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Review Article

Design Analysis of a Peristaltic Hose Pump

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Abstract: Chemicals and prepared liquid food are very useful and essential in the field of science. Virtually nothing could exist or be made and there is hardly any process that could be completed without the use of essential chemicals at one stage or another. The immensely vast uses of chemicals demanded that it should be transferred from one point to another (pumping). To achieve this end, a great number of pump types and designs are available for various industrial and domestic applications. Flexible hose pump, (peristaltic pump). Being one of the modern and widely used for pumping chemicals, pharmaceutical liquids, and liquid foods. This research work seeks to design and fabricate a flexible hose pump. The design considerations and material selections for various components were based on the fluid being chemical. The manufacturing and fabrication processes were selected such that local technicians using locally available materials and being cheaper can construct it.
Keywords: Peristaltic Pump, fluid chemical, essential chemicals.

1.0 INTRODUCTION

Man, in his ever changing society has always had need to move essential liquid from one point to another. This is right from period of civilization with the advent of technology the need of pumping liquid increase tremendously and the complication of the liquid also increase, in the early stage it was mostly water for irrigation and consumption but today various liquids are discovered which are essential to man, his need to transfer them to a suitable place (Balogun olumide Abudid Azeez (1998). Technology & science has made it possible that some of the liquids to be handled are quite different from the liquid (water) we use to know, therefore the conventional way of handling the earlier liquid cannot work with this modern liquid which are completely prepared by man to suit his needs (Ilugbusi (2001). Most of which are dangerous to man him and should be handle with care, and therefore there is the need for man to device a means of handling this liquid that are harmful to him in a safe way, and that is why special pump are developed to handle such liquid (Cecil Jenson and Jay D. Helse (1996)). Although some liquids that may be required to be handled carefully are not always dangerous to man but, they require cleaners and some are used as children medicine popularly called syrups. This modern pump could handle such liquids under complete seal condition and the fear of contamination is minimized and there will be an assurance of cleanness (Fagbenie M. O. (2000).

This modern handling device called hose pump is a modern machine designed to eliminate contact of the moving element of the pump with the liquid being pumped, which in most cases is not so with other pumps. And that is the uniqueness of the hose pump. And that is the aim of designing and constructing a pump that can simply pump special liquid like, chemicals, pharmaceutical liquids and liquid foods, which need careful handling in our industries (P. K Wag. (2003)). The universal domination of flexible hose pumps of various kind of design and application in pharmaceutical industries, food processing industries, research laboratories, and chemical plants. Makes life easy. As would be expected for such important equipment, various designs operating on different conditions are available in the market. For all classes of pumps, flexible hose pump, stands out with specific range of applications. Under different operating conditions such as specific gravity, rated capacity, low discharge and differential pressure, gravity feed and low temperature. This is surely a reflection of the merits of hose pump over other pumps. This operating condition surely is beyond the scope of a single design and construction and as such immense modifications have in the recent times taken place. However, some common but special features, which enhance its

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acceptability over others for similar applications, include: Minimum maintenance, relatively low cost, wide choice of arrangement, compactness/portable, ease of installation, durability (RoNald A. Waish (1999).

Flexible hose pump is ideal for pumping acidic, corrosive chemical powder, pharmaceutical and food processing. The simple reason is that it is designed to eliminate all contact of moving parts of the pump with the fluid being pumped, self-prime pump, run dry safety and can function as a vacuum pump and low down time, few maintainable parts available in the pump. The research was successful and has brought a lasting solution to the problem encountered in pumping acidic, corrosive pharmaceutical liquids and liquid foods in our industries (R.S Khurmi & J.K Gupta (2004).

