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# OPERATIONAL BEHAVIOR AND PERFORMANCE OF PUMPS IN PHYSICAL MODELING AT RIVER RESEARCH INSTITUTE, FARIDPUR.

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## Abstract

This paper deals with the operational behavior of pump and pump performance characteristics, installation, maintenance and major trouble and counter measures of pumps mainly used in modern water works specially for River Research Institute (RRI). The aim of this paper is to provide an engineer with basic information on pump characteristics that will enable him to make a first estimate of the number, dimensions and types of the pumps he will need and will provide him with a sound basis for choosing the right type of pump for the job. Maximum efficiency of pump was found 92% at 350 $m^3$/min specific speed. Pump performance was expressed by characteristic curves for total head, shaft power and efficiency. For satisfactory pump operation it is necessary to examine the suction condition prevailing at the pump inlet. It was observed that available net positive suction head ($H_{SV}$) was always larger than the required net positive suction head (NPSH). It is recommended to provide the available NPSH to be more than 1.3 times the value of $H_{sv}$. When a demand pattern against the time was plotted it was observed that the demand must be met with the selected number of unit of operation. It is recommended that the number of pumping units and their rated capacities must be determined so that the cost involved in investment and operation is economically viable. The investment cost will be increased with the increase of the number of units of pumps. From the study it was observed that a larger unit is preferable in view of efficiency providing less operating cost per unit capacity pumped. Periodic maintenance is needed for long survival of the pump.

## Introduction

Pump is the heart of any hydraulic system as it determines both the efficiency and reliability of the system. River Research Institute (RRI), Faridpur conducts many physical modeling to investigate river morphology. To effectuate these studies pumps are to create water flow. The pumps used at RRI are centrifugal pumps. A centrifugal pump is a rotodynamic pump that uses a rotating impeller to increase the pressure of a fluid. The pumps are designed on the principle that mechanical energy is converted into fluid energy by rotational motion of an impeller and the liquid leaving by the impeller is collected by a casing so that the liquid is lifted up or forced into a pressure vessel. There are many types of

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pumps, such as reciprocating, rotary, regenerative and jet types. The majority of heavy duty pumps used in modern water works facilities and liquid handling industries are of turbo type such as centrifugal, mixed flow and axial flow pumps (Ritzema 1994).

The hydraulic efficiency of a centrifugal pump depends significantly on the impeller and casing geometries and small changes in geometrical details can lead to large changes in performance (Moussa 2014). Important characteristics of centrifugal pump (1) Pressure head: Pressure is the driving force which is responsible to movement of liquid fluid (2) Friction head: Friction is the resisting force that slows down fluid particles. (3) Flow head: Flow rate is the amount of volume that is displaced per unit time. The objective of the paper is to provide the fundamental knowledge and information regarding determination of pump specification, selection of types, operating conditions and routine maintenance for application of pumps in water works for Physical modeling at RRI

**Literature review**

Modeling of pump application and efficiency has been addressed in the literature by several authors. Wilson (1946) published the basic models for the torque and volumetric efficiencies of positive displacement pumps. Using Wilson's basic model, Shlosser (1961) introduced nonlinear terms to account for the leakage flow that occurred at high Reynolds number flow and torque losses due to fluid acceleration. Zarotti and Narvegna (1981) demonstrated that this assumption was inadequate as the models deviated substantially from experimental data across a wide operating range of the pump. Consequently, these authors proposed more sophisticated models to account for the variation in loss coefficients. Pourmaovahed (1992) published his work which identified the large amount of scatter that exists in experimental efficiency data. This work has since been used to reconsider not only the reliability of the test data itself, but also the reliability of the previous modeling that has been done based upon these data. Bacharoudis et al. (2008) stated that various parameter such as performance of impeller, blade angles affect the pump performance and energy consumption. Navier-Stokes equations and Computational Fluid Dynamics (CFD) finite volume was used to calculate the performance of each impeller, the flow pattern and the pressure distribution in the blade passages. The results showed that increase in outlet blade angle causes a significant improvement of the hydraulic efficiency of pump. Taber (2011) investigated the influence of impeller diameter and speed on performance of centrifugal pump. The results showed that change in impeller speed and diameter has significant impact on performance of centrifugal pumps. Affinity laws were used to predict the performance of centrifugal pump at reduced speed or smaller diameter impeller. It was found that decrease in impeller diameter result in the reduction of the head, flow and also drops the efficiency.

