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Research Article

Performance of a Centrifugal Slurry Pump

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Abstract: The aim of this study was to experimentally investigate the effect of speed, concentration and size of slurry on the performance of a centrifugal pump. For this purpose a facility was built where the performance of a centrifugal slurry pump was examined using aggregate slurry. Three sizes of slurry with three concentrations and at three impeller speeds were used for the performance investigations of a centrifugal slurry pump. As a reference performance the performance of centrifugal slurry pump was also tested with clean water. The performance of pump has been reported as variations of head, power and efficiency at various flow rates along with the system characteristics of the pump. The results reveal that the pump performance is grossly affected by the type of slurry, its concentration and size. Besides this the variation in speed also affects the performance as is observed in pumps with water. The maximum decrease in the head, with respect to clear water, at the operating point was found to be 47% for aggregate for size 20 mm, 15% concentration and 2600 rpm. The maximum decrement in efficiency at operating point for aggregate was found to be 47% for 4 mm size, 15% concentration and at 2200 rpm. The power increment requirement for aggregate was 9% for 4 mm size, 15% concentration and 2600 rpm.

Keywords: Aggregate, concentration, performance, pump, slurry

INTRODUCTION

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, level of turbulence, temperature and absolute (or dynamic) viscosity of the carrier fluids. Slurry can be either settling or non-settling. Slurry in which the solids do not settle to the bottom, but remain in suspension for a long time is termed as non-settling slurry. Slurry pumps are the comprehensive range of centrifugal slurry pumps for use in mining, chemical and industrial applications. Slurry pump can never be as efficient as a water pump even when they both handle water. Its vanes must be thicker in slurry pumps than in water pumps to allow for wear. Because of this extra thickness, there must be fewer vanes, otherwise the passageways would be too narrow and would affect pump performance. As a consequence, fluid in this impeller cannot be guided as closely as in a water impeller and this in turn results in reduced pumping head and efficiency. Another factor affecting both head and efficiency in slurry pumps is the actual presence of solids in the slurry. The difference between water velocity and solids velocity is called slippage. The average velocity of the slurry is somewhere between the velocity of water and that of the solids. Centrifugal slurry pump are being used extensively for pipe line transportation system because of their capabilities to economically convey large size abrasive solid in bulk. Stepanoff (1965) concluded that the solid particles do not absorb, store, or transmit pressure energy, but it was difficult to establish the effect of solid on pump performance. Chand *et al*. (1985) have performed extensive experiments using fly ash, sand, iron ore and coal dust at concentrations up to 26% by volume at three 1000, 1200 and 1400 rpm and have reported improvements in head and efficiency of the pump with increase in concentrations of solid as well as polymer additives. Fairbank (1942) found that the head developed by the pump for water decreases with increase in either concentration of medium particle size of sand/clay. Wiedenroth (1970) attributed the head reduction to the additional friction losses in the flow passages due to the suspension solids. Vocaldo *et al*. (1974) have experimentally investigated the performance of rubber-lined and metal centrifugal slurry pumps handling sand material of different particle sizes and clay at two speed of 1180 and 1780 rpm. The head loss for rubber-lined pump was found to be higher than that for the metal pump which they

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attributed to the higher absorption of particle kinetic energy by the lining. The loss in the head and efficiency of the pump was found to be equal at various solid concentrations. Burgess and Riezes (1976) have experimentally evaluated the pump performance for slurries at various pump speeds and found that the head loss is a function of particle size, solid concentration and specific gravity of solids. Sellgren (1979) has reported that the decrease in the head is function of solid concentration, specific gravity and particle drag coefficient. Walker and Goulas (1984) observed that the drop in the head and efficiency of the pump handling non-Newtonian slurries depend on the rheological properties of the slurry and the pump Reynolds number. Sellgren and Vappling (1986) have investigated the effect of solid concentration for two tailings materials on the performance of a 100 mm centrifugal slurry pump having closed impeller. They observed fall in the head and the efficiency with increase in solid concentrations. They attributed this phenomenon to the increased disc friction losses caused by fine particulate slurries and to the break-down of boundary layers in the flow through the impeller due to coarse sized. Gahlot *et al*. (1992) investigated the performance of two 50 mm centrifugal slurry pumps made of two different materials namely Ni-hard (metal) and rubber-lined having closed and open impellers respectively with coal and zinc tailings slurries at 1450 rpm in the concentration range of 0-57% by weight. They observed that the head and the efficiency of the pump decrease with increase in solid concentration, particle size and specific gravity of solids where as they are fairly independent on the pump flow rate. Ni *et al*. (1999) have found out that the head reduction factor and efficiency reduction factor values were about 15% for a centrifugal pumps which near used for pumping narrowly graded sand with a d_{50} value of 370 microns and for a delivered volumetric solid concentration value of 35%. Sellgren *et al*. (2000a) have observed experimentally that in case of industrial suspension the pump head and efficiency reduces in the best efficiency region. The efficiency is more affected by this suspension than head. However, operation with a highly non-Newtonian suspension at lower flow rates shows an unstable head curve. It was investigated that with the scrubber sludge there was sharp reduction in head at flow rates below 40% of the BEP-value. Sellgren *et al*. (2000b) showed that the addition of clay to sand slurries has been found to reduce the pipeline friction losses, thus lowering the pumping head and power consumption. Pump water heads and efficiencies are decreased by the presence of solid particles.

