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# Dewatering of Kerosene using Hydrocyclone

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## ABSTRACT

Water/oil emulsion is considered as the most refractory mixture to separate because of the interference of the two immiscible liquids, water and oil. This research presents a study of dewatering of water / kerosene emulsion using hydrocyclone. The effects of factors such as: feed flow rate (3, 5, 7, 9, and 11 L/min), inlet water concentration of the emulsion (5%, 7.5%, 10%, 12.5%, and 15% by volume), and split ratio (0.1, 0.3, 0.5, 0.7, and 0.9) on the separation efficiency and pressure drop were studied. Dimensional analysis using Pi theorem was applied for the first time to model the hydrocyclone based on the experimental data. It was shown that the maximum separation efficiency; at split ratio 0.1, was 94.3% at 10% concentration and 11 L/min flow rate; at 0.3 split ratio, was 70.8% at 10% concentration and 11 L/min flow rate; at split ratio 0.5, was 82.1% at 12.5% concentration and 11 L/min flow rate; at split ratio 0.7, was 70% at 11 L/min, for 5%, 7.5%, and 12.5% concentrations; at 0.9 split ratio was 96.8% at 11 L/min flow rate and 5% concentration. The maximum separation obtained within these ranges of variables was 96.8% at 0.9 split ratio, 11 L/min flow rate and 5% concentration. The maximum pressure drop recorded was 3.6 bar at split ratio 0.1 and 11 L/min flow rate for all concentrations. The correlations obtained by the dimensional analysis were; $E = 17.0161 * Re^{0.1532}$ at split ratio 0.1, $E = 11.885 * Re^{0.1670}$ at split ratio 0.3, $E = 13.393 * Re^{0.1653}$ at split ratio 0.5, $E = 7.4186 * Re^{0.2138}$ at split ratio 0.7, and $E = 35.9590 * Re^{0.0778}$ at split ratio 0.9. As an average $E = 14.8516 * Re^{0.1477}$ for all the studied variables.

**Keywords:** hydrocyclone, water/kerosene emulsion, dewatering, dimensional analysis, Pi theorem.

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# ازالة الماء من الكيروسين باستخدام الهايدروسايكلون

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**الخلاصة**

يعتبر مستحلب الماء في النفط المزيج الاكثر صعوبة في الفصل بسبب تداخل سائلين عديمي الامتزاج , الماء والنفط . يقدم هذا البحث دراسة عن نزح المياه في مستحلب الماء/ الكيروسين باستخدام الهيدروسايكلون. تمت دراسة تأثير عوامل مثل: معدل الجريان الداخل (11,9,7,5,3 لتر / دقيقة) ، وتركيز الماء الداخل في المستحلب (5 ٪,7.5%,10%,12.5%,15 ٪ من حيث الحجم) ، ونسبة التقسيم (0.1 ,0.3 , 0.5 ,0.7, 0.9) على كفاءة الفصل وفرق الضغط. طبق التحليل الابعادي باستخدام نظرية Piلاول مرة لنمذجة الهايدروسايكلون على اساس البيانات العملية. لقد تبين أن اقصى كفاءة فصل عند نسبة تقسيم 0.1 كانت 94.3% لتركيز 10% و معدل جريان 11 لتر/ دقيقة; عند نسبة تقسيم 0.3 كانت 70.8% بتركيز 10% ومعدل جريان 11 لتر/ دقيقة; عند نسبة تقسيم 0.5 كانت 82.1% لتركيز 12.5% ومعدل جريان 11 لتر / دقيقة; عند نسبة تقسيم 0.7 كانت 70% عند معدل جريان 11 لتر / دقيقة ولتراكيز 5%, 7.5%, و12.5; عند نسبة تقسيم 0.9 كانت 96,8٪ عند معدل جريان 11 لتر / دقيقة وتركيز 5٪. اقصى فصل تم الحصول عليه ضمن هذه النطاقات للمتغيرات كان 96,8٪ عند نسبة تقسيم 0.9 , معدل جريان 11 لتر / دقيقة ، وتركيز 5٪. وكان أقصى فرق ضغط مسجل 3.6 بار عند نسبة تقسيم 0,1 و معدل جريان 11 لتر / دقيقة لكل التراكيز. ان العلاقات التي تم الحصول عليها بواسطة التحليل الابعادي كانت عند نسبة تقسيم 0,1 $E = 11.885 * Re^{0.1670}$ , عند نسبة تقسيم 0.3, $E = 17.0161 * Re^{0.1532}$ عند نسبة تقسيم 0.5, $E = 13.393 * Re^{0.1653}$ عند نسبة تقسيم 0.7, $E = 7.4186 * Re^{0.2138}$ عند نسبة تقسيم 0.9 $E = 35.9590 * Re^{0.0778}$. كمعدل $E = 14.8516 * Re^{0.1477}$ لكل المتغيرات التي درست.