2.0 Design Analysis

3.0 2.1 Description of the peristaltic hose pump

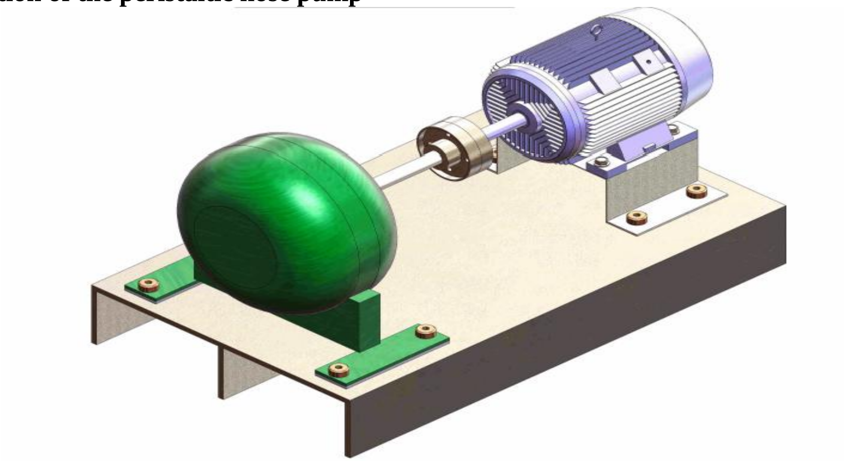

Fig-1: The Peristaltic Hose Pump

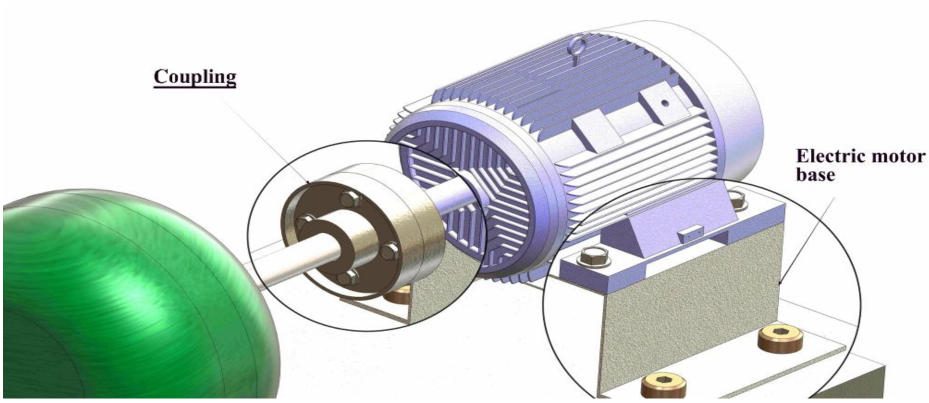

Fig-2: The Peristaltic Hose Pump

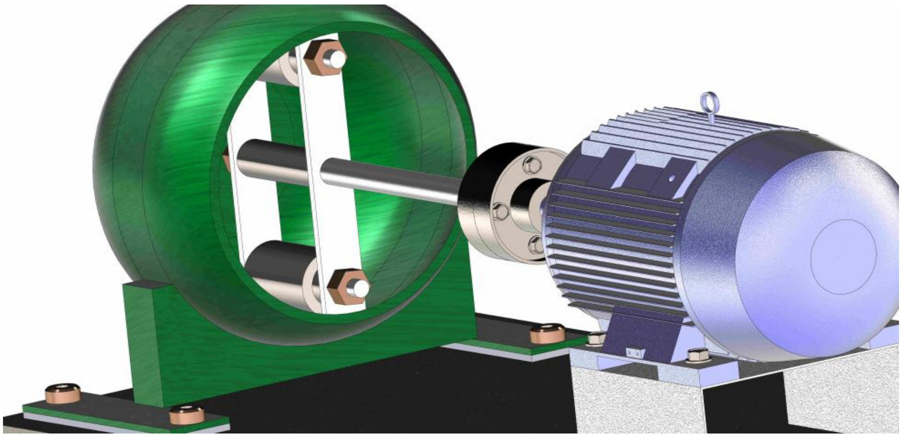

Fig-3: The Peristaltic Hose Pump

2.1.1 Casing

As shown in Figure 1, 2 and 3 above, a steel pipe of 145mm inner diameter and 160mm outer diameter is cut with a power-sawing machine to a length of 110mm. It was machined on a lathe by facing to the length of 100mm and boring the inner diameter 150mm and a thickness of 10mm. Two holes directly opposite each other are bored on the cylinder to accommodate the suction and discharge pipes. The casing is welded to base, which will be bolted to the bed plate. And the joints between the suction and discharge pipe, and casing should be welded.

2.1.2 Cover

A thin mild steel plate of 3mm thin is cut out of diameter 160mm and holes bored for the fastening of bolts of 10mm.

2.1.3 Bed Plate

A U-shape iron bar of 90mm high is to be cut into 450mm length. Two pieces of this will be produced and welded together the weld surface should be smooth with hand grinder and file. Slots and circular holes are to be cut to accommodate bolts and nuts for fastening electric motors and casing to the bedplate

2.1.4 Electric Motor

An electric motor of suitable speed and torque is required to drive the pump.

2.1.5 Bearing

The bearings accurately locate the shaft and carry radial and thrust loads. Ball bearing is used in this project. Because of its suitability and availability.

2.1.6 Pump Shaft

A steel rod of 25mm diameter was machined to 16mm outer diameter of 50mm length. One end of the shaft will be bored to a size 18mm and 35mm depth also a key way is to be cut to hold in place the electric motor shaft and pump shaft. The other will be bored and threaded for m10 bolt that holds the rotating members to the shaft.

2.1.7 Rollers or Shoes

