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Analyzing the Performance of Alternating Current (AC) Single Phase Centrifugal Pump in Handling Different Types of Liquids

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Abstract: In industries, organizations, and homes, liquids are conveyed for different purposes. It may be for industrial purposes or domestic purposes. The process involved in conveying liquid can make the liquid safe or unsafe for the purpose for which the liquid is intended to be used. Most industries use centrifugal pumps in pumping liquids. The use of centrifugal pumps in industries, organizations, and homes depends on the output pressure needed. Usually, the centrifugal pumps which are used for domestic purposes have a maximum capacity of four horsepower (4hp) as output power. the mass flow rate of water is different from that of diesel, engine oil, and hydraulic oil. Therefore, a centrifugal pump with a specific horsepower will handle each liquid differently, especially in relation to its volumetric flow rates. The study analyzed the volumetric flow rate of different liquids like water, hydraulic oil, engine oil, and diesel from a centrifugal pump of a specific capacity within specific periods. A volume of 40 m^3 of one of the liquids under study was put into the bucket. The end of the hose connected to the suction nozzle was placed inside the bucket containing the liquid. The other end of the hose connected to the discharge nozzle was also placed into the measuring container. The pump was then switched on. The timer was connected to switch off the pump every 30 seconds. The highest volume of liquid that the pump pumped is water at a mean volume of 49.5860 m^3. The mean volume obtained after performing the experiments on diesel is 48.0800 m^3 which is lower than that of water. the mean volume of hydraulic oil and engine oil are 31.850 m^3 and 25.8100 m^3. The differences in the kg/m^3 of the various liquid under study affect the velocity at which the liquids move when pumped. The head of each liquid is proportional to the mass of the liquid and the viscosity of each liquid is proportional to the volumetric flow of the liquid.

Keywords: Conveying Liquids, Centrifugal Pump, Volumetric Flow Rate

1. Introduction

Conveying liquids from one point to another point occurs in every sphere of our life for a comfortable existence. In industries, organizations, and homes, liquids are conveyed for different purposes. It may be for industrial purposes or domestic purposes [1, 2]. Many processes or methods are employed in conveying liquids. These methods employed may be based on reasons such as the type of liquid, the distance at which the liquid is being carried, and what the liquid will be used for [3]. Conveying volatile and highly inflammable liquids like petrol should be done in an enclosed chamber or conduit so that it will not vaporize or inflame [4]. Considering the distance to convey liquids, the volatility and flammability make it very expensive to convey petrol through a long conduit for a long distance. Therefore, shuttle tankers are used to convey petrol and diesel from the refinery to the various fuel filling stations because of the distance involved [5]. The use(s) of the liquid will determine which process should be used in conveying the liquid. The process involved in conveying liquid can make the liquid safe or unsafe for the purpose for which the liquid is intended to be used. Closed conduits are usually used in conveying liquids from one place to another. Examples of such conduits are PVC pipe, rubber hose, copper pipe, aluminum pipe, etc. Different types of conduits are used to handle different types of liquid for different purposes.

There may or may not be a steady-state flow of liquid if the gravitational force is used to convey liquid from an elevated point to a lower point depending on the frame of reference. This is because the flow increases as the pressure of the liquid at the elevated point increases and decreases as the pressure decreases. However, it will be difficult to convey liquid from a lower point to an elevated point or from one place to another with the same elevation without the assistance of a mechanical device like a pump since gravitational force act from an elevated point to a lower point [6]. To convey liquid from a lower point to an elevated point, the liquid has to move with a force that is greater than the gravitational force acting on it and this will require a device that will give the liquid that kind of force in order to overcome the gravitational force [7]. In industries, pumps are often used to handle various types of liquid from one point to another [8]. In light industries, homes, and other places where there is no electricity, pumps are powered either mechanically or manually [2].

Most industries use centrifugal pumps in pumping liquids. The use of centrifugal pumps in industries, organizations, and homes depends on the output pressure needed. Usually, the centrifugal pumps which are used for domestic purposes have a maximum capacity of four horsepower (4hp) as output power. Usually, the output power of centrifugal pump cannot be controlled. Each pump has a specific output as designed and can neither be changed manually nor automatically. That is, a specific centrifugal pump has a specific power output [9]. Therefore, if you need different outputs of pump to perform different work you need to purchase different capacities of pumps to perform each work [10].

The properties of each liquid affect its flow rate. For instance, the mass flow rate of water is different from that of diesel, engine oil, and hydraulic oil. Therefore, a centrifugal pump with a specific horsepower will handle each liquid differently, especially in relation to their volumetric flow rates.

