perforated baffles or plates that are placed perpendicular to the flow, located in the liquid collection section of the separator. These baffles dampen any wave action that may be caused by incoming fluids. The waves may result from surges of liquid entering the vessel. In long horizontal vessels, usually located on floating structures, it may be necessary to install wave breakers so that liquid level controllers, level safety switches, and weirs perform properly [35].

Mist Extractors, also called demisters, are commonly used internal devices to remove mist (very small dispersed droplets) from gaseous streams [22]. They are used in the oil and gas industry as internal devices in gravitational separators in the primary oil processing unit to minimize carryover by the affluent gas stream. The gas drag force causes small liquid particles to follow the gas stream. Mist extractors must therefore somehow intervene the natural balance between gravitational and the drag forces. This can be accomplished by reducing the gas velocity (hence reduce drag), introduce additional forces by use of cyclones or increase gravitational forces by boosting the droplet size (impingement) [36]. The selection of mist extractor is based on evaluation of (Droplet sizes that must be removed, tolerated pressure drop, Presence of solids and the probability or risk of plugging because of this, and Liquid handling in the separator). The rate of droplets following the gas stream is governed by simple laws of fluid mechanics; Mist extractors' operations are usually based on a design velocity and depend on the demister type and the manufacturing company. Some functions of mist extractors include: (Collect/capture drops, remove drops, avoid maintenance problems, and keep costs as low as possible). Common types of mist extractors are: (Wire mesh pads, Vane packs, Demisting cyclones) [23, 37, 38]. See **Figures 3** and 4 for a full description of the separator part and process.



A. **Mist** focuses on removing small droplets from the gas.
B. **Coalescence** focuses on combining small droplets within the liquid to accelerate separation between oil and water.

Figure 3 A: HTPS B: Multilayer mist eliminator [5, 23], C: Mist eliminator layer, D: Droplet removal, E: Work procedure

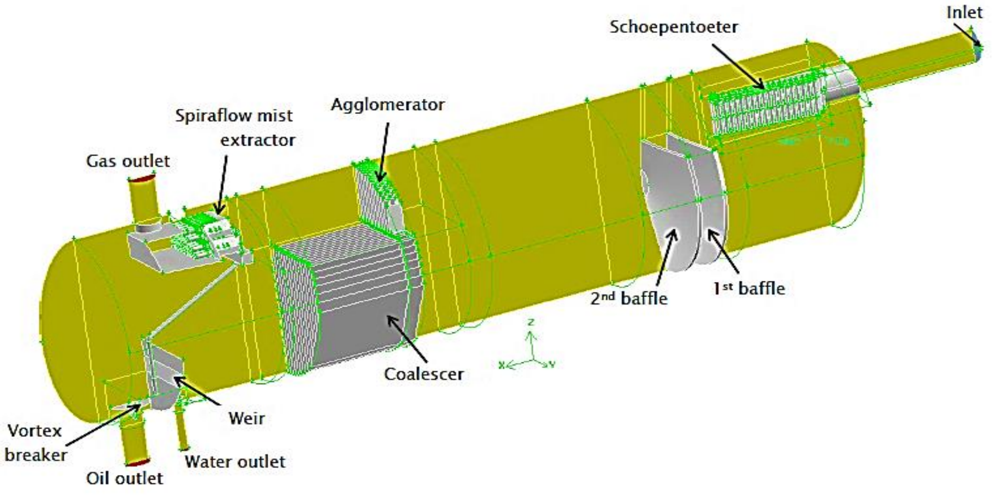


Figure 4: component of HTPS [39]

7. Troubleshooting

Frequent problems with separators are:

1. Liquid carryover (CO) in the outlet gas stream.

2. Inability to maintain a constant liquid level.

3. Failure of coalescing devices to function properly so that one or both liquid Streams

contain an excessive quantity of the other liquid.

8. Operational Challenges in HTPS: Analysis and Solutions

HTPS are fundamental components in the initial stages of oil and gas processing, where the produced fluid stream is separated into gas, oil, and water phases. However, the efficiency of this separation process faces significant challenges due to several operational problems, most notably foaming, emulsions, and CO/carry-under phenomena. These issues adversely impact product quality, process efficiency, operational safety, and environmental compliance, as shown in **Figure 5,** Operational Challenges in HTPS.

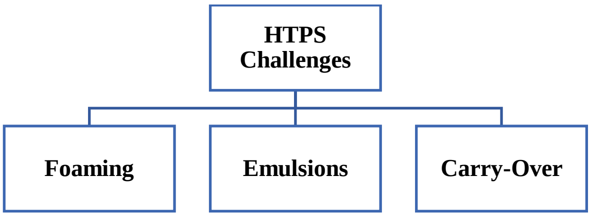


Figure 5: Operational Challenges in HTPS

- Foaming:

A complex physico-chemical phenomenon that occurs when natural surface-active agents in the crude oil (such as asphaltenes and resins) stabilize gas bubbles, forming a stable, sponge-like foam inside the separator vessel [5, 40-42].

Causes:

The presence of these natural surfactants, combined with turbulent flow and a sudden pressure drop, enhances bubble stability and prevents them from collapsing [43].

Impacts:

- Erroneous Level Control:

Foam can obscure sight glasses and interfere with level transmitter readings, leading to control valve malfunctions and a loss of proper level control within the vessel.

- Product Contamination:

It causes liquid CO (oil droplets in the gas outlet stream) and gas carry-under, reducing the purity of the final products.

- Reduced Throughput:

Foam occupies a significant volume within the separator, reducing the effective space available for liquid separation and limiting processing capacity.

- Emulsions:

An emulsion is a semi-stable mixture of two immiscible liquids, where one is dispersed in the other as tiny droplets. In separators, a "water-in-oil" (W/O) emulsion often forms, where water droplets are trapped within the oil phase [5].

Causes:

Emulsions form due to intense mixing of the fluid stream through chokes, valves, or pumps, and the presence of natural emulsifying agents (asphaltenes, salts, fine solids). These agents act as a film around the water droplets, preventing their coalescence and separation by gravity [44, 45].

Impacts:

- Wet Crude Oil:

Elevated water content in the outlet crude oil, exceeding specifications required for transportation or refining.

- Contaminated Water:

High oil content in the produced water effluent, exceeding permitted limits for safe environmental disposal, necessitates costly further treatment.

- Equipment Corrosion:

Stable emulsions can accelerate corrosion processes in pipelines and tanks.

- Carry-over (CO)

The liquid CO phenomenon, where liquid droplets escape with gas, is a prevalent operational challenge in gas-liquid separators [46]. Liquid CO leads to foaming issues and performance reduction within the separator, Downstream absorption DEng 2024 [5, 47]. CO in a separator refers to the unintended movement of one phase (usually liquid) into the outlet stream of another phase (typically gas). In other words, it's when droplets of liquid, such as oil or water, are carried over with the gas phase as it exits the separator [21, 42, 46]. There are several causes of it, as shown in **Figure 7**.

- CO:

The entrainment of liquid droplets (water or oil) in the outgoing gas stream.

- Carry-Under:

The entrainment of gas bubbles in the outgoing liquid stream.

- Water CO:

The entrainment of water droplets in the outgoing oil stream.

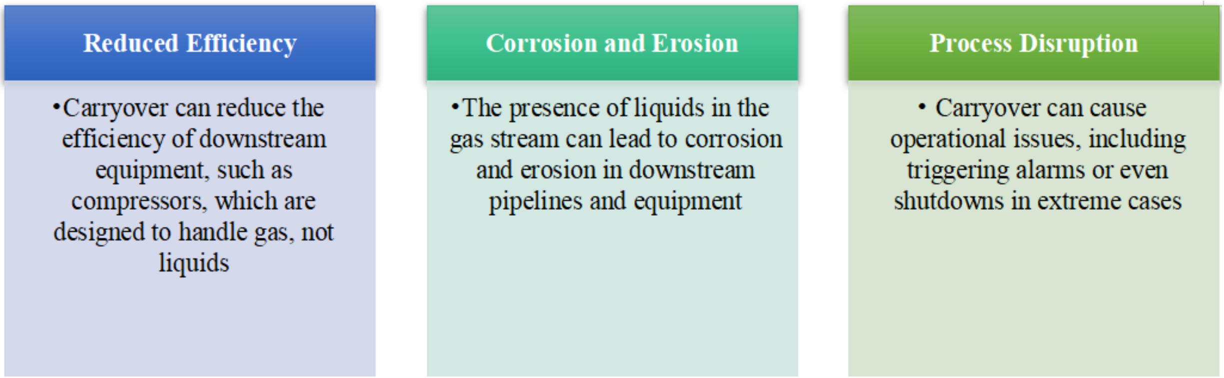
- Oil CO:

The entrainment of oil droplets in the outgoing water stream.

