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Performance Evaluation of a Liquid-Liquid Cylindrical Cyclone (LLCC) for Oil-Water Separation

I A Dharma[1], A Widyaparaga[2, 3, 4], F I Faza[2]

[1] Department of Mechanical Engineering, Universitas Islam Indonesia, Jalan Kaliurang km. 14.5, 55584, Yogyakarta, Indonesia
[2] Department of Mechanical and Industrial Engineering, Universitas Gadjah Mada, Jalan Grafika No. 2, 55281, Yogyakarta, Indonesia

[3] Centre for Energy Studies, Universitas Gadjah Mada, Sekip Blok K1.A, 55281, Yogyakarta, Indonesia

[4] E-mail: adhika@ugm.ac.id

Abstract. In this experimental study, the type of Hydrocyclone Separators that used is Liquid-Liquid Cylindrical Cyclone (LLCC). The objective of this experimental study is to understand the influences of operating and design parameters such as inlet velocity, split- ratio, and vortex finder diameter towards the result of separation process (LLCC's performance). The separation performance of LLCC is determined by measuring the watercut that goes through the lower output called as underflow. The examined inlet mixture velocity in this experimental study are 1 m/s and 1.2 m/s with split-ratio variation of 5%, 15%, 30%, 45%, 60%, 75%, and 90%. The diameters of vortex finder that used in this experimental study are 18 mm, 22 mm, and 27 mm. All variables are tested under a constant inlet oil volume fraction 25%. From the experiment with those various variables, LLCC can achieve 99% of watercut with different Optimum Split Ratio (OSR) for each inlet mixture velocity and vortex finder diameter.

1. Introduction

Indonesian territory is a strategic area for trading activities and sea transportation. It has an impact on the higher number of ship passing through the Indonesian seas and increasing the volume of waste oil. Higher waste pollution will damage the environment. [1]

This study develops a new method that is cheaper and more efficient to prevent the waste pollution by separating the oil content in the water so that LLCC (Liquid Liquid Cylindrical Cyclone) separators have been designed. However, the LLCC is not to replace the conventional separators. LLCC or generally called Hydrocyclone Separators is often used as a last step to clean up a small quantity of oil remaining in the water to the minimum level after the primary separation so water can legally to be discharged into the sea. [2] Some studies have been carried out to study the performance and behaviour of LLCC with different design and different operating parameters [3]-[6], to investigate the flow characteristics [7], and to develop the control systems [8]-[9].

Unfortunately, each particular LLCC design has its own behavior. It make LLCC difficult to operate. Thus, a standard is required between non-dimensional design parameters and the operating parameters to obtain best performance. Those proposed standard is called LLCC Behaviour Map. To the best of the author's knowledge, LLCC Behaviour Map has not been systematically studied yet. However, despite its helpfulness, its not easy to build this map. The big experimental database of LLCC systems for oil and water separation is needed to supporting LLCC Behaviour Map. Therefore, this study is conducted as a first step to develop the established LLCC Behaviour Map. The purpose of this study is to obtain some experimental data related to the performance of LLCC to supporting the big experimental database of LLCC.

2. Methods

The experimental facility was established in Fluid Mechanics and Heat and Mass Transfer Laboratory, Department of Mechanical and Industrial Engineering, Faculty of Engineering, Universitas Gadjah Mada. Fig. 1 shows a schematic of the flow loop system. Kerosene and water were selected as the initial working fluids. Water and kerosene have a density of 997 kg / m^3 and 820 kg / m^3 and dynamic viscosity of 0.00086 kg / ms and 0.00164 kg / ms respectively at 27^o C. A loading dye (red) was added to the kerosene to improve flow visualization.