According to Mukesh [8], the pump converts the energy of a prime mover (an electric motor or turbine) first into velocity or kinetic energy (the rotor of the motor begins to turn. The shaft of the rotor is coupled to the impeller of the pump). The impeller of the pump is the rotating part that converts driver energy into the kinetic energy created by a centrifugal force. The volute or diffuser is the stationary part that converts the kinetic energy into pressure energy [8]. When the impeller rotates, it spins the liquid sitting in the cavities between the vanes outward and provides centrifugal acceleration. As liquid leaves the center of the impeller, a low-pressure area is created causing more liquid to flow toward the suction nozzle of the pump. Because the impeller blades are curved, the fluid is pushed in a tangential and radial direction by centrifugal force. This force acting inside the pump is the same one that keeps water inside a bucket that is rotating at the end of a string. The centrifugal pump has a suction nozzle and a discharge nozzle. The liquid enters the suction nozzle, then into the center of the impeller. The weight of the liquid that enters the pump through the suction nozzle will have an impact on the blade of the impeller. This can cause a reduction in the kinetic energy given to the liquid which is directly proportional to the velocity at the edge or the vane tip of the impeller since the flow rate is proportional to speed [7]. Therefore, more force will be required to pump a liquid that has more weight in order to maintain the velocity of the liquid than that of a liquid that has less weight.

If a centrifugal pump of a specific power produced a specific force, in handling different liquids of different weights, there is the likelihood that the pressure output of the liquids might be different. This to an extent will affect the volumetric flow rate of the various liquids under study. The volumetric flow rates of the liquids may differ since the liquids under study have different weights. A pump that is used to pump water which has less weight, when used to pump engine oil which is heavier than water will affect the performance of the pump. The weight of the oil will exert much force on the blade, restricting the impeller to rotate at the velocity at which it has to rotate. This increases the frictional force between the blade and the oil. The frictional force generates an amount of heat in the pump which is conducted through the shaft of the impeller to the stator of the motor.

Over the years, various research has been conducted to analyze the performance of a centrifugal pump relating to: 1). The impeller design [11-14], 2). the wear of the pump [15-17], 3). the electrical power supply to the pump [9], and 4). The materials it handles; a). solids [16] and b). fluids [6, 18, 19]. Rehman et al. [20] analyzed the performance of a centrifugal pump using various working fluids to predict the cavitation of the centrifugal pump. Their study considered fluids like saline water, crude oil, and gasoline. They used an industrialized double-volute pump to handle the fluid, which according to Anderson [21], it can be less efficient and more expensive as compared to the single-volute model.

The study is to use a single-phase, single-volute centrifugal pump to find the volumetric flow rate of different liquids like water, hydraulic oil, engine oil, and diesel from a centrifugal pump of a specific capacity within specific periods; The differences in volumetric flow rate of the various liquids which is being handled by the same centrifugal pump, and the maximum heights (pressure head) that the single volute centrifugal pump can pump these various liquids.

2. Methodology

The target population for the study was the industries in the Akwapem South Municipal Assembly that make use of a centrifugal pump to pump the following liquids: engine oil, water, diesel, and hydraulic oil. Random sampling was used to select an industry from four industries in the Akuapim South Municipal Assembly in the Eastern Region of Ghana, which make use of all the following liquids under study: water, diesel, engine oil, and hydraulic oil. In total, one drum of engine oil, one drum of water, one drum of diesel, and one drum of hydraulic oil were fetched from the reservoirs of the selected industry for the experiment.

The Bucket-Stopwatch experiment was used to find the volumetric flow of the liquids.

The following instruments/apparatus were used for the experiment: centrifugal pump, pipe hose, electrical cables, timer, contactor, measuring container, measuring cylinder, and bucket.

2.1. Experimental Set-up

The centrifugal pump was put on the ground and was ensured that it was well-leveled. The pipe hoses were connected to the pump's suction and discharge nozzle. The bucket and the measuring container were closely placed beside the pump. The end of the hose connected to the discharge nozzle was put into the measuring container whiles the other end of the hose connected to the suction nozzle was put into the bucket. The measuring container and bucket height was one meter from the ground.

2.2. Method of the Experiment Carried out

A volume of 40 m^3 of one of the liquids under study was put into the bucket. The end of the hose connected to the suction nozzle was placed inside the bucket containing the liquid. The other end of the hose connected to the discharge nozzle was also placed into the measuring container. The pump was then switched on. The timer was connected to switch off the pump every 30 s. After every 30 s, the volume of liquid pumped was measured five consecutive times. After the experiment, the pump was properly dried and cleaned for the next experiment. This experiment was repeated for all the liquids under study.