Ni *et al*. (2000) have evaluated slurry pump performance of three types of narrow graded sands with volumetric concentration up to 44% experimentally. The pump efficiency in the coarse sand slurry service may drop almost 60%, compared to that to that of water service. The head ratio and efficiency ratio drops faster at solid volumetric concentration of about 35%. However, the pump efficiency drops much faster than pump head when volumetric concentration is less than 15%. Gandhi *et al*. (2001) also reported the performance of two centrifugal slurry pumps for three solids materials having different particle size and found that head and efficiency of the pump decrease with increase in solid concentration, particle size and slurry viscosity. Satoshi *et al*. (2006) have found that pump efficiency with surfactant solutions was higher than that with tap water and increased with an increase in surfactant concentration. The value of maximum flow

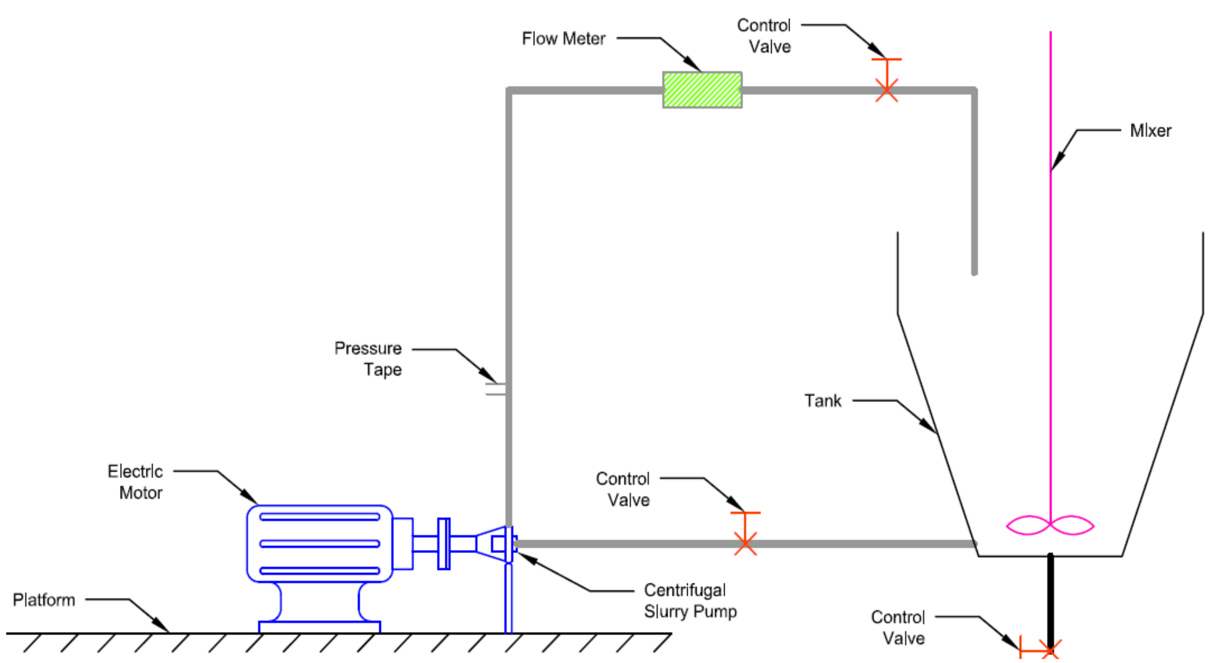

Fig. 1: Schematic diagram of test loop

rate also increased. The total pump head increased with an increase in concentration and the shaft power decreased with a decrease in the impeller rotating speed. The subject matter of this study was an experimental investigation of the effect of speed, concentration and size of slurry (aggregate) on the performance of a centrifugal slurry pump. During investigation three sizes of slurry for three concentrations and at three impeller speeds were used for the performance evaluation of the pump.

MATERIALS AND METHODS

For the purpose of investigation of performance of a slurry pump, a test loop was constructed to conduct slurry transportation under controlled condition so the effect of different pump and slurry parameters could be investigated. The loop was 50 mm diameter and has a total length of 30 m along with other necessary components. The main components of a facility are shown in Fig. 1.
The experimental set up consisted of:

- A tank 1×1×1 m an size and made of carbon steel
- AWEMCO-WEIR centrifugal slurry pump
- Pressure transducer
- Magnetic flow meter
- Different type of valves
- Electrical panel with variable speed drive

Performance of pump was initially determined experimentally with clear water as fluid. In the test loop, all plug valves were first closed and the mixing tank, suction and delivery pressure measurement tubes were properly filled up with water and purged off all the air bubbles.

The delivery plug valve was then opened and adjusted to desired flow rate. The measurements indicated by different instruments namely magnetic flow meter, power analyzer, pressure transmitter and tachometer were noted. These measurements were repeated for various delivery valves opening to cover entire operating range of pump flow rate. During every flow rate measurement proper time were given to stabilize the indicated values of the instruments. Similar procedure was followed for slurry pump at 1000, 1400, 1800, 2200, 2600 and 3000 rpm, respectively speeds.

