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S. EL-Agouz, Hagar Alm ElDin Mohamed, Elsaid Nossir

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S. A. EL-Agouz, Hagar Alm ElDin Mohamed, and Elsaid Nossir
Mechanical Power Engineering Department, Faculty of Engineering, Tanta University, Tanta, Egypt.

Abstract- **Study on slurry pump performance has attracted much interest in many engineering fields. When pumps are required to handle slurries. The pump head and efficiency are mainly affected by the solid size, solid concentration and solid density. Centrifugal slurry pumps are benign used extensively for pipeline transportation systems and phosphate extraction industry because of their capabilities to economically convey large size abrasive solids in bulk. There is a lack of information about the effect of slurry on the performance characteristics of conventional centrifugal pumps when working without and with cavitation. A test rig with a testing centrifugal pump was constructed. The suction pipe between the mixing tank and pump inlet was designed to avoid solid deposition in suction pipe and to keep the pressure loss between the sump and the pump as low as possible. The rig was designed so that the flow rates, suction pressure, rotational speed, and solid concentration could be varied independently. The results showed that the head generating capability and pump efficiency decrease, also the power consumption increases with increasing solid concentration, consequently the head and efficiency of the pump with NPSH decreases with increasing the solids concentration and particle size, and cavitation inception accelerates with increase the solid concentration.**

Keywords- **Slurry pumps; two phases pumps; performance curves; non-cavitation**.

1. Introduction

Sediments in rivers lakes and marine areas sometimes Detailed information is need to study the effect of solids on the pump head and power consumption in order to achieve reliable and energy efficient operation. Environmental concerns mean that contaminated needed to be removed and transport for treatment or on-land containment [1-5]. When removing contaminated sediments, it is normally important to limit the amount of water used in the handling and transportation [5-7].

Therefore, traditional dredging methods directly coupled to pumping may not always be usable. Clam shell bucket dredging seems often to be the most effective method to get a sediment-water mixture (slurry) with low water content, which also is suitable for pumping [8-10]. Dependent on local conditions, pumps and feeding equipment may be located on a barrage, or pontoon in the area or onshore where the dredged material is unloaded for further pumping or containment [11].

Slurry is essentially a mixture of solids and liquids. Its physical characteristics are dependent on many factors such as size and distribution of particles, concentration of solids in the liquid phase, size of the conduit, level of turbulence, temperature, and the absolute (or dynamic) viscosity of the carrier [12]. Nature offers examples of slurry flows such as seasonal floods that carry silt and gravel [8-7]. Every year during the flood season, the Nile transports massive amounts of silt over thousands of miles to the Saharan desert. Natural slurry flows, even in very dilute forms, can have negative effects on the environment if not properly managed [13]. Particles may be found in nature as soils or may be created by the processes of crushing, milling, and grinding [19]. For applications such as dredging, nature soils are pumped without any crushing or grinding. For mining processes an sizing equipment, crushing and milling slurry preparation mixing and pumping [14,20].

Centrifugal slurry pumps are commonly known as the work horse of in-plant solid handling systems, and are used extensively for hydraulic transportation of solids through pipelines for short and medium distances [4,5]. The performance of such pumps is evaluated for slurries by conducting experiments with actual slurry or estimated on the basis of the performance characteristics obtained with water [15,21,22]. Further, it may not be feasible to determine the characteristics of a prototype at the desired speed in the laboratory due to limitations in measurement and supply systems [16-17,20,23]. Hence one has to depend on scale-model studies, and then use similitude to obtain the characteristics of the prototype [10].

Centrifugal pumps are used for pipeline transport of dredged masses of silt, sands and gravel, some-times at water contents as low. The concentration of solids by mass expresses as the mass of dry solids over the mass of water plus the mass of dry solids [17-18,23]. For a centrifugal slurry pump to accurately match a pipeline system, it is necessary to know how the presence of solids will affect the pump performance [14,23,22]. If accurate corrections are not made, it is likely that the pump and the system will be mismatched, which will accelerate the rate of wear and increase operating and maintenance costs. When pumps are required to handle slurries, the pump head and efficiency are mainly affected by the solid size, solid concentration and solid density [12,21,22].