**الكلمات الرئيسية:** هايدروسايكلون, مستحلب الماء/الكيروسين, ازالة الماء, التحليل الابعادي, نظرية Pi .

## 1. INTRODUCTION

Separation of water and oil from their mixtures and emulsions has been an active area in water – oil treatment, in industry and in academic research **(Li, 2019)**. Liquid-liquid mixtures, in general and especially water/oil emulsions, are commonly encountered in the chemical and petrochemical industries. Many researches in different fields investigated the separation of oil from water seeking for water treatment or water from oil seeking for oil recovery. For these issues many processes of different mechanisms were suggested to reach this goal such as: flotation, coalescence, electrocoagulation, centrifugation, and cycloning **(Wolbert, Ma and Aurelle, 1995)**. Hydrocyclone is one of the separation equipment that was originally used to separate solid-fluid mixtures efficiently. Later it was experienced to separate liquid-liquid mixtures in oil industry either using dewatering to upgrade the oil products or using deoiling to treat oily water. Hydrocyclones are known for their simple design, ease of operation, low cost, and low power consumption. It has a cylindrical section and a conical section. A centrifugal movement of the inlet liquid mixture established due to the tangential inlet. This is known as free-like vortex that continues to the conical section and leads the heavy liquid to the underflow opening by this action. Another vortex is formed in the core of the hydrocyclone which assists in leading the light liquid to emerge from the overflow opening through the vortex finder tube **(Wolbert, Ma and Aurelle, 1995)**. Extensive studies were published aiming to identify the performance of the hydrocyclone by a mathematical formula. Ghodrat and coworkers **(Ghodrat *et al.*, 2014)** studied numerically the multiphase flow in a hydrocyclone with different configurations using CFD. They showed that the configurations of hydrocyclone size and spigot diameter strongly affected the multiphase flow leading to a different performance. Bram and coworkers **(Bram *et al.*, 2018)** developed a model using CFD based on flow resistance and oil trajectory analysis to optimize the deoiling performance in a hydrocyclone. The results provided a fundamental overview of how the operational conditions affected separation efficiency. Liu and coworkers **(Liu *et al.*, 2018)** designed a magnetic hydrocyclone which superimposed a magnetic field on the centrifugal field in separating oil from water. High separation efficiency 98.1% was achieved by coupling the centrifugal field with magnetic field due to pushing oil droplets to the center of the hydrocyclone and the collision of the droplets with the magnetic particles. Huang and coworkers **( Huang et al, 2018)** conducted a series of experiments and numerical simulations to study the separation performance in liquid-liquid hydrocyclone. The results showed increasing in separation efficiency by increasing the rotation speed. Because of multiple and varied factors affecting the performance of the hydrocyclone, the previous studies based on the numerical manipulation to represent a specific aspect within the range limited by the study. In this research efforts were focused on a new trend of treatment to represent the experimental data by a generalized model that could be formulated through an application of the basic mathematical foundations rather than simulations. Expressing the factors affecting the separation efficiency of the hydrocyclone using dimensional analysis gave the proposed model the reality, flexibility and practicality. The model was tested for its good representation of the experimental data by estimating the correlation coefficient using Excel program. If the model well matched the practical situation, a good approximation to a new design could be reached. Furthermore, the best performance of an existing design could be achieved. The design and operational factors studied in this research were: the split ratio, the inlet water concentration, and the feed flow rate.

## 2. Experimental Work

### 2.1 Materials

The materials used in the research were: kerosene from local market, ethanol (Abs. 100% HPLC grade, Belgium), distilled water (Laboratory grade).

### 2.2 Equipment

Hydrocyclone made of acrylic with dimensions illustrated in Table 1. Feed tank of 20 L capacity. Rotameter (0 - 15 L/min). Pressure gauges (0 - 8 bar). Valves. Homogenizer (Ultra turrax, 10000 rpm, Germany). Two pumps: the first one is QB60, HP 0.5, China. The second one is model stronger water pump streen centrifugal electro-pump, model stp-a5, HP 1.5, China.. UV-spectrophotometer Genesis 10 UV, USA.

**Table 1. The dimensions of the hydrocyclone (Maryam, 2019).**

| Dimension | Hydrocyclone diameter | Inlet diameter | Overflow diameter | Underflow diameter | Cylindrical section length | Vortex finder length | Angle of cone | Thickness |
|---|---|---|---|---|---|---|---|---|
| Value, cm | 4 | 0.57 | 0.8 | 1 | 8 | 1.3 | $9^o$ | 1 |

### 2.3 Procedure

The two pumps were connected in series to the hydrocyclone as shown in Fig.1. Samples of water/kerosene emulsions of the adjusted initial water concentration were prepared by mixing water with kerosene in the feed tank using the homogenizer at 10000 rpm for 30 min. The initial concentrations were: 5%,7.5%, 10%, 12.5%, and 15% water by volume. The inlet flow rate was changed for each concentration as follows: 3, 5, 7, 9, and 11 L/min. The split ratio which is defined by the ratio of the overflow flow rate to the inlet flow rate $\frac{Q_o}{Q_i}$ were also changed for each set of experiments as follows: 0.1, 0.3, 0.5, 0.7, and 0.9. Samples from the overflow and the underflow were taken for each experiment and analyzed using UV-spectrophotometer for water content.

## 3. Results and Discussion

### 3.1 Effect of feed flow rate on the separation efficiency

The grade of separation of light and heavy products is limited in that it is possible to obtain one pure product, but never two. For example, when solid particles are extracted from their suspension, the isolated solids must have the ability to flow from the underflow gap transferring by some of the liquid. Similarly, as already noted, the separation of two immiscible liquids one pure liquid can be obtained, but not both **(Bradley,1965).** Figure 2 shows the effect of inlet flow rate on the separation efficiency for different initial water concentrations at split ratio 0.1. It was observed that the efficiency increased with increasing flow rate for all concentrations. This was interpreted by increasing the centrifugal force with increasing feed flow rate which led to increase the free-like vortex that carried the heavier liquid downward to the underflow. So, the separation was more efficient at high flow rates. This is in agreement with Hosseini et al. **(Hydrocyclone *et al.*, 2015).** The separation efficiency had no regular behavior with the initial water concentration. It was noticed that the minimum 5% and the maximum 15% water concentrations had a comparable curve. This was due to the low value of the split ratio i.e. the narrow opening to discharge the overflow liquid (the lighter liquid – kerosene). The narrow opening minimized the chance for water drops to escape from the overflow whether the concentration of water was high or low. So, the separation efficiency was of high values especially at high flow rates. The maximum separation efficiency obtained at split ratio 0.1 was 94.3% at 10% concentration and 11 L/min flow rate.