The following flow parameters were measured during experimental:

- Pressure raises a cause pump by using pressure sensor.
- Flow rate of slurry by using magnetic flow meter.
- Speed of pump by a non contacting tachometer.
- Power pump by measuring power outside volt and ampere.

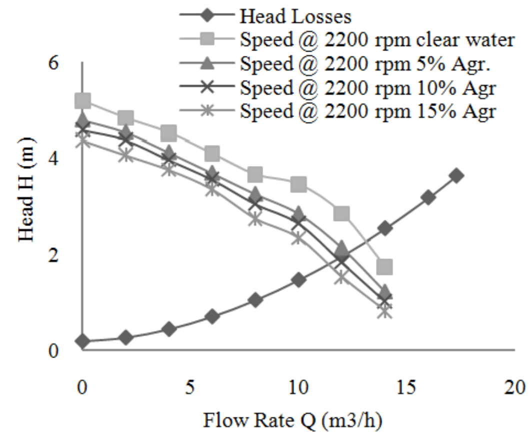

Fig. 2: Head characteristics of pump with 4 mm aggregate at 2200 rpm

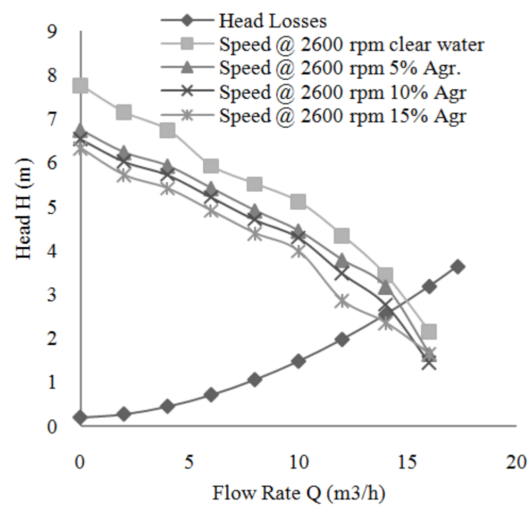

Fig. 3: Head characteristics of pump with 4 mm aggregate at 2600 rpm

RESULTS AND DISCUSSION

The head developed, power and efficiency of the pump for clear water were measured at various volume flow rates to estimate the head-capacity, power capacity and efficiency-capacity characteristics. The pump performance was evaluated with water and aggregate at three speeds. Three sizes of aggregate at three concentrations for three speeds were investigated.

Effect of concentration of slurry on the performance of a pump can be studied either in terms of concentration based on weight or concentration based on volume. This study concerned the effect of concentration of slurry by weight. The concentrations used for both aggregate and clinker was 5, 10 and 15%, respectively. Figure 2 to 4 show head characteristics for 4 mm size of aggregate for different concentrations at different speeds. It is observed that the head decreases with the increase in concentration and decrement in the head (ΔH), which is the difference between maximum head produced with water and the present condition

