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The Effects of Liquid Density and Impeller Size with Volute Clearance on the Performance of Radial Blade Centrifugal Pumps: An Experimental Approach

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Abstract:- This study was carried out to experimentally investigate the effect of impeller size with volute clearance and liquid density on the performance of radial blade centrifugal pumps. Three impeller sizes of 121.54mm, 109.38mm and 97.23mm with respective volute clearance of 6mm, 12mm and 18mm were considered, and five different liquid blend which comprise of water, two liquids that are denser than water and two other liquids that are less-dense than water (with respective liquid densities of: 1197 kg/m^3, 1097 kg/m^3, 1000kg/m^3, 898.2 kg/m^3 and 798.4 kg/m^3). In the experimental set-up, the pump flow capacity were varied from 12m^3/hr to 62m^3/hr at interval of 5m^3/hr and the corresponding pump power consumption, attained pump head were recorded and pump efficiency were determined. Microsoft excel was used to evaluate the trend, performance trend was used to develop the pump performance model showing the relationship between the various parameters. The results from the investigation revealed that with the various impeller sizes of 121.54mm, 109.38mm and 97.23mm of respective volute clearance of 6mm, 12mm and 18mm, the attained optimum efficiency were 74.42%, 54.78 and 33.54% respectively at a correspondence optimum pump head of 23.66m, 20.60m and 18.87m. The results also showed that there is a direct relationship between pump power consumption and process liquid density, while showing an inverse linear relationship between the pump instantaneous start up power and impeller diameter. It was therefore concluded among others that liquid with higher density will usually require higher power to initiate and maintain flow at constant flow rate and impeller size. It is then recommended among others that pump designers, application engineers and users of centrifugal pumps should consider possible increase in pump power consumption when working with a process application that has higher tendency for dynamic increase on the process fluid density.

I. INTRODUCTION

A centrifugal pump is simply a mechanical device designed to move liquid by means of the transfer of rotational energy from the driven rotor called the impeller to the working fluid. Over the years, there has been progressive studies in the field of centrifugal pump internal flow mechanism with the sole aim of understanding how to improve on the design and performance of centrifugal pump, these advances have necessitated the possibilities for pump designers to carry out analysis of the various flow conditions and phenomena that occurs inside the centrifugal pump (Ahmed, 2015).

The study by Yang *et al.*, (2012) revealed that traditionally, fluid flow through centrifugal pumps are exceedingly complex, involving curvature, system rotation, separations, turbulence, unsteadiness and secondary flows, Gonzalez *et al.*, (2002) stated that the geometry of the flow is often asymmetric due to the volute shape, as a result, these relative motion between the impeller and volute characteristic usually generates an unstableness which often affects not only the overall pump performance, but also responsible for some inherent pressure fluctuations, hydraulic noise and unforeseen hydrodynamic forces. (Jafarzadeh, *et al.*, 2021). The impeller design particularly deals with the number of blades, the vane angle, blade height, width and the blade structure.

Several studies have shown that the performance of centrifugal pump depends mainly on the process interactions within the internal features of the centrifugal pump wet-end, i.e., impeller, volute and diffuser, these usually predicts the output characteristics of the fluid flow at the pump internal. (Cheah *et al.* 2018) Asymmetric flow structures and a transient asymmetric flow force distribution are usually present within the pump impeller. That has always resulted in operating point-dependent on hydrodynamic forces, which cannot be compensated with a mare mechanical imbalance (Caridad & Kenyery 2005). Higher levels of these transient characteristics are usually detrimental to the pump efficiency and operational smoothness while in practice, these pressure fluctuations in most extreme cases can possibly be manipulated to diminish by some calculated modifications of the pump internal and blade features, and the pump efficiency is made to improve from the former (Carravetta *et al.*, 2011). However, in actual practice, changes on the process parameter away from that considered during the pump design and selection usually may present significant fluctuations on the pressure and velocity field even at the design point (Choi *et al.*, 2006).

Generally, since centrifugal pumps are usually expected to operate effectively over a wide range of flow application regime, and the flow within the centrifugal pump is seen to be with rotating stall, characterized by the presence of distinct cells of flow separations on the impeller circumference, rotating at a fraction of the impeller revolution rate, and these are seen as a result of the complexity of the flow structure within the impeller- volute body, the part-load flow in radial blade centrifugal pumps could poses a major challenges for accurate flow and performance prediction.

The Centrifugal pump which is usually designed and procured, installed and expected to work efficiently over a defined range of flow and operating conditions. But in actual service, the pump which was actually designed and produced to operate efficiently within a given range of flow regime and process conditions as was considered during the pump design using a defined fluid and process conditions. Actual operations of the pump at the field have shown that most centrifugal pumps in operation faces variant process operating conditions which are not always in agreement with the actual design conditions of the Pump, most critical operations have been at a range outside the design considerations of specific applications, thus in most critical cases, these has necessitated some experienced field operators and maintenance engineers to adopt to making some critical field modifications on the pump internal (wet end) in order to ensure and maintain the pump availability to sustain operation and production, one workable approach adopted by experienced operators and maintenance team to improve on the performance of centrifugal pumps under such drastic changes on the process conditions has been by modifications of the impeller feature, and the outcome of a well calculated impeller modifications have actually improved the pump performance and efficiency by reducing some cross flow, reducing some secondary incidence flows, and decrease backflow areas at the impeller outlets. Since impeller vane (blade) features are known be among the notable design parameters that predicts the performance of the centrifugal pump, as it predicts the internal flow field and the overall performance of the centrifugal pump.

Predicting the pump performance constitutes an important challenge when a produced pump is expected to fit into a given installation and to effectively perform over a wide range of operating conditions, These challenges has been very difficult since we are expected to predict the pump performance at variable operating conditions under variant process operating condition etc. most especially since modifications of the pump internal have always been adopted by pump users with the sole aim of improving the pump performance and efficiency in most critical operations with variable process fluid conditions, thus a proper understanding of the pump internal flow mechanism and characteristic at various operating conditions at both design and off-design conditions are usually required.

Since field experience has shown that some well calculated modification of the pump impeller feature usually have shown some significant influence on the stability of the pump operation. Outcomes of such field modifications on the flow elements are not yet fully understood and well documented and made available for most pump users, thus in most cases are usually a costly trial and error approaches in solving the problems associated with the pump process fluid instability at the field. However, a detailed comparison of the transient characteristics of a radial blade centrifugal pump with respect to operational changes on the process fluid density and impeller volute clearance has not been fully exhausted and presented to the knowledge of this study in open literatures. Thus, this study is intended to further experimentally investigate the overall performance of a radial blade centrifugal pump under variant blade conditions with respect to variant process fluid density over a full range of the pump capacity. Adequate information for such operations are not always available to evaluate the adequacies of such pump performance at these variable process density conditions. Thus, the need to seek to develop some reference guide for the expected outcome of such impeller to volute modifications which is the main expectations from this work. The study was intended to experimentally investigate the overall performance of the centrifugal pump with respect to changes on the process fluid density with changes on the impeller size and volute clearance of radial blade centrifugal pump, thus, the study objectives includes:

- To determine the effect of changes in process fluid density and impeller size and volute clearance on the performance of radial blade centrifugal pump in terms of power consumption using experimental approach.
- To determine the effects of changes in impeller size with volute clearance and change in fluid density on the radial blade centrifugal pump performance in terms of the pump attained head and capacity using experimental approach.
- To determine the effects of changes in impeller size with volute clearance and change in fluid density on the radial blade centrifugal pump performance in terms of the pump Efficiency using experimental method

II. MATERIALS AND METHODS

Two key design elements of a centrifugal pump that were selected for an examination of their effects on the pump performance are: impeller diameter with volute clearance and process fluid density. Figure 1 showed the rig arrangement of the experimental set-up for the study.

A. *Test Objective: -*

To conduct a practical test on a radial blade centrifugal pump, as to ascertain the pump performance at various operating conditions with the different impeller size with its volute clearance and fluid densities.

B. *Experimental Procedure: -*

The major variables were considered dependent variables which are the pump performance parameters and they include pump power, pump efficiency and pump head, and the independent variable includes, impeller size, fluid density and flow rate, The experimental study considered three different impeller sizes: 121.54mm, 109.38mm and 97.23mm which was 6mm, 12mm and 18mm volute clearance. Five liquid bled of different densities which comprised of water, two liquid blend of hydrocarbon mixture that are less dense than water and another two other liquid blend that are denser than water, the simulation procedure is as follows:

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- Pump of impeller size: 121.53mm (6mm volute clearance) was selected from the unit operation and the liquid blend with highest density (1197 kg/m^3) was selected as the inlet start-point fluid.
- The pump power consumption and attained pump head were monitored while the pump discharge flow rate was varied from 12m^3/hr, 17m^3/hr, 22m^3/hr, 27m^3/hr…….67m^3/hr. at intervals of 5m^3/hr. For the 12 different data points while the corresponding pump power consuption were recorded and tabulated.
- Procedure 2 was repeated by installing an impeller of 109.38mm diameter which has 18mm impeller – volute, pump power consumption and attained pump head were monitored and recorded with changes in flow rate within the same interval of 12m^3/hr, 17m^3/hr, 22m^3/hr, 27m^3/hr…….67m^3/hr.
- Procedure 3 was also repeated using a 97.23mm diameter impeller which has 18mm impeller- volute clearance, pump power consumption and attained head pump and maximum capacity was monitored and recorded, the flow rate was within the same interval of 12m^3/hr, 17m^3/hr, 22m^3/hr, 27m^3/hr…….67m^3/hr.
- Procure 2, 3 and 4 above were repeated for the remaining four liquids (1097 kg/m^3, 1000kg/m^3, 898.2 kg/m^3 and 798.4 kg/m^3) and the corresponding values of required variables were recorded and tabulated
- Finally, pump efficiency was calculated for each of test conducted with each of the impeller side and fluid densities, the corresponding values of needed variables were recorded and tabulated.