As already shown in Figure 1, water and kerosene were stored in different tanks, wherein each tank has a maximum capacity of 250 liters. Each tank was connected to one pump that are equipped with by-pass line. Water and kerosene were pumped (P-1 and P-2) from the tank to the mixture tube. The flow rate of water and kerosene were set by using gate valve (V-2 and V-4). The water flow rate was measured by using a rotameter (I-1) that mounted on water line. While the kerosene flow rate was measured by using a turbine digital flowmeter (I-4) that mounted on kerosene line. Check valve (V-5 and V-6) were mounted for each line of water and kerosene to prevent backflow. After passing through the mixture tube, water and kerosene will be mixed and entering into LLCC through tangential inlet. The oil-rich flow and the water-rich flow will be out through the overflow and the underflow respectively. The valves (V-9 and V-11) in both the overflow and underflow allow to control the flow rates of fluid leaving from the LLCC. After being separated, both the overflow stream and the underflow stream flow into the separator to the further separation under the gravitational force. Finally, the water and kerosene will be returned to the tank by using circulation pump respectively (P-3 and P-4). At the overflow and inlet there are sample lines that is used to take samples. The flow in overflow is dominantly by oil, therefore the samples taken are to calculate the oil volume fraction. This sample is put on cylinder glass and left resting for 10-15 minutes (until water and oil separated by gravitational force). A camera with frame rate video recording 1000 – 3000 fps, and maximum resolutions 1280 x 800 pixels is placed in the front of LLCC to take the visualization (photographs) data. 50 Watt LED lamps were used as a light source.

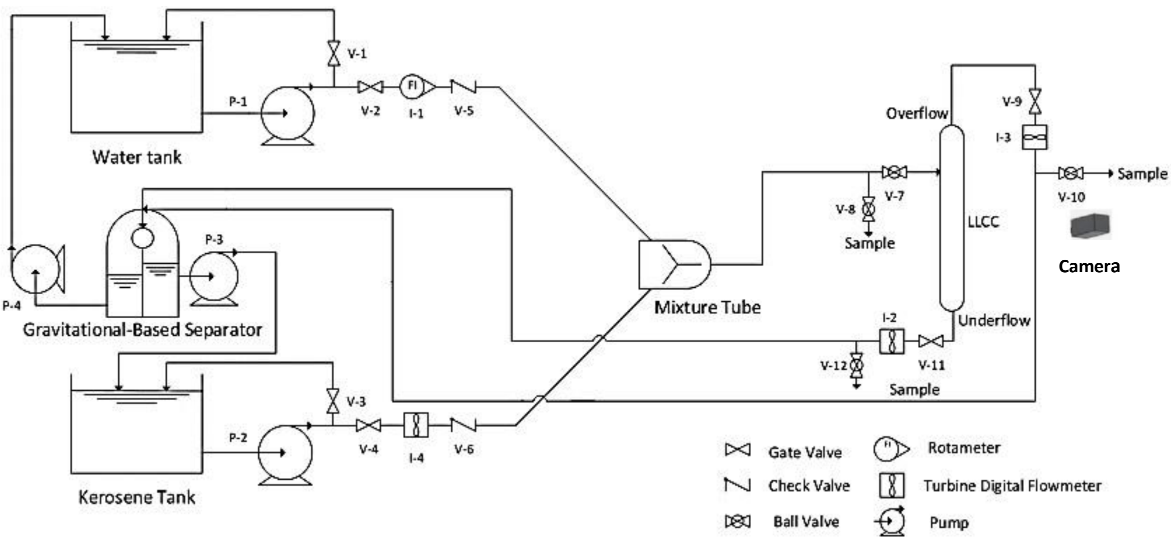

Figure 1. Schematic Diagram of the LLCC Experimental Facility.

The dimension of LLCC is given in Figure 2. LLCC was made from transparent acrylic pipes to enable the visual observation of separating process. The vertical pipe of LLCC is a 1300 mm height (*H*) and 50 mm *ID* with 16 mm *ID* horizontal tangential inlet (*d*). The inlet is attached to the LLCC 300 mm below its top (*h*). The lower section below the inlet is 1000 mm long. The underflow line is an 18 mm *ID* pipe.