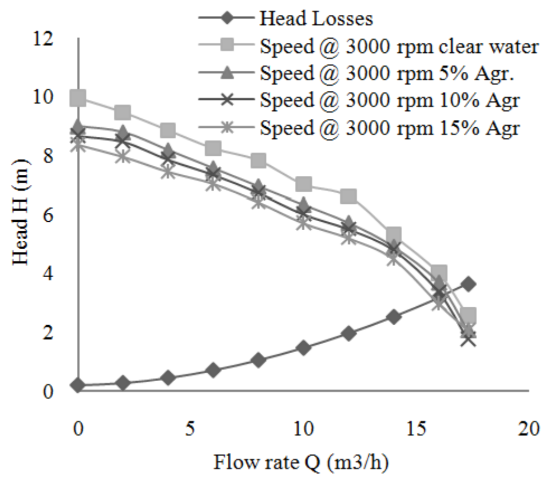

Fig. 4: Head characteristics of pump with 4 mm aggregate at 3000 rpm

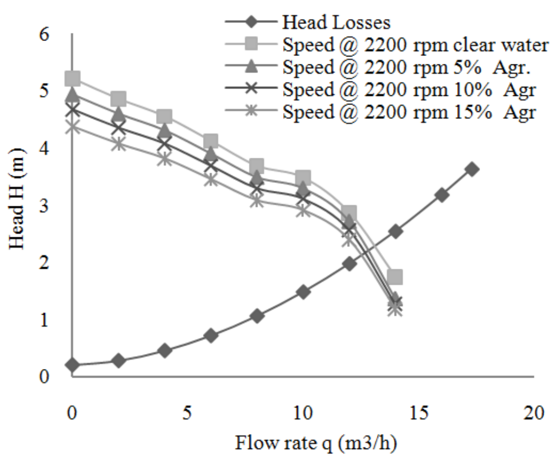

Fig. 5: Head characteristics of pump with 13 mm aggregate at 2200 rpm

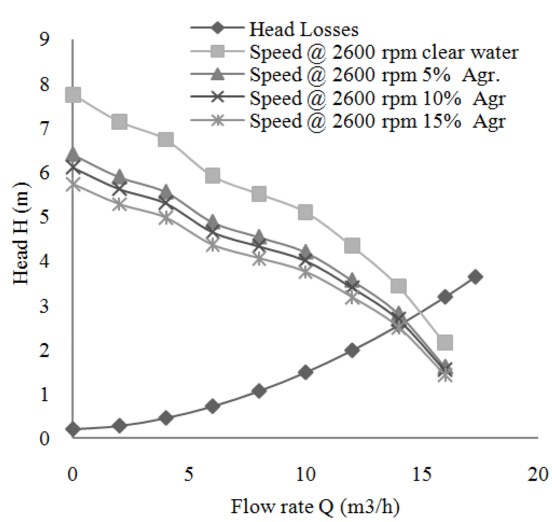

Fig. 6: Head characteristics of pump with 13 mm aggregate at 2600 rpm

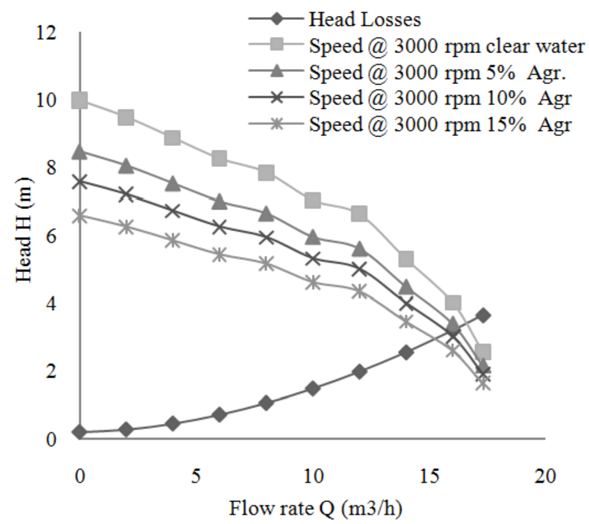

Fig. 7: Head characteristics of pump with 13 mm aggregate at 3000 rpm

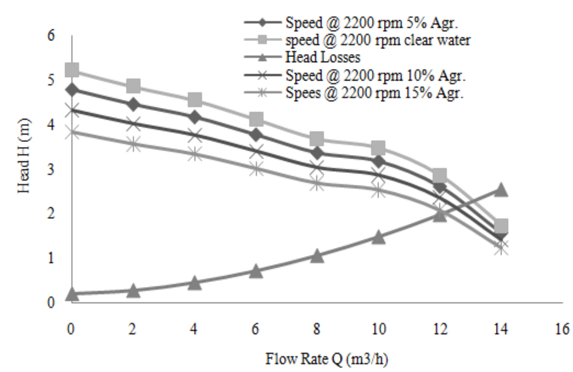

Fig. 8: Head characteristics of pump with 20 mm aggregate at 2200 rpm

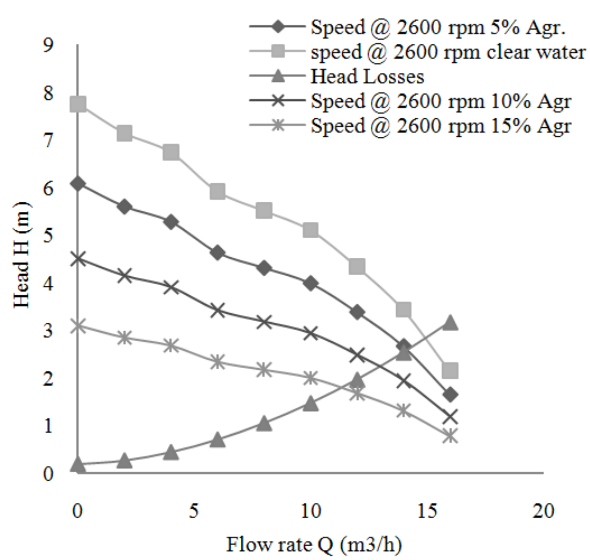

Fig. 9: Head characteristics of pump with 20 mm aggregate at 2600 rpm

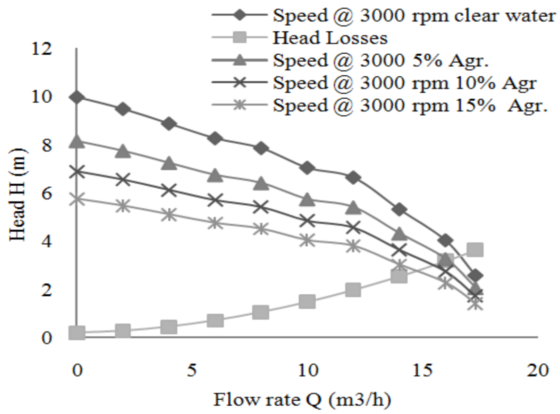

Fig. 10: Head characteristics of pump with 20 mm aggregate at 3000 rpm

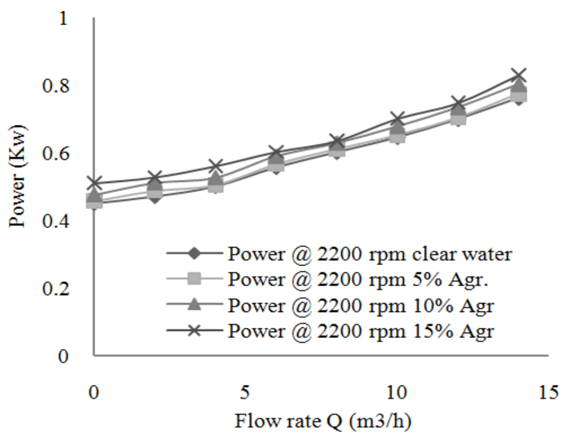

Fig. 11: Power characteristics of pump with 4 mm aggregate at 2200 rpm

decreases with the increase in speed. This is attributed to the internal losses in the pump passage which decrease with the increase in speed because of less stay time of slurry in the pump. The differences in decrements between the different concentrations vary from 10 to 4% for 5 to 15% change in concentrations. A similar variation is observed for slurry size of 13 and 20 mm except that variations in the head are observed to be more at higher sizes. These variations are shown in

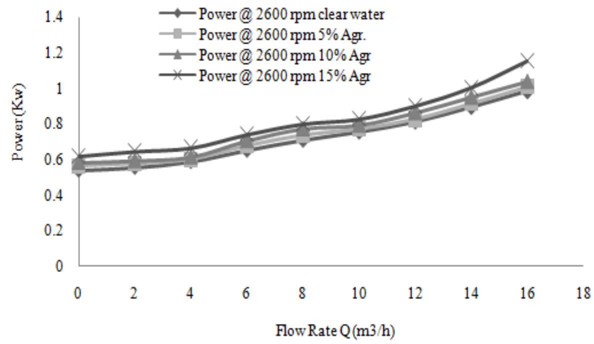

Fig. 12: Power characteristics of pump with 4 mm aggregate at 2600 rpm

Fig. 5 to 7 for 13 mm size and Fig. 8 to 10 for 20 mm size. The actual decrements of maximum head at different concentrations of aggregate as shown in Table 1.