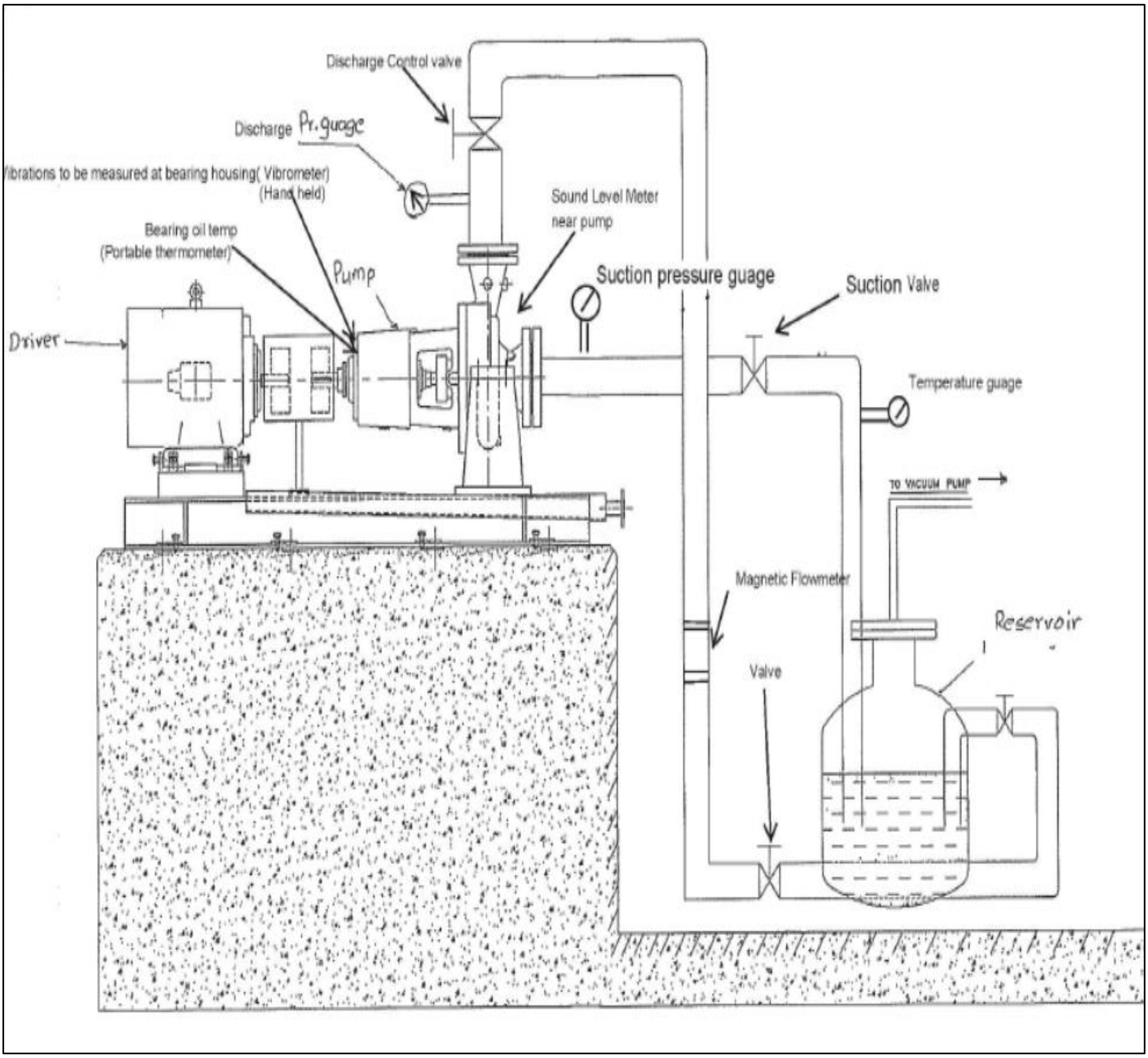

Fig 1: Experimental Test Rig Set-up (Schematic)

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III. RESULTS AND DISCUSSIONS

A. Results and Discussions on Effect of Impeller Size and Fluid Density on Pump Power

➢ *Experimental Relationships Between Fluid Flow Rate and Pump Power for the Five Fluid Samples When Operating with Impeller Size of 121.54mm with 6mm Volute Clearance.*

Figure 2 showed the graphs of the relationship between fluid flow rate and pump power for the five fluid samples (1197 kg/m^3, 1097 kg/m^3, 1000kg/m^3, 898.2 kg/m^3 and 798.4 kg/m^3) while operating with pump impeller size of 121.54mm with 6mm volute clearance. The pattern of the trend line slopping upwards from left to right implying that there is direct and positive relationship between fluid flow rates and pump power requirement for all the five different liquids considered. This also implies that increased pump power is needed to generate high fluid flow rate. Thus, when higher fluid flow rate is required, pump with higher power capacity will be required irrespective of the nature or density of fluid involved.

The graphs also revealed that the trend line of the liquids with highest density designated as series-5 positioned on the topmost part of the chart followed while the denser liquid designated as series-4 all above the trend line of water which designated as series 3 while the two other liquids that are less dense than water all lined up sequentially below the trend line of water and they are designated as series-2 and series-1 respectively. These trend line patterns shows that for a given fluid flow rate, denser liquid usually consume more power than less dense liquid. This could also be attributed to the facts that denser liquids are more viscous, more heavier and with more intermolecular force of attractions than less dense liquids, Hence, more energy is required to initiate flow in heavier liquids compare to lighter fluid. Therefore, organizations or application engineers that are working with denser liquid would deploy pump with higher power capacity to initiate a particular flow rate as compare to another process application that is working with less dense fluid.

For the first liquid with the highest density in the series and designated as Series-5 in the chart, a model was developed which mathematically represent the relationship between pump power and fluid flow rate. The model is expressed as:

$$\mathbf{y = 0.0466x + 1.787} \qquad \textbf{(1)}$$

where y represents the pump power consumption and x is the fluid flow rate. Replacing y with P and x with Q for more convenient we have equation 1 expressed as:

$$\mathbf{P = 0.0466Q + 1.787} \qquad \textbf{(2)}$$

The model, as seen in equation 2, is a simple direct and linear equation. The slope of the model also being the coefficient of Q, is 0.0466 while the intercept on the pump power axis is 1.787kw. Technically, the slope of the model implies that for every one unit increase in fluid flow rate requires 0.0466 unit increase in pump power consumption to pump the liquid designated as series-5. Also, the intercept implied that the initial power required to initiate flow of the liquid designated as series-5 when the flow rate is considered as instantaneously zero is 1.787kw.

The R^2 value expresses the degree or level of model fitness. It is a statistical indicator that explains the ability of a model to predict the dependent variable from independent variable. R^2 value of one (1) means that the model is 100% perfect and can predict the dependent variable without any forms of error, thus suggested that both dependent and independent variable have perfect predictable relationship, while R^2 value of zero (0) means that the model cannot predict the dependent variable, which means that both dependent and independent variables have no relationship. Hence, R^2 value of 0.99reported in this model means that the model has 99.0% accuracy level in predicting the power consumption requirement of the pump for any change in the fluid flow rate while the 1.00% error represent other error factor that were not captured in the model.

For the second liquid with the higher density than water and designated as Series-4 in the chart, the model developed to mathematically represent the relationship between pump power and fluid flow rate, is expressed as:

$$\mathbf{y = 0.0429x + 1.636} \qquad \textbf{(3)}$$

where y represents the pump power consumption and x is the fluid flow rate. Replacing y with P and x with Q for more convenient we have equation 3 expressed as:

$$\mathbf{P = 0.0429Q + 1.636} \qquad \textbf{(4)}$$

The model, as seen in equation 4, is also a simple direct and linear equation. The slope of the model also being the coefficient of Q, is 0.0429 while the intercept on the pump power axis is 1.636. Technically, the slope of the model implies that for every one unit increase in fluid flow rate requirement from the pump as concerns pumping the fluid designated as Series-4, 0.0429unit increase in pump power consumption in required. Also, the intercept implies that the initial power required to initiate flow of the liquid designated as series-4 when the flow rate is considered as instantaneously zero is 1.636kw.

The R^2 value expresses the degree or level of model fitness. It is a statistical indicator that explains the ability of a model to predict the dependent variable from independent variable. Hence, R^2 value of 0.99 reported in this model means that the model has 99.6% accuracy level in predicting the power consumption requirement of the pump for any change in the fluid flow rate while the 1.0% error represent other error factor that were not captured in the model.

For the third liquid (water) designated as Series-3 in the chart, the model developed to mathematically represent the relationship between pump power and fluid flow rate, is expressed as:

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y = 0.0395x + 1.484 **(5)**

where y represents the pump power consumption and x is the fluid flow rate. Replacing y with P and x with Q for more convenient we have equation 4.5 expressed as:

P = 0.0395Q + 1.484 **(6)**

The model, as seen in equation 6, is also a simple direct and linear equation. The slope of the model also being the coefficient of Q, is 0.0395 while the intercept on the pump power axis is 1.484. Technically, the slope of the model means that for every one unit increase in fluid flow rate requirement from the pump as regard to pumping water designated as series-3, 0.0395 unit increase in pump power consumption in required. Also, the intercept implied that the initial power required to initiate flow of water designated as series 3 when the flow rate is considered as instantaneously zero is 1.484kw.