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This study proposed non-dimensional parameters for the LLCC design. The non-dimensional design parameters of LLCC is shown in Table 1.

Table 1. Non-dimensional Design Parameters of the LLCC Comparing to the Other Studies.

Non-dimensional parameters	This Study	Oropeza Vazquez, et al. [4]	H.-f. Liu, et al. [3]
d/D	0,32	0,53 with istalled nozzle 25% of the in- let full cross sectional area)	0,44 with istalled nozzle in the inlet (20% of the in- let full cross sectional area)
h/H	0,23	0,47	0,11
D	50 mm	50,8 mm (2 inch)	50 mm
H	1300 mm	2413 mm (95 inch)	900 mm

Comparing to the other studies, the LLCC design that used in this study has different non-dimensional parameters. LLCC behavior map is constructed from the relationship between non-dimensional parameters design, operating parameters, and separation performance of LLCC. Hence, this study has an added value for the development of this map. In this case, the effect of other parameters such as oil viscosity (type of oil that used), pipe friction, temperature, can be ignored.

The operating parameters in this study were inlet mixture velocity, inlet oil volume fraction, and split-ratio. The examined inlet mixture velocity were 1 m/s dan 1,2 m/s and throughout the experiment, the inlet oil volume fraction was kept constant at 25%. Split-ratio is varied at 5%, 15%, 30%, 45%, 60%, 75% and 90%. These operating parameters were tested on three variations of vortex finder diameter (D_o), that are 18 mm, 22mm, and 27 mm with Vortex Finder Depth (*L*) is 0 mm. Split-Ratio (*SR*) is defined as the ratio between the flow rate in the overflow (Q_o) and the flow rate in the inlet (Q_i). Split-ratio is calculated by using equation as follow:

$$SR = \frac{Qo}{Qi} \quad (1)$$

The separation performance of LLCC was calculated by measuring watercut (water content) in underflow.

Kerosene and water were selected as the initial working fluids. Kerosene was selected as working fluids on grounds of easy availability, non-hazardous, non-explosive, fast separation, appropriate optical characteristics, non-degrading properties, and has low emulsification. A dye (red) was added to the kerosene to improve flow visualization of the separation phenomena.

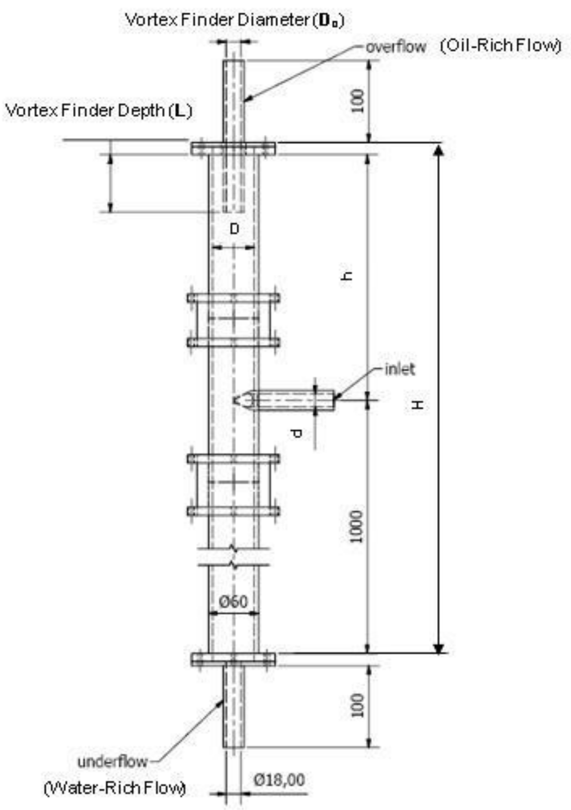

Figure 2. The Dimension of LLCC.

3. Results and Discussion

The experimental results on the effect of split-ratio (*SR*) and inlet velocity (V_m) to watercut percentage on the underflow will be discussed. The experimental data of this study is represented generally in Figure 3.

