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Sizing, Simulation and Economics Analysis of Two-Phase and Three-Phase Well Fluid Separator

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***Abstract* – The sizing and simulation of oil and gas separation plant with chemical injection system for the reduction of foam was done with the considerations of material balance, energy balance, equipment sizing, separation plant costing and safety and environmental considerations. Design models for the oil and gas separation plant for the separation of raw crude with silicon chemical injection for reduction of foam were presented. The design models were developed for each of the constituents of oil and gas separation plant which were 2-phase separator, heat exchanger and 3-phase separator and foam injection system. The operational data obtained were from the design from ASPEN HYSYS simulation environment which serve as input to the computer program developed using MATLAB & SIMULINK compiler. The feed conditions into the separator were temperature at 60^{o}C, pressure at 12bar, molar flow of 5172Kgmole/hr and mass flow of 8.870e5Kg/hr, and the separator yield or product specifications are temperature of 40^{o}C, pressure of 0.3172bar, molar flow of 3161Kgmole/hr and mass flow of 8.401e5Kg/hr. The chemical injection produce was BS&W of 13% and chemical injection rate of 112L/day. In addition, equipment cost of the oil and gas separator from Aspen Hysys software showed N164.9m and N139.68m for 3-phase and 2-phase separators respectively.**

Keywords: Heat Exchanger, Chemical Injection, Foaming, Cost Analysis, Aspen Hysys Software

I. INTRODUCTION

Water produced from reservoirs is a brine solution with considerable dissolved salt and as such necessitates removal to overcome corrosion and problems in handling and refining equipment. This separation is achieved at the well fluid (gas-oil) separation vessel or plant located near the oil field [1]. Enerevba *et al*. posited that crude oil in its raw form produced from wells undergoes the following three processes to yield useful petroleum products viz: surface oil operations for gas-oil-water separation and further treatment of crude oil, treatment of associated natural gas, and fractionating the crude oil into different products. However, during the surface oil operations for gas-oil-water separation, foam is encountered which makes the separation processes of the crude oil difficult [2]. According to Nejat *et al*, the causes of foam in crude oil separation are impurities other than water in crude oil that are impractical to remove before an inlet stream reaches the separator. Foam in a separator affects the liquid phase, and if a large foam layer is present, liquid levels must be reduced to prevent or stop liquid carry-over. Since foam has a high volume/weight ratio, it occupies a large amount of the vessel space thereby decreasing the space available for liquid collection or gravity settling [3]. Hence if foam is uncontrolled, it becomes impossible to remove separated gas or degassed oil from the well fluid separator or vessel without entraining some of the foam in the liquid or gas outlets [4].

Based on the research study of Anders (2020), the amount of foam produced depends on the nature and amount of the surfactant, design of the existing process system and the level of gas release (pressure drop). Surfactants responsible for foaming stability in crude oils are like those that stabilize emulsions such as resins and asphaltenes [5]. Hrishikesh *et al*. in their research design and analysis of storage tank stated that compressed gases (gas tank) or liquids are stored in storage tanks. These tanks can have different sizes, ranging from 2 to 60m diameter or more [6]. Also, Rasak & Mike (2013) carried out a systematic investigation on various of design procedures. Storage tank design was done using variable design point method. The finite element analysis of storage tank was done using ANSYS software. This sloshing effect on storage tank was mainly considered in their research, the statistic and word loud analysis were also done using ANSYS [7]. Furthermore, Soleymani & Sacidabadan (2013) in their work design and development of a 10 million liters capacity petroleum product storage tank clearly stated that in Nigeria, the demand for petroleum products are on the increase and the need for reliable and safe storage facilities is on increasing demand. This has called for indigenous design and development of these facilities to augment the existing ones, and hence, to conserve foreign exchange and enhance job iniation.in DPK, PMS, and AGO [8]. Also, Martin *et al*. in their research titled applied process simulation driven oil and gas separation plant optimization using surrogate modeling and evolution any eflornithines stated that the optimization of a realistic oil and gas separation using Latin hyperchess sampling (LHs) and regions process simulations, surrogate models using kinging have been established for selected model responses [9]. The main funding in the work of Falode & Ojumoda (2015) is that which a high pressure is prefers in the first separation stage apparently a unique optimal setting for the pressure in downstream separators does not appear to correlation between the separator pressure and the applied inlet temperature exist, where different combinations of pressure and temperature yields equally optional results [10]. In addition, Ries & Aitstaedt (2014) in their work titled comparative study of chemical and physical foaming methods for injection. Molded thermoplastic polyurethane, stated that thermoplastic polyurethane is one of the most versatile thermoplastic materials being used in a myriad of industrial and commercial applications [11].