The R^2 value expresses the degree or level of model fitness. It is a statistical indicator that explains the ability of a model to predict the dependent variable from independent variable. Hence, R^2 value of 0.99 reported in this model means that the model has 99.0% accuracy level in predicting the power consumption requirement of the pump for any change in the fluid flow rate while the 1.0% error represent other error factor that were not captured in the model.

For the Fourth liquid which is less dense that water and designated as Series-2 in the chart, the model developed to mathematically reveal the relationship between pump power and fluid flow rate, is expressed as:

y = 0.0358x +1.282 **(7)**

where y represents the pump power consumption and x is the fluid flow rate. Replacing y with P and x with Q for more convenience, we have equation 7 expressed as:

P = 0.0358Q +1.282 **(8)**

The model, as seen in equation 8, is also a simple direct and linear equation. The slope of the model also being the coefficient of Q, is 0.0358 while the intercept on the pump power axis is 1.282. Technically, the slope of the model means that for every one unit increase in fluid flow rate requirement from the pump as regard to pumping water designated as Series-2, 0.0358 unit increase in pump power consumption in required. Also, the intercept implied that the initial power required to initiate flow of liquid designated as series-2 when the flow rate is considered as instantaneously zero is 1.282kw.

The R^2 value expresses the degree or level of model fitness. It is a statistical indicator that explains the ability of a model to predict the dependent variable from independent variable. Hence, R^2 value of 0.99 reported in this model means that the model has 99.0% accuracy level in predicting the power consumption requirement of the pump for any change in the fluid flow rate while the 1.0% error represent other error factor that were not captured in the model

For the Fifth liquid which is most less-dense fluid in the series and designated as Series-1 in the chart, the model developed to mathematically reveal the relationship between pump power and fluid flow rate, is expressed as:

y = 0.0328x + 1.097 **(9)**

where y represents the pump power consumption and x is the fluid flow rate. Replacing y with P and x with Q for more convenience, we have equation 9 expressed as:

P = 0.0328Q + 1.097 **(10)**

The model, as seen in equation 10, is also a simple direct and linear equation. The slope of the model also being the coefficient of Q, is 0.0328 while the intercept on the pump power axis is 1.097. Technically, the slope of the model means that for every one unit increase in fluid flow rate requirement from the pump as regard to pumping water designated as series-1, 0.0328 unit increase in pump power consumption in required. Also, the intercept implied that the initial power required to initiate flow of liquid designated as series-1 when the flow rate is considered as instantaneously zero is 1.097kw.

The R^2 value expresses the degree or level of model fitness. It is a statistical indicator that explains the ability of a model to predict the dependent variable from independent variable. Hence, R^2 value of 0.99 reported in this model means that the model has 99.0% accuracy level in predicting the power consumption requirement of the pump for any change in the fluid flow rate while the 1.0% error represent other error factor that were not captured in the model

Overall, these results show that for a pump with impeller size of 121.54mm, dense Liquids required higher power consumption to initiate flow in conditions of instantaneous zero flow rate in the order of 1.787kw, 1.686kw, 1.481kw, 1.282kw and 1.097kw for the Liquids along descending order of densities expressed as: series-5, series-4 series-3 series-2 and series-1 respectively. The results also show that for flowing fluid, denser Liquids also required higher value of power consumption to generate a unit increase in their flow rate in the order of 0.0466kw, 0.0429kw, 0.0395kw, 0.0358kw and 0.0328kw for the Liquids along descending order of densities expressed as: series-5, series-4 series-3 series-2 and series-1 respectively.

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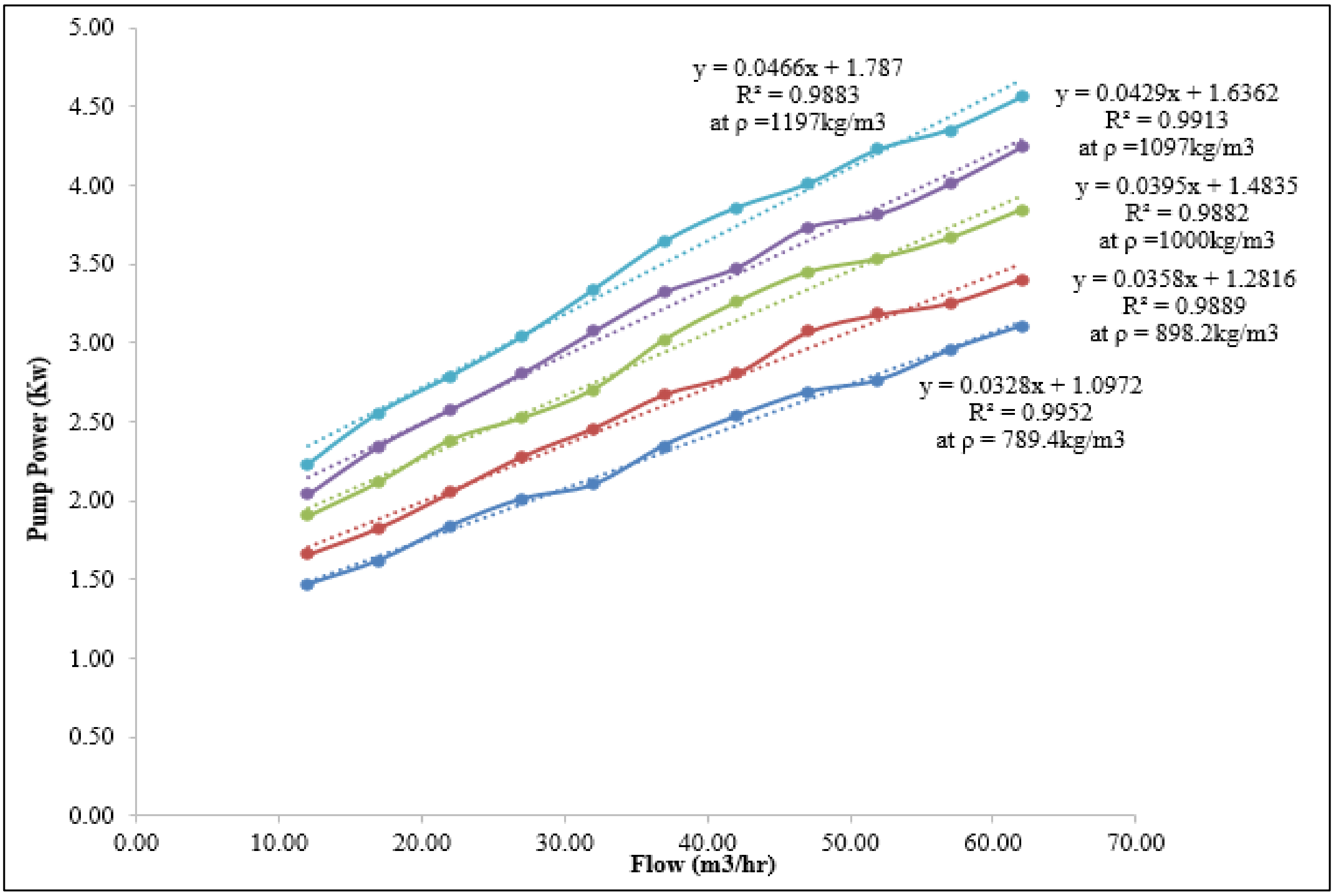

Fig 2: Experimental Test Relationship between Fluid Flow Rates and Pump Power for the Five Fluid Samples when Operating with Impeller Size of 121.54mm
(Series5=1197 kg/m^3, Series4= 1097 kg/m^3, Series3= 1000kg/m^3, Series2= 898.2 kg/m^3, Series1 798.4 kg/m^3)

- *Experimental Relationships between Fluid Flow Rate and Pump Power for the Five Fluid Samples When Operating with Impeller Size of 109.38mm*

Figure 3 shows the graphs of the relationship between fluid flow rate and pump power for the five fluid samples operating with impeller size of 109.38mm and 12mm volute clearance. The pattern of the trend lines slopping upwards from left to right implies that there is direct and positive relationship between fluid flow rate and pump power requirement for all the five different fluids considered. This means that increased pump power is needed to generate high fluid flow rate. Thus, when higher fluid flow rate is required, pump with higher power consumption is required irrespective of the nature or density of fluid involved.

The graphs also revealed that the trend line of the liquids with highest density designated as Series-5 positioned on the topmost part of the chart followed by the denser liquid designated as series-4 all above the trend line of water designated as series 3 while the two liquids that are less dense than water all lined up sequentially below the trend line of water and they are designated as series-2 and series-1 respectively. These trend line patterns revealed that for a given fluid flow rate, denser liquid requires higher pump power than less dense liquid. This could be attributed to the facts that denser liquids are heavier than less dense liquids, hence, more power is required to initiate flow in heavier fluid compare to lighter fluid. Therefore, organization or application engineers that is working with denser fluid would require pump with higher power consumption to initiate a particular flow rate as compare to another process applications that is working with less dense fluid.