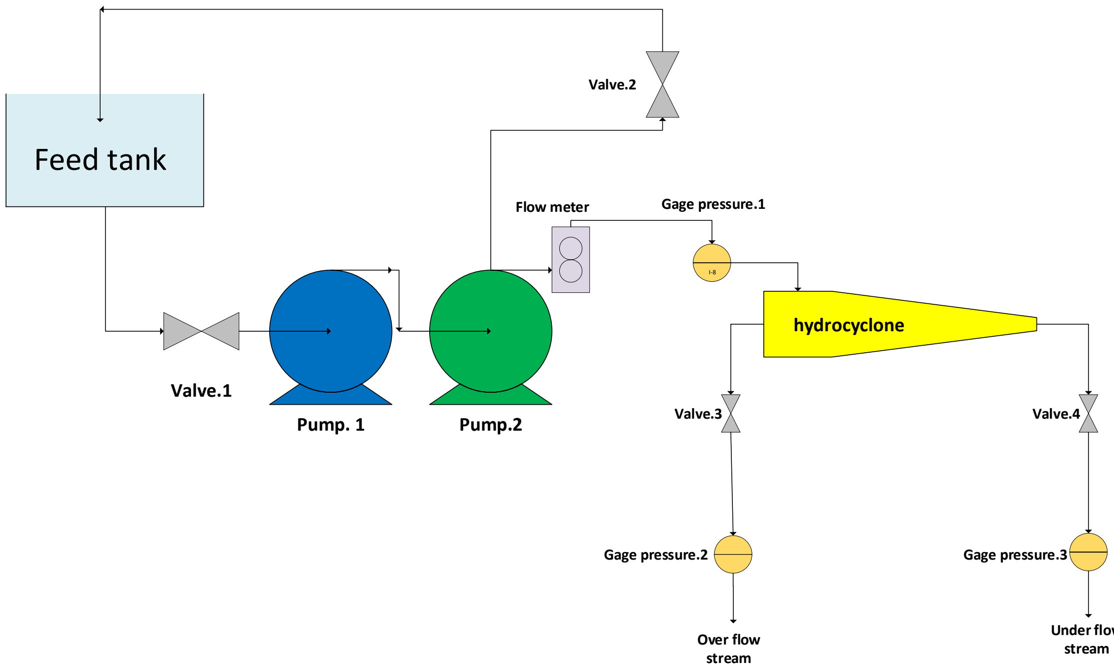


**Figure 1.** Hydrocyclone set-up.

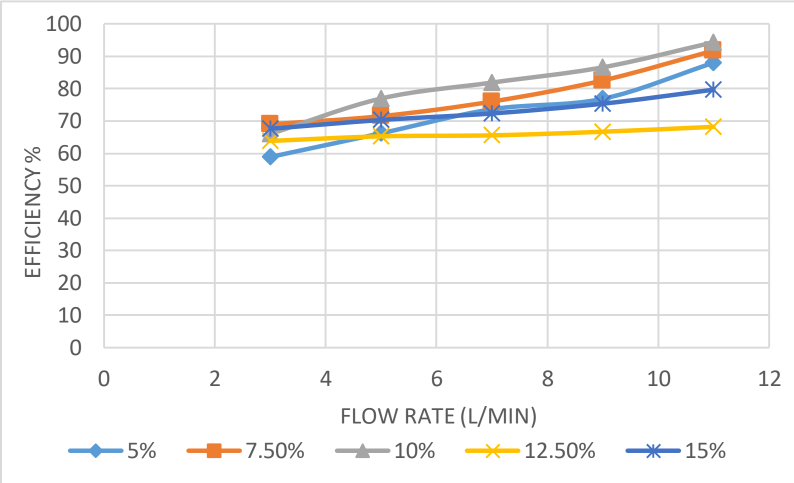


**Figure 2.** Effect of feed flow rate on the separation efficiency for different inlet water concentrations at split ratio 0.1.

**Fig.3** shows the separation efficiency as a function of the inlet flow rate for different initial water concentrations at split ratio 0.3. It was observed that the curves were more divergent from each other for different water concentrations than the curves in **Fig. 2** especially at low flow rates. At high flow rates they were very close to each other. This might be explained by the wider overflow opening than in the previous case of **Fig.2**. At low flow rates the chance for water drops to escape from overflow was more expected because of low centrifugal force that gave the tiny drops this chance. So the separation efficiency differed noticeably for different concentrations. As the concentration increased the separation efficiency increased. This could be attributed to the increased coalescence of water drops as the concentration increased. Drops coalescence produced larger drops that facilitated the separation. As the flow rate increased, high centrifugal force generated that forced water drops to discharge through the underflow. In this case the concentration was of little effect, so the curves were convergent. Because of complex hydrodynamics as well as many factors affecting the operation of the hydrocyclone, some irregular behaviors found here and there. It was also observed that the magnitudes of the separation efficiency as a whole were lesser than those in Fig.2. The maximum separation efficiency at split ratio 0.3 was 70.8% at 11 L/min and 10% water concentration. It was thought that the separation efficiency decreased with increasing split ratio. So, a balance between water concentration in the feed, the flow rate, and the split ratio must be done to obtain high separation efficiency. This was in agreement with Liu, Yan, and Gao**(Liu, Yan and Gao, 2018).**

Even with a good control solution, the hydrocyclone efficiency can still be very sensitive to variations in feed flow rate that can be influenced by upstream separation processes. The flow rate is equally important for the separation quality of the hydrocyclone. If the flow is insufficient through the hydrocyclone, the swirling motion within it will not occur or the velocity will not be sufficient. If this happens, the centripetal force will not be able to separate the lighter from the heavier fluid **(Durdevic, Pedersen and Yang, 2017)**.