Therefore, formation of foams which is disastrous in oil and gas operations must be removed completely via injection method, which is the most efficient and most economical way of foam reduction. For well fluid to be ready for commercial purposes, it is expected that the crude must attain certain criteria that include:

- Basic sediment and water (BS&W) that is practical description of some contaminants in petroleum and the technique used to measure it should be less than or equal to 0.5%
- Pounds of salt per thousand barrels of crude oil (PTB) should be less than or equal to 25PTB. Therefore, to achieve this fit most crude oil dehydration plants consist of heaters to heat up the well fluid to certain temperature to enable easy separation. However, the heater treater is quite expensive to purchase and also to maintain. Hence the need to bypass the heater treater through the application of chemical injection using SiO_2, polyvinyl, polyamine, polyoxyethylene, polyoxypropylene and Ether emulsifier to achieve the required water and salt content of the crude before transportation from location to another as well prior to exportation.

Thus, this research study is focused on modeling or sizing, simulation and economics analysis of oil-gas separator with chemical injection system for reduction of foam and salt. This is achieved by performing material and energy balances on the two phase and three phase separators, equipment sizing, simulation of oil-gas separator via Aspen Hysys software, validation of simulation results with plant data and economic analysis of the processes.

II. MATERIALS AND METHODS

A. Methods

i. Material Balance Analysis

The general principle of conservation of mass was applied in deducing the material balance analysis for the oil-gas separator vessel or plant as expressed in Equation (1)

$$\frac{\text{Rate of Accumulation of Mass}}{\text{Time}} = \frac{\text{Inflow of Mass}}{\text{Time}} - \frac{\text{Outflow of Mass}}{\text{Time}} + \left(\frac{\text{Generation of Mass}}{\text{Time}}\right) - \left(\frac{\text{Consumption of Mass}}{\text{Time}}\right) \quad (1)$$

For a separator plant operating at steady state operational process with no chemical reaction occurring in the process, Equation (1) reduces to:

$$\left(\frac{\text{Inflow of Mass}}{\text{Time}}\right) = \left(\frac{\text{Outflow of Mass}}{\text{Time}}\right) \quad (2)$$

ii. Material Balance of Two-Phase Separator

By applying the principles of material balance analysis expressed in Equation (2) for a Two-phase separator shown in Fig. 1 yields:

$$M_1 = M_2 + M_3 \quad (3)$$

iii. Material Balance of Three-Phase Separator

Similarly, the application of material balance analysis in Equation (2) to a Three-phase separator that separates the feedstock into three respective components as shown in Fig. 2

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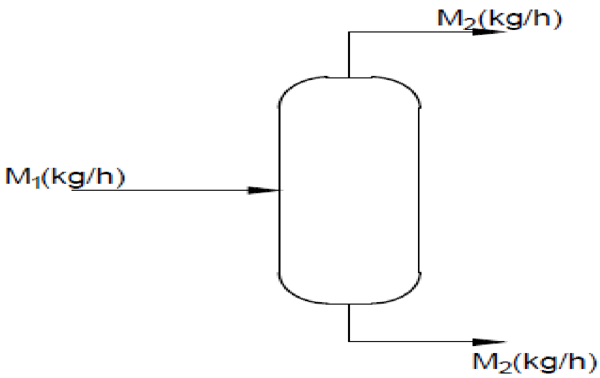