For the first liquid with the highest density in the series and designated as Series-5 in the chart, a model was developed which mathematically represent the relationship between the pump power and fluid flow rate. The model is expressed as:

$$y = 0.0489x + 1{,}717 \quad (11)$$

where y represents the pump power consumption and x is the fluid flow rate, replacing y with P and x with Q for more convenience, we have equation 11 expressed as:

$$P = 0.0489Q + 1.717 \quad (12)$$

The model, as seen in equation 12, is a simple direct and linear equation. The slope of the model also being the coefficient of Q, is 0.0489 while the intercept on the pump power axis is 1.717. Technically, the slope of the model implies that for every one unit increase in fluid flow rate required from the pump as concerned pumping the fluid designated as series-5, 0.0489 unit increase in pump power

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consumption in required. Also, the intercept implies that the initial power required to initiate flow of the Liquid designated as series-5 when the flow rate is considered as instantaneously zero is 1.7171kw.

The R^2 value expresses the degree or level of model fitness. It is a statistical indicator that explains the ability of a model to predict the dependent variable from independent variable. R^2 value of one (1) means that the model is 100% perfect and can predict the dependent variable without any forms of error, thus suggested that both dependent and independent variable have perfect predictable relationship, while R^2 value of zero (0) means that the model cannot predict the dependent variable, which means that both dependent and independent variables have no relationship. Hence, R^2 value of 0.990 reported in this model means that the model has 99.0% accuracy level in predicting the power consumption requirement of the pump for any change in the fluid flow rate while the 1.00% error represent other error factor that were not captured in the model.

For the second liquid with the higher density than water and designated as Series-4 in the chart, the model developed to mathematically reveal the relationship between pump power and fluid flow rate, is expressed as:

$$\mathbf{y = 0.0447x + 1.608} \quad \mathbf{(13)}$$

where y represents the pump power consumption and x is the fluid flow rate, replacing y with P and x with Q for more convenient we have equation 13 expressed as:

$$\mathbf{P = 0.0447Q + 1.607} \quad \mathbf{(14)}$$

The model, as seen in equation 14, is also a simple direct and linear equation. The slope of the model also being the coefficient of Q, is 0.0447 while the intercept on the pump power axis is 1.607. Technically, the slope of the model implies that for every one unit increase in fluid flow rate requirement from the pump as regard to pumping the fluid designated as series-5, 0.0447 unit increase in pump power consumption in required. Also, the intercept implies that the initial power required to initiate flow of the Liquid designated as series-5 when the flow rate is considered as instantaneously zero is 1.607kw.

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The R^2 value expresses the degree or level of model fitness. It is a statistical indicator that explains the ability of a model to predict the dependent variable from independent variable. Hence, R^2 value of 0.99 reported in this model means that the model has 99.0% accuracy level in predicting the power consumption requirement of the pump for any change in the fluid flow rate while the 1.00% error represent other error factor that were not captured in the model.

For the third liquid (water) designated as Series-3 in the chart, the model developed to mathematically represent the relationship between pump power and fluid flow rate, is expressed as:

$$\mathbf{y = 0.0395x + 1.529} \quad \mathbf{(15)}$$

where y represents the pump power consumption and x is the fluid flow rate, replacing y with P and x with Q for more convenient we have equation 15 expressed as:

$$\mathbf{P = 0.0395Q + 1.529} \quad \mathbf{(16)}$$

The model, as seen in equation 16, is also a simple direct and linear equation. The slope of the model also being the coefficient of Q, is 0.0395 while the intercept on the pump power axis is 1.529. Technically, the slope of the model implies that for every one unit increase in fluid flow rate requirement from the pump as regard to pumping the liquid (water) which is designated as series 3, 0.0395unit increase in pump power consumption in required. Also, the intercept implies that the initial power required to initiate flow of water designated as series 3 when the flow rate is considered as instantaneously zero is 1.529.

The R^2 value expresses the degree or level of model fitness. It is a statistical indicator that explains the ability of a model to predict the dependent variable from independent variable. Hence, R^2 value of 0.98 reported in this model means that the model has 98.0% accuracy level in predicting the power consumption requirement of the pump for any change in the fluid flow rate while the 2.00% error represent other error factor that were not captured in the model.

For the Fourth liquid which is less dense that water and designated as Series-2 in the chart, the model developed to mathematically represent the relationship between pump power and fluid flow rate, is expressed as:

$$\mathbf{y = 0.0345x + 1.393} \quad \mathbf{(17)}$$

where y represents the pump power consumption and x is the fluid flow rate, replacing y with P and x with Q for more convenience, we have equation 17 expressed as:

$$\mathbf{P = 0.0345Q + 1.393} \quad \mathbf{(18)}$$

The model, as seen in equation 18, is also a simple direct and linear equation. The slope of the model also being the coefficient of Q, is 0.0345 while the intercept on the pump power axis is 1.393. Technically, the slope of the model implies that for every one unit increase in fluid flow rate requirement from the pump as regard to pumping water designated as series-2, 0.0345unit increase in pump power consumption in required. Also, the intercept implies that the initial power required to initiate flow of Liquid designated as series-2 when the flow rate is considered as instantaneously zero is 1.3931kw.

The R^2 value expresses the degree or level of model fitness. It is a statistical indicator that explains the ability of a model to predict the dependent variable from independent variable. Hence, R^2 value of 0.97 reported in this model means that the model has 97.0% accuracy level in predicting the power consumption requirement of the pump for any

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change in the fluid flow rate while the 3.00% error represent other error factor that were not captured in the model

For the Fifth liquid which is most less-dense fluid in the series and designated as Series-1 in the chart, the model developed to mathematically represent the relationship between pump power and fluid flow rate, is expressed as:

$$y = 0.0327x + 1.135 \qquad (19)$$

where y represents the pump power consumption and x is the fluid flow rate, replacing y with P and x with Q for more convenience, we have equation 19 expressed as:

$$P = 0.0327Q + 1.135 \qquad (20)$$

The model, as seen in equation 20, is also a simple direct and linear equation. The slope of the model also being the coefficient of Q, is 0.0327 while the intercept on the pump power axis is 1.135. Technically, the slope of the model implies that for every one unit increase in fluid flow rate requirement from the pump as regard to pumping water which is designated as series-1, 0.0327 unit increase in pump power consumption in required. Also, the intercept implies that the initial power required to initiate flow of Liquid designated as series-1 when the flow rate is considered as instantaneously zero is 1.1351kw.

The R^2 value expresses the degree or level of model fitness. It is a statistical indicator that explains the ability of a model to predict the dependent variable from independent variable. Hence, R^2 value of 0.99 reported in this model means that the model has 99.0% accuracy level in predicting the power consumption requirement of the pump for any change in the fluid flow rate while the 1.00% error represent other error factor that were not captured in the model

Overall, these results showed that for a pump with impeller size of 109.38mm, dense Liquids required higher power consumption to initiate flow in conditions of instantaneous zero flow rate in the order of 1.717kw, 1.607kw, 1.529kw, 1.393kw and 1.135kw for the various liquids along descending order of densities expressed as: series-5, series-4 series-3 series-2 and series-1 respectively. The results also showed that for flowing fluids, denser Liquids also required higher value of power consumption to generate a unit increase in their flow rate in the order of. 0.0489kw. 0.0447kw, 0.0395kw, 0.0345kw and 0.0327kilowatt for the Liquids, along descending order of densities expressed as: series-5, series-4 series-3 series-2 and series-1 respectively.