The objective of this research is to study the performance characteristics of centrifugal slurry pump by using sand-water at different size for no – cavitation and cavitation conditions at various pump speed. In order to fulfill this objective an experimental set up designed to measure the pump flow rate, pump manometric head, pump power consumption and pump speed with different concentrations of suspended solids. An experimental study of the effect of slurry on the non-cavitation and cavitation performance of a centrifugal pump at various particle size, solid concentration and various operating conditions of pump has been done. The operating conditions were, flow rate ranged from 1 m^3/h to 17.61 m^3/h, rotational speed ranged from 2000 to 3000 rpm, the solid concentration ranged from 5 to 15 percent by volume for three sorts of sands(fine, medium and coarse sand).

The objective of this research is to study the performance characteristics of centrifugal slurry pump by using sand-water for non-cavitation and cavitation conditions at various pump speed. In order to fulfill this objective an experimental set up is designed to measure the pump flow rate, pump manometric head, pump power consumption and pump speed with different concentrations of suspended solids.

2. Design and construction of the test rig

2.1 General rig description

A line diagram of the rig is shown in figure, and a list of its major component is present. The actual physical arrangements appear in figure. Test rig is installed in professor Hager hydro machinery laboratory's of mechanical power Dept. at Faculty of Engineering Tanta University.

The test rig consists of a 1 HP centrifugal pump. Provided with mixing tank, flow meter, measuring devices, pipe lines and valves.

The pump is fitted on a base of iron frame with plain impeller without any change in its suction side for primary tests. It is connected with a mixing tank by suitable pipe of 1.5" diam for suction and of 2" diam delivery sides of the pump. The suction pipe between the mixing tank and the pump inlet was made horizontal and as short as possible to avoid any deposition of solid and to reduce friction losses. The mixing tank is supplied with water from the mains for primary tests. and then by adding the suitable of solid to water in a mixing tank to reach the required concentration. Two ball valves are fitted. One at the suction side and the other at the delivery side. These valves are used to establish the performance and cavitation test of the pump. The volume flow rate is measured by using ultrasonic flow meters. These flow meter are located on the delivery side. After the flow meter a gate valve is fitted to prevent the effect of air on pipe line. The type of the plain impeller of pump is a semi-open impeller with 4 curved vanes.

A calibrated Bourdon pressure gauges are mounted on both the delivery and suction flanges to measure the manometric delivery head. And the manometric suction lift.

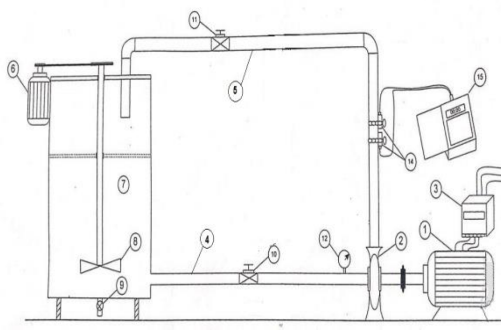
The complete specifications for the test rig are as follows:

1- The test rig is a closed circuit.
2- It has a variable rotational speed.
3- It has a variable pressure up to 1 bar. This was taken as the original design valve.
4 -It has a continuously-variable flow rate through the inlet section of the pump up to the maximum limit of the pump.
5 -It is capable of using variety of solid-water (slurry) mixture at various solid concentrations.

TABLE 1.
TEST RIG PROCESSES SUMMARY

Experiment Variables			
Speed	Concentrations	Pipes	Slurry
1-3000 rpm 2-2500 rpm 3-2000 rpm	1-15% cv 2-10%cv 3-5% cv	1-1.5 " for suction 2-2 " for delivery	1-Coarse sand (800 mm) 2-Medium sand (400 mm) 3-Fine sand (250)

Fig. (1). Photograph of test circuit



1. Motor pump drive
2. Centrifugal pump
3. Variable speed drive
4. Suction pipe
5. Delivery pipe
6. Mixer tank motor
7. Mixer tank
8. Fans mixer
9. Drain pipe
10. Suction control valve
11. Delivery control valve
12. Suction pressure gauge
13. Delivery pressure gauge
14. Transducers

Fig. (2). Experimental test rig layout

2.2 Measurement Devices For Test rig

The study of the performance of the centrifugal slurry pumps should be made with accurate and sensitive devices because a small change in flow parameters will introduce undesirable error in pump characteristics. This suction describes the measurements required to perform centrifugal slurry pump experiments.