Patel and Doshi (2013) examined the influence of blade angle on performance of a centrifugal pump. The investigation of blade exit angle was expensive and lengthy process thus a mathematical model was developed to investigate the effect of blade angle on performance of centrifugal efficiency. It was found that, both head and efficiency of centrifugal pump increase with the increase in blade exit angle. Kumar et al. (2014) examined the effect on impeller parameters such as number of blade, inlet blade angle etc. on the performance of centrifugal pump. The Computational Fluid Dynamics (CFD) analysis was implemented and velocity and pressure distribution were predicated. The optimum values of impeller were discussed and guidelines were presented in order to improve the efficiency of centrifugal pumps.

## Methodology

A number of journal, books, reports, lecture notes, pump catalogues were collected and studied thoroughly on application of pumps and pumps characteristics for water works. Theoretical knowledge was gathered and necessary reviews were drawn on the basis of easy operation and maintenance of the pumps.

### Specific speed

Hydraulic performance of a turbo pump is determined by three important factors. These are capacity, speed and total head. Using these three factors, we can determine the specific speed by the following equation

$$N_\alpha = \frac{N\,Q^{1/2}}{H^{3/4}} \qquad \text{eq. (1)}$$

Where, N = speed (rpm), Q = capacity (cum/min), H = total head (m)

The specific speed in the above equation is an essential criterion to determine the impeller shape as well as hydraulic characteristics of the pump. The shape of pump impeller varies continuously according to the values of specific speed. In general small values of the specific speed are suitable for high heads with small capacities while large values are for low heads with large capacities. (Manual for short course on application of pumps for irrigation and drainage)

**Efficiency and required Power**

The efficiency of a pump is defined as a ratio of the pump output to the shaft power input. The pump output refers to the theoretical hydraulic power imparted to the liquid leaving the pump and is obtained by multiple of liquid density, capacity and total head as given by

$$L_W = d.g.(Q/60).(H/1000)kW \qquad \text{eq. (2)}$$

Where, $L_W$ = pump output, d = density of liquid (kg/m$^3$), g = acceleration of gravity (m/s$^2$), Q = capacity (m$^3$/min), H = total head (m)

The above equation could be reduced to

$$L_W = 0.163 \times Y \times Q.H \qquad \text{eq. (3)}$$

Where, Y = Specific weight of liquid (kgf /litre)
Then the efficiency of pump is given by

$$e_P = 0.163 \times Y \times Q.H / L_P \qquad \text{eq. (4)}$$

Where $L_P$ = Shaft power input (kW).

Pump performance was expressed by characteristic curves for total head, shaft power and efficiency plotted on the ordinates against capacity on the abscissa. (Manual for short course on application of pumps for irrigation and drainage)

**Suction performance**

For satisfactory pump operation it is necessary to examine the suction condition prevailing at the pump inlet. The suction condition is best expressed in terms of “available” NPSH (Net positive Suction Head). This is calculated by

$$H_{SV} = H_A + h_S - h_i - h_V \qquad \text{eq. (5)}$$

Where, $H_{sv}$ = NPSH available (m), $H_A$ = absolute pressure head acting on suction liquid lever (m), $h_S$ = actual suction head (m), (for suction lift it becomes a minus value), $h_i$ = friction loss head in suction pipe (m), $h_V$ = saturated vapor pressure head (m).

The value of required NPSH can be obtained from "Suction specific speed" S defined by the following equation.

$$S = \frac{N Q^{1/2}}{h_{sv}^{3/4}} \qquad \text{eq. (6)}$$

Where, S = suction specific speed, N = speed of pump (rpm), Q = capacity (cum/min), $h_{sv}$ = NPSH required (m)
(Manual for short course on application of pumps for irrigation and drainage)

**Determination of total heads**

Total head of a pump is obtained by the sum of actual head and hydraulic losses in the connected pipes, fittings and valves and is given by

$$H = H_a + H_r \qquad \text{eq. (7)}$$

Where H = total head (m), $H_a$ = actual head (m), $H_r$ = sum of total losses (m)

Actual head refers to the static difference between suction and discharge liquid levels prevailing during pump operation.
(Manual for short course on application of pumps for irrigation and drainage)

**Selection of pump type**

As a preliminary consideration, the hydraulic type of pump was selected according to the total head required for the pump to be used. A general guide for type selection in terms of the total head is given in the following table for conventional pumps, in which applicable bore sizes are also shown.