Rollers are to be constructed from Teflon or Aluminum bar of 50mm diameter. This should be machined to an outer diameter for 40mm and 60mm length. Provision should be made for bearing No 6000zz at both ends of the roller and m10 bolt passing through.

2.1.8 Flexible Hose

A flexible hose 8 mm inner diameter and have durable thickness that was coiled to 150mm diameter without collapsing, And return to its shape after pressing between rollers and casing.

3.0 Basic Theory of Flexible Tube Pump

Fluid pressure is measured with respect to two pressure references; zero pressure and atmospheric pressure. Fig 4.1 illustrate Pressure measure with respect to true zero pressure reference is known as absolute pressure while that measured with respect to atmospheric pressure is known as gauge pressure.

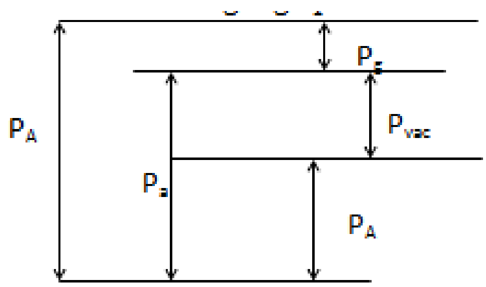

Fig-4.1: Illustrate pressure terms

Most pressure gauges read excess of the test pressure over the atmospheric pressure at the locality. Absolute pressure and gauge pressure are these related by

$$P_A = P_g + P_a \qquad 4.1$$

Also, since barometer measures the atmospheric pressure, barometric pressure is thus synonymous with atmospheric pressure. A vacuum measurement is simply a pressure below atmospheric (negative gauge pressure).

$$P_A = P_a – P_{vac}. \qquad 4.2$$

That is, P_A = Absolute Pressure, P_a = Atmospheric Pressure, P_{vac} = Vacuum Pressure.

Another important pressure term is the vapor pressure of the liquid being pumped. This is the pressure attended by every liquid at any temperature above its freezing point due to the formation of vapor at its free surface. This is a function of temperature of the liquid, the higher the temperature, the higher the vapor pressure. In any pumping systems the pressure at any point should never be reduced below the vapor pressure corresponding to the operating temperature because the liquid will form vapor, which will partially or completely stop liquid flow into the pump.