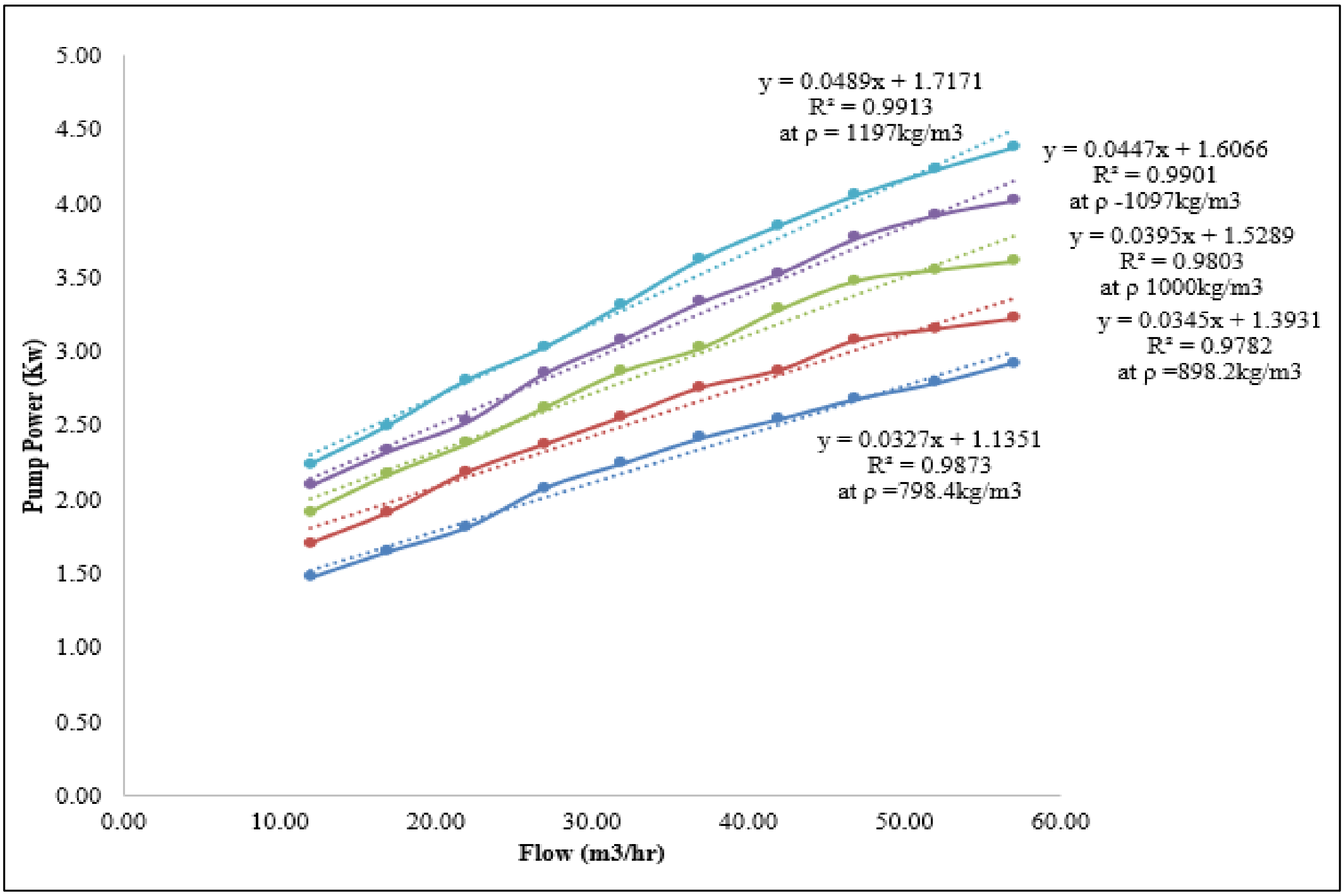

Fig 3: Experimental Test Relationship between Fluid Flow Rates and Pump Power for the Five Fluid Samples when Operating with Impeller Size of 109.38mm
(Series5=1197 kg/m^3, Series4= 1097 kg/m^3, Series3= 1000kg/m^3, Series2= 898.2 kg/m^3, Series1 798.4 kg/m^3)

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- *Experimental Relationships between Fluid Flow Rate and Pump Power for the Five Fluid Samples when Operating with Impeller Size of 97.23mm*

Figure 4 showed the graphs of the relationship between fluid flow rates and pump power for the five fluid samples operating with impeller size of 97.23mm and 18mm impeller – volute clearance. The pattern of the trend lines slopping upwards from left to right implying that there is direct and positive relationship between fluid flow rate and pump power consumption for all the five different fluids considered. This implies that increased pump power is needed to generate high fluid flow rate. Thus, when higher fluid flow rate is required, pump with higher power consumption will be required irrespective of the nature or density of fluid involved.

The graphs also revealed that the trend line of the liquids with highest density designated as series-5 positioned at the topmost part of the chart followed by the denser liquid designated as series-4 all above the trend line of water designated as series-3 while the other two liquids that are less dense than water all lined up sequentially below the trend line of water and they are designated as series-2 and series-1 respectively. These trend line patterns revealed that for a given fluid flow rate, denser liquid consumes higher pump power than less dense liquid. This could be attributed to the facts that denser liquids are heavier than less dense liquids, hence, more power is required to initiate flow in heavier fluid compare to lighter fluid. Therefore, organizations or application engineers that are working with denser fluid would require pump with higher power consumption to initiate a particular flow rate as compare to another process applications is working with less dense fluid.

For the first liquid with the highest density in the series and designated as Series-5 in the chart, a model was developed which mathematically represent the relationship between pump power and fluid flow rate. The model is expressed as:

$$\mathbf{y = 0.0455x + 1.933} \tag{21}$$

Where y represents the pump power consumption and x is the fluid flow rate, replacing y with P and x with Q for more convenience, we have equation 21 expressed as:

$$\mathbf{P = 0.0455Q + 1.933} \tag{22}$$

The model, as seen in equation 22, is a simple direct and linear equation. The slope of the model also being the coefficient of Q, is 0.0455 while the intercept on the pump power axis is 1.933. Technically, the slope of the model implies that for every one unit increase in fluid flow rate required from the pump as concerned pumping the fluid designated as series-5, 0.0455 unit increase in pump power consumption in required. Also, the intercept implies that the initial power required to initiate flow of the Liquid designated as series-5 when the flow rate is considered as instantaneously zero is 1.933kw.

The R^2 value expresses the degree or level of model fitness. It is a statistical indicator that explains the ability of a model to predict the dependent variable from independent variable. R^2 value of one (1) means that the model is 100% perfect and can predict the dependent variable without any forms of error, thus suggested that both dependent and independent variable have perfect predictable relationship, while R^2 value of zero (0) means that the model cannot predict the dependent variable, which implies that both dependent and independent variables have no relationship. Hence, R^2 value of 0.99 reported in this model means that the model has 99% accuracy level in predicting the power consumption requirement of the pump for any change in the fluid flow rate while the 1% error represent other error factor that were not captured in the model.

For the second liquid with the higher density than water and designated as Series-4 in the chart, the model developed to mathematically represent the relationship between pump power and fluid flow rate, is expressed as:

$$\mathbf{y = 0.0428x + 1.714} \tag{23}$$

where y represents the pump power consumption and x is the fluid flow rate, replacing y with P and x with Q for more convenient we have equation 23 expressed as:

$$\mathbf{P = 0.0428Q + 1.714} \tag{24}$$

The model, as seen in equation 24, is a simple direct and linear equation. The slope of the model also being the coefficient of Q, is 0.0428 while the intercept on the pump power axis is 1.714. Technically, the slope of the model implies that for every one unit increase in fluid flow rate requirement from the pump as regards to pumping the fluid designated as series-5, 0.042 unit increase in pump power consumption in required. Also, the intercept implies that the initial power required to initiate flow of the liquid designated as series-5 when the flow rate is considered as instantaneously zero is 1.714kw.

The R^2 value expresses the degree or level of model fitness. It is a statistical indicator that explains the ability of a model to predict the dependent variable from independent variable. Hence, R^2 value of 0.990 reported in this model means that the model has 99.0% accuracy level in predicting the power consumption requirement of the pump for any change in the fluid flow rate while the 1.00% error represent other error factor that were not captured in the model.

For the third liquid (water) designated as Series 3 in the chart, the model developed to mathematically represent the relationship between pump power and fluid flow rate, is expressed as:

$$\mathbf{y = 0.0406x + 1,509} \tag{25}$$

where y represents the pump power consumption and x is the fluid flow rate, replacing y with P and x with Q for more convenient we have equation 25 expressed as:

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P = 0.0406x + 1.509 **(26)**

The model, as seen in equation 26, is also a simple direct and linear equation. The slope of the model also being the coefficient of Q, is 0.0406 while the intercept on the pump power axis is 1.509. Technically, the slope of the model implies that for every one unit increase in fluid flow rate requirement from the pump as regard to pumping water designated as series 3, 0.0406 unit increase in pump power consumption in required. Also, the intercept implies that the initial power required to initiate flow of water designated as series 3 when the flow rate is considered as instantaneously zero is 1.509kw.

The R^2 value expresses the degree or level of model fitness. It is a statistical indicator that explains the ability of a model to predict the dependent variable from independent variable. Hence, R^2 value of 0.990 reported in this model means that the model has 99.0% accuracy level in predicting the power consumption requirement of the pump for any change in the fluid flow rate while the 1.0% error represent other error factor that were not captured in the model.

For the Fourth liquid which is less dense that water and designated as Series-2 in the chart, the model developed to mathematically represent the relationship between pump power and fluid flow rate, is expressed as:

y = 0.0358x + 1.380 **(27)**

where y represents the pump power consumption and x is the fluid flow rate, replacing y with P and x with Q for more convenience, we have equation 27 expressed as:

P = 0.0359Q+ 1.380 **(28)**

The model, as seen in equation 28, is also a simple direct and linear equation. The slope of the model also being the coefficient of Q, is 0.0358 while the intercept on the pump power axis is 1.380. Technically, the slope of the model implies that for every one unit increase in fluid flow rate requirement from the pump as regard to pumping water designated as series-2, 0.0358 unit increase in pump power consumption in required. Also, the intercept implies that the initial power required to initiate flow of liquid designated as series-2 when the flow rate is considered as instantaneously zero is 1.380kw.

The R^2 value expresses the degree or level of model fitness. It is a statistical indicator that explains the ability of a model to predict the dependent variable from independent variable. Hence, R^2 value of 0.990 reported in this model means that the model has 99.00% accuracy level in predicting the power consumption requirement of the pump for any change in the fluid flow rate while the 3.0% error represent other error factor that were not captured in the model.

For the Fifth liquid which is most less-dense fluid in the series and designated as Series-1 in the chart, the model developed to mathematically represent the relationship between pump power and fluid flow rate, is expressed as:

y = 0.0304x + 1.233 **(29)**

where y represents the pump power consumption and x is the fluid flow rates, replacing y with P and x with Q for more convenience, we have equation 29 expressed as:

P = 0.0304Q + 1.233 **(30)**

The model, as seen in equation 30, is also a simple direct and linear equation. The slope of the model also being the coefficient of Q, is 0.0304 while the intercept on the pump power axis is 1.233. Technically, the slope of the model implies that for every one unit increase in fluid flow rate requirement from the pump as regard to pumping water designated as series-1, 0.0304 unit increase in pump power consumption in required. Also, the intercept implies that the initial power required to initiate flow of Liquid designated as series-1 when the flow rate is considered as instantaneously zero is 1.233kw.