2.2.1 Pressure Measurements

The monometric delivery head was measured by using calibrated bourdon pressure gage in the range of 0-1 bar. The accuracy of the gauge was ± 0.5 % of span. The monometric suction head was measured by using calibrated Bourdon vacuum pressure in the rang 0f -1 – 0 bar with accuracy of ± 0.5 % of the span.

2.2.2 Volume Flow Rate Measurements

The volume flow rate of water and slurry through the test section is measured by using ultrasonic flow meter and the accuracy of the measuring the flow rate was ± 1.6 % from the measured quantity of the flow rate and it is necessary to enter all data about the pipe (outer diameter, material, thickness) and about the liquid (type, temperature, viscosity) into the controlotron unit through the control display unit. The water flow rate or the average flow velocity can be displayed on the screen of the controlotron unit.

2.2.3 Power Input Measurement

The input power, p (w) to electric motor was measured by using a power analyzer with an accuracy of . The power analyzer type is C.A 8220 with maximum ampere of 6500 amperes, and maximum voltage of 600 volts.

3. Test Conditions

It was noticed that the concentration of solid particles does not vary during running the experimental testes. It was checked repeatedly during the testes. The delivered concentration by weight (Cv) for fine, medium, coarse sand varied from 5 % to 15 %. The flow rate was varied from 1 m^3/h to 17.61 m^3/h. The pump speed was operated different rotational speeds from 2000 to 3000 rpm. The experiments were carried out at almost equal room temperature and atmospheric pressure.

4. Experimental Appartus And Test Rig

In this section the effect of changing the flow rate, rotational speed, particle size and solids concentration on the pump performance and cavitation characteristics are presented.

4.1 Effect of Concentration of Solids on Pump Performance

The experimental results on the centrifugal pump with water and different solid-liquid mixtures concentration ratios at operating speed of 3000 rpm are presented in figures (3). These figures show the performance characteristics of centrifugal pump at a speed of 3000 rpm for water and different concentration ratios (by volume) of fine sand, medium sand, coarse sand. The concentrations of particle rang (5% - 15 %) for sand slurries. From the results it is shown that with increasing the percentage of concentration, the pump head and efficiency are decreased while the pump with the pump power input is increasing in comparison with the performance of the pump with clear water. From the results it is shown that all curves have the same trend as that with clear water. This is may be due to increasing the energy needed to maintain the solid in suspension and motion with the increase of concentration of solids.

4.2 Effect of The Particle Size Distribution of Solids on Pump Performance

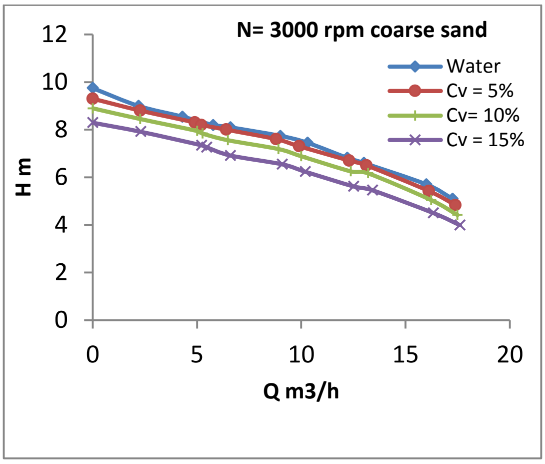
The particle size distribution of the solids has a strong influence on the pump performance characteristics. Fig (4) represent the pump performance at different particle size at constant pump speed and constant solid concentrations. It is shown from this figure that the particle size has a small effect on the pump performance at low solid concentration for all speed, but at high solid concentration cv = 15 % percent (by volume) the head and efficiency reductions are affected significantly by the increase in particle size, consequently the input power increase due to the increase in particle size. For coarser slurry the head loss is more due to the extra energy required to keep the coarser particles in motion. The increasing in particle size fives additional loss and therefore a higher value of power was input to the motor. For coarse slurry the deterioration in performance arises from the energy losses owing to slip between the liquid and the particles as the mixture accelerates or decelerates through the pump, and interactions among the solid particles, as well as between solid particles and internal walls of the pump.