3.1 Head

Pressure and head are different ways of expressing the same value. In the vernacular of the industries, when the term pressure is used it generally refers to units is PSI, whereas head refer to feet (m) of liquid being pumped. These values are mutually convertible, one to the other, as follows:

$\frac{Psi\ x\ 7031.1}{Sg}$ kg/m^2 4.3

Pressure or heads are most commonly measuring by means of a pressure gauge.

3.2 Pump speed

The speed (N) of a rotary pump is the number of revolutions of the driving or main rotor per unit time when no gear reduction or increase exist between the drive shaft and the main rotor. The speed may be measured and set. Its units are rpm.

The angular speed $\omega = \frac{2(3.143)N}{60}$ radians/sec 4.4

linear velocity of the pump (v) = ωr 4.5

Where r, = radius of the pump housing inner radius minus twice the flexible tube thickness.

3.3 Pump Pressure

The absolute pressure of the fluid at any location in the pump, expressed in the common unit of pounds per square inch (Psi) or Newton per meter square N/m^2, is the total pressure there, and is the basis for other pressure definitions associated with pump operation. The pressure associated with pump operating characteristics of a rotary pump involves conditions where the velocity pressure (P_v) caused by fluid velocity is small compared to the total pressure and may be neglected, or where the fluid velocities are sufficient like that of the velocity pressure cancel when the total pressure difference is computed.

3.4 Pump Slip

Slip in rotary pumps is the quantity of fluid, which leaks from the OTO volume to the OTI volume per unit time. Slip depends on the clearance between the rotating and stationary members that defines the "leak path orifice" on the differential pressure between the OTO volume and OTI volume, and on the characteristics of the fluid handled (in particular the viscosity). In those rotary pumps where liquid velocity is high, it may be secondarily dependant on pump speed.

Slip in a rotary pump occurs only when a pressure difference exist between the inlet and outlet chambers of the pump, this pressure difference cause the pumped fluid to flow between the outlet and inlet chambers through clearance between rotors and body members. It has the same effects as a shunt or bypass around the pump from outlet port to the inlet port. The effect of pressure on slip is complex and directly proportional to pressure.

S = $\frac{KPtd}{V}$ 4.6

Where, k = coefficient of slip; $P_{td} = P_d - P_s$; P_d = Discharge pressure; P_s = inlet pressure, V = viscosity of the fluid

3.5 Capacity

The capacity of a pump is the quantity of liquid moved per unit time by the pump. When measured in the unit of volume, this quantity is referred to as volumetric capacity, and is designated normally by a letter Q. the Unit of Q in common use includes m^3/s, m^3/hr, gallons per minute (Gpm), liters/sec. S. I system introduce mass capacity (m) which is the quantity of liquid per unit time delivered by the pump M and Q are connected by a relationship as given below:

$M = \rho Q$ (Kg/s). 4.7

Ith a peristaltic tube pump, the liquid can be drawn from a container up to 914.4mm below the pump, and will pump up at least 3048mm absolute minimum. The performance of a flexible member pump is dependent on the material chosen for the flexible member. The bulk medium must be high enough to keep distortion of the flexible member under pressure within functional limit. In many cases as in the flexible vane and flexible tube pumps, the ability of the flexible member to spring back to its original shape (recovery) after the compression by the pumping action is essential, once flattened, where to remain flat and not spring back to its tubular shape the pump would not operate. The diameter of the tube, speed of pumping element and the particular network the pump is connected to determine the capacity. For a rotary pump operating with zero slip the capacity of the pump is called displacement capacity Q_d. (Karassik *et al*., 1974).

$Q = KDN - S = Q_d - S$. 4.8

Where K = 0.004329, S and Q in GPM, D in feet and N in rpm.

