Hydrocyclone optimisation to separate oil and water in the separator

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Abstract. The conventional 3-phase separator installed cannot anticipate the increase in fluid flow so that the oil content carried into the produced water from the separator consistently exceeds the upper operating threshold. This study aimed to test the application of a hydrocyclone device to a 3-phase horizontal separator. Hydrocyclones are widely used as auxiliary devices to optimise oil separation by minimising oil carried into the produced water stream. This study made a comparison between installing a hydro cyclone at the inlet with a 3-phase horizontal separator. Applying a hydrocyclone at the inlet of a 3-phase horizontal separator increases the efficiency of the separation process in production. Proper design improvements with Hysys and flow characteristics with CFD can reduce the oil content carried in the produced water stream below 20 mg/l. The results of this study can support de-bottlenecking to increase production to a production target of above 375 kbps. A robust application of engineered hydrocyclones with correct production and operating shrouds has been experienced to optimise the separation process by up to 92%.

1. Introduction

Located in the North Caspian Sea, the XXX field production rate has not yet reached the production plateau by the design of the production equipment. One reason is that the oil content carried out into the produced water flow from the separation process in three phases horizontal separators still exceeds the upper operating threshold of 20 mg/l or off-spec.

High carried oil content becomes a burden for the downstream water treatment unit. Due to the design limitations of the process equipment, the required specifications of the incoming water are to be below 20 mg/l [1]. Otherwise, the treated water cannot meet the local government environmental specifications stipulates that water discharged into Evaporation Ponds must have an oil content of less than 5 mg/l [2].

The XXX field has made several planned efforts to increase production: secondary recovery with raw gas injection, followed by scheduled desander and descaling pipeline. Further, installing a demulsifier in 2020 has increased the efficiency of separation by successfully reducing the oil content to a level of 27 mg/l from above 40 mg/l to the same water cut-rate and production rate. Nevertheless, it still cannot able to reduce oil content below 20 mg/l. Therefore, looking at the designing and optimising the separator condition self would get the most optimum operations [3].

This research focuses on defining correct operating and production envelopes and refining the design by applying the hydrocyclone separation technique at the inlet of the installed separator, whereas this technique has been proven successful in other oil fields.
2. Methodology

Benchmarking data from successful separation optimisation techniques applied, and production, operations, and design data are collected from a secondary source and the XXX field as a primary source. The methodology used is divided into the main steps below.

The literature reviews the most applicable techniques for optimisation of three-phase gravity separation processes firstly. Hydrocyclone application with proper engineering design and correct production and operating parameters have been experienced in optimising the separation process up to 92% [4, 5].

And then review the inlet type of hydrocyclone in terms of most functionality applied shown in table 1 as follows.

| Inlet Type Tool Inlet Function                                      | Diverter Plate | Vane Inlet | Inlet Hydrocyclone |
|--------------------------------------------------------------------|----------------|------------|-------------------|
| Reduces feed flow momentum and ensure good distribution of gases and liquids | Good/Poor      | Good       | Good              |
| Separating high pouring liquids                                    | Poor           | Good       | Good              |
| *De-foam*                                                          | Poor           | Average    | Good              |
| Prevents re-entrainment / scaling of separated fluids              | Average/Poor   | Good       | Good              |

Collect data from such oil fields successfully on hydrocyclone inlet type applied with typical water cut, production, and oil content. As in the Angsi field from Peninsular Malaysia Operation (PMO) PETRONAS Carigali Sdn, Bhd. (PCSB) has proven that a modified separator is installed by installing a hydrocyclone inlet separator itself [6]. After that, collect historical data from the XXX field on water cut, production, and oil content as shown in graphic 1 as follow;

![Figure 1. Oil content to water cut and production.](image-url)
Re-run simulation with the defined production and operating envelopes resulted from earlier simulation by applying hydrocyclone at the inlet of three-phase separators. Perform fine adjustment aiming at optimum efficiency of separation. And then simulate flow characteristics by CFD on the applied hydrocyclone to fine-tune the design. Finally, evaluate the efficiency of separation for all scenarios.