4.3 Effect of Pump Rotational Speed On Pump Performance

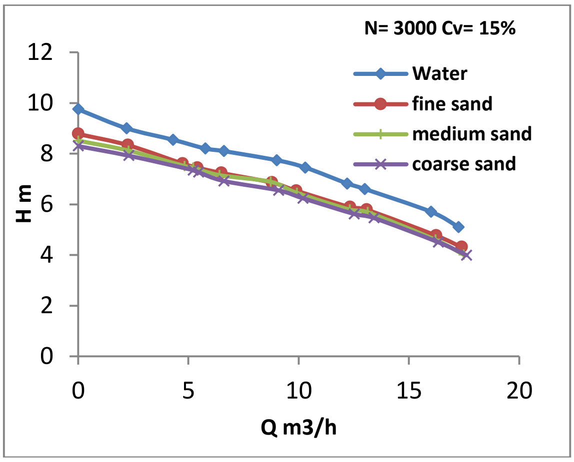
The performance of the pump was evaluated at three pump rotational speeds, varied from 2000 to 3000 rpm with water and three slurries. Figure (5 (a)-(c)) represents the pump performance characteristics with coarse sand slurries at solid concentration Cv = 15 percent by (volume) with different pump speed. Figure (5(a)) shows the variation of pump head with capacity at all speeds. It is seen that the pump head decreases with the increase in pump capacity at any given speed.

Figure (5(b)) shows the variation of pump input power with pump capacity at all speed. The pimp input power at any pump capacity increases with the increase in pump speed. Figure (5(c)) shows the variation of pump efficiency with pump capacity at all speeds. The pump efficiency at any flow rate decreases with decrease in pump speed at high flow rate. Figure (6 (a)-(c)) Shows the pump performance characteristics with medium sand slurry at solid concentration

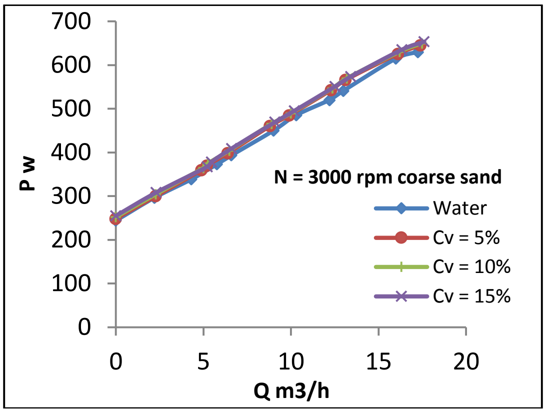
Cv = 15 % percent (by volume) with different pump speed. Also figure (7(a)-(c)) represents the pump performance characteristics with fine sand slurries at solid concentration Cv = 15 % percent (by volume) with different pump speed. From this observation it can be concluded that the low solids concentration has no effect on the pump head developed is decreased for all speeds. Further increase in solids in concentration, Figs (5-7) show a decrease in pump head at all speeds. This is due to the increase in hydraulic losses at all flow rates. It is also seen that increase in solids concentration leads to increase the deviations in pump head characteristics observed at different speeds.