The capacity of a rotary pump is the net quantity of fluid actually delivered by the pump per unit of time through its out port or port fluid is essentially non–compressible, capacity is numerically equal to the total volume of liquid displaced by the pump per unit of times minus the slip all expressed in the same units. The capacity of a rotary pump operating with zero slip is called the displacement capacity Q_d.

$Q = KDN - S = Q_d - S$; K = the losses constant; D = Displacement of the pump;

N = Pump speed in rpm; S = pump slip.

From equation 4.8 substituting for D

$Q = K\pi^2 D_i d_i^2 N - S$ 4.9

$8Q = K\pi^2 D_i d_i^2 N - S$

$$d_i = \sqrt{\frac{8Q + S}{K\pi^2 D_i N}}$$

If slip is assumed to be zero

$$d_i = \sqrt{\frac{8Q}{K\pi^2 D_i N}} \quad 4.10$$

3.6 Pump Displacement (D)

Rotary pump displacement is the total net fluid volume transferred from OTI volume to OTO volume during one complete revolution of the driving rotor. The unit is m^3/revolution. For any given pump, the displacement depends only upon the physical dimensions of the pump elements and the pump geometry for variable displacement; the pump usually is rated at its maximum displacement. For the peristaltic flexible tube pump the displacement D, is given by the formula below.

Displacement D_p = length x cross–sectional Area.

$= L \times \pi d_i^2/4$ 4.11

Where $L = \pi D_i/2$

$$D_p = \frac{\pi D_i}{2} \times \frac{\pi d_i^2}{4}$$

Pump displacement $D_p = \frac{\pi^2 D_i d_i^2}{8}$ 4.12

Pump displacement $D_p = \frac{\text{pump capacity } Q_p}{\text{Pump speed } N_p}$

Cross – sectional area of flexible tube fluid passage,

$$A = \frac{\pi d_i^2}{4} \quad 4.13$$

Length of the tube in the pump

½ πD_i

Displacement = L x a

$= \frac{1}{2}\pi D_i \times \pi d_i^2/4$

$= \frac{\pi^2 D_i d_i^2}{8}$

Where, D_i = inner diameter of the housing

d_i = inner diameter of the tube.

4.0 Design Calculation

The condition of use of a flexible tube pump can vary all the way from pumping of water to chemicals, wide range of capacities and low head. Evaluation of pump design features for satisfactory operation; safety and maintenance therefore vary with the particular process application. In designing a pump, the application must be clearly defined. That is the duty of the pump should be identified. The pump is required to deliver a stated quantity of liquid in unit time, when working at a speed against a specified head or pressure.

From the information given, the following will ultimately determine pump design specification and materials. Capacity range of liquid to be moved, deferential head required. The net position suction head of the pump (NPSH). Pump speed, viscosity of liquid to be moved, specific gravity of the liquid tube moved, other liquid characteristic e.g. Viscosity, density & flash point, pump construction.

4.1 System Analysis

Electric motor specifications are: Power 370 Watt, speed1410 rpm

4.2 Design of Shaft

Adequate rigidity and strength are the main criteria for shaft design. The pump shaft is subjected to combine effect of tension, compression, bending and torsion, as a result of cyclic nature of the load. Shaft failures are almost fatigue type. The major consideration in sizing the shaft is to limit stress to a level that will result in a satisfactory life for the pump. This requires the determination of shaft diameter by considering the effect of torsion and bending moment on the shaft. From R. K Rajput (2002), the shaft torque is given by equation 5.1

Shaft torque $T = p/\omega$ 5.1

Where $\omega = \pi N/30$

$= \frac{147.6}{30}$ rad/sec.