Figure 11 to 19 depict the variation of power consumed (input power) in case of aggregate slurry for different concentration, size and speeds. From these graphs it is evident that the power consumed increase with increase in flow rate and concentration at all the speeds and for all sizes. The different in the power consumed (ΔP), which is different as the power consumed at operation point for water and the slurries concentrations, is not significantly effected of by speed where as the change in sizes have significant effect on the power decrement. The different in the power consumed is highest for aggregate size of 20 mm at 3000 rpm. It decreases both with the size and concentration

Figure 20 to 28 depict the variation of efficiency in case of aggregate slurry at different concentration, size and speeds. From these graphs it is evident that the efficiency decrease with increase in flow rate and concentration at all the speeds and for all sizes. The maximum efficiencies at flow rate 10 m^3/h. The difference in the efficiency (Δη), which is different as the efficiency at operation point for water and the slurries concentrations, is significantly effected of by speed where as the change in sizes have significant

Table 1: Variations in operating point performance of aggregate

Concentration (%)	Size (mm)	ΔH (%) 2200 rpm	ΔH (%) 2600 rpm	ΔH (%) 3000 rpm	ΔP (%) 2200 rpm	ΔP (%) 2600 rpm	ΔP (%) 3000 rpm	Δη (%) 2200 rpm	Δη (%) 2600 rpm	Δη (%) 3000 rpm
5	4	16.36	9.390	12.50	-1.41	-1.027	-0.80	24.770	16.650	12.73
	13	7.15	13.300	23.17	-3.12	0.870	-3.24	11.900	22.230	27.80
	20	6.25	15.933	16.56	-3.54	-6.770	-3.58	12.100	27.043	23.05
10	4	20.51	14.360	15.50	-3.54	-3.340	-3.41	36.270	27.550	21.39
	13	8.50	15.900	20.19	-3.70	-0.790	-1.98	16.180	28.110	28.67
	20	13.24	32.027	25.67	-6.38	-3.490	-6.70	24.124	63.312	39.42
15	4	26.23	17.660	16.39	-4.53	-8.850	-6.61	47.038	38.100	28.56
	13	9.03	20.410	27.42	-4.11	-3.060	-2.57	20.480	34.690	41.08
	20	20.80	46.410	33.84	-8.50	-4.150	-7.79	36.730	71.500	52.64