The R^2 value expresses the degree or level of model fitness. It is a statistical indicator that explains the ability of a model to predict the dependent variable from independent variable. Hence, R^2 value of 0.990 reported in this model means that the model has 99.0% accuracy level in predicting the power consumption requirement of the pump for any change in the fluid flow rate while the 3.0% error represent other error factor that were not captured in the model

Overall, these results showed that for a pump with impeller size of 97.23mm, dense Liquids required higher power consumption to initiate flow in conditions of instantaneous zero flow rate in the order of 1.933kw, 1.714kw, 1.509kw, 1.380kw and 1.233kw for the Liquids along descending order of densities expressed as: series-5, series-4 series-3 series-2 and series-1 respectively. The results also showed that for flowing fluids, denser Liquids also required higher value of power consumption to generate a unit increase in their flow rate in the order of 0.0455kw, 0.0425kw. 0.0406kw, 0.0358kw and 0.0304kw for the various liquids, along descending order of densities expressed as: series-5, series-4 series-3 series-2 and series-1 respectively.

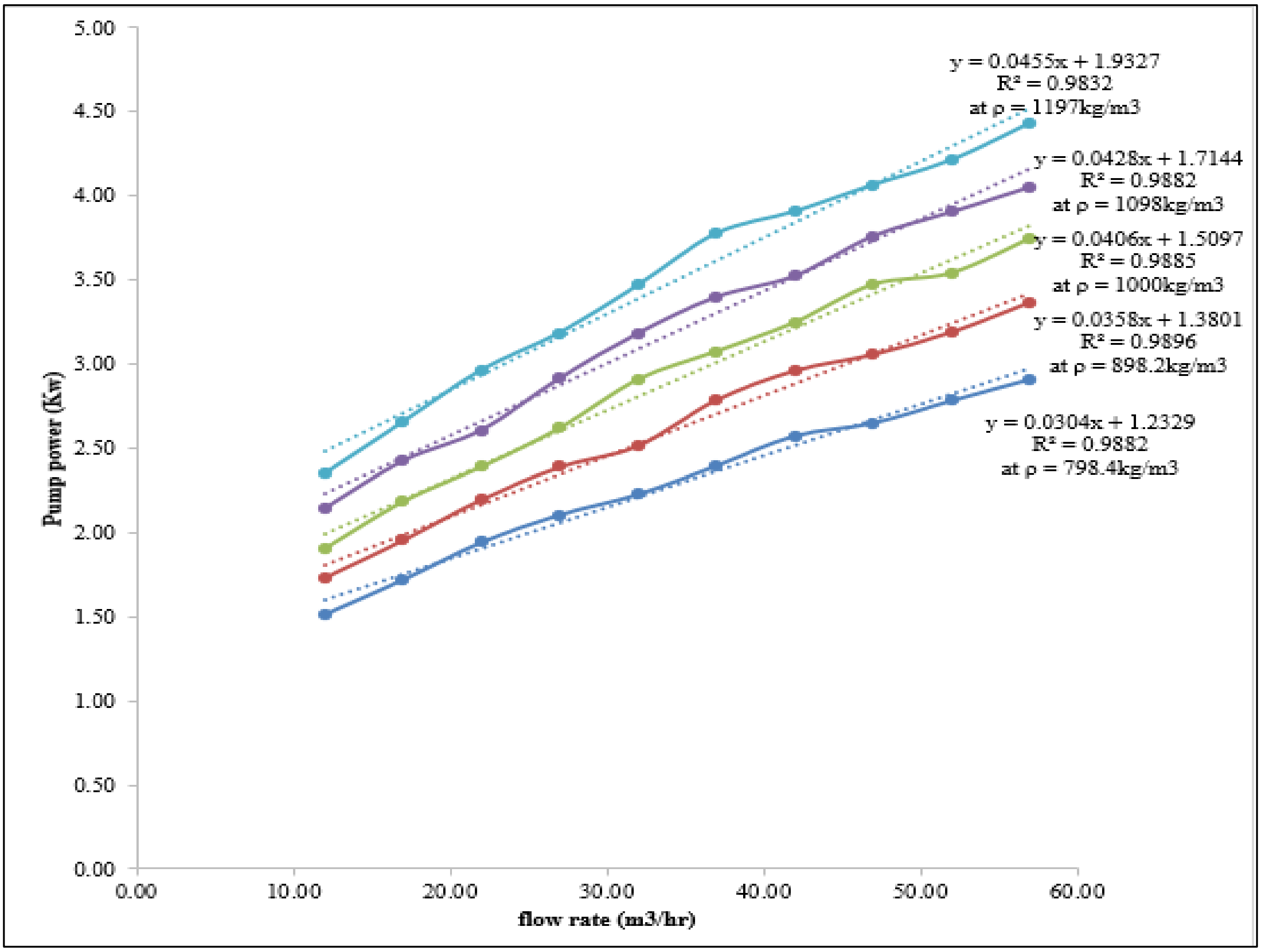

Fig 4: Experimental Relationship between Fluid Flow Rates and Pump Power for the Five Fluid Samples when Operating with Impeller size of 97.23mm
(Series5=1197 kg/m^3, Series4= 1097 kg/m^3, Series3= 1000kg/m^3, Series2= 898.2 kg/m^3, Series1 798.4 kg/m^3)

The general overview of the results revealed that liquid with higher density required higher power to initiate flow at zero instantaneous rate for each of the five impeller sizes considered in the study at a constant flow rate. This implies that there is direct linear relationship between power requirement and density at constant impeller size and constant flow rate. Hence, for a particular impeller size. These results are in agreement with the general expectation because high-dense liquid implies high weight per unit volume while low dense liquid implies low weight per unit volume dense higher amount of power will be required to move or propel such high dense liquid compare to low dense liquid.

The results also showed that bigger impellers require smaller instantaneous start-up power for each of the five liquids considered at constant fluid flow rate. This trend implied that there is inverse linear relationship between impeller size and instantaneous start-up pump power to a particle flow rate which means that increase in size of impeller resulted to corresponding decrease in instantaneous start-up power of the pump This result is in line with generation expectation because for a liquid of known density L to be pumped from instantaneous zero (0(flow rate to a constant flow rate Q, bigger pumps with bigger impeller will requires smaller power as the size of the impeller will compensate for the extra required power while smaller pumps with smaller impeller will require higher pump power as the smaller impeller will be compensated with extra power.

B. Results and Discussion on Impeller Size, Fluid Density and Pump Efficiency

➢ *Relationships between Fluid Flow Rate and Pump Efficiency for the Fluid Samples when Operating with Impeller Size of 121.54mm*

Figure 5 showed the graphs of the relationship between fluid flow rate and pump Efficiency for the five fluid samples operating with impeller size of 121.54mm. A single trend line was revealed in the chart while another part of the chart revealed that there are five different series line represented as series-5 to series-1. This showed that the trend line of the five series is combined to form one trend which means that there is no substantial or significant difference between the pump efficiency of the five different liquids considered at different flow rate and operating with impeller size on 121.56mm, Hence, suggesting that density of the liquids have no substantial effect on change in pump efficiency with change in flow rate.

The pattern of the trend lines also sloped upwards from left to right at the initial stage, then reached a certain topmost position and gradually slopped downward from left to right. This trend line pattern revealed that the relationship between flow rate and pump efficiency is not linear but quadratic for all the five different liquids considered. This means that there is a particular flow rate at which the pump efficiency is maximum, and beyond this flow rate, the pump will operate at low efficiency level. Hence, we need to conducted optimization analysis in order to ascertain the optimal flow rate for the pump and the corresponding optimum efficiency of the pump with impeller size of 121.54mm.

The differential calculus analysis was used for the optimization, and it is based on the mathematically fact that the maximum point for quadratic function with concave shape or minimum point of quadratic function with convex shape occur at the point when; $\frac{\partial y}{\partial x} = 0$ in which y is the pump efficiency and x is liquid flow rate. The quadratic model developed showed that the pattern is concave, hence, a maximum point which correspond to optimum point is the pattern will occur at $\frac{\partial y}{\partial x} = 0$ and the model is presented as;

$$\mathbf{y = = -0.0275x^2 + 2.6065x + 12.713} \qquad \mathbf{(31)}$$

using PE to represent pump efficiency and Q for liquid flow rate, equation 4.51 become

$$\mathbf{PE = -0.0275Q^2 + 2.6065Q + 12.713} \qquad \mathbf{(32)}$$

Hence,

$$\frac{dPE}{dQ} = \mathbf{-0.0550Q+2.607} \qquad \mathbf{(33)}$$

Therefore, the maximum or optimum efficiency of the pump will occur when

$$-0.0550Q+2.67= 0$$

And solving the simple equation for the value of Q we have that $\mathbf{Q = 47.40m^3/hr.}$

Therefore, the Optimum Pump Efficiency will occur at the point where liquid flow rate is $47.40m^3/hr$. Substituting the value of Q= 47.40 in equation 32 we have that

$$PE_{max} = \mathbf{-0.0275(47.40)^2 + 2.6065(47.40) + 12.713}$$
$$PE_{max} = -61.78+123.55+12.713 = 74.49\%$$
$$\boldsymbol{PE_{max}} = \mathbf{74\ 49\%}$$

This result means that for pump operating with impeller size of 121.54mm the optimum pump efficiency is 74.49% and the flow rate possible at the point is 47.40M3/hr. irrespective of the density of the liquid involved.