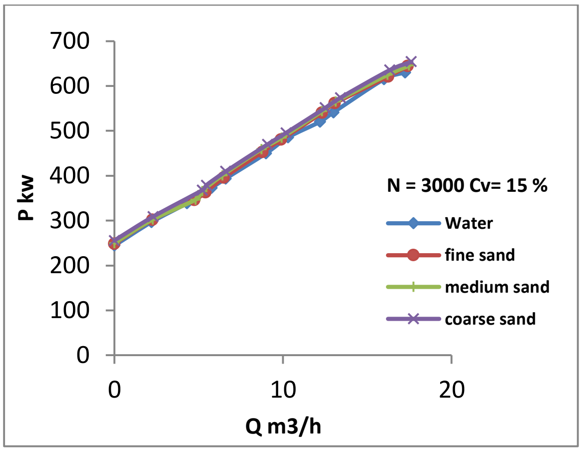
(a) Head-Capacity Characteristics



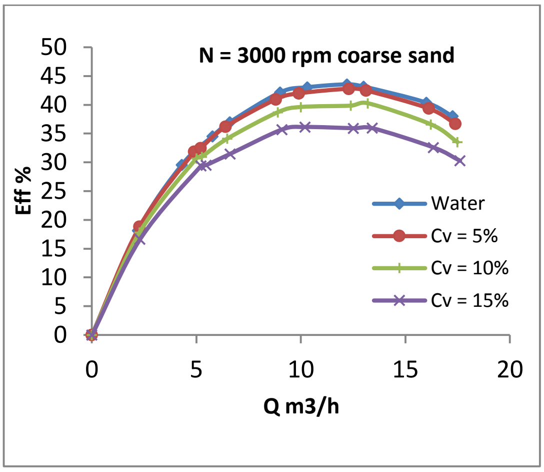
(b) Head-Capacity Characteristics



(b) Power-Capacity Characteristics

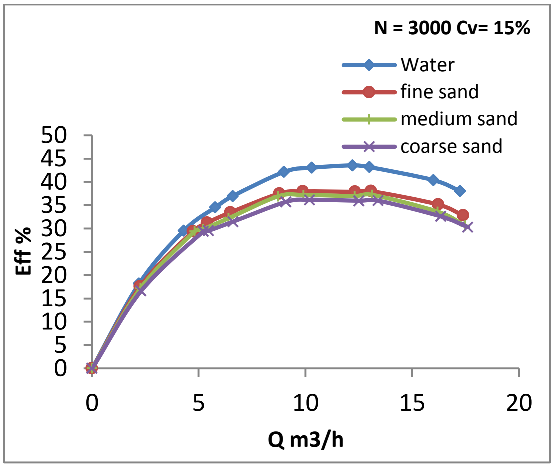


(b) Power-Capacity Characteristics



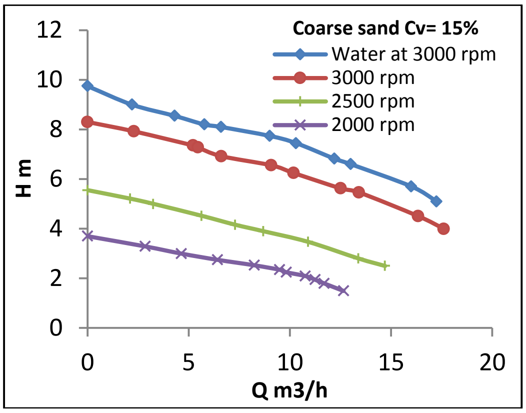
(c) Efficiency-Capacity Characteristics

Fig (3). Performance characteristics with coarse sand (d= 0.8 mm) at 3000 rpm

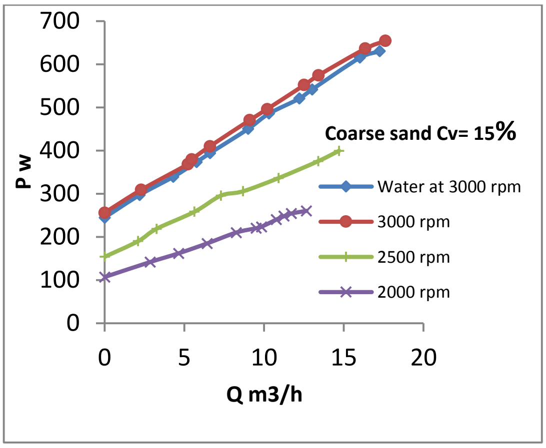