The Forces used by the pump to pump the various liquids were determined using the relation: $(F) = mass\ (M) \times acceleration\ (g)$

Given an area (A), and a fluid flowing through it with uniform velocity (C) with an angle θ away from the perpendicular direction to A, the volumetric flow rate

$$(Q) = A \cdot C \cos\theta$$

In the special case where the flow is perpendicular to the area A, that is, $cos\theta\ =\ 1$, the volumetric flow rate

$$(Q) = A \cdot C.$$

Therefore, the velocity (C) at which respective liquids will move when pumped is

$$C\ =\ \frac{Q}{A}$$

The densities of the respective liquids were determined using the relations

$$density\ of\ water\ = \frac{mass\ of\ water}{volume\ of\ water}$$

$$density\ of\ diesel\ = \frac{mass\ of\ diesel}{volume\ of\ diesel}$$

$$density\ of\ hydraulic\ oil\ = \frac{mass\ of\ hydraulic\ oil}{volume\ of\ hydraulic\ oil}$$

$$density\ of\ engine\ oil\ = \frac{mass\ of\ engine\ oil}{volume\ of\ engine\ oil}$$

The maximum height of respective liquids pumped is determine by the relation.

$$Pressure\ = density\ (\rho) \times acceleration\ due\ to\ garvity (g) x\ height (H)$$

$$\therefore H\ = \frac{P}{\rho g}$$

3. Results and Discussion

3.1. Volumetric Flow Rate of Water

Table 1. *Results of volume of water pumped within the interval of 30 seconds.*

Time (s)	Volume (m^3)
30	16.48
60	33.06
90	49.49
120	66.02
150	82.50

Table 2. *Results of volume of diesel pumped within the interval of 30 seconds.*

Time (s)	Volume (m^3)
30	15.95
60	32.05
90	48.10
120	64.35
150	79.95

Table 3. *Results of volume of hydraulic oil pumped within the interval of 30 seconds.*

Time (s)	Volume (m^3)
30	10.85
60	21.55
90	31.50
120	42.3
150	53.05

Table 4. *Results of volume of engine oil pumped within the interval of 30 seconds.*

Time (s)	Volume (m^3)
30	8.85
60	17.55
90	25.50
120	34.25
150	42.90

Comparison the volumetric flow rate of the liquids under study

Table 5. *Descriptive results on volumetric flow rate of the liquids under study.*

Volume	N	Mean		Std Deviation	95% Confidence interval for mean
		lower boundary	Upper boundary		
Water	5	49.5860	25.96881	17.3415	81.8305
Diesel	5	48.0800	25.34614	16.6086	79.5514
Hydraulic oil	5	31.8500	16.62720	11.2046	52.4954
Engine oil	5	25.8100	13.40958	9.1598	42.4602

Table 6. *ANOVA of the volumetric flow rate of the liquids under study.*

volume	sum of squares	df	mean squares	F	P-value
Between Group	2097.474	3	699.158	1.577	.234
Within Group	7092.347	16	443.272		

From Table 6, the degree of freedom (df) = (3,16) indicates that out of the total of 20 experiments that were done on all the liquids, when between 3 to 16 experiments are conducted on all the liquids, it is likely that the same results will be recorded by the researcher.

The significance level of the study is 0.05 but from the analysis of the results generated from the experiment, the $P-value = 0.234$. This value is greater than 0.05, therefore the test is not significant. This means there is no significant difference between the volumetric flow rate of the various liquids under study.

3.2. Experiment on Water

From Table 5, it could be seen that water recorded the highest volumetric flow among the liquids under study with a mean of 49.5860 m^3. This is because the force generated in the pump is greater when pumping water than any of the liquids under study.

$$Force\ (F) = mass\ (m)\ x\ acceleration\ due\ to\ gravity\ (g)$$

The Force used to pump a m^3 volume of water

$$(F_w) = m\ x\ g = 1 \text{ x } 9.8 = 9.8\ N$$

Water has its maximum density of 1 g/cm^3 at 4°C.