9. Mitigation Strategies

Proper sizing and design, flow control, and effective mist elimination are the main mitigation strategies to be considered. However, CO is a critical issue that needs to be managed to maintain the efficiency and safety of the separation process. Troubleshooting Procedure for Liquid CO in the Outlet Gas Stream. Pressure drop measurement should be made at the design gas rate. High-pressure drops indicate plugging. Internally inspect if necessary. Excessive wave action in liquid: Check or install horizontal baffles [17, 34, 42].

Shown in **Figure 6, the** Consequences of CO.

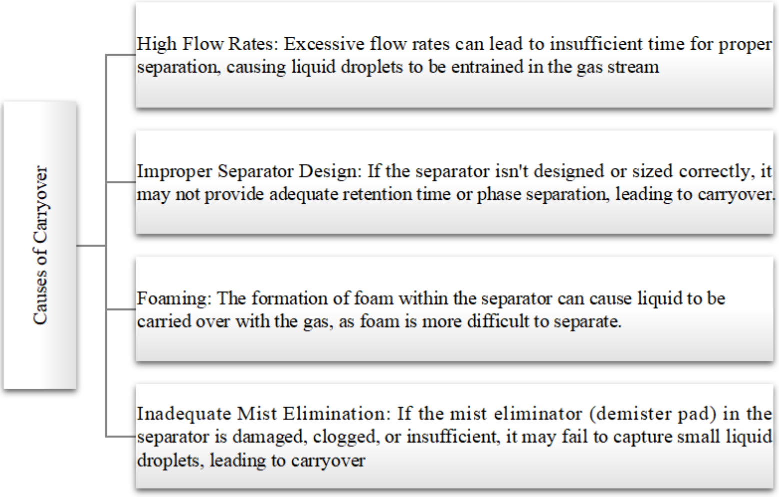


- Carryover can reduce the efficiency of downstream equipment, such as compressors, which are designed to handle gas, not liquids

- The presence of liquids in the gas stream can lead to corrosion and erosion in downstream pipelines and equipment

- Carryover can cause operational issues, including triggering alarms or even shutdowns in extreme cases

Figure 6: Consequences of CO [48, 49].



High Flow Rates: Excessive flow rates can lead to insufficient time for proper separation, causing liquid droplets to be entrained in the gas stream

Improper Separator Design: If the separator isn't designed or sized correctly, it may not provide adequate retention time or phase separation, leading to carryover.

Foaming: The formation of foam within the separator can cause liquid to be carried over with the gas, as foam is more difficult to separate.

Inadequate Mist Elimination: If the mist eliminator (demister pad) in the separator is damaged, clogged, or insufficient, it may fail to capture small liquid droplets, leading to carryover

Figure 7: CO causes. [43, 50]

Impacts:

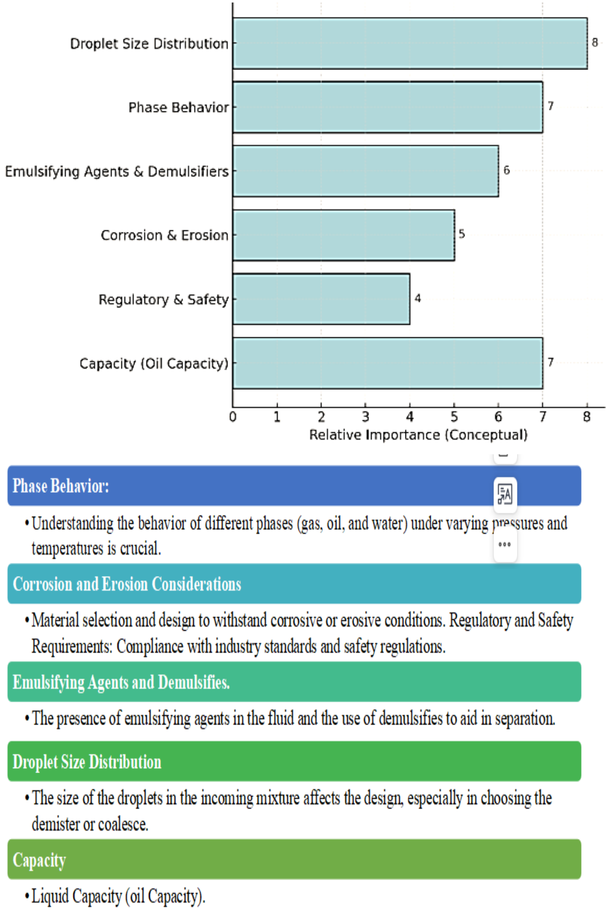
- Economic Losses: Loss of saleable oil product.
- Downstream Equipment Damage: Liquid CO into gas compressors can cause catastrophic and expensive damage.
- Operational and Environmental Hazards: Upset conditions in downstream processing units and environmental pollution if oily water is discharged.

10. Factors Affecting the Separation Process

There are several factors that affect operation and separation between phases [13]. The Changes on it will give a fluid stream, which will change the amount of gas and oil leaving the separator [51]. Foaming and emulsions will also affect the capacity of separation in a separator. Foam must be broken to obtain a good gas-oil separation [34]. It takes time (length) to break out physically; chemicals like silicon compounds may be used [5, 52, 53] [43, 48] as shown in **Figure 9.**

11. Separator Design

The design of a separator in the petroleum industry depends on several key parameters. Those parameters ensure efficient separation of gas, oil, and water, and include several Design factors as mentioned in **Figure 8** Design and operational Factors Influencing HTPS Performance [5, 17, 19].



Phase Behavior:

- Understanding the behavior of different phases (gas, oil, and water) under varying pressures and temperatures is crucial.

Corrosion and Erosion Considerations

- Material selection and design to withstand corrosive or erosive conditions. Regulatory and Safety Requirements: Compliance with industry standards and safety regulations.

Emulsifying Agents and Demulsifies.

- The presence of emulsifying agents in the fluid and the use of demulsifies to aid in separation.

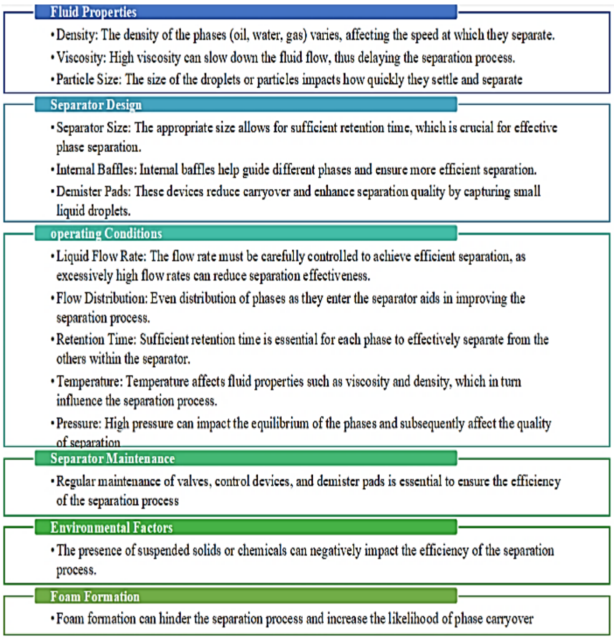
Droplet Size Distribution

- The size of the droplets in the incoming mixture affects the design, especially in choosing the demister or coalesce.

Capacity

- Liquid Capacity (oil Capacity).