Those figures below showed the effect of the split-ratio and inlet mixture velocity (V_m) to the underflow watercut of the separation process performed by LLCC on each variation of the vortex finder diameter. The change of watercut is greatly influenced by the split-ratio. The increasing split-ratio will raise the watercut until its maximum point. The higher split-ratio that is operated will created the aperture of gate valve more opened on overflow than underflow. This causes a high flow (Q_o) that passes through overflow. Thus, the most of fluids entering LLCC will flowing through overflow, especially oil that have lower density, and make the watercut value in high split-ratio can reached 99%, as well otherwise.

To obtained the maximum watercut value (up to 99%), LLCC should be operated before the oil content move to the underflow or before oil drag occurs. The LLCC's operating limit before the occurrence of oil drag is called optimum split-ratio (OSR). Therefore, the LLCC must operate in higher OSR to obtained the best separation performance. Figure 4 showed the separation behaviour inside LLCC. The photograph indicated the occurring of oil drag.

On the other hand, Inlet mixture velocity (V_m) affected the OSR. From the graphs above, it can be seen that higher inlet mixture velocity changed the value of OSR. For higher inlet mixture velocity, the maximum value of underflow watercut occurred at lower OSR. This is happened because high flow velocity causes the oil to push toward the underflow resulting in lowering of the quality of the watercut.

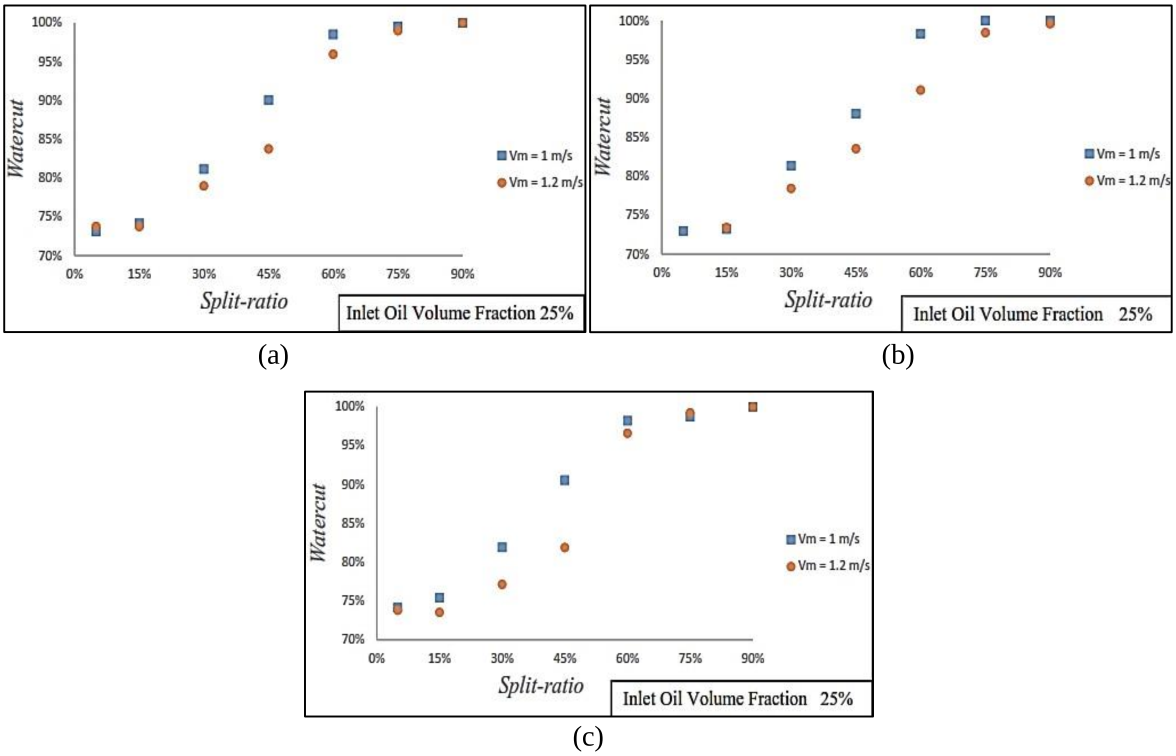

Figure 3. The Effect of Inlet Mixture Velocity and Split-Ratio to the Underflow Watercut. (a) D_o=18 mm; (b) D_o=22 mm; (c) D_o=27 mm