Fig. 1*: Two-Phase Separator*

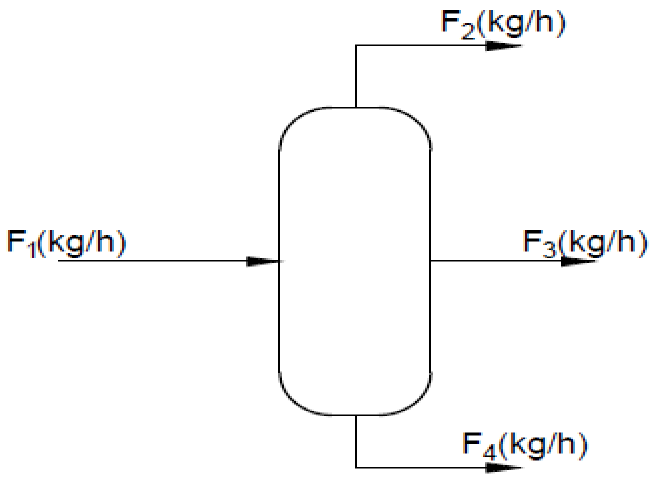


Fig. 2: *Three-Phase Separator*

Applying the principles of material balance given in Equation (2) gives

$$F_1 = F_2 = F_3 + F_4 \qquad (4)$$

iv. Energy Balance Analysis

The general energy balance equation for the separator plant operating at steady state with no chemical reaction occurring in the process is expressed by Equation (5)

$$\left(\frac{\text{Inflow of energy}}{\text{tune}}\right) = \left(\frac{\text{Outflow of energy}}{\text{tune}}\right) \qquad (5)$$

v. Energy Balance of Two-Phase Separator

Applying the energy balance expression in Equation (5) on a Two-phase separator as highlighted in Fig. 3

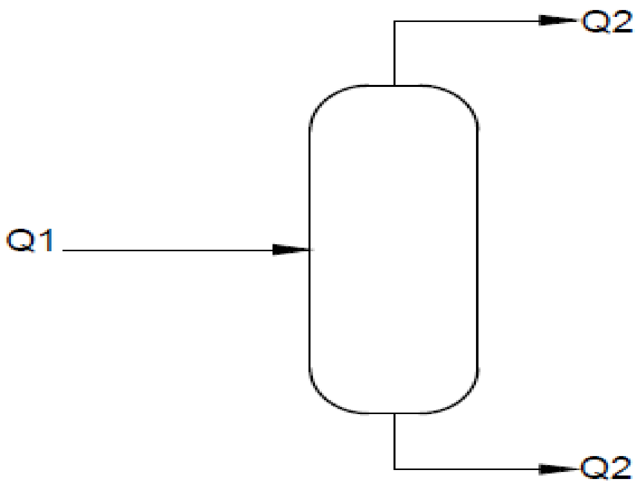
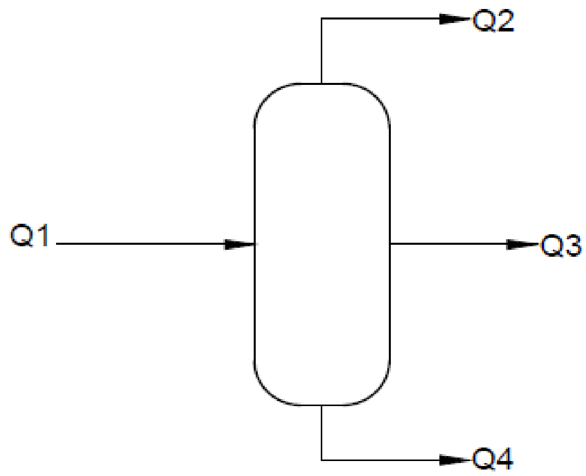


Fig. 3: *Two-Phase Separator*

The energy balance equation on Fig. 3 yields

$$Q_1 = Q_2 + Q_3 \qquad (6)$$



vi. Energy Balance of Three-Phase Separator

Also, applying Equation (5) on a Three-phase separator shown in Fig. 4 yields

Fig. 4: *Three Phase Separator*

$$Q_1 = Q_2 + Q_3 + Q_4 \qquad (7)$$

vii. Separator Sizing

The sizing analysis of Two-phase and Three-phase separators are based on length to diameter ratio of 4 ($(\frac{L}{D} = 4)$) and vessel is a perfect cylinder. The volume of the separator is expressed thus:

Volume of Separator = Volumetric Rate $\times$ $Retention\ time \times 2$ (8)

B. Process Description

The simulation of well fluid separator for separating oil and gas was simulated with ASPEN HYSYS software. The parameters or data obtained from the ASPEN HYSYS design operation were applied in the sizing and simulation of the developed models for separating oil and gas with silicon chemical injection for the reduction of foam. The operational conditions or data deduced from the ASPEN HYSYS simulation software were incorporated and applied as data for the MATLAB & SIMULINK computer program designed. These operational data were obtained from the worksheet and properties of each of the unit operations in the ASPEN HYSYS simulation environment. The diagrams for the process description are shown in Fig. 5.

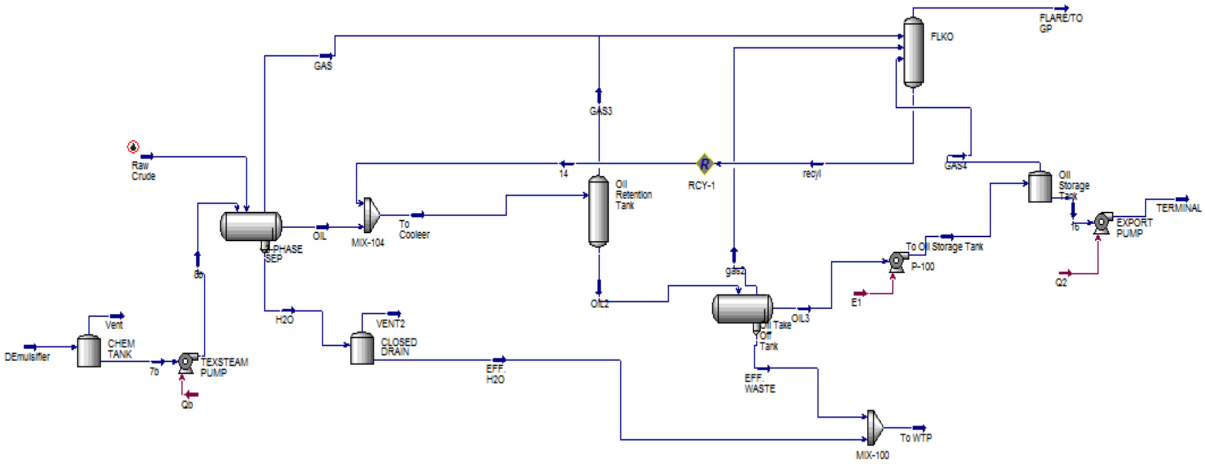


Fig. 5: *Aspen Hysys Oil and Gas Separator Flow Diagram*

III. RESULTS AND DISCUSSION

A. Results

The models developed from material, energy and sizing are solved and applied in the simulation of oil and gas separator using injection system for the reduction of foam. The data obtained from the worksheet of Aspen Hysys design serves as inputs data for the MatLab software. The results obtained from the MatLab simulation software for Two-phase, Three-phase and heat exchanger analysis are presented thus.

TABLE I: SIMULATION OF TWO-PHASE SEPARATOR

Length (m)	Volume of Vessel (m^3)	Diameter (m)	Volumetric -Flow Rate (m^3/hr)
8	25.13274123	2	100.28
16	201.0619298	4	300.28
24	678.5840132	6	500.28
32	1608.495439	8	700.28
40	3141.592654	10	928.8

TABLE II: SIMULATION OF THREE-PHASE SEPARATOR

Flowrate (Kg/hr)	Column Area(m^2)	Diameter (m)	Height (m)
0.002447	2.67E-04	0.01842942	65.17183028
0.003447	3.76E-04	0.021873351	80.73161562
0.0025447	2.77E-04	0.01879373	68.86081776
0.0027447	2.99E-04	0.019518306	75.80518853
0.0029447	3.21E-04	0.02021693	81.39172819