Substituting ω,

$$T = \frac{30P}{\pi N} = \frac{30 \times 270}{\pi \times 1410} = 2.5\text{Nm}$$

But the peak torsion stress τ_{max} is given by

$\tau_{max} = Tr/J$ 5.2

Given that,

$R = d/2$, $J = \pi d^4/32$ 5.3

Then,

$\tau_{max} = Tr/J = 8\text{mm}$

Taking the design stress as 0.75 τ_{max} , and for mild steel, τ_{max} = 40 Mpa. Then, we have. The calculated value of ‘d’ is at the least cross section and as such to provide for keyway, take care of stress concentration, bending moment and other design factor, a solid mild steel shaft of 16mm diameter shall be used Force on shaft F_s = T/r = $\frac{2.50,}{}$ 0.008 = 312.5N. The general practice is to use a square key which has a height equal to one fourth of the shaft diameter.

i.e. $h = d/4$ 5.7

The length of the key is determined by the strength requirement and this is evaluated by calculating the shear stress, assuming that the forces are uniformly distributed along the length of the key (Khurmi and J. K. Gupter).

Torque on key = $T_k = \tau_{max}$ h L r
5.8

Since, r = d/2, h = d/4, $T_d = 0.75\ \tau_{max}$, L=1 5.8

4.3 Bearing Selection

The basic dynamic rating is expressed by the equation.

$L_{io} = (c/p)^q$ 5.9

Where L_{io} is the basic rating life in millions of revolution

C = Basic dynamic load rating

P = Equivalent dynamic bearing load.

q = Exponential of life equation. (3 for ball bearing,10/3 for roller bearing)

Equivalent is given by equation 5.10

$p = x F_r + YF_a$ 5.10

Data required for calculation of equivalent dynamic load are given in bearing tables. The calculated value of the load ratio, c/p, and life (L_{io}) are set out in life calculation chart. For bearings at constant speed, it is more convenient to deal with basic rating life expressed in operating hours with the equation,

$L_{io} = \frac{10^6}{60n} (c/p)^q$ (if the speed is given) 5.11

For this design the motor speed is 1410 rpm

Under a constant load of 312.5N and to achieve a basic rating life of 20,000 operating hour's minimum, the bearing size required is

$L_{io} = \frac{10^6}{60n} (c/p)^q$

c = 1728.4N

4.4 Casing Design

The casing construction will be fabricated and machined. The material used is mild steel, the surface will be machined to give smooth surface finish while the joints will be Arc-welded.

4.5 Stress in Cylindrical Pump Housing

This case of thin cylinder subjected to an internal pressure only. A thin cylinder is defined as one which satisfy the relationship t/d <1/20 i.e. the ratio of the thickness t to the diameter d is less than 1/20. Because of this relationship, the hoop and longitudinal stresses are constant over the thickness and radial stress is more and negligible, the radial stress must have a value equal to that of the internal pressure and the outside or external radial stress must be equal to zero.

4.6 Roller or Shoes Design

This is an element of the pump, which dictates the performance of the pump. Its design therefore requires an understanding of the force interactions on the component. Design of the roller or shoes requires determination of casing diameter; the hose diameter, roller diameterpeed of motor, bearing.

To push the liquid effectively in the tube the casing diameter is 150mm and the hose diameter is 11mm is fitted in a groove in the inner side of the casing; it is required to be compressed to class in the groove as shown in the figure below.

Force on the rollers or shoes F_R L σ_L

$$F_R = \frac{\text{Torque transmitted by the shaft}}{\text{Distance of the roller center from shaft center}} = 18.867N \quad 5.18$$

4.7 Stresses in the Rollers.

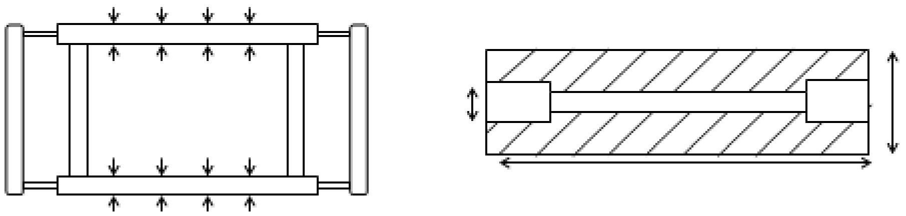

Fig-5: (a) side view (b) sectional view

4.8 Compressive stress exist in the roller, force on the rollers F_R

$$F_R = \frac{\text{Torque transmitted by the shaft}}{\text{Distance of the roller center from shaft center}}$$