**Table 1.** Selection of pump types

| Pump Type | Specific Speed | Total Head | | Bore |
|---|---|---|---|---|
| | | **Horizontal** | **Vertical** | |
| Centrifugal (Radial Flow) | 100-600 | Single Stage 10-150m | Single Stage 10-200m | >40mm |
| | | Multistage>50m | Multistage>10m | |
| Mixed flow | 400-1400 | 4-15m | Single Stage 4-60m | >200mm |
| | | | Multistage>10m | |
| Axial flow | 1300-2000 | <6m | <8m | >300mm |

For the required capacity and the total head, the pump speed can be obtained by

$$N = \frac{\left(N_{\alpha} H^{\left(3/4\right)}\right)}{Q^{\left(1/2\right)}} \qquad \text{eq. (8)}$$

Selection of higher specific speed may result in smaller pump size. When the pump is directly coupled with an electric motor or and engine, the speed must be adjusted to suit the rated speed of the selected prime mover. The synchronous speed of a three phase AC motor is given by

$$N_{mn} = 120\,Hz / N_P \qquad \text{eq. (9)}$$

Where, $N_{mn}$ = motor Synchronous speed. Hz = frequency of AC Electric Source. $N_P$ = number of poles.

## Results and discussion

The value of pump efficiency depends mainly on the specific speed and capacity of the pump is shown in Figure 1.

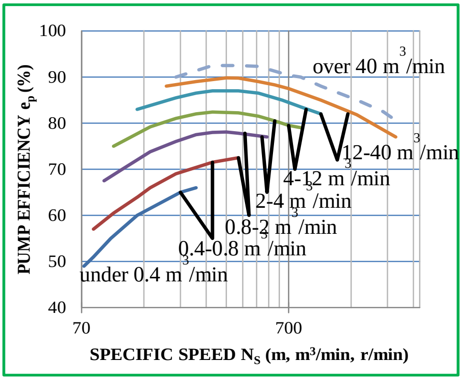


**Figure 1.** Pump efficiency versus specific speed curves

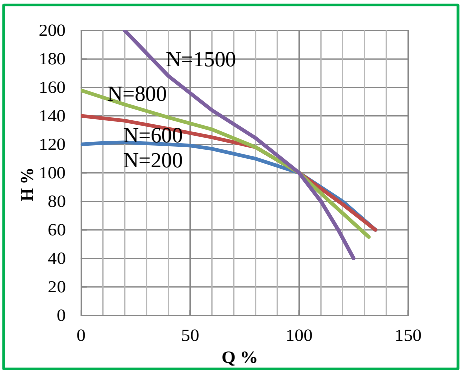


**Figure 2.** Pump characteristics for different specific speed

### Pump characteristics

The forms of characteristic curves were closely related to the values of specific speed as shown in Figure 2. In which each characteristic was given in percentage of the value at the best efficiency point. Each characteristic has the following tendency:

a) Total head capacity

For small specific speed values, the curve is flat with a small shut off to rated head ratio. Whereas the curves becomes steep as the specific speed increases.

b) Shaft power

The shaft power attains the minimum value at shut off for small specific speed values, rising as capacity increases. For mixed flow range, it remains about the same at all capacities. Whereas for an axial flow pump it increases remarkably towards the shut off.

c) Efficiency

The variation in efficiency against capacity is more favorable for smaller values of specific speed.

The value of available NPSH was solely determined by installation conditions of a pump are shown in Figure 3.