The amount of energy given to the water is proportional to the velocity at the edge or vane tip of the impeller. This kinetic energy of a liquid coming out of an impeller is harnessed by creating a resistance to the flow. The first resistance is created by the pump volute (casing) that catches the liquid and slows it down. In the discharge nozzle, the liquid further decelerates, and its velocity is converted to pressure:

$$P_w = F_w / A_w$$

$$P_w = 9.8 / 3.69 = 2.65 \text{ N/m}^2.$$

Therefore, the pressure required to pump a $m^3$of water is 2.65 N/m^2

Given an area (A), and a fluid flowing through it with uniform velocity (C) with an angle θ away from the perpendicular direction to A, the flow rate

$$(Q) = A \cdot C \cdot cos\ \theta$$

In the special case where the flow is perpendicular to the area A, that is, $cos\ \theta = 1$, the volumetric flow rate

$$(Q) = A \cdot C$$

From Table 1, for the first 30 seconds an amount of 16.48 m^3 of water was pumped. This means that, the rate of flow of water

$$(Q_w) = (16.48 \text{ x}10^{-3})/30$$

$$Q_w = 16.48/30 = 5.49 \text{ x}10^{-4} \text{ m}^2\text{/s}$$

Since the area of the cross-section of the hose (A) $= \pi r^2$

$$A = 3.142 \text{ x } 1.175$$

$$= 3.69 \text{ m}^2$$

Therefore, the velocity (C_w) at which the water moved when pumped by the pump is

$$C_w = Q_w/A$$

$$C_w = (5.49 \text{ x}10^{-4}) / 3.69$$

$$=1.49 \text{ x}10^{-4} \text{ m/s}$$

The maximum height of water pumped by the pump is

$$P = \rho g H$$

$$H = P/\rho g$$

= (2.6/1) x 9.8

= 0.265 m

The speed at which the water moved when pumped by the centrifugal pump is 1.49 x10^{-4} m/s which is higher than any of the liquids under study. This is because the impeller revolved at a higher speed. This agrees with the suggestion by Mukesh [8] that the faster the impeller revolves or the bigger the impeller is, the higher the velocity of the liquid at the vane tip and the greater the energy imparted to the liquid.

3.3. Experiment on Diesel

From Table 5, it could be seen that the mean of the volumetric flow of the five experiments performed on diesel is 48.0800 m^3. It could be seen that the volumetric flow of diesel is less than that of water. This is contrary to the view of Ghidhan et al. [22] who suggested that a liquid with less density will have a high flow rate.

Diesel has a density of 0.885 kg/m^3.

Therefore, the force used to pump a m^3 volume of diesel is

$$F_d = m \, x \, g = 0.885 \text{ x } 9.8$$

= 8.67 N

Knowing the force required to pump a m^3 of volume of diesel, the pressure needed to pump the same amount of m^3 of diesel is $P_d = F_d / A_d$

The area A_d = 3.69 m^2 since it is the same hose used to perform the experiment.

P_d = 8.67 / 3.69

= 2.35 N/m^2

Given an area (A), and a fluid flowing through it with uniform velocity (C) with an angle θ away from the perpendicular direction to A, the flow rate

$$(Q) = A \cdot C \cdot cos\,\theta.$$

If $cos\,\theta = 1$ then $Q = A.C$

From Table 2, for the first 30 s an amount of 15.95 m^3 of diesel was pumped. This means the rate of flow of diesel

(Q_d) = (15.95 x10^{-3}) /30

Q_d = (15.95 x10^{-3}) /30

= 5.31 x10^{-4} m^3/s

Therefore, the velocity (C_d) at which the diesel moved when pumped by the pump is

$$C_d = Q_d/A$$

C_d = (5.31 x10^{-4}) / 3.69

= 1.44 x10^{-4} m/s

The maximum height of diesel pumped by the pump is

$$P = \rho g H$$

$$H = P/\rho g$$

= (2.35/0.855) x 9.8

= 0.280 m

Mukesh [8] suggested that the faster the impeller revolves or the bigger the impeller is, the higher the velocity of the liquid at the vane tip and the greater the energy imparted to the liquid. It could be realized that the velocity of the diesel is less than that of water even though water is denser than diesel. This is contrary to the view of Ghidhan et al. [22] who suggested that less dense liquids should have a high velocity than denser liquids. Since diesel is less heavy than water it is expected that the velocity of diesel will be greater than water, but the results show otherwise.

3.4. Experiment on Hydraulic Oil

From Table 5, it could be seen that the mean of the volumetric flow rate of the five experiments performed on hydraulic oil is 31.8500 which is lower than that of water and diesel. Ghidhan et al. [22] indicated that liquids with high density have a low flow rate as compared to liquids with less density.