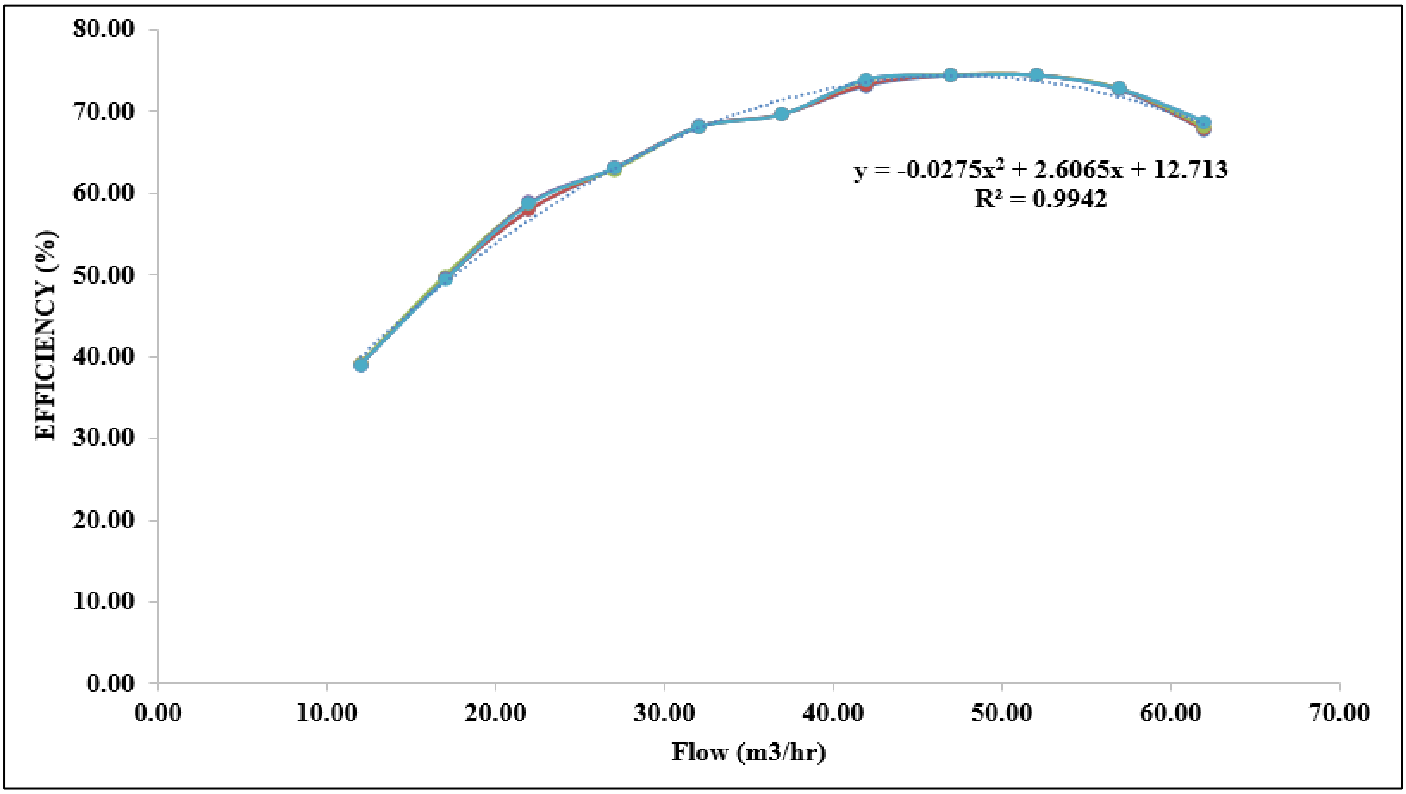

Fig 5: Experimental Relationships between Fluid Flow Rates and Pump Efficiency for the Five Fluid Samples When Operating with Impeller Size of 121.54mm.
(Series5=1197 kg/m^3, Series4= 1097 kg/m^3, Series3= 1000kg/m^3, Series2= 898.2 kg/m^3, Series1 798.4 kg/m^3)

➢ *Experimental Relationships between Fluid Flow Rate and Pump Efficiency for the Five Fluid Samples when Operating with Impeller Size of 109.38mm.*

Figure 6 showed the graphs of the relationship between fluid flow rate and pump Efficiency for the five fluid samples operating with impeller size of 109.38mm. A single trend line was revealed in the chart while another part of the chart revealed that there are five different series line represented as series-5 to series-1. This showed that the trend line of the five series is combined to form one trend which means that there is no substantial or significant difference between the pump efficiency of the five different liquids considered at different flow rate and operating with impeller size on 109.38mm, Hence, suggesting that density of the liquids have no substantial effect on change pump efficiency with change in flow rate.

The pattern of the trend lines also sloped upwards from left to right at the initial stage, then reached a certain topmost position and gradually slopped downward from left to right. This trend line pattern revealed that the relationship between flow rate and pump efficiency is not linear but quadratic for all the five different liquids considered. This means that there is a particular flow rate at which the pump efficiency is maximum, and beyond this flow rate, the pump will operate at low efficiency level. Hence, we need to conducted optimization analysis in order to ascertain the optimal flow rate for the pump and the corresponding optimum efficiency of the pump with impeller size of 109.38mm.

The differential calculus analysis was used for the optimization, and it is based on the mathematically fact that the maximum point for quadratic function with concave shape or minimum point of quadratic function with convex shape occur at the point when; $\frac{\partial y}{\partial x} = 0$ in which y is the pump efficiency and x is liquid flow rate. The quadratic model developed showed that the pattern is concave, Hence, a maximum point which correspond to optimum point is the pattern will occur at $\frac{\partial y}{\partial x} = 0$ and the model is presented as:

$$\mathbf{y = -0.0234x^2 + 2.2208x + 11.963} \qquad \mathbf{(34)}$$

using PE to represent pump efficiency and Q for liquid flow rate, equation 34 become

$$\mathbf{PE = -0.0234Q^2 + 2.2208Q + 11.963} \qquad \mathbf{(35)}$$

Hence,

$$\frac{dPE}{dQ} = \mathbf{-0.0468Q+2.2208} \qquad \mathbf{(36)}$$

Therefore, the maximum or optimum efficiency of the pump will occur when

$-0.0468Q+2.2208= 0$

And solving the simple equation for the value of Q we have that **Q = 47.45** m^3/hr**.**

Therefore, the Optimum Pump Efficiency will occur at the point where liquid flow rate is 47.96m^3/hr. Substituting the value of Q= 47.96 in 35 we have that

PE_{max} = $-0.0234(47.45)^2 + 2.12208(47.45) + 11.965$
PE_{max} = -52.21+104.42+12.689 = 65.80%
$\boldsymbol{PE_{max}}$ **= 65.80%**

This result means that for pump operating with impeller size of 109.38mm the optimum pump efficiency is 65.80% and the flow rate possible at the point is 47.45m^3/hr. irrespective of the density of the liquid involved.

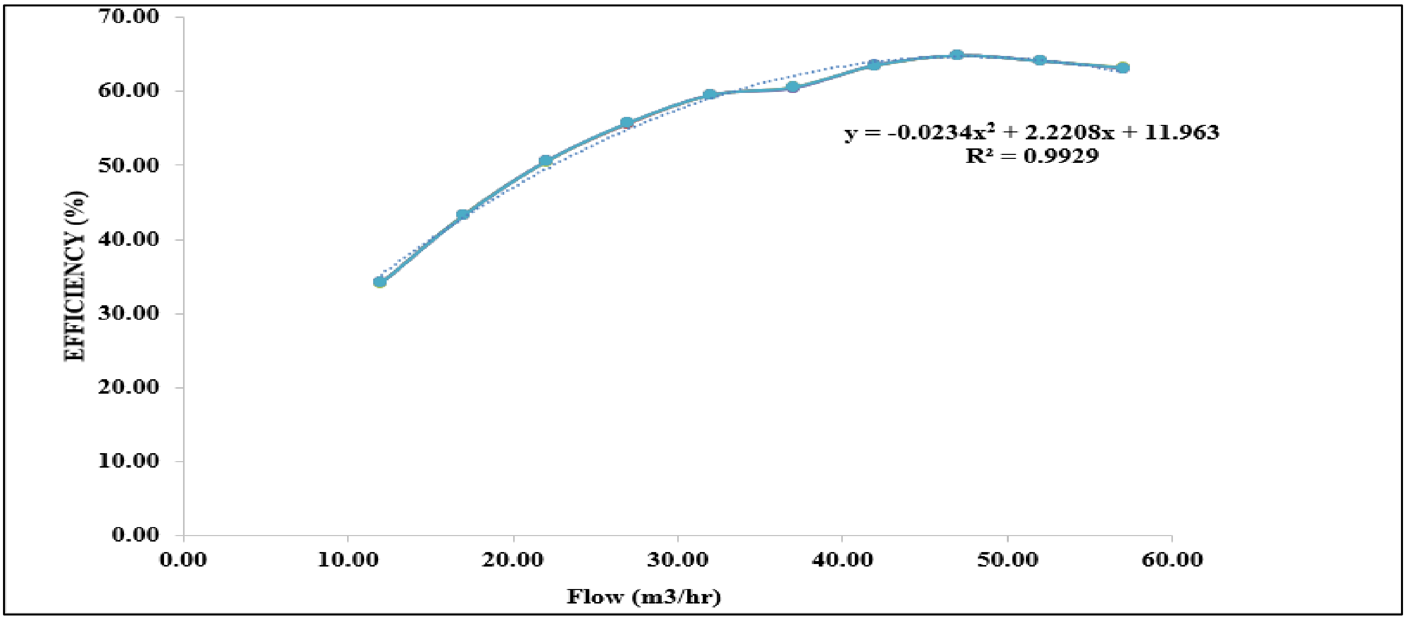

Fig 6: Graph of Experimental Relationships between Fluid Flow Rate and Pump Efficiency for the Five Fluid Samples Operating with Impeller Size of 109.38mm.
(Series5=1197 kg/m^3, Series4= 1097 kg/m^3, Series3= 1000kg/m^3, Series2= 898.2 kg/m^3, Series1 798.4 kg/m^3)

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- *Experimental Relationships between Fluid Flow Rate and Pump Efficiency for the Five Fluid Samples when Operating with Impeller Size of 97.23mm.*

Figure 7 showed the graphs of the relationship between fluid flow rate and pump Efficiency for the five fluid samples operating with impeller size of mm. A single trend line was revealed in the chart while another part of the chart revealed that there are five different series line represented as series-5 to series-1. This shows that the trend line of the five series is combined to form one trend which means that there is no substantial or significant difference between the pump efficiency of the five different liquids considered at different flow rate and operating with impeller size on 97.23mm, Hence, suggesting that density of the liquids have no substantial effect on change in pump efficiency with change in flow rate.