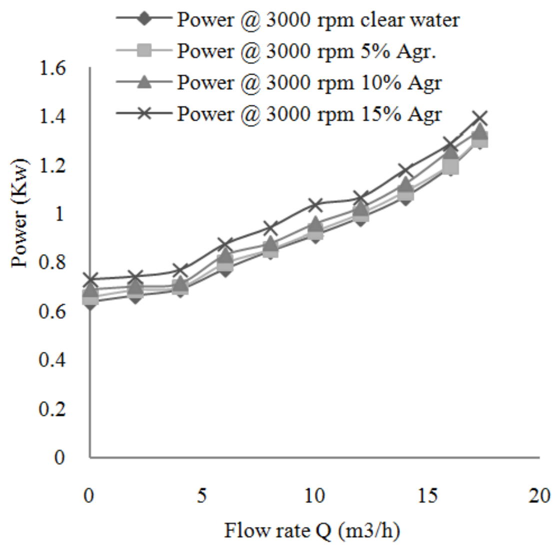

Fig. 13: Power characteristics of pump with 4 mm aggregate at 3000 rpm

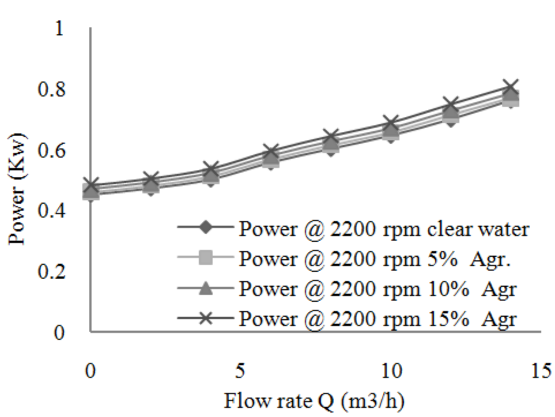

Fig. 14: Power characteristics of pump with 13 mm aggregate at 2200 rpm

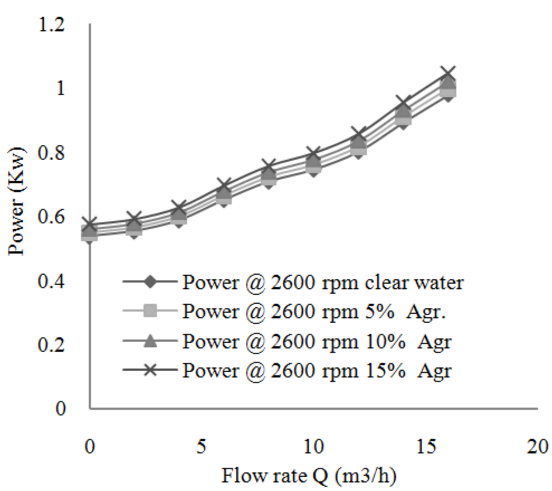

Fig. 15: Power characteristics of pump with 13 mm aggregate at 2600 rpm

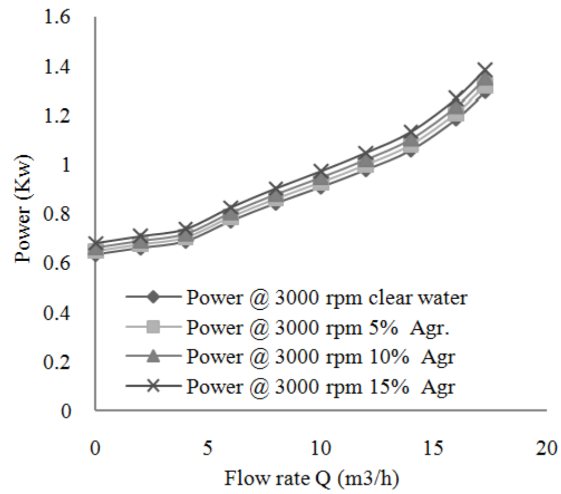

Fig. 16: Power characteristics of pump with 13 mm aggregate at 3000 rpm

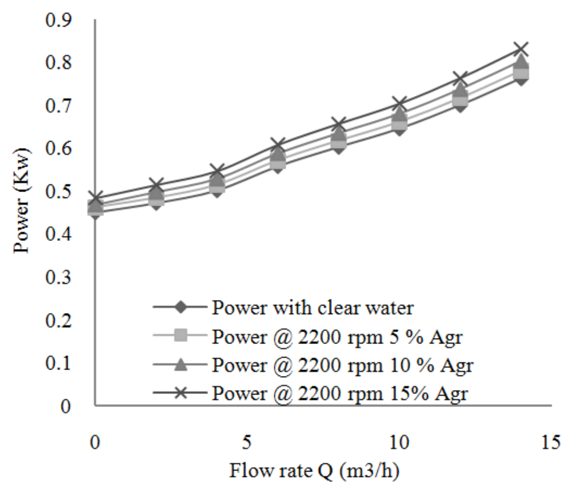

Fig. 17: Power characteristics of pump with 20 mm aggregate at 2200 rpm

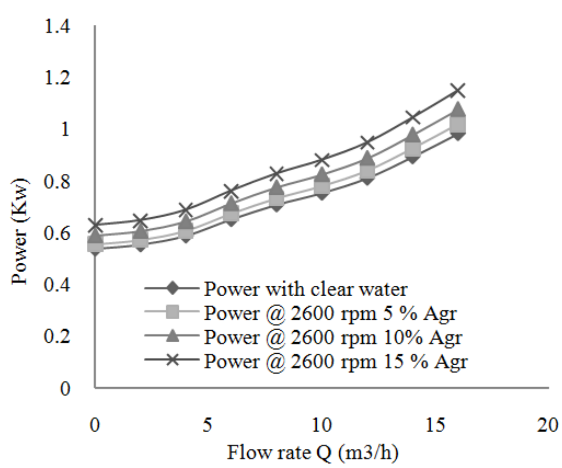

Fig. 18: Power characteristics of pump with 20 mm aggregate at 2600 rpm

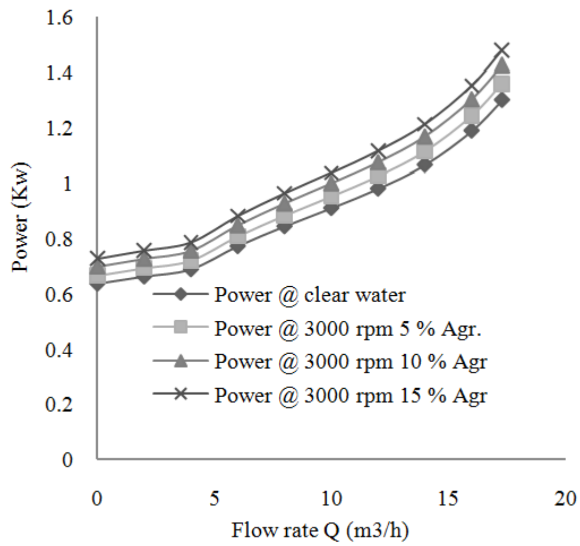

Fig. 19: Power characteristics of pump with 20 mm aggregate at 3000 rpm