The mass of m^3 of hydraulic oil is 1.2 kg.

$$F_h = m \, x \, g = 1.2 \text{ x } 9.8 = 11.76 \text{ N}$$

Knowing the force required to pump a m^3 of volume of hydraulic oil, pressure needed to pump the same amount of m^3 of hydraulic oil is $P_h = F_h / A_h$. The area A_h = 3.69 m^2 since it is the same hose used to performed the experiment.

P_h = 11.76 / 3.69

= 3.19 N/m^2

Therefore, the pressure at which the hydraulic oil was pumped by the pump is 10.62 N/m^2.

From Table 2, for the first 30 seconds an amount of 15.95 m^3 of water was pumped. This means the rate of flow of water

(Q_h) = (10.85 x 10^{-3}) /30

Q_h = (10.85 x10^{-3})/30

= 3.62 x 10^{-4} m^3/s

Therefore, the velocity (C_e) at which the hydraulic oil moved when pumped by the pump is

$$C_h = Q_h/A$$

C_h = 3.62 x 10^{-4} / 3.69

$$= 9.80 \text{ x } 10^{-5} \text{ m/s}$$

The maximum height of hydraulic oil pumped by the pump is

$$P = \rho g H$$

$$H = P/\rho g$$

$$= (3.19/1.22) \text{ x } 9.8$$

$$= 0.267 \text{ m}$$

It could be realized that the velocity of the hydraulic oil is less than that of water and diesel. This means that the impeller revolved faster when pumping water and diesel than when pumping hydraulic oil as suggested by Mukesh [8].

3.5. Experiment on Engine Oil

From Table 5, it could be seen that the mean of the volumetric flow rate of the five experiments performed on engine oil is 25.8100 which is the lowest mean among the liquids under study. The lowest mean of the volumetric flow rate of engine oil compared to the other liquids under study agrees with Ghidhan et al. [22] who indicated that liquids with high density have low volumetric flow.

The mass of 1 m^3 of engine oil is 1.25 kg. If force

$$(F) = m \, x \, g$$

then the force used to pump a m^3 volume of hydraulic oil is

$$F_e = m \, x \, g = 1.25 \text{ x } 9.8$$

$$= 12.25 \text{ N}$$

Knowing the force required to pump a m^3 of volume of hydraulic oil, pressure needed to pump the same amount of m^3 of hydraulic oil is

$$P_e = F_e \,/\, A_e$$

The area A_e = 3.69 m^2 since it is the same hose used to performed the experiment.

$$P_e = 12.25 / 3.69$$

$$= 3.32 \text{ N/m}^2$$

Therefore, the pressure at which the hydraulic oil was pumped by the pump is 3.32 N/m^2.

From Table 2, for the first 30 s an amount of 15.95 m^3 of water was pumped. This means the rate of flow of water

$$(Q_e) = 8.85 \text{ x } 10^{-3} /30$$

$$Q_e = 8.85 \text{ x } 10^{-3} /30$$

$$= 2.95 \text{ x } 10^{-4} \text{ m}^3\text{/s}$$

Therefore, the velocity (C_e) at which the engine oil moved when pumped by the pump is

$$C_e = Q_e/A$$

$$C_e = 2.95 \text{ x}10^{-4} / 3.69$$

$$= 7.99 \text{ x}10^{-5} \text{ m/s}$$

The maximum height of engine oil pumped by the pump is

$$P = \rho g H$$

$$H = P/\rho g$$

$$= (3.32/ 1.250) \text{ x } 9.8$$

$$= 0.271 \text{ m}$$

It could be realized that the velocity of the engine oil is less than that of water, diesel and hydraulic oil even though the force generated in the pump when pumping engine oil is higher than the other liquids. This is contrary to Mukesh's [8] suggestion that the centrifugal force acting inside the pump is the same one that keeps liquids inside a bucket that is rotating at the end of a string.

4. Conclusions

The differences in the mass per liter of the various liquid under study affect the velocity at which the liquids move when pumped. The velocity at which the various liquids moved also affected the volumetric flow of the liquid. The velocity of the liquid is proportional to its volumetric flow rate. The head of each liquid is proportional to the mass of the liquid. The viscosity of each liquid is proportional to the volumetric flow of the liquid.

5. Recommendations

We strongly recommend that:

1. Pumps should be purchased to handle only one type of liquid.
2. More auxiliary parts of pump like seals and bearings should be available when a low horsepower pump (0.5hp) is used to pump a liquid with high viscosity.
3. The extractor fan of the pump should always be functioning especially when pumping liquids with high viscosity.

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