(c) Efficiency-Capacity Characteristics

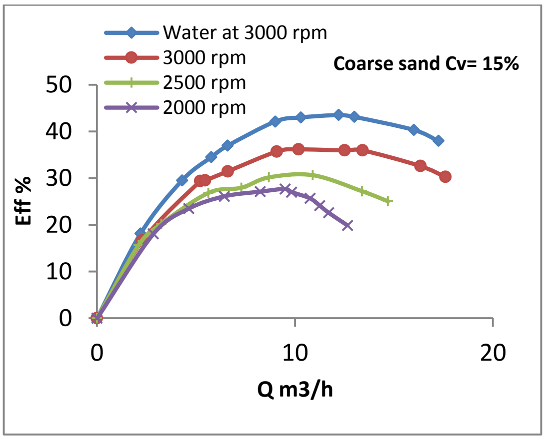
Fig (4). Performance characteristics with different particle size at cv= 15% and 3000 rpm



(a) Head-Capacity Characteristics

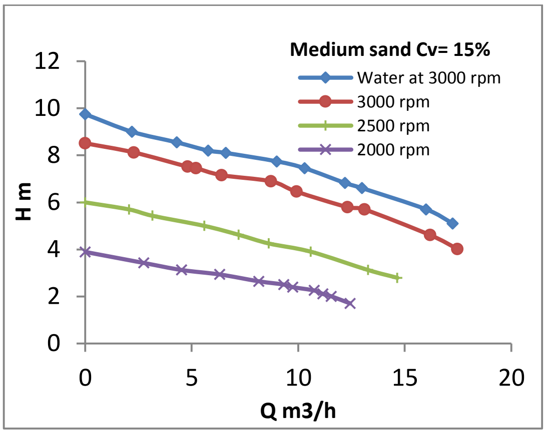


(b) Power-Capacity Characteristics

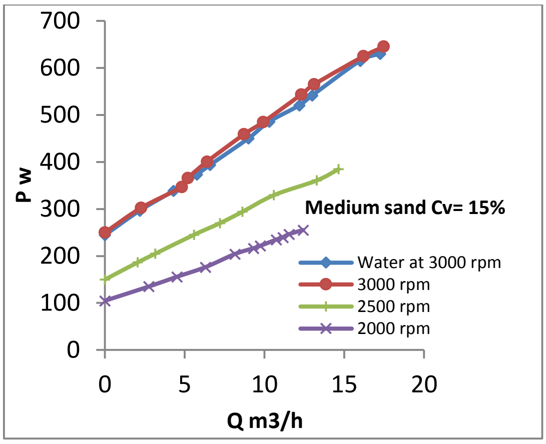


(c) Efficiency-Capacity Characteristics

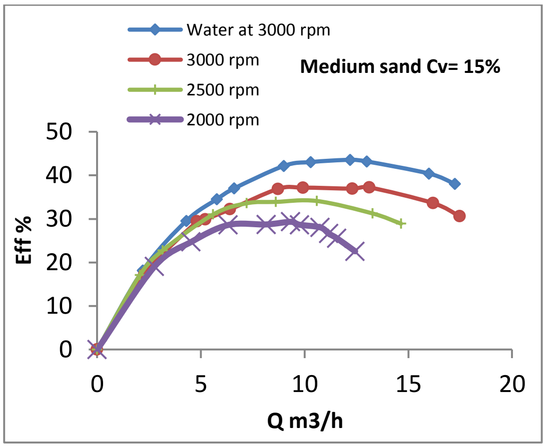
Fig (5). Performance characteristics with different pump speed at cv= 15% for coarse sand (d=0.8 mm)