TABLE III: SIMULATION OF HEAT EXCHANGER

Temperature Correction Factor	Temperature (^{0}C)	Inner Diameter (m)	Temperature Difference (^{0}C)	Inside Coefficient	Pressure Drop (Psi)	Overall Heat Transfer Coefficient	Heat (kJ)
0.02	30	1	0.056103682	2659.246221	4.04E-06	0.018895122	0.046973833
0.021	32	2	0.058908866	1558.665847	2.02E-06	0.030593702	0.1521137
0.022	34	3	0.06171405	1149.537051	1.35E-06	0.047965204	0.357728759
0.023	36	4	0.064519234	931.2071283	1.01E-06	0.080326183	0.798773097
0.024	38	5	0.067324418	794.0180794	8.08E-07	0.168511552	2.094623593

B. Discussions

i. Model Validation

The results obtained after the simulation was validated with plant data from crude oil desalter plant to account for its variation or deviation thereby testing for the efficiency or effectiveness of the overall simulation process

TABLE IV: COMPARISON OF SIMULATION MODEL WITH PLANT DATA

Parameter	Plant Composition	Simulation Composition	Deviation (%)
Residual Water	0.0200	0.0180	10.00
Treated Crude	0.9800	0.9820	0.0020

It can be deduced from Table IV that the percentage deviation or minimum absolute error between simulation and plant data for residual water and treated crude are 10% and 0.002% respectively. Hence, the simulation model result is valid within a tolerance limit of $\pm 10\%$ and can be used in simulating and performing sensitivity analysis on the industrial oil and gas separator. In addition, equipment costing was carried out on the Two-Phase, Three-Phase and Heat Exchanger units as shown in Table V

TABLE V: EQUIPMENT COSTS FOR OIL AND GAS SEPARATOR

Equipment	Cost in Dollar (US$)	Cost in Naira (₦)
2-Phase Separator	288,000.00	139,680,000.00
Heat Exchanger	65,000.00	31,525,000.00
3-Phase Separator	340,000.00	164,900,000.00

ii. Effect of Volumetric Flow Rate on Two-Phase Separator

The variation of volumetric flow rate with volume of two-phase separator is highlighted in Fig. 6. However, as liquid from the heat exchanger enters the 2-phase separator, the volumetric flow rate increases and thus increases the volume of the product in the separator which are liquid oil at the bottom and gas at the top. The surfactants are to reduce foaming from forming in the 2-phase separator. If the volumetric flow rate is at optimum rate, then foam may not form due to the presence of the surfactants in the system. Then the liquid from the heat exchanger should be allowed to flow through the 2-phase separator to at most optimum volumetric flow rate to ensure proper separation of liquid (crude oil) and gas from the inlet crude oil. At most, the volumetric flow rate should be 25-30m^3/hour to avoid more volume of foam from forming in the separator as the liquid level of the crude oil in the separator may reduce due to the presence of foam.

iii. Effect of Volumetric Flow Rate on Length of 2-Phase Separator

Increase in volumetric flow rate, increases the liquid level in the separator which are oil at the bottom and gas at the top. If the volumetric flow rate is at optimum rate, then foam may not form due to the presence of the surfactants in the system and moderate flow rate of crude oil into the separator. Then the liquid from the heat exchanger should be allowed to flow through the 2-phase separator to at most optimum volumetric flow rate to ensure proper separation of liquid (crude oil) and gas from the inlet crude oil to a great length of the separator, but higher flow rate favours foam formation even with the presence of the surfactant or the silicon chemical injection to reduce foam. Thus, the volumetric flow rate should be 25-30m^3/hour to avoid foam from forming at a great length of the separator in the separator as the liquid level of the crude oil in the separator may reduce due to the presence of foam even with the action of the surfactants.

