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Performance Comparison between Recycled Single Stage and Double Stage Hydrocyclones

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Abstract

This research presents a comparison of performance between recycled single stage and double stage hydrocyclones in separating water from water/kerosene emulsion. The comparison included several factors such as: inlet flow rate (3,5,7,9, and 11 L/min), water feed concentration (5% and 15% by volume), and split ratio (0.1 and 0.9). The comparison extended to include the recycle operation; once and twice recycles. The results showed that increasing flow rate as well as the split ratio enhancing the separation efficiency for the two modes of operation. On the contrary, reducing the feed concentration gave high efficiencies for the modes. The operation with two cycles was more efficient than one cycle. The maximum obtained efficiencies were 97% and 97.5% at 5% concentration, 11 L/min, and 0.9 split ratio for twice recycled single stage and double stage hydrocyclones, respectively. The pressure drop was the same for the two modes of operation. It was concluded that using recycled single stage hydrocyclone was more economical since it reduced the cost of additional hydrocyclone.

Keywords: hydrocyclone, kerosene, separation efficiency, split ratio

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1- Introduction

Water-in-oil emulsions are commonly found in the petroleum industry, for example in petroleum refineries and pipeline transportation stations[1]. The crude oil production containing emulsified water poses problems, such as the corrosion of transport systems and catalyst poisoning during the refining phase.

The simplicity of extracting petroleum water differs with the aging of the emulsion[2].

Most of free water can be removed by simple settling. The other two forms need more effective separation like operating at high temperature, centrifugal separation, vacuum dehydration, coalescing filtration and bleed from bottom of oil compartment.

Centrifugal separation is an efficient way to maintain the lubricant's free water cleanliness and most emulsified liquid [3] and this can be done by using liquid-liquid hydrocyclone. Because produced oil is often accompanied by significant amounts of water, it is important to provide separation facilities for oil and water before selling the oil.

The oil industry has been turning to the use of hydrocyclone to satisfy this need[4]. Conventional hydrocyclone (two-product) are used for various applications, including sorting, thickening, de-slimming and dewatering[5].

Current hydrocyclone water - oil separation mainly uses specific centrifugal forces between oil and water to achieve rapid separation[6].Osei and Al-Kayiem[7] presented an experimental study of a liquid–liquid hydrocyclone to separate oil from oil/water emulsion with 90% water cut at different flow rates and temperatures.

The results showed that the percentage separation efficiency was higher than 80% in the flow split ratio between 0.6-0.7 for all the flow and temperature cases. Fluid temperature slightly impacted the hydrocyclone performance and the pressure drop ratio inversely affected the separation efficiency. Bram et al. [8] use CFD models to study several aspects of deoiling hydrocyclone and thus enabling model-based control.

They experimentally validated their original and modified models using a pilot plant hydrocyclone. It was shown that the modified model performed better during all the tests.

Schummer, Noe, and Baker [9] investigated the axial and tangential velocity fields inside a rotating wall hydrocyclone using Low Doppler Velocimetry (LDV) measurements aiming at oil/water separation.

Velocity measurements showed the influence of rotation speed and flow rate on the resulting acceleration field but the tangential profiles barely affected by flow withdrawal through an annular downstream exit [10]. In this study, it was intended to get more efficient separation of water/kerosene emulsion than using only one hydrocyclone.

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Produced kerosene treating equipment performance is commonly described in terms of its "water removal efficiency." This efficiency considers only the removal of dispersed water[11].

Split ratio, $F=\frac{Q_o}{Q_i}$ (1) [12]

Where: Q_o is overflow rate (L/min) and Q_i is inlet flow rate (L/min).
Percentage separation efficiency,
$\%E=1-\frac{C_o}{C_i}\times 100\%$ (2) [12]

Where: C_o is overflow water concentration (ppm) and C_i is inlet water concentration (ppm).

Pressure drop, $\Delta p = p_i - p_o$ (3)

Where: p_i is the inlet pressure (bar) and p_o is the overflow pressure (bar).

2- Experimental Work

2.1. Materials and Equipment

a. Materials

- Kerosene (from local market).
- Ethanol (Abs.100% HPLC grade, Belgium).

b. Equipment

- pump no.1 (streen centrifugal electro-pump model STP-A5, Qmax=65 L/min, Hmax=56m, HP=1.5)
- pump no.2 (stronger water pump QB60, Qmax=30 L/min, Hmax=30 m, HP=0.5)
- Hydrocyclone (locally designed and fabricated)
- UV spectrophotometer Genesis 10 uv (0-3) absorbance, USA.
- Pressure gage, (0-8) bar, China.
- Homogenizer, Ultra turrax, 10000 rpm, Germany.