(a) Head-Capacity Characteristics

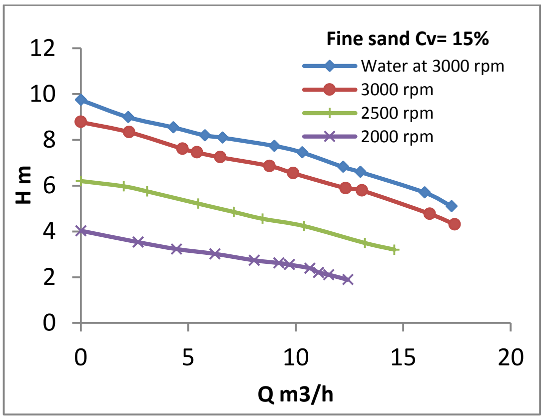


(b) Power-Capacity Characteristics

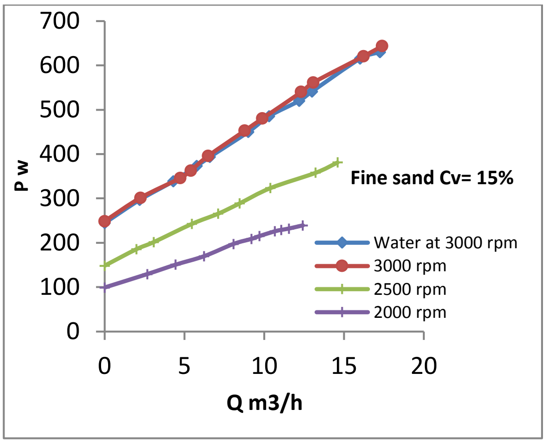


(c) Efficiency-Capacity Characteristics

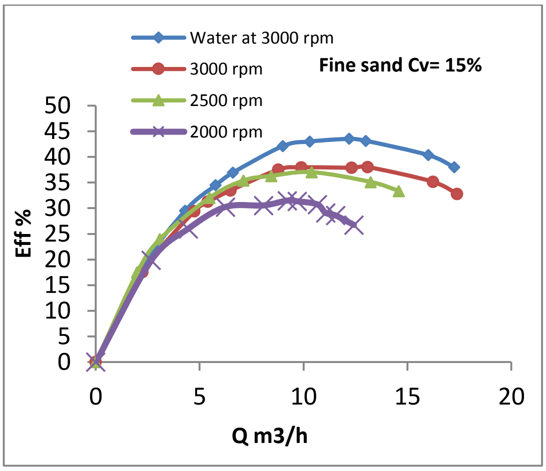
Fig (6). Performance characteristics with different pump speed at cv= 15% for medium sand (d=0.4 mm)



(a) Head-Capacity Characteristics



(b) Power-Capacity Characteristics



(c) Efficiency-Capacity Characteristics

Fig (7). Performance characteristics with different pump speed at cv= 15% for fine sand (d=0.25 mm)

5. Conclusions

From the previous literature review it can be seen that there is a conflict information about the effect of various factors such as solid concentration, and impeller speed on the performance characteristics of centrifugal slurry pumps. Detailed information is needed to study the effect of solids on pump head and power consumption in order to achieve reliable and energy-efficient operation. However, the amount of experimental data available in the literature is fairly limited and it is still difficult to find any reliable correlation or procedure for calculating head reduction factor over a wide range of physical properties of solids and operating conditions.

Moreover, very little known about the effect of broad particle size distribution, cavitation inception, breakdown and pattern during pumping slurry on the characteristics of centrifugal slurry pumps. Therefore, measurements are required to establish these effects. To achieve these requirements, an experimental test rig is designed and constructed to conduct the required experiments.

Based on the results obtained in the hydraulic at Tanta University, the following more important conclusions can be drawn.

1. The head and efficiency of the pump are decreased with increasing in solid concentration, and particle size, while at low concentration the change in pump performance was found to be small.
2. The head and efficiency of the pump with NPSH decrease with increasing the solid concentration and particle size
3. The valve of head reduction are higher than the valves of the efficiency reduction at the same concentration.
4. The head and efficiency reduction factors are in increased linearly with increasing solids concentration.
5. The power ratio increases linearly with the increasing the solid concentration for all types of slurries and the rate of increase power ratio for all types of slurries is lower than the rate of increasing of the mixture specific gravity.
6. Cavitation accelerates with increase the solid concentration, particle size, and pump speed.

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