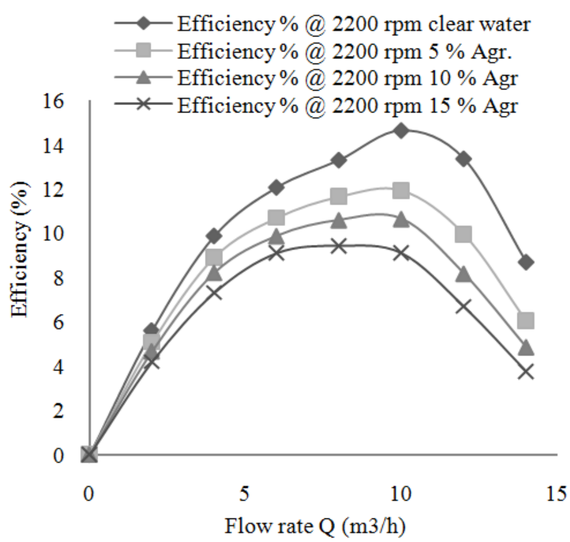

Fig. 20: Efficiency characteristics of pump with 4 mm aggregate at 2200 rpm

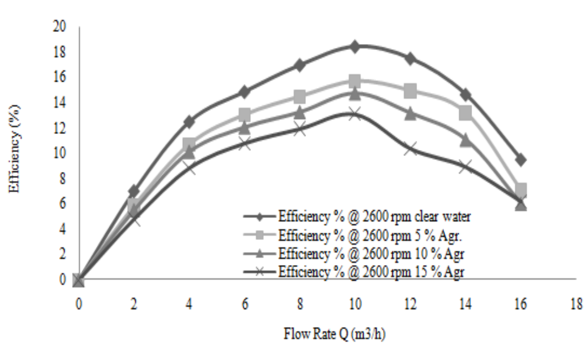

Fig. 21: Efficiency characteristics of pump with 4 mm aggregate at 2600 rpm

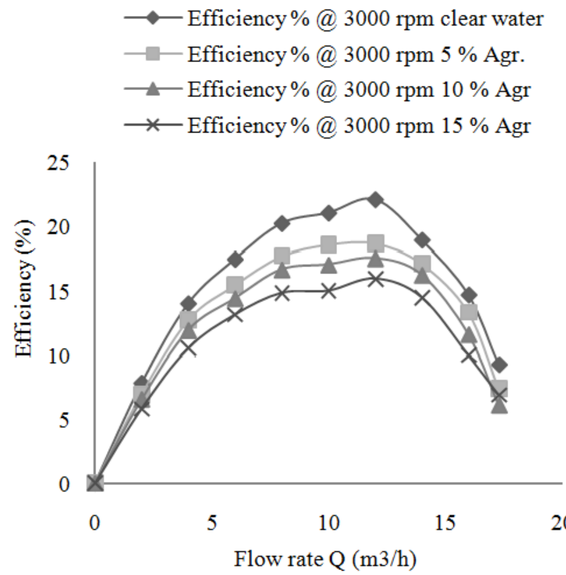

Fig. 22: Efficiency characteristics of pump with 4 mm aggregate at 3000 rpm

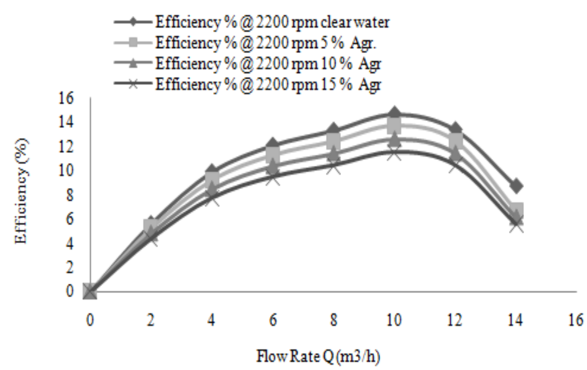

Fig. 23: Efficiency characteristics of pump with 13 mm aggregate at 2200 rpm

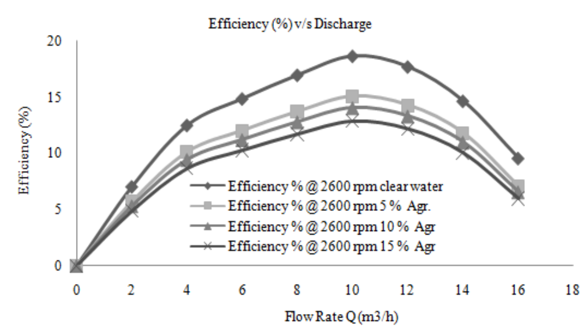

Fig. 24: Efficiency characteristics of pump with 13 mm aggregate at 2600 rpm

effect on the efficiency decrement. The different in the efficiency is highest for aggregate size of 20 mm at 3000 rpm. It decreases both with the size and concentration.