Figure 8: Design and Operational Factors Influencing HTPS Performance



Fluid Properties

- Density: The density of the phases (oil, water, gas) varies, affecting the speed at which they separate.
- Viscosity: High viscosity can slow down the fluid flow, thus delaying the separation process.
- Particle Size: The size of the droplets or particles impacts how quickly they settle and separate

Separator Design

- Separator Size: The appropriate size allows for sufficient retention time, which is crucial for effective phase separation.
- Internal Baffles: Internal baffles help guide different phases and ensure more efficient separation.
- Demister Pads: These devices reduce carryover and enhance separation quality by capturing small liquid droplets.

operating Conditions

- Liquid Flow Rate: The flow rate must be carefully controlled to achieve efficient separation, as excessively high flow rates can reduce separation effectiveness.
- Flow Distribution: Even distribution of phases as they enter the separator aids in improving the separation process.
- Retention Time: Sufficient retention time is essential for each phase to effectively separate from the others within the separator.
- Temperature: Temperature affects fluid properties such as viscosity and density, which in turn influence the separation process.
- Pressure: High pressure can impact the equilibrium of the phases and subsequently affect the quality of separation

Separator Maintenance

- Regular maintenance of valves, control devices, and demister pads is essential to ensure the efficiency of the separation process

Environmental Factors

- The presence of suspended solids or chemicals can negatively impact the efficiency of the separation process.

Foam Formation

- Foam formation can hinder the separation process and increase the likelihood of phase carryover

Figure 9: Factors Affecting the Separation [49, 54] [5]

12. Review paper from 2017-2025

- **(Summarize study)**

The oil produced from a wellhead typically contains multiple components. Due to this multi-component nature, the amount of liquid recovered in the separator increases with the pressure at which the separation occurs. The liquid will contain some light components that may vaporize in the storage tank downstream of the separator [44, 45]. Several factors that effected on the TPSH performance were the first design part and the second operation parameters, such us pressure, temperate, flow rate and the retention time. If the initial separation pressure is too high, too many light components will remain in the liquid phase at the separator and later be lost to the gas phase at tank conditions, leading to crude oil wastage [55, 56]. Conversely, if the pressure is too low, very few light components will stabilize as liquid, resulting in their loss as gas by the end of the process of any component in the process stream to flash into vapor depending on its partial pressure. Accordingly, the partial pressure component in a vessel is the number of molecules of that component in the vapor space divided by the total number of molecules of all components in the vapor space, multiplied by the vessel pressure[57]. As a result, if the vessel pressure is high, the partial pressure of the component will also be high, causing more molecules of that component to remain in the liquid phase. Additionally, as the pressure increases, the liquid flow rate out of the separator also rises [16, 58, 59].

[60] Investigated liquid flow behavior in a pilot-scale HTPS through mesh independence and sensitivity analyses. Their findings revealed that oil flow rate exerted the greatest influence on separation efficiency, followed by water flow rate, whereas gas flow rate and weir height had comparatively minor effects.

[37] Investigated the effect of changing separator operating conditions, such as temperature, pressure, and flow rate, on product properties. Showed that increasing the inlet pressure decreased the outlet gas flow rate, and the methane mole fraction increased. However, as the temperature increases, the flow rate of the outlet gas stream increases, causing a reduction in the methane and a decrease in the heating duty of the heat exchanger; no effect of flow rate changing is observed.

[61] Showed that increased inlet pressure decreased gas outlet flow, and liquid flow rate increased. Conversely, raising the feed temperature increased gas outlet flow and decreased liquid flow, respectively.

[62] Demonstrated that the increase in temperature increases gas liberation by reducing gas solubility, while it decreases oil viscosity. These changes enhance droplet coalescence and improve the density contrast between oil and water phases, both of which facilitate faster and more efficient phase separation by increasing the mobility and flow rates of the individual phases. Moreover, a longer residence time improves separation by allowing gravity-driven settling of the oil, water, and gas phases. However, the long residence period enhances the disengagement of each phase, resulting in higher separation efficiency and a reduced likelihood of carryover. These results agreed with previously reported works [63-65].

[43] Emphasized the importance of factors like retention time and pressure-temperature effects in the design process of TPSH.

[63] Explained that both pressure and temperature significantly impact retention time, with optimal combinations leading to improved oil–water separation and reduced liquid carryover. The study demonstrated the effectiveness of RSM in identifying critical operating conditions and provides a systematic approach for optimizing separator performance in oilfield applications. The design of HTPS plays a decisive role in determining the efficiency of oil, water, and gas separation in oilfield processing facilities. Several studies emphasize that the geometry and internal configuration of the separator directly influence the hydrodynamics and phase disengagement.

[60] Showed the different inlet designs, baffle configurations, and retention times, effected of geometry and operating parameters influence phase separation by used CFD.

[66, 67] Investigated the authorize full visualization of flow distribution, droplet dynamics, and gas liquid solid interactions inside separators. Their study identified the Design improvements such as Baffle arrangements, and weir configurations improving the efficiency of separation and reduce carryover. Also, analysis influence parameters effect on phase distribution and separation quality such as water and oil flowrates, retention time, and turbulence intensity significantly.[31] Optimized baffles design to improve phase separation by minimizing carryover and increased efficiency. CFD models were used to evaluate the effects of baffle whole size, spacing, and arrangement on flow distribution and droplet coalescence. [68, 69] Studied flow behavior, droplet coalescence, and velocity profiles under various operating conditions, allowing comparison of different design alternatives also the configuration optimized reduced carryover, increased separation efficiency, and more stable fluid interfaces compared to conventional designs. [25] reviewed studies on turbulent flow structures caused by inlet diverter interactions, which enhance separation efficiency and reduce design costs by enabling simulation of different configurations for optimized designs. The review also addressed key design parameters, including oil properties

affecting separation, inlet diverter design, mean residence time, separator diameter (using Monnér and Svrcek or Arnold and Stewart methods), weir height for interface control, and droplet size and distribution, all of which significantly influence separation performance.

[70] Reported that the separator geometry, particularly the length-to-diameter (L/D) ratio, has a significant impact on flow distribution and separation efficiency. They found that an optimal L/D ratio maximizes efficiency, while deviations from this ratio reduce performance.

[71] studied the ratio of length-to-diameter and retention time influence on the separation efficiency of a two-phase horizontal separator. Then shown at increasing L/D improved interface stability and flow stratification thereby enhancing separation efficiency. Also, longer retention times enhanced the separation. [72] showed that the divergent geometry reduces carryover, stabilizes the interface between oil and water phases and, enhances coalescence and droplet collision. By introduced a novel divergent coalescence separator designed to enhance oil–water separation efficiency. Also analyzed internal flow patterns, droplet coalescence, and phase distribution to assess the separator's performance. [40] Showed that foam presence significantly alters phase mobility, suppresses fingering compared with conventional multiphase flow, and enhances sweep efficiency. That by investigated the Riemann problem for three-phase foam flow in porous media, focusing on the complex interactions among gas, liquid, and foam phases.

[51] Showed indicated that even small deviations in design parameters could significantly affect separation efficiency, liquid carryover, and gas entrainment. Moreover, the studied highlighted the importance of accounting for parameter uncertainties during the design stage to ensure reliable and robust separator performance under varying operational conditions. [73] Demonstrated that the optimized porous plate configuration improved oil–gas separation, minimized carryover, and stabilized flow patterns compared with conventional designs. [74] Demonstrated that AI-driven optimization effectively balances operational efficiency with product quality, providing faster and more accurate recommendations compared with conventional empirical methods. Also, enhanced the performance and reliability of complex multistage separation systems in petroleum processing.