2.2. Experimental Procedures

a. Recycled Single Stage Hydrocyclone

Fig. **1** shows the experimental set-up. By closing valve 6 and opening valve 2 the second hydrocyclone was omitted and the operation was done by one hydrocyclone only. The overflow was recycled once and twice. The concentration of water in the feed was changed (5% and 15%). At each concentration the feed flow rate was changed (3, 7, and 11 L/min).

The split ratio was also changed (0.1 and 0.9) for each concentration. The concentrations of water in kerosene were measured in the overflow and in the underflow using uv- spectrophotometer for each experiment in single and double cycles.

b. Double stage hydrocyclone

The experimental procedure began by connecting the two hydrocyclones in series, the overflow of the first hydrocyclone entered the second one as feed. So, it could offer two-stage separation process. Again, the two pumps were connected in series to the hydrocyclone inlet. By closing valve 2 and opening valve 6 these pumps pushed the water-oil feed emulsion from the feed tank to the two hydrocyclones in series and this action provided a suitable centrifugal force to make a good separation of water from oil in two stages. The feed flow rate was changed (3,5,7,9, and 11 L/min) for each water feed concentration (5% and 15%) each at two split ratios (0.1 and 0.9). As mentioned before the concentrations of water in kerosene were measured using uv- spectrophotometer.

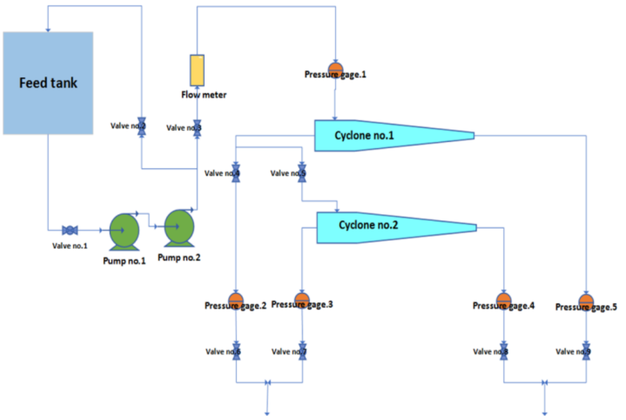

Fig. 1. Experimental set-up

3- Results and Discussion

The results obtained from the experiments were presented as follows:

3.1. Effect of Flow Rate on Separation Efficiency for Recycled Single Stage Hydrocyclone

The effect of flow rate on percentage separation efficiency for water concentrations 5% and 15% at split ratio 0.9 using once and twice recycled single stage hydrocyclone is presented in Fig. **2**. It is obvious from the figure the direct effect of flow rate on the percentage separation efficiency for all cases. This behavior was attributed to increasing the centrifugal force in the hydrocyclone with increasing flow rate. The lowest effect noticed was at 15% water concentration for one recycle operation.

This might be because of the high concentration of water in the feed that did not show a noticeable removal of water as the flow rate increased.

The percentage separation efficiencies were in the order: 5% concentration of two recycles, 5% concentration of one recycle, 15% of two cycles, and 15% of one recycle. So, the effect of two recycles was very obvious except at the highest flow rate 11 L/min for 5% concentration.

It was noted that the maximum percentage separation efficiency 97% was achieved equally well at 5% concentration for one and two cycles at the highest flow rate, 11 L/min. That is because at the highest flow rate the ratio of water molecules emerged from the overflow were the same for one and two cycles, no further water molecules could be emerged because of the low inlet concentration. In 15% concentration case the enhancement was clear because of the large amount of water molecules in the feed.

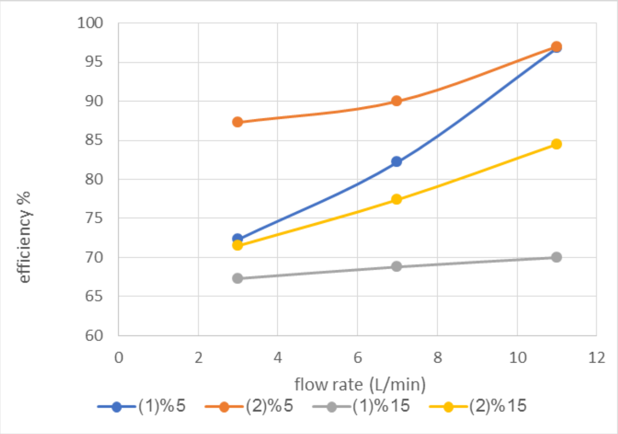

Fig. 2. Effect of flow rate on separation efficiency at 0.9 split ratio for once and twice recycled single stage hydrocyclone: (1) refers to one cycle and (2) refers to two cycles

The comparison between the percentage separation efficiencies at 5% and 15% water concentrations revealed the superiority of the separation at 5% concentration. This is because the amount of water removed at 5% concentration was comparable to that presented in the feed which was not the case at15% concentration case.