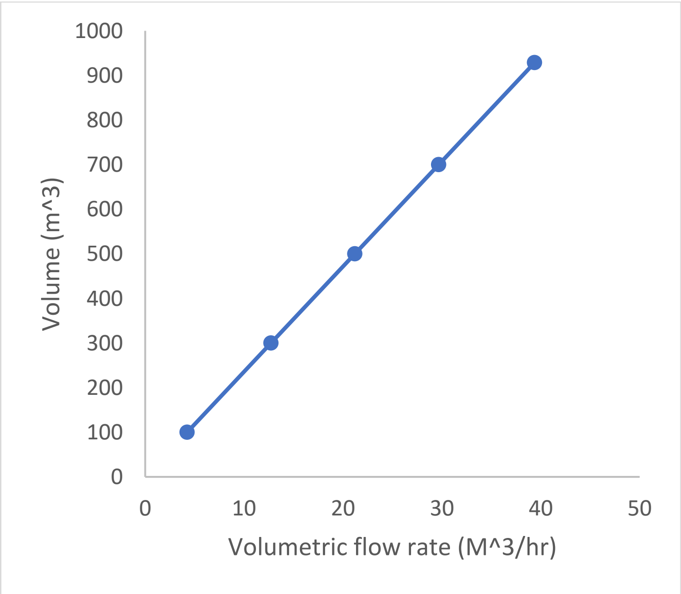


Fig. 6: Effect of Volumetric Flow Rate on Volume of 2-Phase Separator

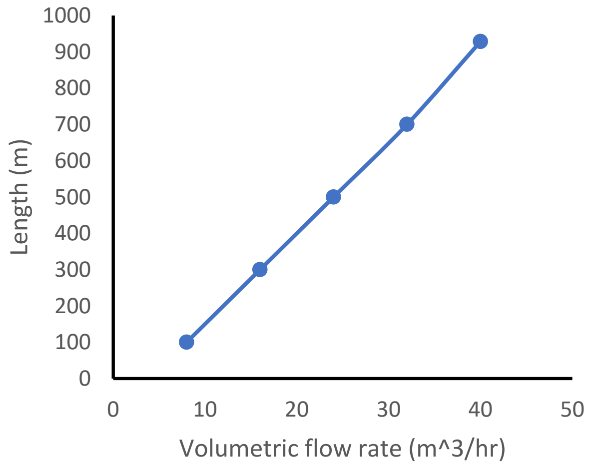


Fig. 7: Effect of Volumetric Flow Rate on Length of 2-Phase Separator

iv. *Effect of Volumetric Flow Rate on Diameter of Separator of 2-Phase Separator*

Fig. 8 depicted the graph of the variation of volumetric flow rate with diameter of 2-phase separator, thus there is a linear relationship between volumetric flow rate and diameter of two-phase separator as shown by the line of best fit.

However, as liquid from the heat exchanger enters the 2-phase separator, the volumetric flow rate increases and then increases the diameter of separator of the liquid level in the separator.op. At the optimum volumetric flow rate, foam formation may be impacted due to the presence of the surfactants or silicon chemical injection. Thus, the liquid from the heat exchanger should be allowed to flow through the 2-phase separator to at most optimum volumetric flow rate to achieve optimum diameter of separator to ensure proper separation of liquid (crude oil) and gas without the formation of foam

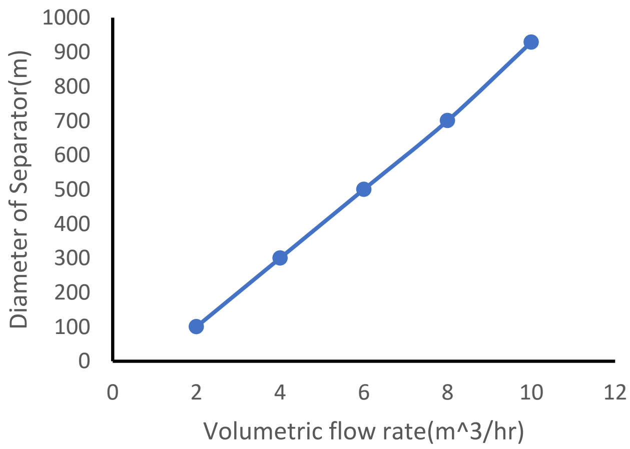


Fig. 8: Effect of Volumetric Flow Rate on Diameter of Separator of 2-Phase Separator

v. *Effect of Flow Rate on Column Area of 3-Phase Separator*

The variation of well fluid flow rate with column area of 3-phase separator depicts a gradual change in flow rates leads to a corresponding change in the column area as highlighted in Fig. 9. As Demulsifier from the pump enters the 3-phase separator with the well fluid (raw crude), the flow rate increases and then fills the column area of separator.