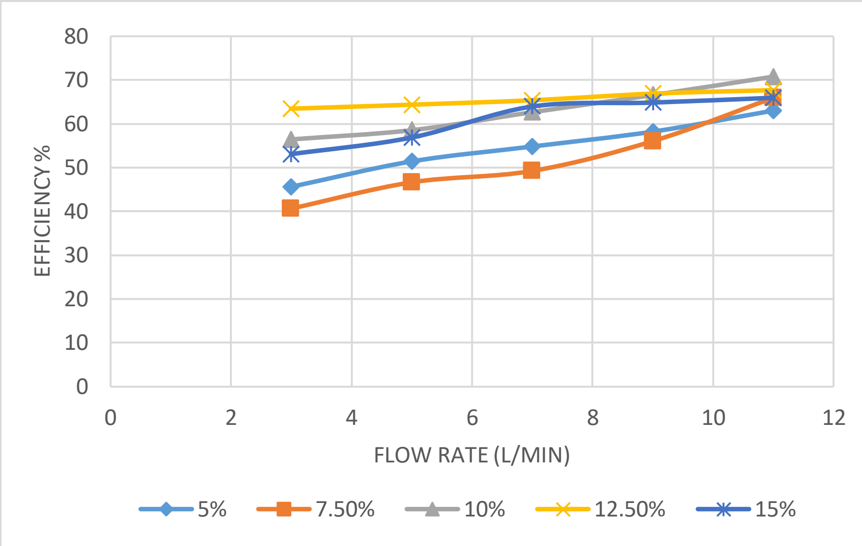


**Figure 3.** Effect of feed flow rate on the separation efficiency for different inlet water concentrations at split ratio 0.3.

**Fig.4** shows more linear and divergent curves of separation efficiency especially for water concentration 12.5% which showed the maximum separation efficiency 82.1% at split ratio 0.5 and 11 L/min flow rate. Again, the values of separation efficiency were lesser than those in Fig. 2 but higher than those in **Fig.3**. At split ratio 0.5 there were equal openings of both the overflow and the underflow; therefore, the density difference governed this situation by letting the lighter liquid to go through the overflow and the heavier through the underflow. Changing water and oil flow rate can upset hydrocyclone performance and results in changing the water cut underflow**(Mathiravedu, Limited and Mohan, 2010)**. **Fig.5** shows different case by the appearance of high nonlinear curves with obvious peaks at mid flow rates. Also, the values of the separation efficiency were lesser than those in **Fig. 4** but were comparable with those in Fig.3. It was noticed that whether the split ratio was 0.3 or 0.7 the separation was less efficient than other split ratios. Therefore, the dependence of the separation efficiency on the split ratio was believed to be nonlinear. As mentioned previously this would give the chance for more water drops to run through the overflow especially when the underflow was of smaller opening. This case might cause some mixing between phases near the tip of the vortex finder which let more water drops to find their way from the overflow. The maximum separation efficiency at split ratio, 0.7 was about 70% at 11 L/min, for 5%, 7.5%, and 12.5% water concentrations. **Fig.6** shows the highest values of separation efficiency among the previous sets of experiments. The curves were almost horizontal except for 5% water concentration indicating that the flow rate had no effect on the separation efficiency at the concentrations more than 5% for the split ratio 0.9. This was because of the large opening of the overflow which gave good opportunity for the lighter liquid – kerosene to flow through.

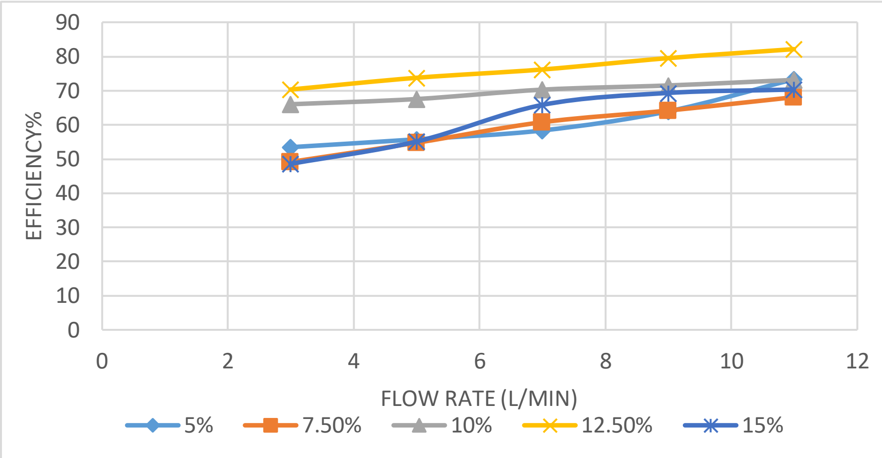


**Figure 4.** Effect of feed flow rate on the separation efficiency for different inlet water concentrations at split ratio 0.5.