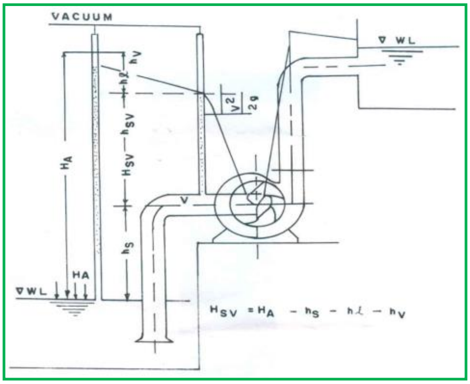

**Figure 3.** Net positive suction head

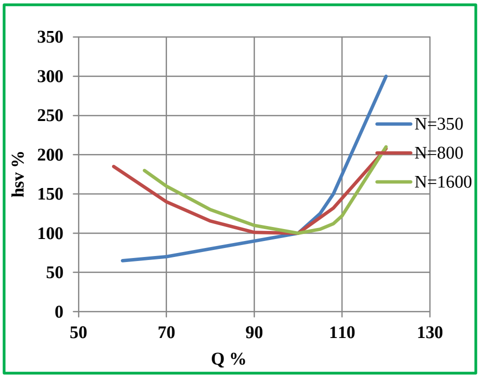

**Figure 4.** Variation of required NPSH against capacity

Figure 4 shows the tendency of required NPSH variations against capacity for representative values of specific speed. The available NPSH, $h_{SV}$ must always be larger than the required NPSH. It is recommended to provide the available NPSH to be more than 1.3 times the value of $h_{sv}$ as given by equation

$$h_{sv} = \left[ \frac{N Q^{1/2}}{S} \right]^{4/3} \qquad \text{eq. (10)}$$

**Adaptability to variable demand**

In pumping services, the demands often fluctuate considerably according to time periods and seasons of the year and purposes. When an appreciable variation in demand exists, pumping must be divided into several units and different sizes. It must be noted that the most economical operations could be attained by operating the pump in its optimum efficiency point without throttling. A demand pattern against the time is shown in Figure 5 it was observed that the demand must be met with the selected number of unit of operation. The demand can be expressed in the order of required capacity interims of operating time duration as shown in the Figure 6. When two identical large pumps and one small pump are considered $V_{1p}$, $V_{2p}$, $V_{3p}$ represent the pump capacities with one, two, three units respectively.

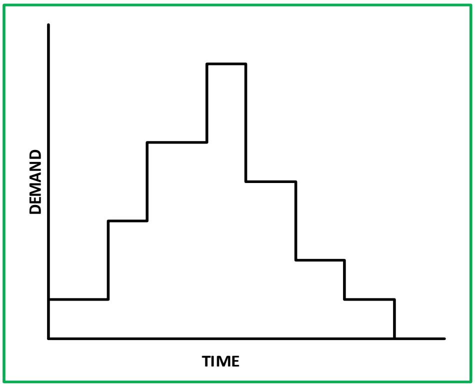


**Figure 5.** Demand vs. Time curve

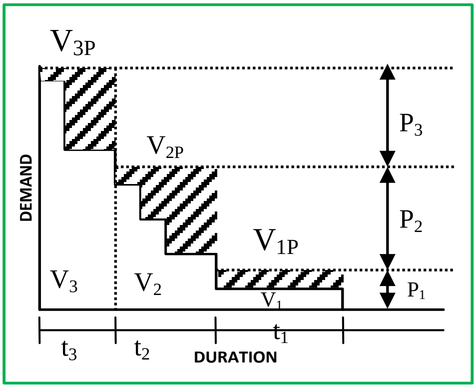


**Figure 6.** Demand vs. Duration curve

As the demands for respective periods are given by $V_1$, $V_2$, $V_3$ the excess capacities are expressed by the hatched area which should be made minimum to attain a higher degree of adaptability.

For centrifugal pumps the pump speed can be checked as shown in Figure 7, in which $H_S$ represents the suction actual head minus the head losses at the suction side. The operating capacity range was assumed to be up to 120% of the BEP (best efficiency point).

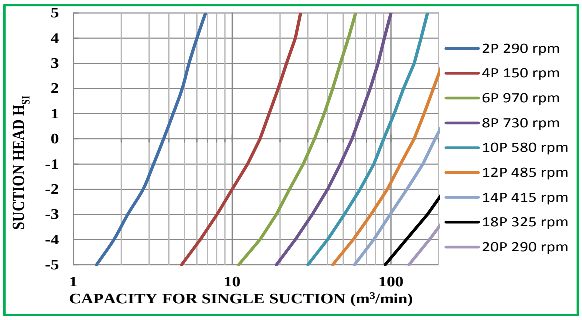


**Figure 7.** Suction head and speed for centrifugal pumps

## Basic features of pump operation

### Installation of pumps

To provide proper functioning of pumping equipment, it is necessary to follow established installation procedures as outlined below.

#### a) Foundation

In most cases, the pump was installed on a concrete foundation. The foundation is required to have sufficient strength to withstand the weight of pumping unit and dynamic load exerted by its operation. The base plate of pump is usually fixed by means of anchor bolts, for ample sized holes must be provided for grouting in the foundation or the base plate itself.