The pattern of the trend lines also sloped upwards from left to right at the initial stage, then reached a certain topmost position and gradually slopped downward from left to right. This trend line pattern revealed that the relationship between flow rate and pump efficiency is not linear but quadratic for all the five different liquids considered. This means that there is a particular flow rate at which the pump efficiency is maximum, and beyond this flow rate, the pump will operate at low efficiency level. Hence, we need to conducted optimization analysis in order to ascertain the optimal flow rate for the pump and the corresponding optimum efficiency of the pump with impeller size of 97.23mm.

The differential calculus analysis was used for the optimization, and it is based on the mathematically fac that the maximum point for quadratic function with concave shape or minimum point of quadratic function with convex shape occur at the point when; $\frac{\partial y}{\partial x} = 0$ in which y is the pump efficiency and x is liquid flow rate. The quadratic model developed showed that the pattern is concave, Hence, a maximum point which correspond to optimum point is the pattern will occur at $\frac{\partial y}{\partial x} = 0$ and the model is presented as;

$$\mathbf{y = -0.0215x^2 + 1.9887x + 8.7618} \qquad \mathbf{(37)}$$

using PE to represent pump efficiency and Q for liquid flow rate, equation 37 become

$$\mathbf{PE = --0.0215Q^2 + 1.9887Q + 8.7618} \qquad \mathbf{(38)}$$

Hence,

$$\frac{dPE}{dQ} = \mathbf{-0.0430Q+1.9887} \qquad \mathbf{(39)}$$

Therefore, the maximum or optimum efficiency of the pump will occur when

$$-0.043Q+1.9887= 0$$

And solving the simple equation for the value of Q we have that **Q = 46.24m^3/hr.**

Therefore, the Optimum Pump Efficiency will occur at the point where liquid flow rate is 46.42m^3/hr. Substituting the value of Q= 46.24 in equation 4.58 we have that

$$PE_{max} = \mathbf{-0.0215(46.24)^2 + 1.9887(46.24) + 8.7618}$$
$$PE_{max} = -45.97+91.96+8.7618 = 54.76\%$$
$$\boldsymbol{PE_{max}} = \mathbf{54\ 74\%}$$

This result means that for pump operating with impeller size of 97.23mm and 18mm volute clearance the optimum pump efficiency is 54.74% and the flow rate possible at the point is 46.24m^3/hr. irrespective of the density of the liquid involved

Overall, the results revealed that pumps with size of 121.36mm, 109.86mm, 97.23mm, have optimum liquid flow rates of 46.76m^3/hr, 47.96m^3/hr and 44.80m^3/hr. respectively and pump efficiency of 74.42%, 65.90% and 54.78% respectively. These results implied that larger impeller have higher optimum flow rate and efficiency as compare to pumps of smaller impeller size irrespective of the density of the fluid involved.

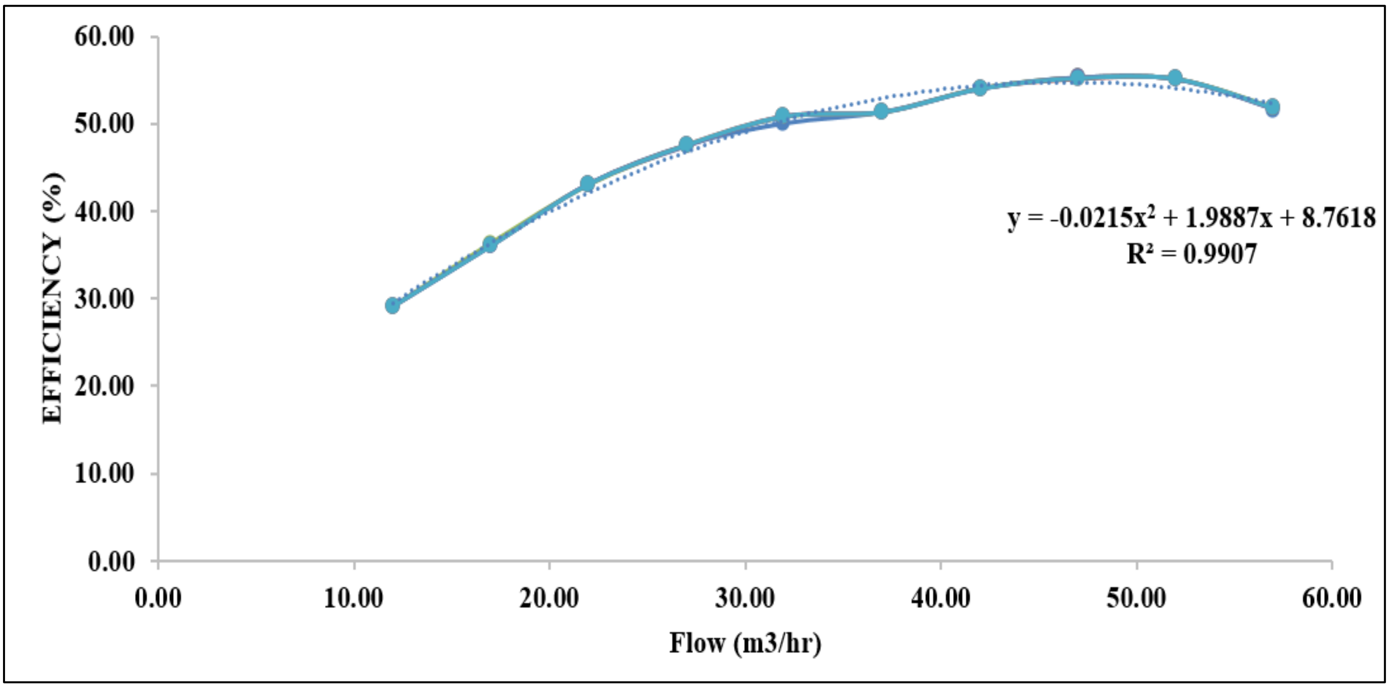

Fig 7: Graph of Experimental Relationships between Fluid Flow Rates and Pump Efficiency for the five Fluid Samples When Operating with Impeller Size of 97.23mm
(Series5=1197 kg/m^3, Series4= 1097 kg/m^3, Series3= 1000kg/m^3, Series2= 898.2 kg/m^3, Series1 798.4 kg/m^3)

IV. CONCLUSION

Baseed on these findings, it was concluded among others that; One, liquid with higher density will require higher power to initiate flow at zero instantaneous rate and constant flow rate which implies that there is direct linear relationship between pump power consumption and liquid density at constant impeller size and constant flow rate. Two, larger impellers size pumps will require smaller instantaneous start-up power for any liquid to flow at constant rate and this also implies that there is an inverse linear relationship between impeller size and instantaneous start-up power to a particle flow rate, thus, increase in size of impeller will result to corresponding decrease in instantaneous start-up power and also smaller operating power. Thus, pumps with larger impeller sizes will develop higher optimum pump efficiency while pump with smaller impeller will develop smaller optimum efficiency regardless of the density of the liquid,

RECOMMENDATIONS

➢ *Based on these Conclusions, it was Recommended among others that:*

- Any organization or pump application Engineer requiring to perform any modification or alteration on centrifugal pump impeller or on any parts of the pump internal/ liquid-end, it is recommended to conduct a detailed analysis on the possible effect of such modification on the overall performance of the pump, especially any modifications on those part that have direct contact with the process fluid, such as the pump impeller, volute, diffuser etc.
- Any organization or pump application Engineer working on a process application that may require dynamic fluctuations of the process fluid density, it is recommended to consider to provide a safe compensation margin on the motor rated power, as to compensate for the anticipated power increase during a positive change on the process fluid density.
- Any organization or pump applications Engineer working on a process application that may require drastic and dynamic fluctuations of the process fluid density, where possible; it is recommended to conduct a detailed analysis of the liquid to be pumped using the full range of anticipated product density, in order to assure and guarantee an optimum performance with the selected unit and the power rating.
- Users of centrifugal pumps should consider possible increases in hydraulic torque, when sizing or selecting pump drivers for a process application that has possibilities for dynamic process fluid density, since it is established, that denser fluids will require more torque than less-dense fluid.

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