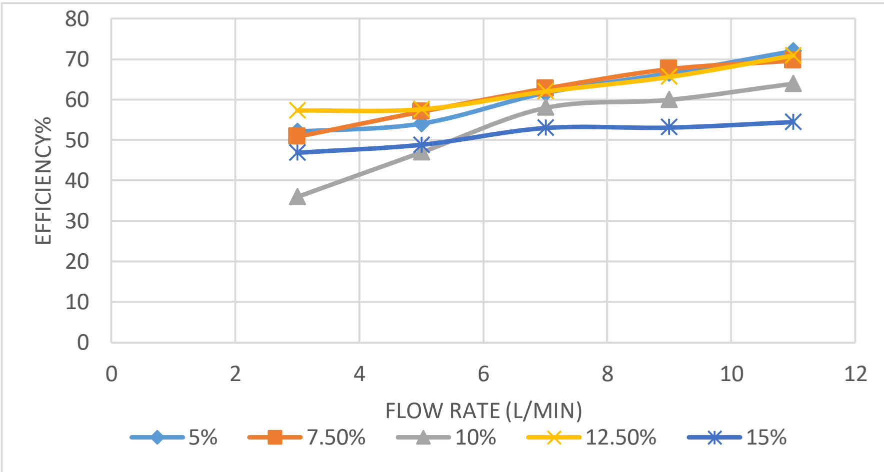


**Figure 5.** Effect of feed flow rate on the separation efficiency for different inlet water concentrations at split ratio 0.7.

For water concentration 5% the flow rate had obvious effect on the separation efficiency. The higher the flow rate the higher the swirling movement was in the hydrocyclone that led a lot of water drops to the underflow. The maximum separation efficiency was 96.8% at 11 L/min at split ratio 0.9.

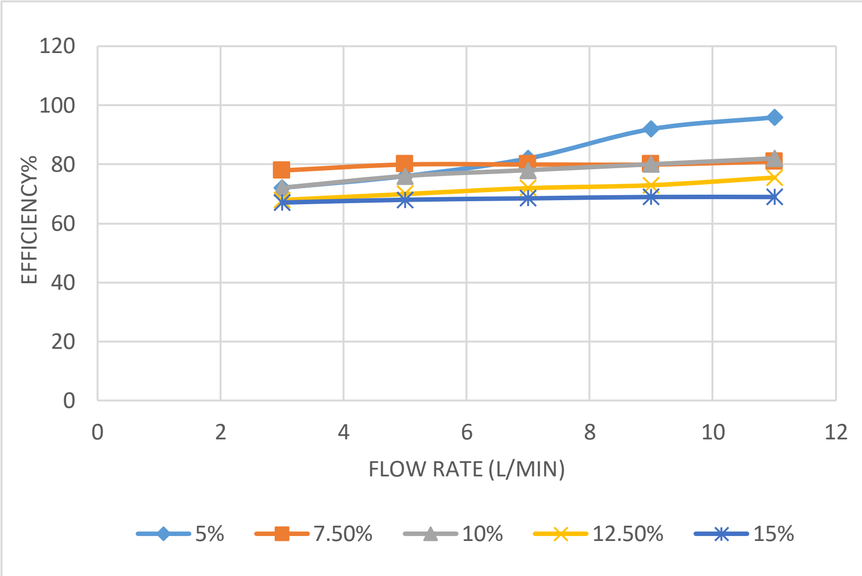


**Figure 6.** Effect of feed flow rate on the separation efficiency for different inlet water concentrations at split ratio 0.9.

### 3.2 Effect of split ratio on separation efficiency

The effect of flow rate was obvious from the previous section. Increasing flow rate enhanced the separation efficiency for a specific initial concentration. So **Fig. 7** shows the effect of changing the split ratio on separation efficiency for different water concentrations at the maximum feed flow rate 11 L/min. It was clearly noticed that the split ratio had strong effect on the separation efficiency at its terminal values i.e. 0.1 and 0.9 for different water concentrations. At these split ratios the curves were more divergent at 0.9 than at 0.1. This was explained by the large opening of the overflow at split ratio 0.9 which affected the separation efficiency for different water concentrations. The maximum obtained efficiency was 96.8% for 5% water concentration at split ratio 0.9 as mentioned before. This indicated that the lower the concentration the higher the separation efficiency and the purer the kerosene was. The mid values of the split ratio 0.3, 0.5, and 0.7 exhibited lower efficiencies with 0.3 and 0.7 being the lowest according to the discussion presented previously. From this discussion the split ratio must be low for high water concentrations and high for low water concentrations to achieve the best separation.

### 3.3 Effect of inlet flow rate on pressure drop

The cyclone pressure drop has three main components including (1) inlet loss, (2) cyclone friction loss, and (3) outlet loss. Of all these, the loss by friction is of great significance such as the loss at the vortex finder due to contraction **(Demir, Karadeniz and Aksel, 2016)**. **Fig. 8** shows the effect of inlet flow rate on the pressure drop at different split ratios. From the figure it was clear that the pressure drop increased with increasing inlet flow rate due to increasing the centrifugal force and swirling movement. This is in agreement with the findings of Ficici, Ari, and Kapsiz **(Ficici, Ari and Kapsiz, 2010) .**