13. Optimization of the horizontal 3-phase separator

Given the essential importance of oil separators and the multitude of factors affecting their separation efficiency, extensive research has been conducted to optimize their performance and increase oil recovery. In this research, some of these studies will be highlighted and reviewed:

- **By Sizing And Designing**

(Ahmed et al. at 2019) [75], This study presents an approach for calculating the dimensions of HTPS by designing different vessel configurations based on the fluid properties of an Iranian gas/condensate field. Using computational fluid dynamics (CFD) methods, notably, differences in vessel length compared to existing separators were observed. The results confirmed that the CFD model is capable of accurately investigating separator performance. The optimized length and diameter of the designed separator were compared with those currently used by a major Iranian oil producer, revealing improvements. To address the design gaps, a 3D CFD model was developed to optimize the dimensions of the separators. The study used two multiphase models (VOF and DPM) with the k-ε turbulence model, along with the DRW model to account for random particle movement

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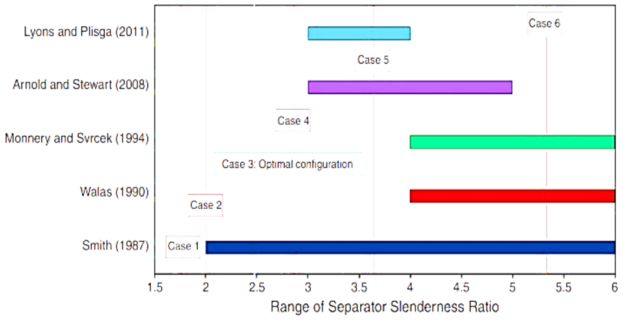


Figure 10: comparison of the slenderness ratio of cases 1-6 [75]

(B Campbell) [76] Explored the weaknesses and proposes manageable approaches to quantifying each then optimizing the separator by dimensions when selecting the two-phase and HTPS the sizing methodology sometimes was inadequate. The ways to sizing methods varying from the simple “back-of-the-envelope” to the far more complicated. The weaknesses associated include:(Quantification of flow, droplet size and distribution quantification, Velocity profile, and Separator component). The study also studies operational problems like the liquid in the gas or gas in the liquid, and calculates the droplet size and effect in the side part of the separator mathematically.

(Joe at 1982) [77] Presented a separator design with analysis that can be applied to predict the performance of any separator. The study highlighted that the presence of H_2S in the water exacerbates corrosion problems. To address various water separation challenges in wash tanks, a high-rate separator was developed. The design objectives included handling over 25,000 barrels of liquid per day (bbl/d), achieving high separation efficiency, ease of installation, long-term reliability, and minimizing installed cost. This separator has no moving parts, is inherently corrosion-resistant, and requires low capital investment. It was relatively inexpensive to install, cheaper than a similarly sized free-water knockout, and it incurs no operating costs. Field tests indicated that, most of the time, the separator’s actual performance closely matches its ideal design.

(Méndez et al. at 2018) [78] Studied, the main sizes of a separator were determined for a specific oil-gas mixture using the empirical correlations from API and literature. To analyze the effects of the position of the diverter and perforated plates on the separation efficiency, two-phase flow simulations were conducted using CFD software ANSYS CFX. The simulations were carried out for two different diverter plate distances from the inlet; they were also performed with perforated baffle plates when the diverter plate on inlet. Finally, this study has demonstrated that the internal design of oil-gas separators is important, because even a very small increase in separation efficiency may save money, see **Figure 11** for the simulated condensate and water-particle mass distribution within each vessel at the plane’s location.

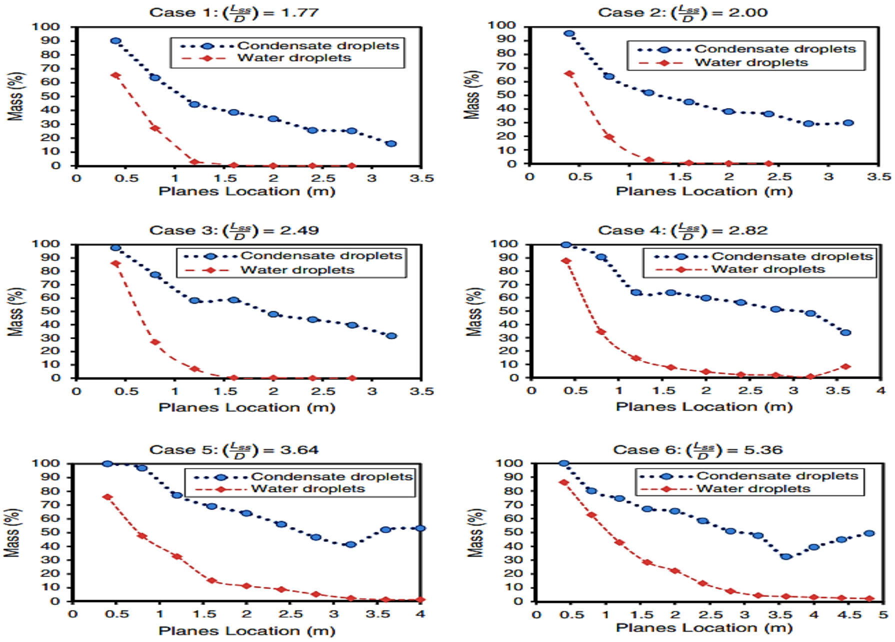


Figure 11: the simulated condensate and water particle mass distribution within each vessel at the plane’s location [78]

(Svrcek et al., 2011) [79] This study reviewed the important literature on the design and CFD simulation of multiphase separators. Optimizing the design of new separators and solving problems with existing designs. In the classic methods, vapour–liquid and liquid–liquid separation compartments are designed based on droplet settling theory. Moreover, the retention time of the liquid phase is selected based on empirical data or heuristics for establishing a safe and smooth operation of the separator and downstream equipment. In the experimental research projects, pilot plant-scale separators were used for the study of the phase separation phenomenon. While some theses focused on the study of liquid–liquid separation, or focused on the study of vapor–liquid separation.

(Monnery and Svrcek, 1994) [80] Shown the rating and sizing of 3-phase separators can be done by empirical methods based on the vertical droplet velocity of a liquid droplet in a continuous phase. This vertical velocity can be calculated by Stoke's Law [Where ρo and ρw describe the density of the phases regarding an oil dispersion in a continuous water phase].

(Farman, 2022) [81] Studied two different scenarios that take place using equations introduced by Arnold and Stewart and the API12J Specification to find the optimum separator size for the Jambur field. The results of the calculations revealed that in the first case, the separator diameters are 68 inches for the first stage and 66 inches for both the second and third stages. In comparison, the second case yields smaller separator diameters: 60 inches for the first stage and 54 inches for the second and third stages. Both cases were evaluated based on API 12J standards to determine the more suitable option. It was concluded that the second case provides greater operational flexibility and is easier to manage and maintain. To determine the optimal separator pressures and the appropriate number of stages for the Jambur field, various scenarios involving different pressure levels and stage counts were analyzed. Found that the best operating pressure was 7oo, 300, and 120 psi for the first, second, and third stage, respectively. Also found that the benefit of adding a new stage didn’t cover the cost of the new stage.

(Kim, Dan et al. at 2014) [82] Investigated offshore oil production optimization by determining the best operating conditions to maximize production and profits while minimizing costs and environmental impact. Aspen HYSYS was used for process simulation along with a stochastic optimization strategy to maximize profits. The study found that recycling within the process provided greater flexibility in controlling crude oil vapor pressure, and adding separation stages increased overall process efficiency. However, achieving both higher production and improved Reid Vapor Pressure (RVP) control required additional operational costs.

(Grødal and Realff , 1999) [83] Addressed the main operational challenges faced by separators and proposed achieving optimal performance at minimal cost using consecutive quadratic programming techniques. The optimization models were built upon existing separator design theories and relationships, with a set of equations and inequalities independent of the solution method, allowing for broad flexibility in modifications. The model was initialized based on settling theory to guide the optimization process.

(Sulaiman, Sidiq et al. 2024) [21] Investigated the causes of liquid CO and foaming in the gas sweetening process at Iraq's Khor Mor gas-condensate plant. Using Aspen HYSYS v.11, the study evaluated droplet size distribution and gas–liquid separation efficiency of the plant's separators. Persistent liquid CO issues were identified, leading to the proposal of an adjustable smart separator design based on the Arnold–Stewart semi-empirical procedure. This design dynamically adapts to changes in feed composition and operating conditions, significantly improving separation efficiency. The innovation enhances gas–liquid separation, mitigates foaming, and provides a cost-effective, robust solution for maintaining consistent operational performance.