The surfactants or silicon chemical injection are applied to prevent foam formation during the separation process. The essence of the 3-phase separator is to separate the raw crude into 3-phases which are gas, oil and water, At optimum flow rate, foam formation may be hindered due to the presence of the surfactants

silicon chemical injection used for foam reduction the foam formed during the separation of gas, water from the oil in the system and moderate flow rate of raw crude into the 3-phase separator would be require optimum column area of 3-phase separator.

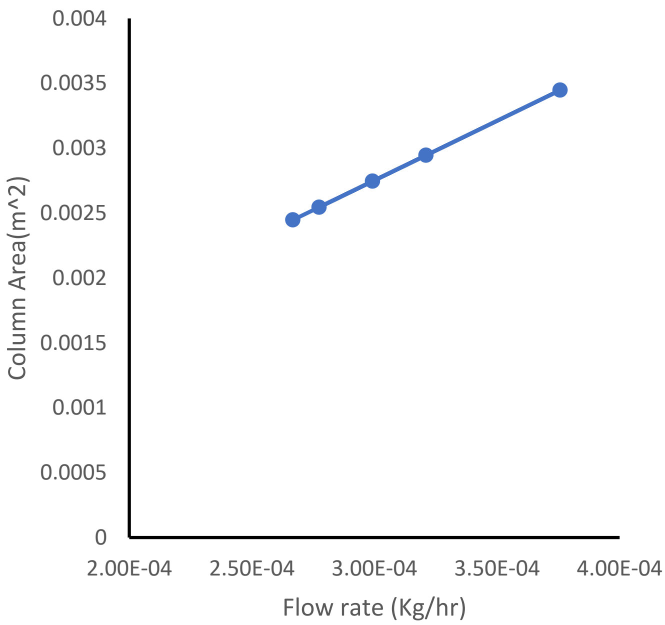


Fig. 9: Effect of Flow Rate on Column Area of 3-Phase Separator

vi. Effect of Flow Rate on Height of 3-Phase Separator

Well fluid flow rates effects on the height of three-phase oil well separator was studied and shown in Fig. 10, which tends away from linear relationship to non-linear curve as depicted.

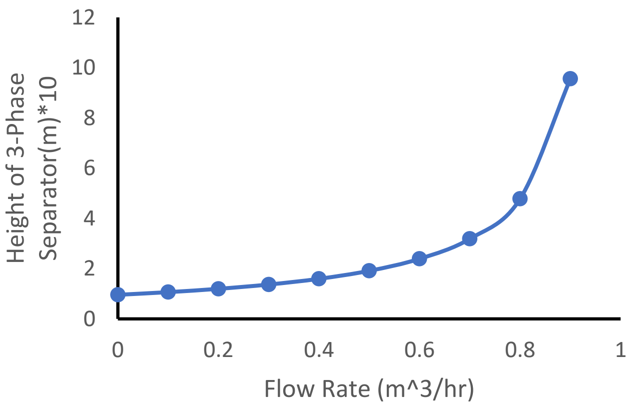


Fig. 10: Effect of Flow Rate on Height of 3-Phase Separator

However, as demulsifier from the pump enters the 3-phase separator with the raw crude, the flow rate increases and then increases the height of fluid in the three-phase separator to a point before it increases upwards. Also, optimum flowrate is required in the separator to prevent formation of foam due to the presence of the surfactants or silicon chemical injected to reduce the foam formed during the separation process.

vii. Effect of Inner Diameter on Pressure Drop of Heat Exchanger

The effects of heat exchanger inner diameter on pressure drop in the exchanger was studied, as the diameter of the separator increases, there is corresponding pressure drop in the exchanger as depicted in Fig. 11.