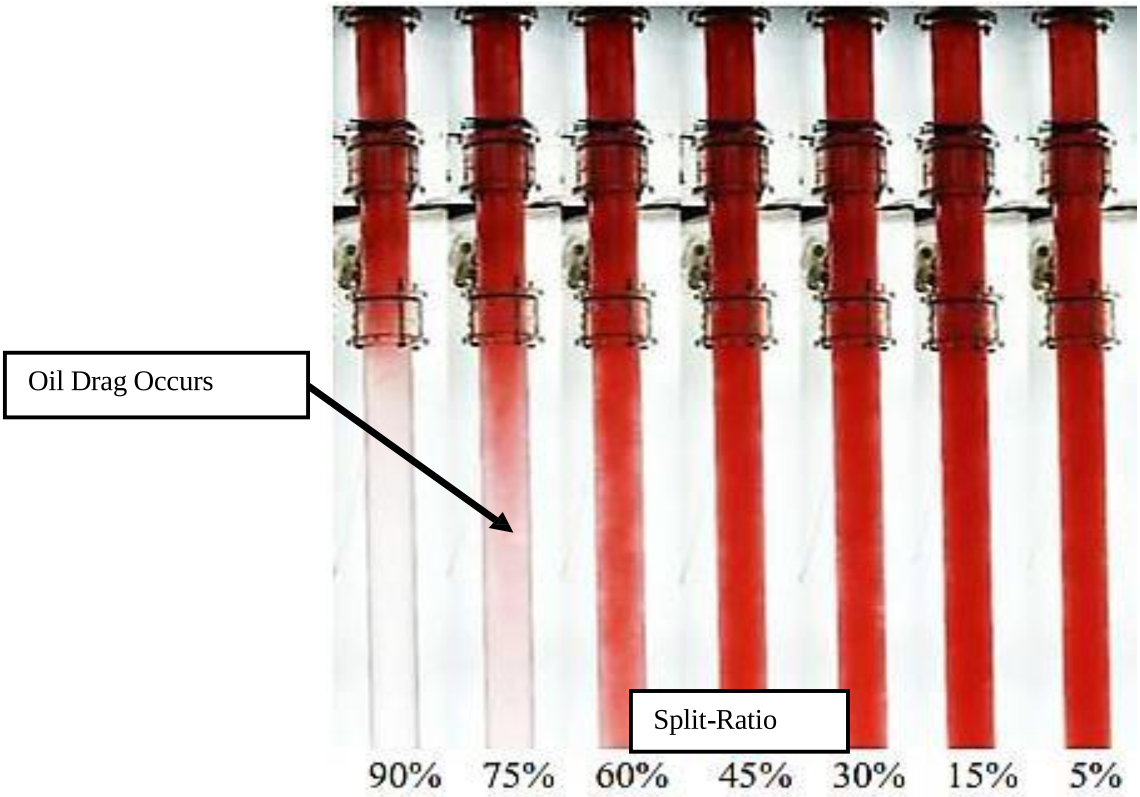

Figure 4. The photographs of separation behaviour inside LLCC under different split-ratio (D_o = 22 mm, Vm = 1 m/s)

4. Conclusion
From the result and discussions, the main conclusion can be drawn that the watercut value obtained from the LLCC separation process reached 99%. The LLCC should be operated in the higher of OSR to obtained the best performance of LLCC. The increasing of inlet mixture velocity would reduce the value of OSR. Separation phenomena in visualization data (photographs) explained how the oil drag occurs.

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