(Prasetiawan et al. , 2017) [84] This study employed the dimensions of HTPS in a simulation conducted for an oil and gas company in Indonesia. Computational Fluid Dynamics (CFD) was applied using the Volume of Fluid (VOF) method combined with the k-ε turbulence model to analyze the separation process. The simulation results illustrated both concentration and velocity distributions of the phases within the HTPS. The concentration distribution revealed a clear division between the upper and lower regions of the fluid. A steady-state modeling approach was adopted, which highlighted instances of oil and vapor being entrapped in the water phase due to reversed flow phenomena. Additionally, the simulation detected the presence of water within the vapor outlet stream, indicating incomplete phase separation and performance limitations under certain operating conditions.

(Kharoua, et al. at 2012) [50] In this study, new efficient internals are suggested for the HTPS, based on a study observed by a CFD model that develops influence for the inflow properties. A combination of the Eulerian-Eulerian multiphase and k-ε turbulence models was used to show the complex behavior of the flow inside the separator, some case studies has been done with comparing the results to the performance tests in the field, although a mean droplet diameter of 1oo microns was used for the secondary phases, additional simulations with larger droplets revealed that the droplet diameter influences the separator performance considerably.

(Yayla, Kamal et al. at 2019) [85] The study used computational fluid dynamics (CFD) to analyze the performance of a horizontal separator in the petroleum industry. Two separator geometries are considered: one with a straight plate at the top and another with a plate on the side. The study showed the effect of inlet position, the distance between the inlet and the diverter plate, and inlet velocity on separation efficiency. There are three distances (0.1 m, 0.15 m, and 0.2 m) and four velocities (0.25 m/s, 0.5 m/s, 0.75 m/s, and 1 m/s) that are evaluated using the Euler mixture model. The Results get us that the maximum separation efficiency of 99.772%. A negative correlation is found between inlet velocity and separation efficiency, as higher velocities reduce oil retention time. The top-inlet design consistently outperforms the side-inlet design, where efficiency drops to 53.257%.

(Worley and Laurence 1957) [86] Highlighted that oil–gas separation is a scientific process governed by physical principles rather than trial-and-error practice. They explained how separator efficiency depends on vessel geometry, internal configuration, and flow conditions, with gravity settling, centrifugal force, and impingement acting as the main separation mechanisms. The study compared vertical and horizontal separators, noting their respective strengths in handling gas capacity and liquid surges, and laid the groundwork for treating separator design as an engineering science.

(Kharoua, Khezzar et al. 2013) [39] Study examines the performance and internal multiphase flow behavior in an HTPS used by ADCO. Initially, the Eulerian-Eulerian model in ANSYS FLUENT was used.

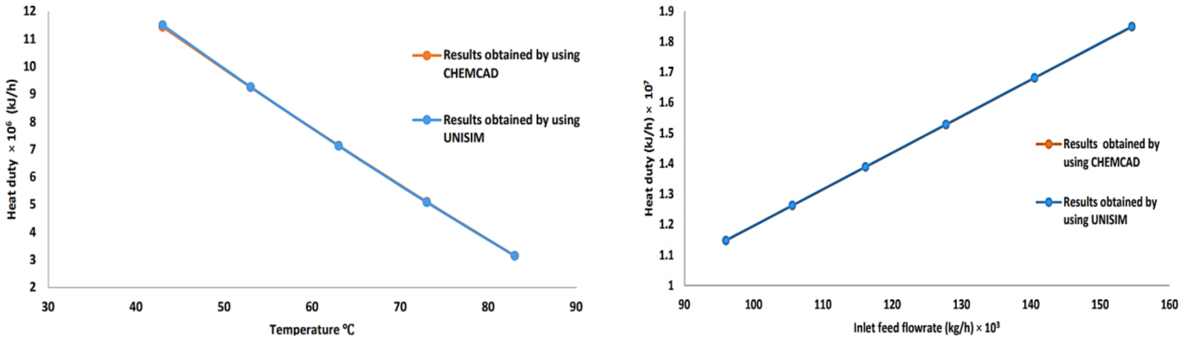
(Hasan and Farman 2024) [65] This study determined the optimal operating pressures for oil and gas separation using ASPEN HYSYS software. The optimal pressures for the second and third-stage separators were found to be 3.0 Kg/cm² and 0.7 Kg/cm², respectively, ensuring the best oil recovery. These values were based on factors like API gravity, oil formation volume, and gas-oil ratio. To further optimize separator sizes, Python code incorporating the Newton-Raphson Method and Lang Cost Method was developed. Experimental studies on sunflower seed separation helped refine productivity and efficiency through adjustments in airflow, deck angles, and oscillation frequency.

(Sivalls 1987) [87] This study addresses design optimization and operational parameters as a foundational resource, covering essential aspects such as separator sizing, internal component configurations, and the mechanics of phase separation. It further examines the influence of key factors, including pressure, temperature, and flow conditions, on overall separator performance. Particular emphasis is placed on the design of horizontal and vertical separators, liquid retention time, gas velocity control, and interface level management. Collectively, these considerations contribute to optimizing separator efficiency and reliability across diverse operational scenarios.

(Li et al. 2025) [51] analyzed the Effects of uncertainty in the design parameters during the design of horizontal gravity oil, gas, and water separators. Highlighting the fluctuations in flow rates, slugging, and other uncertain operating conditions can significantly influence the reliability and efficiency of separator design. Also, to address this challenge, the authors employed stochastic optimization methods, incorporating probabilistic scenarios (P10, P50, and P90) rather than relying on fixed deterministic values. The results showed that accounting for uncertainty in the design stage produces more robust and resilient separators, reducing the risks of underperformance and operational failures in real field conditions.

- **By Operating Parameters**

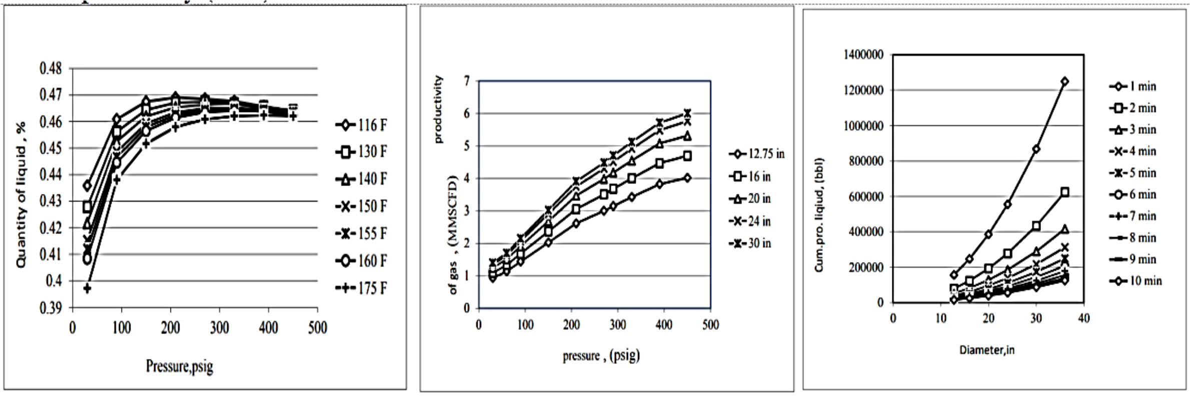
(Al-Mhanna 2018) [88] This study simulated a high-pressure (HP) separator to investigate the effect of varying operating conditions on product properties. The CHEMCAD simulation software package was used, and the results were compared with those obtained from the UniSim software package. Both sets of results showed good agreement with industrial data. The study focused on the impact of changes in gas stream properties, such as temperature, pressure, and flow rate, on process performance and optimization, see **Figure 13,** the HP separator temperature effect on the heating duty of the preheater, and the effect of feed flow rate on the heating duty of the preheater. The findings revealed that increasing the inlet pressure reduced the outlet gas flow rate while increasing the methane mole fraction, and simultaneously raised the preheater heating duty. Conversely, increasing the temperature led to a higher outlet gas flow rate, a reduction in methane content, and a decrease in the heating duty of the heat exchanger. Changes in flow rate, however, were observed to have no significant effect on the system.