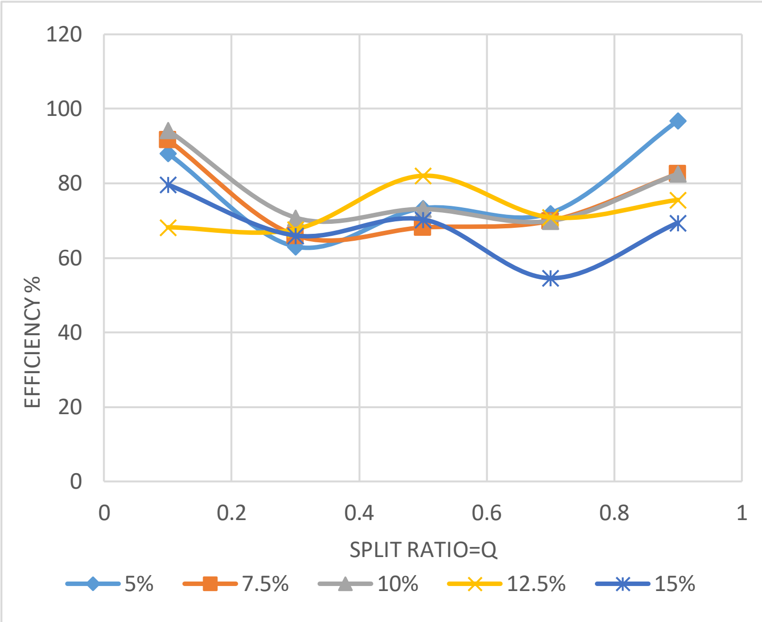


**Figure 7.** Effect of changing split ratio on efficiency at different water feed concentrations for (11 L/min) feed flow rate.

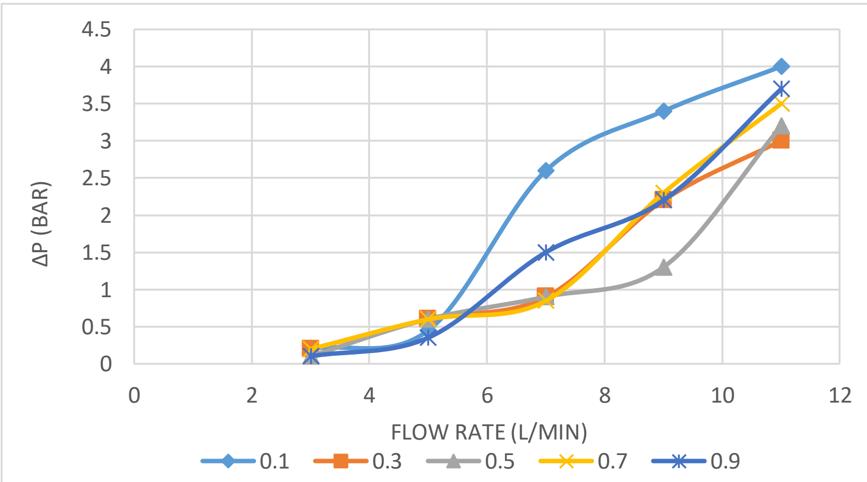


**Figure 8.** Effect of inlet flow rate change on pressure drop at different split ratios.

It was also clear from **Fig. 8** at low flow rates the pressure drop was the same for all split ratios but when the flow rate increased the pressure drop became different for different split ratios and gave the highest pressure drop 3.6 bar for the lowest split ratio 0.1. This was because of the narrow opening that made the outlet loss significant.

## 4. Theoretical Aspects

### 4.1 Mathematical Models of Hydrocyclone

Many attempts were published to model the hydrocyclone. Some researchers used dimensional analysis, others used computational fluid dynamics (CFD) to reach this goal **(Delgadillo and Rajamani, 2005)**. Plitt **(Fredrik, 1977)** launched a series of experiments with fine silica in small cyclones, linking his data with that of Lynch and coworker to derive a hydrocyclone computational model, he concluded that the slope of the reduced efficiency curve was not constant **(LISTER, 1984)** and proposed an expression for pressure drop (Δp) and split ratio (S) as follows:

$$\Delta p = \frac{1.88\ Q^{1.78}\ \exp(0.0055\ Cv}{Dc^{0.37}\ Di^{0.94}\ (L-l)^{0.28}\ (Du^2+Do^2)^{0.87}}$$ **(M.A.Z. Coelho And R.A. Medronho, 1992)**

$$S = \frac{1.9(Du/Do\ )^{3.31}\ (L-e)^{0.54}(Du^2-Do^2)^{0.36}\exp(0.0054\ Cv)}{H^{0.24}\ Dc^{1.11}}$$ **(M.A.Z.Coelho and R.A. Medronho, 1992)**

Ian.c smith (Fredrik, 1977) developed an expression for pressure drop in hydrocyclone by using dimensional analysis with nom-linear regression as follows:

$Cpiu = 1.27\ Re^{0.193}$ (Fredrik, 1977)

$Cpid = 0.67\ Re^{0.233}$ (Fredrik, 1977)

Where:

Cpiu: is the inlet pressure drop at upstream.

Cpid: is the inlet pressure drop at downstream.

### 4.2 Dimensional Analysis Using Pi Theorem

It is essential for the designer as well as for the operator to be able to deal with the effective variables and parameters of hydrocyclone qualitatively and quantitatively in order to reduce cost and effort. To reach this goal, the operating parameters and variables should be compiled in such a way that give realistic expressions of the maximum obtainable efficiency and minimum pressure drop. One of the well-known methods is the dimensional analysis. Dimensional analysis offers a method for reducing complex physical problems to the simplest (that is, most economical) form prior to obtaining a quantitative answer **(Ain, 2001)**. Buckingham's or $\pi$ – theorem states that for a system of n variables with k quantities which are dimensionally independent, there are n – k dimensionless parameters that are appropriately defined the system.

In this regard, the most effective variables define the hydrocyclone are:

$C_i, C_o\ , u_i, d_o, d_i, \rho, \mu, and \Delta p$

Where:

$C_i$ is the initial water concentration

$C_o$ is the overflow water concentration

$u_i$ is the inlet velocity
$d_o$ is the overflow opening diameter
$d_i$ is the inlet opening diameter
$\rho$ is the fluid phase density
$\mu$ is the fluid viscosity
$\Delta p$ is the pressure drop

If $C_o$ and $C_i$ are combined in one dimensionless group representing the separation efficiency then it will express the outcome of the system in addition to $\Delta p$.