3. Results and Discussion

Stokes Law is used as a separation theory to design a separator design with a gravity deposition method where the velocity of rising oil droplets is based on the size and density of the oil droplets. The larger the oil droplet, the faster the oil rise rate or the separation rate will be. Therefore, the separator is designed based on the difference in density between oil and free water. Based on these design criteria, free water will be deposited at the bottom of the separator, while oil with a lighter density will rise to the top of the separator due to differences in density [7].

\[
V_t = K \times G \times D^2 \times (\rho_1 - \rho_2) \mu^{-1} \quad (3.1)
\]

Where:
- \(V_t\) = Increase in oil droplet velocity
- \(G\) = Gravity force for conventional separator
- \(D\) = Droplet diameter
- \(\rho_1\) = Density of continuous phase (water)
- \(\rho_2\) = Density of dispersed phase (oil)
- \(\mu\) = Viscosity of continuous phase (water)
- \(K\) = Constant

On the current data, water cut is directly proportional to the production rate and inversely proportional to the retention time of water in the separator, making the determinants of the separation process in the separator unable to work optimally, so that it becomes inefficient. It makes it one of the bottlenecks for increasing production from wells [8]. Due to the high water-oil ratio, having water as the continuous phase causes the water layer to be thicker than the oil layer. Hence, the larger oil droplets require to travel more than usual from the continuous water phase, resulting in a longer retention time to coalescence. Thus, at a high water cut, the acceleration on centrifugal force provided by the hydrocyclone might assist in breaking the emulsion; hence the water layer is lesser, thus improve the retention time when operated with a higher production rate [9].

The Stokes Law tells the separation efficiency is directly proportional to the size of the droplets that can be manipulated and maintained at all times. The larger oil droplets have less dense need less time to more significant coalescence with oil by emerging rapidly to the interface of the oil emulsion. Acceleration of liquid flow rate contributes to separating the oil from the water phase in less time because allowing the emulsion to break up into an oil and water larger droplets. As the liquid flow rate increases, the high-speed rotating stream creates the centrifugal acceleration of liquid flow in hydrocyclone, allowing gross separation between liquids with different densities [10]. Herewith this justification, simulation with changes of elevated production rate might optimise the oil-water separation efficiency. Thus, oil content might be lower.

Thus, by following the Stokes Law, the separation efficiency is inversely proportional to the continuous phase (water) viscosity. By supplying heat to the fluid causes, the viscosity of the continuous phase (water) is reduced, and the velocity of oil droplets will be faster, resulting in easier separation [3, 11]. The intermolecular forces between the oil-water molecules in the emulsion are reduced by means that the attraction between the two molecules becomes weaker by increasing the temperature of the feed stream and improved overall performance, and decreased the concentration of oil in the water discharge stream [12]. Because water is less viscous from oil, the attraction between water and oil droplets is quickly released with the vortex aids from the hydrocyclone and caused more water to separate from the emulsion. Herewith this justification, simulation with changes of elevated temperature might optimise the oil-water separation efficiency. Thus oil content might be able to lower.
As the separator pressure increases, many light and intermediate components will stay in the gas phase in the separator, and the liquid flow rate out of the separator increases. Pressure at the inlet of the hydrocyclone is an important indicator of where the separation point will take place [13,14]. The separation point is the size at which liquid chance of either to the underflow or overflow. Because water is less viscous from oil, a higher pressure will send more water as fine droplets into the underflow, inversely oil as larger droplets quickly released with the vortex aids from the hydrocyclone and causes more water to separate from the emulsion [15]. Herewith this justification, simulation with changes of elevated pressure might optimise the oil-water separation efficiency. Thus oil content might be able to lower [16].

4. Conclusion
In conclusion, by defining correct operating and production envelopes and refining the design, application of the hydrocyclone separation technique at the inlet of the installed separator resulted from the simulation based on the hypothesis above would be able to optimise the oil-water separation efficiency and would be able to lower oil content in produced water within 20 mg/l.

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