A B

Figure 13 A: HP separator temperature effect on the heating duty of the preheater. Effect of **B:** HP separator feed flow rate on the heating duty of the preheater [88]

(Saleh 2020)[89] Investigated the effect of the operating factors on the efficiency of the separating process of natural gas from oil. The number of separation stages that ensure the highest efficiency of natural gas was also identified. The optimum pressure for each stage of the separation process in the Alif field (block 18) was determined. The flash calculation was used to investigate the effect of pressure and temperature on the separation efficiency. The results show that an increase in pressure when the temperature is constant increases the efficiency of the separation process. The effect of several stages on the separation efficiency was also investigated. It was shown that increasing the number of stages to five stages increases productivity from (0.45%) to (0.99 %). The increase in diameter of the separator from (12, 75 in) to (30 in) increases the efficiency of the separation process by (33%), and the increase in the retention time of oil inside the separator from (1min) to (10 min) increases the efficiency of the separation process by (90%) as shown in **Figure 14** effect of different values for retention time**.**



A B C

Figure 14 A: Quantity of liquid versus temperature and pressure B: Pressure versus. Diameter and productivity of gas at 5 ft C: Cumulative produced liquid vs. diameter at different values of retention time at Lss = 5 ft

(Bahadori, Vuthaluru et al. 2008) [90] The study presented a precise methodology for optimizing separator pressures in a crude oil production unit. The results indicated that oil production could be increased by approximately 5–6 m³/day, with the optimum separator pressures identified for a unit producing 5,724 m³/day of oil. Although naturally occurring reservoir hydrocarbons are typically represented by discrete components or grouped fractions, the gamma probability function was applied to enhance fluid characterization. This approach allowed the plus fraction to be described more accurately through single and multiple carbon number groups, thereby improving the reliability of the overall analysis.

(Olugbenga et al. 2021) [61] Utilizes a specified reservoir fluid stream to simulate an HTPS executed in Aspen HYSYS. Subsequently, a comparative study of the effects of specified inlet operating conditions on the output of gas and oil streams was carried out. The results show that changing the inlet pressure of the separator from 1ooo to 8ooo kPa reduces the gas outlet flow from 1213 to 908.6 kg mol/h, while it increases the liquid flow rate from 374 to 838.o kg mole/h. By changing the temperature of the separator feed stream from 13 to 83 C, the gas outlet stream was raised from 707.4 to 1111 kg mol/h, while the liquid flow rate dropped from 1037.0 to 646.1 kg mol/h.

(Kim, et al.2014) [82] Addressed the growing need for environmentally friendly offshore oil platforms and the optimization of production conditions to maximize profitability while minimizing environmental impact. The study focused on the Reid Vapor Pressure (RVP) of crude oil as a critical environmental specification. Aspen HYSYS was employed for process simulation along with a stochastic optimization strategy (CMA-ES). Results demonstrated that condensate recycling significantly improves control over oil vapor pressure, enhancing overall process performance. Additionally, although increasing the number of separation stages enhances efficiency, balancing production rates with operating costs is crucial for profitability. The study highlights the importance of incorporating environmental constraints into the design of offshore oil production platforms.

(Feng, Chang et al. 2008) [91] Investigated the separation process and efficiency of a horizontal oil–gas separator commonly used in oil-injected compressor units. The study simulated different oil droplet diameters using the discrete phase model coupled with a gas flow model. Oil concentration and separation efficiency were measured via the laser diffraction technique (Malvern). CFD results demonstrated that the trajectory and residence time of oil droplets in the separator vary with droplet size. As the oil injection flow rate increased from 567 to 1182 L/h, the separation efficiency correspondingly improved from 99.81% to 9++9.93%.

$$\eta_{sep} = \frac{Vo,i - Vo,o}{Vo,i} \times 100\%$$

Where: η_{sep}: is the separation efficiency, Vo, i: is the oil flow rate at the separation inlet, Vo, O: is the oil flow rate at the separation outlet.

(Dubas 2016) [19] Designed a gas–oil separation process (GOSP) alongside a gas plant, aiming to ensure that the crude oil leaving the facility meets specific quality criteria: Reid Vapor Pressure (RVP) below 5 psi, water content under 0.3 % by volume, salt content less than 20 PTB, and hydrogen sulfide concentration below 70 ppm. The design involved performing material balance calculations, followed by simulation in Aspen HYSYS to validate accuracy. An economic analysis was also conducted to assess project profitability, revealing that the project is feasible, although more detailed analyses are recommended for higher precision.

(Carvalho et al. 2021) [92] Investigated the fluid dynamic behavior in a horizontal HTPS using the computational fluid dynamics software ANSYS CFX. A detailed analysis of a “Standard Case” was conducted to examine the entire separation process within the vessel. The study evaluated three-phase behavior over simulation time, separation efficiency, fluid flow patterns, internal pressure gradients, and the effect of the diverter baffle. Additionally, variations in inlet fluid flow were considered. Finally, the influence of oil density and viscosity on separation performance was analyzed, showing that higher density and viscosity negatively impact the primary separation process.

(Liang, Zhao et al. 2013) [93] Numerically investigated the flow field of an HTPS using Fluent 6.3.26, taking into account the production conditions at PetroChina Huabei oilfield. The study examined the effects of internal flow patterns, flow rate variations, gas fractions, and water contents on separation efficiency. The results demonstrated that separation efficiencies exceeded 95% under all operating conditions, satisfying accuracy requirements and providing a theoretical basis for the application of HTPS in oilfields. Additionally, the oil–gas–water separation process in a gravity vertical metering separator was simulated using CFD methods.

(Joshy, MA et al. 2022) [94] Investigated various separator models and identified an optimized design using CFD simulations incorporating momentum, continuity, and standard k-ε turbulence equations. Through the application of relevant assumptions and effective model configurations, design criteria for new or modified separators were developed and combined with an industry-based algorithmic design approach. The optimized separator achieved a total separation efficiency of 99.1%, with oil and water droplet separation efficiencies of 100% and 98.7%, respectively, reflecting significant performance improvements over the original design.

(Ahmed, Russell et al. 2020) [95] Developed a capital cost optimization model for sizing HTPS, utilizing GRG non-linear algorithms to minimize the construction costs of horizontal separators under four sets of constraints. The model demonstrated high accuracy, with predictions typically within an absolute error of 5 m^3 and a maximum deviation of 12.5 m^3 for very high gas flow rates, outperforming conventional models based on retention time theory.

(Jonach, Haddadi et al. 2023) [96] Developed a gravity settling model based on separator inlet conditions to assess the water outlet quality in terms of dispersed oil residuals under dynamic operating conditions. The model indicated dynamic variations in oil content during start-up, stabilizing at 14.21 kg/h once optimum operating conditions were reached. Furthermore, a CFD simulation of the separator’s test geometry was performed, providing valuable insights into oil and water phase interactions, although additional refinement is required to accurately quantify oil dispersion in water(see **Figure 15**).

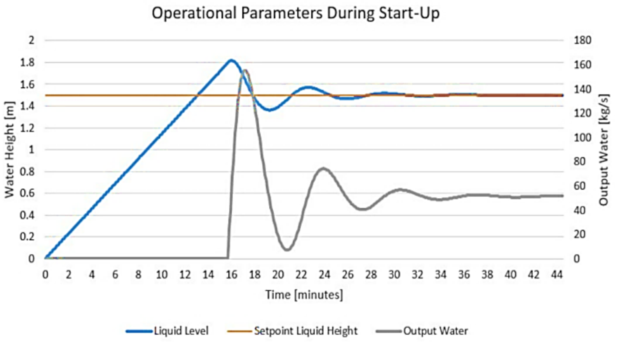


Figure 15: Dynamic states of the operational parameters of a 3-phase separator at start-up

(Noaman 2022) [97] Simulated the utilization of sulfur-rich crude oil from Northern Iraqi fields to determine optimal operational conditions for oil, gas, and water separation. The study also addressed the purification and utilization of acidic natural gas generated during crude oil separation. Using Aspen HYSYS, the research demonstrated its suitability for modeling sales oil and gas properties as well as phase envelope behavior to distinguish between high and low hydrocarbon gases. Additionally, the study examined the effectiveness of two types of cement in stabilizing oil-contaminated soils, investigating their physical, mechanical, and chemical behavior, thereby enabling potential reuse in earth construction applications.