4.1.1 Separation efficiency correlation

According to pi-theorem, the correlation of the separation efficiency may be of the form:

$$f\left( {}^{C_o}/_{C_i}, u_i, d_o, d_i, \rho, \mu \right) = 0 \quad \ldots\ldots (1)$$

Now let $\pi$ stands for the products of the dimensionless groups formed by these parameters, it follows that $\pi$ must equals 1. So:

$$\pi = \left( {}^{C_o}/_{C_i} \right)^{\propto} (u_i)^{\beta} (d_o)^{\gamma} (d_i)^{\delta} (\rho)^{\epsilon} (\mu)^{\sigma} \quad \ldots\ldots (2)$$

Taking the basic units of length, mass, and time to be represented by L, M, and T, respectively, then writing equation (2) by these symbols, $\pi$ can be represented as follows:

$$\pi = (1)^{\propto} (L T^{-1})^{\beta} (L)^{\gamma} (L)^{\delta} (M L^{-3})^{\epsilon} (M L^{-1} T^{-1})^{\sigma} = 1 \quad \ldots\ldots (3)$$

For M: $\epsilon + \sigma = 0$ ………………………….. (4)

For L: $\beta + \gamma + \delta - 3\epsilon - \sigma = 0$ ……………. (5)

For T: $-\beta - \sigma = 0$ …………………………. (6)

From (4): $\sigma = -\epsilon$ ……………………………. (7)

From (6): $\sigma = -\beta$ ……………………………. (8)

So: $\epsilon = \beta$ ……………………………………. (9)

From (5): $\epsilon + \gamma + \delta - 3\epsilon + \epsilon = 0$

$\gamma + \delta - \epsilon = 0$

$\delta = \epsilon - \gamma = \beta - \gamma$ …………………………. (10)

So:

$$\pi = \left( {}^{C_o}/_{C_i} \right)^{\propto} (u_i)^{\beta} (d_o)^{\gamma} (d_i)^{\beta-\gamma} (\rho)^{\beta} (\mu)^{-\beta}$$

$$\pi = \left( {}^{C_o}/_{C_i} \right)^{\propto} (\rho\, u_i\, d_i/\mu)^{\beta} (d_o/d_i)^{\gamma} \quad \ldots. (11)$$

So: $C_o/C_i = F(\,Re, split\ ratio)$

If the split ratio is fixed for a set of experiments, the only independent variable is the Reynolds number, so:

$C_o/C_i = F(Re)^{\beta}$

So: $C_o/C_i = k * Re^{\,\beta}$ ……………………... (12)

To determine the constants, the logarithms of both sides are taken:

$\ln(\ C_o/C_i) = \ \beta \ln(Re) + \ln(k)$ ………………….. (13)

Equation (13) is linear equation so ( $\beta$ ) and (k) values could be estimated by plotting ln( $C_o/C_i$) versus ln (Re) using Excel program for each split ratio. The program is provided with analytical statistics that assessed the resulted correlations as follow:

1- For split ratio = 0.1

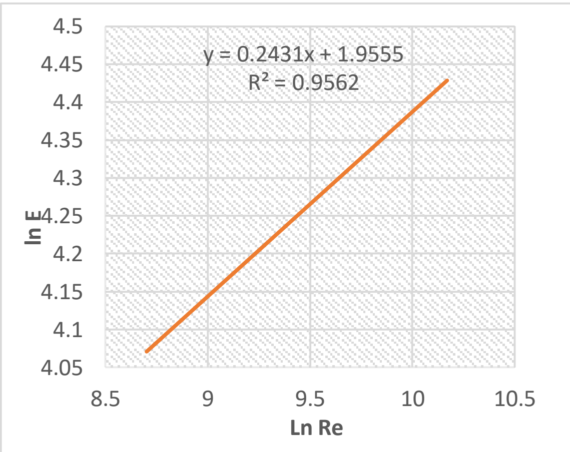


**Figure 9**. Effect of Re on Efficiency at split ratio=0.1 and 5% water feed concentration.

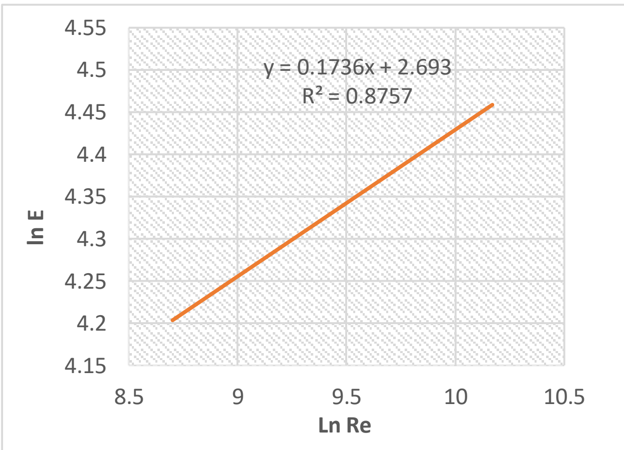


**Figure 10**. effect of Re on Efficiency at split ratio=0.1 and 7.5% water feed concentration.

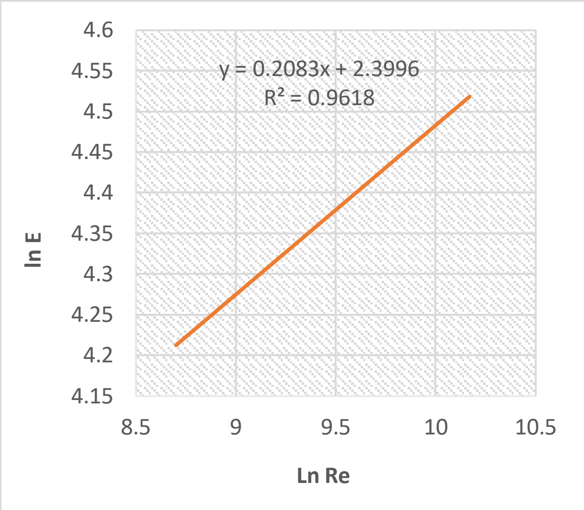


**Figure 11**. Effect of Re on Efficiency at split ratio=0.1 and 10% water feed concentration.

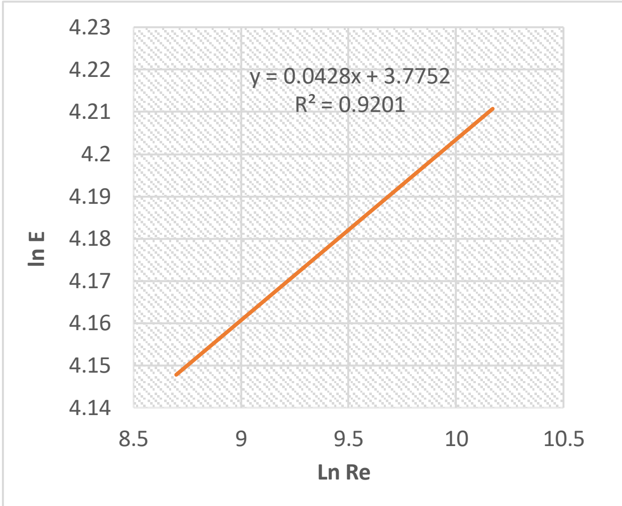


**Figure12**.Effect of Re on Efficiency at split ratio=0.1 and 12.5% water feed concentration.

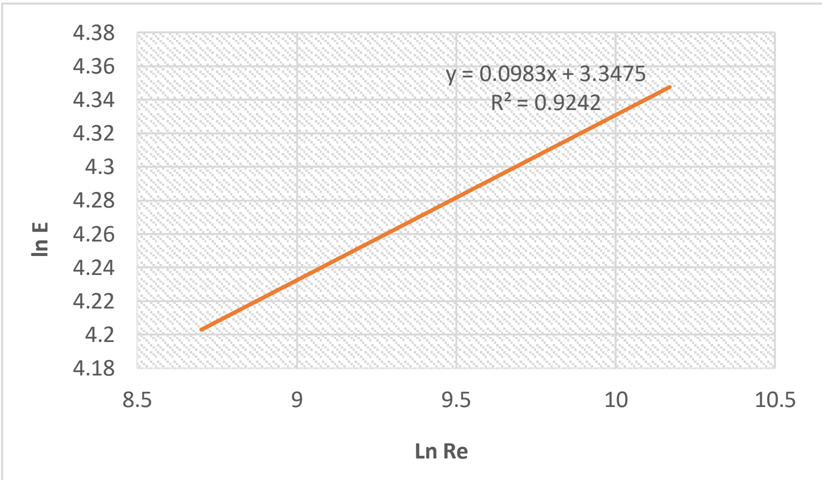


**Figure 13.** Effect of Re on Efficiency (E) at split ratio=0.1 and 15% water feed concentration.

From these figures the average of the constants is:

$\beta$ = 0.1532 , Ln(k) = 2.83416 ⟶ k = 17.0161

Equation (12) becomes:

$$C_o/C_i = 17.0161 * Re^{\,0.1532}$$

Or $E = 17.0161 * Re^{\,0.1532}$

The resulted equation was of significant correlation coefficient, so by the same manipulation, correlations were obtained for all split ratios. They are listed in Table 2.

**Table 2.** The resulted correlations for each split ratio studied in the research.

| Split ratio | Resulted model |
|---|---|
| 0.1 | $E = 17.0161 * Re^{0.1532}$ |
| 0.3 | $E = 11.885 * Re^{0.1670}$ |
| 0.5 | $E = 13.393 * Re^{0.1653}$ |
| 0.7 | $E = 7.4186 * Re^{0.2138}$ |
| 0.9 | $E = 35.9590 * Re^{0.0778}$ |

As an average correlation:

$$C_o/C_i = E = 14.8516 * Re^{0.1477}$$

The average correlation provided a good approximation to the designer or the operator of the factors already affecting the performance of the hydrocyclone.

## 4. CONCLUSIONS

The present research is a study of dewatering of water / kerosene emulsion using hydrocyclone. The effects of factors such as: feed flow rate, inlet water concentration of the emulsion, and split ratio on the separation efficiency and pressure drop were studied. Dimensional analysis using Pi theorem was applied to model the hydrocyclone based on the experimental data. The study revealed that the hydrocyclone was very efficient for water-oil separation. The three factors studied can be ordered as their effect on the separation efficiency as follows: the inlet flow rate, the split ratio, and the inlet water concentration. The maximum separation efficiency obtained was 96.8% at inlet flow rate 11 L/min, split ratio 0.9 and water concentration 5%.

It was concluded that a balance must be done for the best separation. For high concentrations the split ratio must be low and for low concentrations high split ratio must be used to get the best separation efficiency.

Dimensional analysis based on systematic mathematical treatment was adopted to model the hydrocyclone within the scope of this study. The correlations obtained were analyzed by using Excel program and they well fitted the experimental data. They illustrated that Reynolds number was of great effect on the separation efficiency. The average correlation represented the performance of the hydrocyclone was:

$$C_o/C_i = E = 14.8516 * Re^{0.1477}$$

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