$$= \frac{2.50}{0.150 - \frac{0.035}{2}}$$

$$= 18.867N$$

$$\text{Stress on the rollers} = \frac{\text{force on roller}}{\text{Area of roller}} \quad 5.19$$

$$\text{Cross-sectional Area of rollers} = \frac{\pi (D_o^2 - d_i^2) \times 2}{4}$$

$= \pi/4\ (0.035)^2 - (0.025)^2 \times 2$
$= \pi/4\ (0.001225 - 0.000625 \times 2$
$= \pi/4\ (0.0006) \times 2$
$= \pi/2\ (0.0006)$
$= 0.000942477m^2$

Stress on the rollers,
$= F/A$
$= \frac{18.867}{0.000942477}$
$= 20018.50\ N/m^2$
$= 20\ KN/m^2$.

4.9 Flexible Hose

Material Elastomer
Capacity of the pump Q = 16 liters/minutes
$Q = 0.016m^3/min$
Pump speed (Electric motor speed N)
= 1410rpm

Casing inner diameter D_i = 150mm = 0.150m
Losses constant K = 0.72
From equation 4.24

$$d_i = \left(\frac{8Q}{K\pi^2 D_i N} \right)^{½}$$

$$d_i = \left(\frac{8 \times 0.016}{K \times \pi^2 \times 0.150 \times 1410} \right)^{½}$$

From equation 4.22

$$D_i = L \times \frac{\pi d_i^2}{4}$$

And $L = \frac{\pi D_i}{2}$

$= \frac{\pi \times 0.150}{2}$
$= 0.23562m$
$= 235.6mm$

Length of the hose for pumping = 235.6mm

$$\text{Pump displacement } D_p = \frac{L \times \pi d2}{4}$$

$$= \frac{0.23562 \times \pi \times \text{hose diameter}}{4}\ m^3$$

$$= \frac{0.23562 \times \pi \times (0.0092)^2}{4}$$

$= 0.000015663m^3/rev$
$= 0\ 0.01566$ liter/rev

4.10 Pump Efficiency

Several efficiencies can be computed for a pump. The overall unit efficiency (E_o) is the percent of the total power input delivered as pump power output and is computed by the equation. (Karassik *et al.*, 1974).

$$E_o = \frac{whp}{Ehp} \times 100\% \quad 5.20$$

The pump efficiency, or pump mechanical efficiency (E_p), is the ratio of the pump power output to the pump power input. It may be computed by the equation

$$E_p = \frac{whp}{Php} \times 100\% \quad 5.21$$

The volumetric efficiency (E_v) of a pump is the percentage of pump displacement per unit time delivered as pump capacity. The equation for computing the volumetric efficiency is

$$E_v = \frac{231Q}{N_D} \times 100\% = \frac{Q}{Q_d} \times 100\% \quad 5.22$$

Where E_v is in percentage when Q and s are gallons per minutes, D is in cubic feet per revolution, and N is in revolutions per minute. Equation (5.31) may be stated in alternative ways as follows:

$$E_v = \frac{Q}{Q + S} \times 100\%$$

$$E_v = .\frac{KDN - S}{KDN} \times 100\%$$

4.11 Pump Performance

Figure 5.3 shows the change in the displacement capacity (Q_d) capacity (Q) and slip (S), as differential pressure (P_{td}) across the pump, liquid viscosity (ν), and pump speed (N) are varied. (Karassik *et al*,1974).

5.0 CONCLUSION

It is however, concluded that the Pump discharge large volume of water than Engine oil (20W50) this could be as a result of difference in densities of the fluid.

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