(Jonach, Jordan et al. 2022) [98] Employed a gravity-based model using the open-source software DWSim under dynamic conditions to investigate oil residuals dispersed in the water outlet of separators. The optimized results showed that oil in the water outlet stabilized at 14.21 kg/h. To expand the study, a gas–oil separation plant model was developed in Aspen HYSYS V1o with a focus on oil residues in water-bearing components. Various control schemes were integrated to simulate dynamic operating states, and two dynamic scenarios were tested, demonstrating the robustness of the model. While many existing models target gas–oil separation, this study addressed the less-studied issue of residual oil in produced water, providing improved predictive capability for contamination and dynamic variations in water systems. The developed strategies apply to real-world gas–oil separation facilities.

(Sayda and Taylor 2007) [99] Focused on the optimization of dynamic mathematical modeling for HTPS, where liquid–liquid separation was formulated using American Petroleum Institute (API) design criteria. To validate the developed model, a simulation of an oil production facility was implemented, covering both two-phase and HTPS. The results demonstrated that even simplified models reveal significant complexity, highlighting the effectiveness of the approach. The study extends API static design criteria to incorporate hydrodynamics, offering a simpler yet robust modeling framework, with separation processes controlled through PI loops to maintain nominal operating conditions.

(Famisa 2016) [100] Investigated the optimization of an HTPS subsea separator by comparing steady-state and dynamic simulations in Aspen HYSYS with the earlier work of Tyvold. The study applied semi-empirical equations from Stokes' law and the Gas–Liquid Separation Performance Assessment (GSPA) of Barnea and Mizrahi correlations to evaluate the influence of flow rates, oil residence time, and operating conditions. Results indicated that separation efficiency is highly sensitive to parameter variations and boundary conditions derived from experimental or field data. The research concluded that enhancing operational parameters improved the purity of product streams and consequently increased overall separator efficiency.

(Qaroot 2013) [14] Simulated an HTPS using a multiphase mixture model in Fluent v14 to analyze multiphase flow performance for mono-dispersed secondary phases (oil and water). The Discrete Phase Model (DPM) was then applied to study oil carryover for various droplet size distributions (poly-dispersed oil), considering both the presence and absence of breakup and coalescence effects, while modeling the gas-handling components. The K-ε turbulence model was employed to assess turbulence effects in both cases. Droplet distributions with mean diameters of 10, 30, 50, and 80 microns were generated using the Rosin-Rammler size function, based on industrial separator design values (see **Figure 16)**. Simulation results were analyzed in terms of overall separation efficiency, effectiveness of internal components, local size distribution, and residence time, and subsequently compared with field test data from ADCO (Abu Dhabi Company for onshore oil operations).

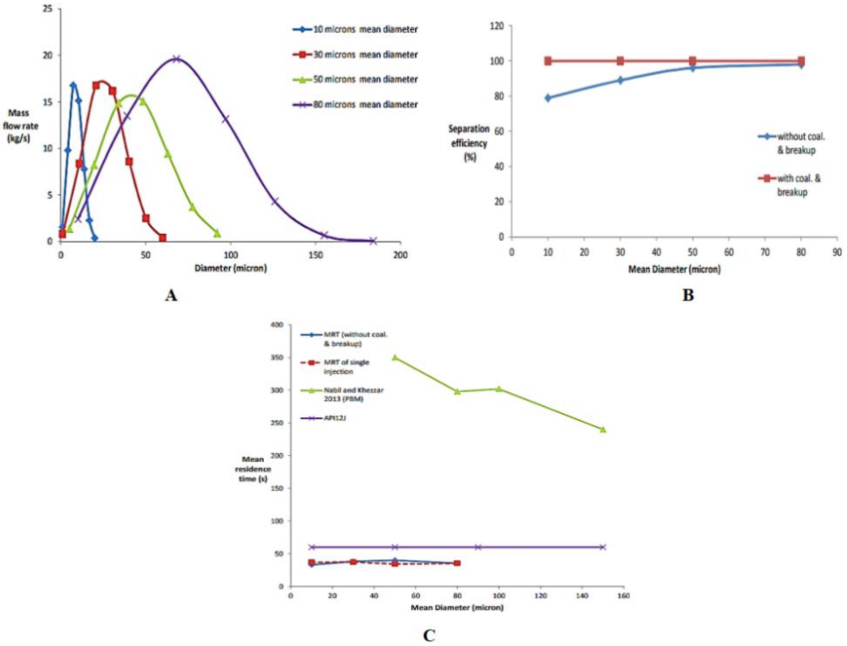


Figure 16 A: Droplet size distributions at the inlet of the separator for different mean oil injections diameters, **B**: Separation efficiency Vs. droplet diameter for poly-dispersed oil droplets, **C**: Mean Residence time Vs. mean droplet diameter[14]

(Jahangiri and Nouri 2014) [101] Conducted a simulation of an HTPS separator using Aspen HYSYS to investigate the differences between key operational parameters obtained from HYSYS and experimental data. The study found minimal discrepancies in oil and gas production rates between the simulation and experimental results, and provided recommendations to further reduce these deviations.

(Couto, Silva et al. 2018) [102] Demonstrated the effectiveness of combining Response Surface Methodology (RSM) with CFD modeling to reduce experimental trials and enhance process optimization in inkjet printing. Using the volume-of-fluid (VOF) model in ANSYS Fluent along with RSM, the study optimized conditions for drop-on-demand (DOD) operations. Numerical simulations were conducted to evaluate key factors influencing droplet formation, including viscosity, surface tension, nozzle diameter, and inlet velocity. A total of 25 simulation runs using a face-centered design were performed, with a mesh study ensuring accuracy. Results indicated that viscosity and nozzle diameter had the greatest impact on droplet break-up time and length, and a multi-stage optimization identified the optimal jetting conditions.

(Sabir, Elamin et al. 2022) [103] Focused on designing and tuning a device capable of managing water level, oil level, and gas pressure in response to feed variations. The study provides a comprehensive mathematical analysis, modeling, and simulation of a crude oil separation process using an HTPS gravity separator, employing MATLAB R2016b-x64 and Aspen HYSYS V10. Bishoy's equations were developed to assist in operating the device, identifying key variables, and analyzing the effects of variable changes on system behavior. The study found that increasing the control valve stem position while reducing the volumetric inflow of oil and water led to significant instabilities in system pressure and liquid levels, posing serious safety risks. MATLAB simulations and Aspen HYSYS analysis demonstrated that the separator effectively distinguishes material and energy streams and determines their properties and compositions (see **Figure 17**).

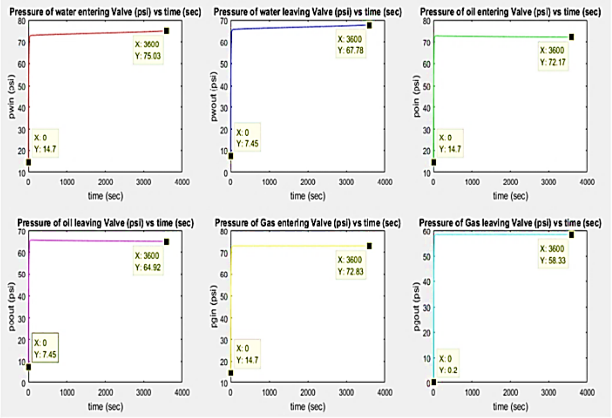
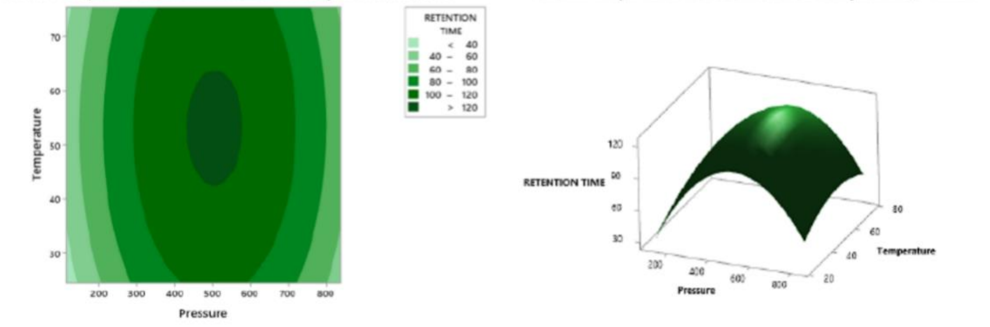


Figure 17: The control valve's stem position of oil was increased [103]

(Li, et al.2023) [104] studied the separation performance of HTPS in an oilfield Central Processing Facility using Stokes' formula. The analysis considered key influencing factors, including oil and water droplet size, fluid residence time and temperature, and demulsified dosage. Based on the "Specification for Oil and Gas Separators," the control loops and operating parameters of each separator were optimized, taking the Halfway Oilfield as a case study. The study optimized the first- and second-stage separators' control loops and operating conditions within a DCS, ensuring high separation efficiency and yielding favorable results.