This discussion makes it clear that working twice recycled single stage hydrocyclone at high flow rate is recommended for separating high water concentration but for low water concentration only one recycle is adequate to give high percentage separation efficiency at high flow rate.

3.2. Effect of Flow Rate on Separation Efficiency for Double Stage Hydrocyclone

It was shown in Fig.4. that the efficiencies of removing water from water-kerosene emulsion for 5% and 15% water concentrations at split ratio 0.1 in the double stage hydrocyclone were approximately coincident at flow rates (3,5,7, and 9 L/min).

The percentage separation efficiencies of 15% concentration were slightly higher than those for 5% concentration at these flow rates. That was because the use of two stages of separation made further separation of water from the emulsion and gave some enhancement in the case 15% concentration because of the large amount of water in the feed but in the case of 5% concentration no further separation occurred because of low water concentration.

At the highest flow rate used in the experiments, 11 L/min, the situation was reversed, namely the separation efficiency of 5% concentration 92.2 % became clearly higher than that for 15% concentration 85.9%.

It was the maximum removal efficiency in this case. The reason behind this was because 0.1 split ratio made the overflow outlet so narrow that water molecules escaped from overflow opening for 15% concentration were comparable to that for 5% concentration at low and moderate flow rates. Little enhancement at 15% concentration was observed. When the flow rate increased to the highest value, the strong vortices offered very big centrifugal force that enabled more water molecules to escape from the overflow leading to decreased separation efficiency at 15% concentration.

Because the escaped molecules formed higher ratio with respect to the inlet concentration in the case of 15% concentration than that in the case of 5% concentration the percentage separation efficiency was noticeably enhanced at 5% concentration. From this argument it is recommended to adopt the double stage hydrocyclone for high water concentrations when the split ratio is low.

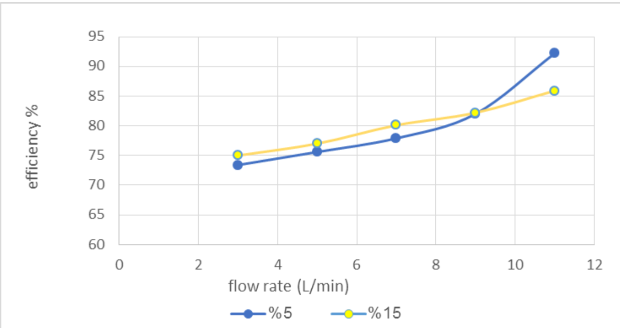

Fig. 3. Effect of flow rate on efficiency at 0.1 split ratio for double stage hydrocyclone

When the split ratio increased from 0.1 to 0.9, the overflow opening was wider than for 0.1 split ratio giving broader way for the water molecules to escape from overflow outlet. Water molecules in the feed of 15% concentration were more than those for 5% concentration, so the molecules escaped were also more leading to decreased separation efficiency at all flow rates as illustrated in Fig.5.

Therefore, the efficiencies of 5% concentration were higher than those of 15% concentration. The effect of flow rate was also noticed in Fig. **4**, the removal of water increased with the increase of the flow rate and the maximum removal value 97.5% was at 11 L/min for 5% water concentration.

Another finding could be extracted from Fig. **4** in comparison with Fig. **3**. That the values of percentage separation efficiencies in Fig.5 were higher than those of Fig. **3** for 5% concentration but they were lower for 15% concentration.

This was explained through the variation of split ratio. The split ratio affected the overall performance of the separation by interaction with the inlet concentration.

As the split ratio increased there was a chance for more water molecules to run away from the overflow opening. When water molecules existed at high concentration in the feed the chance was bigger than at low concentration. According to this explanation using double stage hydrocyclone is essential for low concentration and high split ratio but when the concentration is higher, low split ratio must be used.