#### b) Placement

For positioning the pump unit steel liners are placed between the foundation and the base plate. The liners should be placed at both side of the anchor bolt. Use of a pair of tempered liners is advantageous for fine adjustment. After primary checks on concrete positioning, the anchor bolts can be grouted with mortar.

#### c) Alignment

For providing vibration free operation of pump exact alignment at the coupling is indispensible. Factory adjusted adjustment can be resolved by adjusting respective liners under the base plate. Alignment can be checked with a straight edge and a filler gauge. Installation of connecting pipes and valves must avoid undue forces exerted on the pump exit. After rechecking the alignment, the liners are preferably spot welded and the base plate can be completely grouted after which the coupling bolts are finally inserted.

### Operation procedures

Preparation: Prior to initial startup of a pump the following preparation in general to be performed and confirmed, which also applies when a pump is to be started after a long idle time.

**a) Confirmation on liquid passages**

Suction sump or chamber must be cleaned of filled with liquid to be pumped, piping joints must be tightly connected to ensure leakage free operation.

**b) Check on lubricants**

Amounts of lubricating oils must be checked by oil level gauges etc. The same shall apply for the driving equipment.

**c) Confirmation on power source**

For motor driven pumps due preparation of cabling and electric power should be made. Protective device should be checked for functioning.

**d) Auxiliary equipment and instruments**

All necessary related equipment must be confirmed of their proper functioning.

## Starts and stops

Established order should be followed in performing normal starts and stops. In normal cases the following order should be observed on pump types.

**a) Starting order**

- Confirm that discharge valve is fully closed.
- Confirm that the prime mover is ready to start.
- Confirm that suction liquid level or pressure is normal.
- Start and confirm necessary sealing/lubricating/cooling.
- Priming of pump by vacuum pump if applicable.
- Confirmed that discharge pressure reaches prescribed value after full speed is attained.
- Open discharge valve and check discharge pressure which must correspond to the value within operational range.

**b) Stopping order**

- Fully close the discharge valve. Switch off prime mover.
- Rest prime mover to its starting position.
- After complete stop of pump, stop sealing/lubrication/cooling.

## Maintenance

### Periodic maintenance

To maintain prescribed performance of a pumping unit for its service life, it is indispensible to provide appropriate maintenance services, it is always recommended "preventive maintenance" which is termed as scheduled maintenance be performed to prevent occurrence of troubles and to maintain proper functioning of the equipment. For a motor driven pumping unit to be operated continuously, list of periodic inspection on items is given below:

**Table 2.** Inspection items for pumps

| Interval | Inspection items | Remarks |
|---|---|---|
| Daily | Appearance as to leaks etc<br>Noise & Vibration, Bearing Temperature<br>Gland packing | To be within ambient temperature; +40º c Leakage 1 drop/sec |
| Monthly | Bearing lubricants<br>Gland packing | Check quantity check for gear |
| Every 6 Months | Replacement of bearing Lubricants. Replacement of fixing bolts, Check on Protective devices. | |
| Every 1-4 year | Overhaul inspection rubbing parts and corrosion/erosion of parts | Checks for wear on rubbing parts and corrosion/erosion of wet parts |

### Major troubles and counter measures

During service life of a pump some troubles may be encountered depending on operating conditions. Vibration of a pump is most effectively detected at its bearing and at the top of the unit, and its amplitude and frequency are measured

by vibration meter. Figure 8 shows permissible range of amplitude against pump speed.

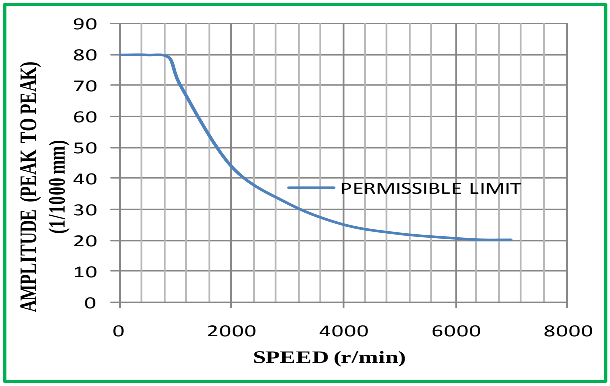


**Figure 8.** Permissible variation amplitude

Vibration modes are classified into: (1) vibration with the same frequency as the pump speed, (2) vibration with frequency several times the pump speed and (3) vibration with irregular frequencies.