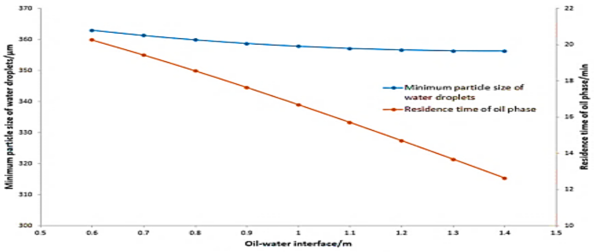
(Song, Liu et al. 2023) [18] Dynamically simulated an HTPS using mass conservation equations to determine the pressure, water level, and oil level within the separator, while mass balance equations of the separated phases were applied to calculate separation efficiency. A PI (proportional-integral) controller was employed to regulate water level, oil level, and pressure by adjusting the openings of the three outlet valves for gas, oil, and water. The model was validated by comparing simulation results with actual field data in terms of valve openings and PI controller parameters. It was used to study separator filling, pressure, and liquid levels, providing detailed analyses of pressures, levels, and valve operations. Additionally, the effects of process parameter changes such as water set-point, weir height, and inlet flow on separation efficiency were examined. This model supports the design of HTPS and the calculation of operating parameters that are difficult to measure during actual operations (see **Figure 19**).

(De Souza Sampaio, Caraschi et al. 2025) [63] Identified key parameters affecting HTPS performance and developed strategies to minimize liquid carryover while improving overall process control. The study highlighted critical influencing factors, including but not limited to the typical sizes of oil and water droplets, fluid residence time and temperature, and the dosage of demulsifying agents. The findings provide practical guidance for enhancing operational reliability and production quality in oilfield processing systems (see **Figure 18**).

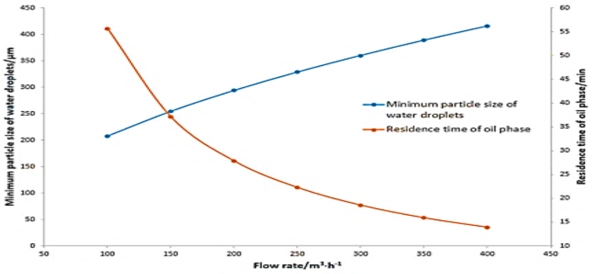


A **B**

Figure 18 A: In line with the Contour Graph, the Surface Graph seen in Figure-5 also shows that the optimum Retention Time range (< 40 s) occurs in the same intervals seen, B: Surface Graph of Retention Time versus Temperature; Pressure.[63]



(a) Under flow rate of 300 m³ h⁻¹



(b) Under interface of 0.8 m

Figure 19: Separation effect of 2nd-stage separator under different operating parameters (95°C) [104]

Nath et al. (2022) [105] analyzed the relationship between predicted and actual variables in an offshore oil and gas separation train using Response Surface Methodology (RSM), investigating how variations in first- and second-stage pressures and temperatures affect oil and gas flow rates to maximize production profit. The results showed that increasing first-stage pressure while decreasing temperature significantly enhanced oil recovery. The optimized operating conditions were determined as $P_1 = 38.08$ bar, $T_1 = 54.09$ °C, $P_2 = 18.00$ bar, and $T_2 = 40.56$ °C, yielding a predicted maximum profit of o.2o8 million USD/day. This study highlights the effectiveness of simulation-driven RSM in improving offshore separation efficiency and profitability (see **Figure 20**).

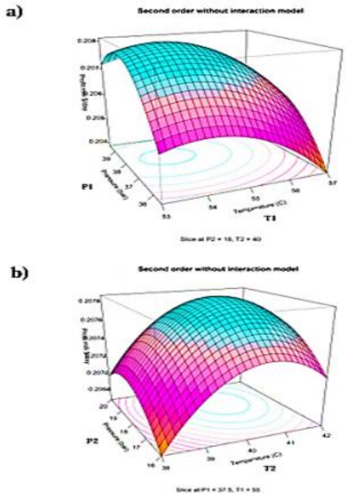


Figure 20: Response surface for the effect of (a. T1 and P1 on Profit function), (b. T2 and P2 on profit function). [105]

Table 1 Comparison between optimization of a horizontal HTPS by operating parameters versus design aspects

Optimization by operating Parameters	Optimization by Design
Involves pressure, temperature, flow rates, and retention time to enhance performance.	Centers on geometry, dimensions, and vessel internals like inlet diverters, baffles, mist extractors, and wave breakers.
Can be dynamically adjusted during operation; suitable for real-time control and adaptation to feed changes.	Fixed after fabrication; modifications require shutdowns or redesign, less flexible than operational tuning.
Generally lower capital cost; requires software and control systems rather than hardware changes.	Higher cost, but results in savings for long-term through less maintenance and better efficiency.
Extensively utilizes simulation tools (Aspen HYSYS, CHEMCAD, MATLAB)	FD models (e.g., ANSYS), empirical sizing (API 12J), and correlation-based methods.
Optimization leads to better phase separation, reduced carryover, and higher recovery of oil/gas.	Directly affects separation zones, residence time, and phase disengagement, yielding greater efficiency.
Improvements are limited by the physical design, cannot fix issues caused by poor internals or sizing.	Once built, it's hard to modify; incorrect design leads to chronic performance issues.
Increased retention time from 1 to 1o min boosted separation efficiency by 90%; optimal pressures raised liquid yield.	Optimized design less separation efficiency by 28–31% enhancement but reduced foaming and carryover.
Improper connections, such as incorrect valve positioning, can lead to operational instability, pressure surges, and safety hazards.	Defect of design like short vessels or poor baffle spacing, can cause carryover and emulsions.
Optimum parameters temperature and pressure control enhance Reid Vapor Pressure (RVP) management and reduces emissions.	The pollution reduces by water and gas, due to Improved separation mange the downstream treatment.
Ideal for existing systems where redesign is not feasible; excellent for offshore or remote operations.	Best for new projects, revamps, or cases where major performance upgrades are required.

14. Conclusion

This study comprehensively examines the categories of HTPS in oil processing production. The efficient separation of oil, water, and gas phases in these vessels directly impacts production quality and operational costs. Our analysis reveals that separator performance is governed by four key factors: inlet fluid properties, internal component design, operating conditions, and residence time distribution. Furthermore, this paper highlights how strategic internal components, including inlet diverters, wave breakers, coalescing baffles, and mist extractors, work synergistically to enhance separation efficiency while mitigating common operational challenges like phase re-entrainment and liquid carryover. Specifically, the study demonstrates that modern optimization approaches, which combine CFD simulations with field performance data, can yield significant improvements in separator effectiveness through operational parameter adjustment. The results show operational challenges can be effectively addressed through mechanical design solutions, targeted chemical treatments, and the selection of optimum input parameters. The results found that maximum separation efficiency requires a dual-focused approach, such as optimizing both the mechanical design and the optimum parameters to reach the specific fluid characteristics and production requirements with the right selection of study methods. Finally, this study provides valuable insights for engineers and operators looking to enhance separator performance, reduce operational costs, and maintain consistent production quality in oil and gas processing facilities. Future studies should focus on developing adaptive separator designs capable of automatically adjusting to varying feed compositions and flow conditions.

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