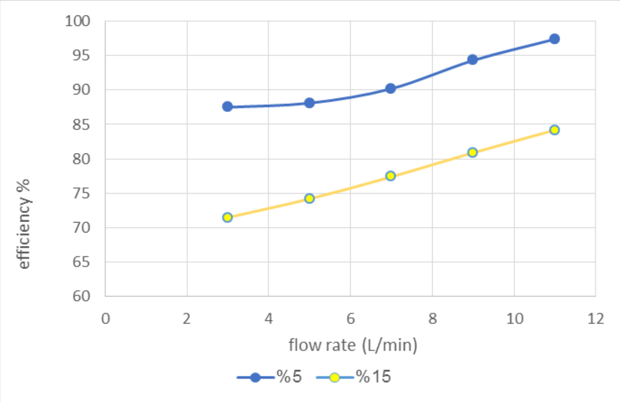

Fig. 4. Effect of flow rate on efficiency at 0.9 split ratio for double stage hydrocyclone

3.3. Effect of Flow Rate on Pressure Drop

Fig. **5** shows the dependence of pressure drop on flow rate for both twice recycled single stage hydrocyclone and double stage hydrocyclone at 5% concentration and 0.9 split ratio. It was clear that both of them had the same pressure drop for all flow rates. The pressure drops related to energy consumption. So, there was no preference between the two modes of operation from energy consumption aspect.

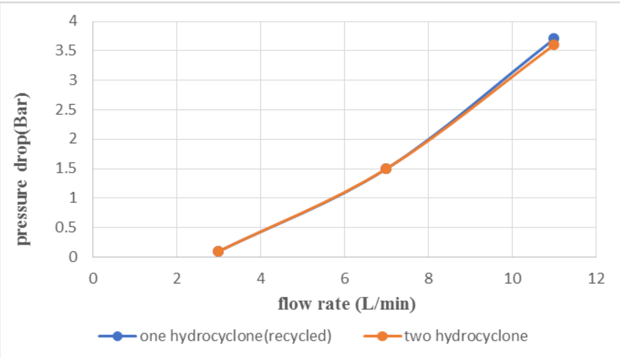

Fig. 5. Effect of flow rate on pressure drop at 5% water feed concentration and 0.9 split ratio

4- Conclusions

From this study it was evident that adopting recycling mode of operation greatly enhanced the separation than using single hydrocyclone. As the cycles increased the enhancement of separation increased. In comparison between the maximum separation efficiencies obtained using twice recycled single stage hydrocyclone 97% and double stage hydrocyclone 97.5% each at 5% concentration, 11 L/min, and 0.9 split ratio, it was clear that the difference between them was insignificant. Furthermore, the pressure drop was also identical.

Therefore, it was concluded that using recycled single stage hydrocyclone was more economical since it reduced the cost of constructing another hydrocyclone.

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مقارنة الاداء بين الهيدروسايكلون احادي المرحلة بعد تدويرالناتج فيه لمرة واحدة وبين الهايدروسايكلون ثنائي المرحلة

مهند عبد الستار رحيم و رغد فريد قاسم

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الخلاصة

يقدم هذا البحث مقارنة الأداء بين الهيدروسايكلون ذي المرحلة الواحدة بعد اعادة تدوير الناتج منه لمرة واحدة فقط وبين الهيدروسايكلون ثنائي المرحلة في فصل الماء من مستحلب الماء / الكيروسين. تضمنت المقارنة عدة عوامل مثل: معدل الجريان الداخل (3،5،7،9،11 لتر\دقيقة)وتركيزالماء الداخل(5 ٪ و 15 ٪ من حيث الحجم) ، ونسبة الفصل (0.1 و 0.9). أظهرت النتائج أن زيادة معدل الجريان وكذلك نسبة الفصل تزيد من كفاءة الفصل لكلا الطريقتين. كذلك أعطى تقليل تركيز الماء الداخل كفاءة عالية لكلى الحالتين ايظا. كانت العملية مع اعادة التدويرللهايدروسايكلون أكثر كفاءة من دورة واحدة لنفس الهيدروسايكلون. كانت أقصى قدر من الكفاءة التي تم الحصول عليها 97 ٪ و 97.5 ٪ بتركيز 5 ٪ ، 11 لتر / دقيقة ، و 0.9 نسبة الفصل للهايدروسايكلون ذي المرحلة الواحدة بعد اعادة التدوير والهايدروسايكلون ثنائي المرحلة على التوالي. كان انخفاض الضغط هو نفسه بالنسبة لطريقتي التشغيل. وخلصنا إلى أن استخدام الهايدروسايكلون أحادي المرحلة المعاد تدويره كان أكثر اقتصادا لأنه خفض تكلفة الهايدروسايكلون الإضافي.

الكلمات الدالة: هايدروسايكلون ، كيروسين ، كفاءة الفصل ، نسبة الفصل