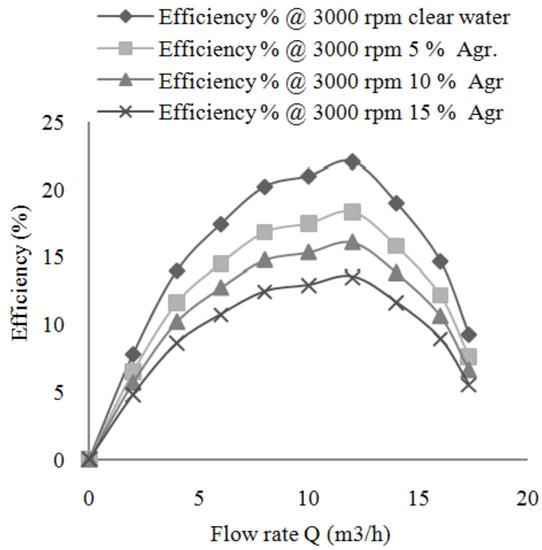

Fig. 25: Efficiency characteristics of pump with 13 mm aggregate at 3000 rpm

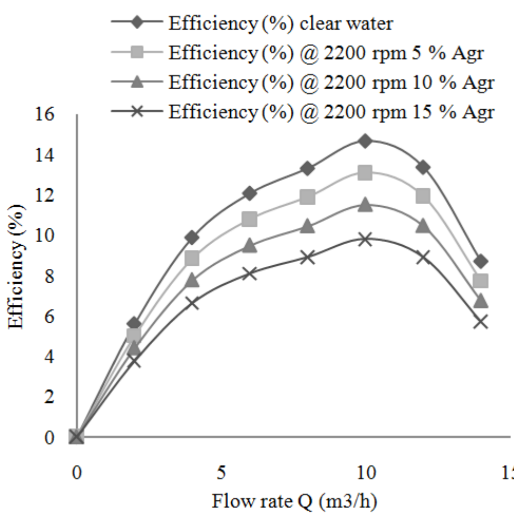

Fig. 26: Efficiency characteristics of pump with 20 mm aggregate at 2200 rpm

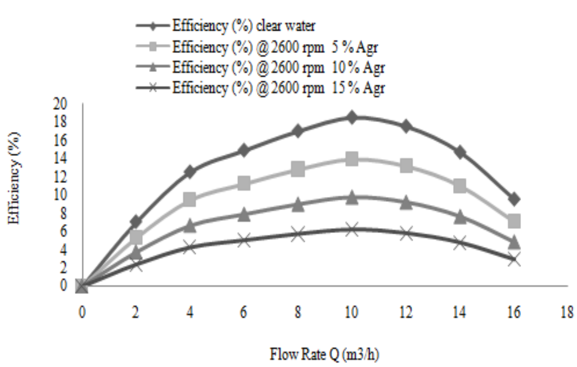

Fig. 27: Efficiency characteristics of pump with 20 mm aggregate at 2600 rpm

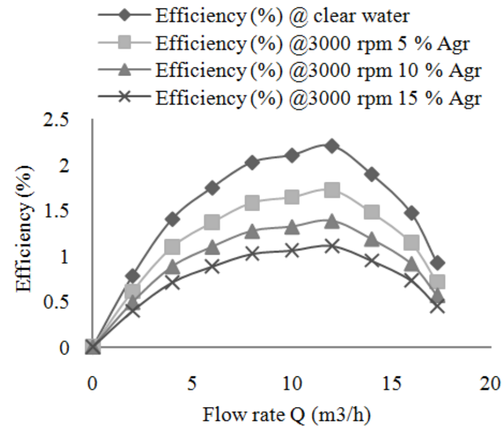

Fig. 28: Efficiency characteristics of pump with 20 mm aggregate at 3000 rpm

CONCLUSION

The following conclusions have been observed in these investigations:

- The head developed by pump and pump efficiency decreased with the increase concentration of the slurry.
- Power input to the pump increase with increase in concentration.
- The head developed by pump and its efficiency decreased with the increase size of the slurry.
- Power input to the pump increase with increase in size of slurry.
- The results reveal that the pump performance is grossly affected by the concentration and size. Besides this the variation in speed also affects the performance as is observed in pumps with water. The maximum decrease in the head, with respect to clear water, at the operating point was found to be 47% for aggregate for size 20 mm, 15% concentration and 2600 rpm. The decrement in efficiency at operating point for aggregate was 47% for 4 mm size, 15% concentration and 2200 rpm. The power increment requirement for aggregate was 9% for 4 mm size, 15% concentration and 2600 rpm.

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