Major causes and counter measures are given in the following Tables 3, 4 and 5 respectively.

**Table 3.** Vibration with the same frequency as the pump speed

| Items | Cause & checks | Counter measures |
|---|---|---|
| Misalignment | Check coupling alignment | Readjustment of alignment |
| Distortion of centering during operation | # Hydraulic thrust acting from discharge pipe<br># High temperature liquid Causing displacement of center height<br># Non uniform diameter of coupling bolt bushings | Apply stay tools on flexible joints<br>Pump type to be changed<br>Use uniform Bushings |
| Inferior Foundation | # Vibration observed on weak foundation<br># Anchor bolts loosened | Reinforce foundation<br>Tighten anchor bolts |
| Unbalance of Rotating component | # Bending of shaft<br># Uneven impeller wear<br># foreign matter inside Impeller<br># Bearing wear | Straighten or replace<br>Balance impeller<br>Remove foreign matter<br>Replace bearing |

**Table 4.** Vibration with frequency several times pump speed

| Items | Cause and checks | Counter measures |
|---|---|---|
| Pressure pulsation | Piping and/or casing vibrate with frequency ZN, where Z = no, of impeller blades,<br>N = pump speed support Vibration with frequency ZN where Z = least common multiple of Z and number of guide vanes. | Enclose clearance between impeller and volute tongue;<br>Reinforce piping or casing<br>Enlarge clearance between impeller and guide vane inlet |
| Antifriction bearing failure | Pump vibrates with frequency PN where P = Number of bolts/rollers, N = pump speed (Bearing temperature often high) | Replace bearing avoid bust/water intrusion into bearing |

**Table 5.** Vibration with irregular frequencies

| Items | Cause and checks | Counter measures |
|---|---|---|
| Partial capacity | Check operating capacity by reading discharge and suction pressures (Vibration is enhanced at capacities less than the rated) | Keep discharge valve full open. Increase capacity by providing bypass piping. |
| Cavitations | Check available NPSH against required NPSH at operating capacity. (Noise is accompanied and pressure gauge fluctuates) | Reduce suction lift.<br>Enlarge suction pipe diameter.<br>Remove clogging. |

## Conclusion

Attempts had been made to find out the classification of pumps, pump performance characteristics, selection of pump types, pump specifications, installation, operation, repair and maintenance, major troubles and counter measures etc. Maximum efficiency of pump was found 92% at 350 $m^3$/min specific speed. Pump performance was expressed by characteristic curves for total head, shaft power and efficiency. For satisfactory pump operation it is necessary to examine the suction condition prevailing at the pump inlet. It was observed that available net positive suction head, ($H_{SV}$) was always larger than the required net positive suction head (NPSH). It is recommended to provide the available NPSH to be more than 1.3 times the value of $H_{sv}$ It is recommended that the number of pumping units and their rated capacities must be determined so that the cost involved in investment and operation is economically viable. The investment cost will be increased with the increase of the number of units of pumps. A larger unit is preferable in view of efficiency providing less operating cost per unit capacity pumped. Investment and operating cost should be kept minimum over and anticipated designed life of pumping equipment. In order to ensure uninterrupted operation it is recommended to install at least two units in most cases. A standby unit is often necessary to replace against breakdown of one unit and for and important application requiring uninterrupted operation over a long period. For proper functioning of pumping units it is necessary to follow established installation procedure such as foundation, placement, alignment etc. For initial startup of the pump care should be taken such as confirmation on power source etc. It is always recommended “preventive maintenance” that is scheduled maintenance should be performed to prevent occurrence of troubles and to maintain proper functioning of the equipment. Periodic inspection is needed to operate a motor driven pumping unit. Periodic inspections are: (1) daily inspection for leakage, noise and vibration, bearing temperature, gland packing etc. (2) Monthly Inspection for bearing lubricants, gland packing etc. (3) For every six months replacement of bearing lubricants and gland packing, tightening of fixing both etc. (4) For each year overhaul inspection is needed. For inspection of motors it is recommended to check noise and vibration, bearing temperature, slip rings brush movement, bearing lubricants, insulation resistance, check on protection devices, replacement of bearing lubricants etc. This review paper hopefully will be useful in application of pumps in physical modeling at RRI.

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