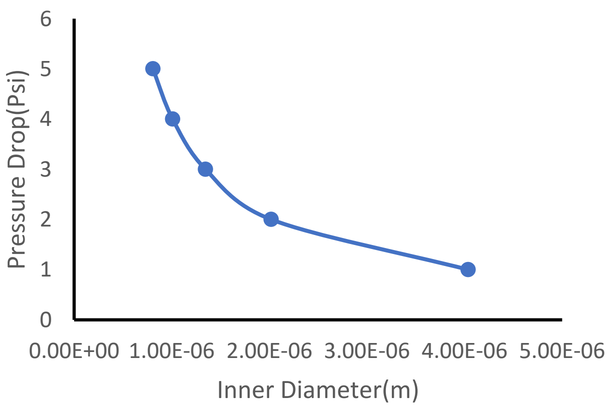


Fig. 11: Effect of Inner Diameter on Pressure Drop of Heat Exchanger

The well fluid is mixed properly and heated up in the exchanger prior to its separation operation, thereby ensuring adequate heat energy is supplied to the fluid to achieve separation process. The pressure drop decrease in the inner diameter of the heat exchanger was due to heat energy absorption from the fluid, thus raising the heat energy. This pressure drop across the heat exchanger was enough to achieve separation in the separator. The desired optimum pressure drop had to be maintained to ensure that the oil was suitable for proper separation process in the separator. At most, the exchanger inner diameter of about 1.5E-06m to 2.0E-06m would be enough for the heat exchanger design to avoid much heat energy gain from the heat exchanger for easy separation process in the separator.

viii. Effect of Overall Heat Transfer Coefficient on Exchanger Heat Duty

The effects of overall heat transfer coefficient on the exchanger heat duty was studied and depicted in Fig. 12. As the overall heat transfer coefficient increases, the quantity of heat in the heat exchanger increases. The quantity of heat energy absorbed during the exchange of heat in the heat exchanger required to raise the heat energy of the oil to a point suitable for separation, this quantity of heat energy would be dependent on the overall heat transfer coefficient of the heat exchanger. Thus, for the overall heat transfer coefficient of 0.5KJ/^{0}Cm^2, 0.056KJ of heat duty will be required for operational process. The overall heat transfer coefficient of about 0.3KJ/^{0}Cm^2 to 0.5KJ/^{0}Cm^2 would be enough for the heat exchanger design for optimum heat energy gain from the heat exchanger for separation process.

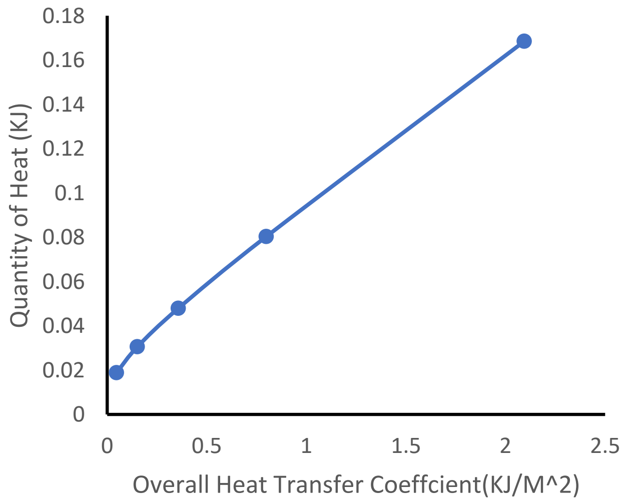


Fig. 12: Effect of Overall Heat Transfer Coefficient on Exchanger Heat Duty

IV. CONCLUSION

Aspen Hysys design and simulation of oil and gas separator unit with associated heat exchanging units were carried out in this research study with the injection of chemical substance (silicon) to reduce or prevent foam formation in the unit. Two-phase and three-phase separators were considered and modelled. Material and energy balances were developed from the first principle while equipment sizing, equipment costing, safety and environmental factors were also considered in this study. The data obtained from Aspen Hysys software design was applied as input data in solving the developed model equations. The optimum results of the 3-phase separator, 2-phase separator and heat exchanging unit were compared with industrial operational oil and gas separators with minimum deviations or absolute error values. Thus, these results and parameters are useful in designing and fabrication of oil and gas separator.

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