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Silt Erosion Effects on Pump Running in Turbine mode

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Abstract: *Silt erosion in hydraulic turbines is a complex phenomenon. It can not only reduce the efficiency but also creates wear, fatigue failure, vibration and finally results in reduction in life of turbines. Pump as Turbine (PAT) is a very good alternative when used for low capacity hydro power plants because of its low cost. In the current study, experiments were executed to study the effects of silt erosion on the performance of PAT. The effects of particular silt size (700-1000 micron) with different concentrations (0.5%, 0.75% and 1%) were studied for different time intervals (18, 36 and 54 hours). The results of silt laden water were compared with the results of clean water condition in non-dimensional form. The silt size and its concentration were found to be the important parameters affecting the material removal from the surface and the efficiency of PAT.*
Keywords: *Pump as Turbine (PAT), Silt concentration, Silt erosion, Silt laden water, Silt size*

I. Introduction

Silt erosion can seriously damage components of hydro turbine and hampers the effective working of hydropower plants. The silt erosion in hydro turbines may lead to wear at localized areas, change in blade profile, induced .So many hydropower projects situated in North-East and Himalayan regions of India deal with sand erosion in turbines [1,2]. Mann and Arya [1] estimated that, India had a loss of US $120–150 million in 1998, due to erosion caused by the sand. Indian government has been promoting small hydro plants which have the capacity up to 25MW, but they are mostly run-of-river projects. Very high sedimentation load has been observed to pass through the turbine in monsoon as it is very difficult to remove all sand particles from water. Quartz content was found to be 70 to 98% which can severely damage components of any turbine because of its hardness (hardness 7 on Moh’s scale) [3-5]. Due to very high silt load in river Sutlej during the year 2003 to 2005, Naptha Jhakri hydropower plant (1500 MW) faced tremendous damage due to erosion caused by sand particles [6]. In normal conditions, sand concentration varies up to 12,000 ppm Sutlej river, but in extreme cases such as floods, landslides it can be as high as 30,000 ppm. Government reported a loss of US $77 million due to shut down of the plant on account of high silt load during this period. Singh[7] studied the site of Tiloth hydropower plant (three units of 30 MW) located on Bhagirathi river. Due to the presence of hard quartz particles (hardness 7 on Moh’s scale) and huge concentration of silt in monsoon up to 4000 ppm, turbines were found highly damaged only after a period of 2600 hrs. In most of the Nepalese rivers, quartz content was found more than 60% [8]. Thapa et al. [9] studied the case of Khimti hydropower plant (60 MW) and found the effects of sand erosion on Pelton turbine components. Though sediment chambers were designed to arrest silt particles, damage was observed within three years of commissioning of the plant. Padhy and Saini [10-12] experimented on the mechanism of erosion caused by sand particles and its effect on performance on the Pelton turbine. Brass was selected as a material for buckets to get significant amount of erosion in shorter time. It was found that for any silt size, erosion rate increases as silt concentration increases. Size of silt particles, concentration of silt, velocity of jet and operating time were found to be major parameters for the loss in efficiency of Pelton turbine. Correlation was developed for the same.

The construction of centrifugal pump is nearly similar to Francis turbine. Use of PAT is a very good alternative for low capacity power plants (<100 kW) with low initial cost, lesser complexity in design, advantage of bulk production, availability for a wide range of heads and flows, easy installation etc. In current study, effects of silt erosion on the performance of PAT was investigated.

II. Experimental Setup

The experimental setup was developed by Dr. S. V. Jain and Dr. R. N. Patel at Institute of Technology, Nirma University. The setup consisted of service pump with motor, bypass line, flow control valve, pump as turbine, draft tube, DC generator with load bank, piping system, underground water tank etc. Schematic diagram and photograph of experimental setup are shown in Fig.1 and Fig. 2 respectively.

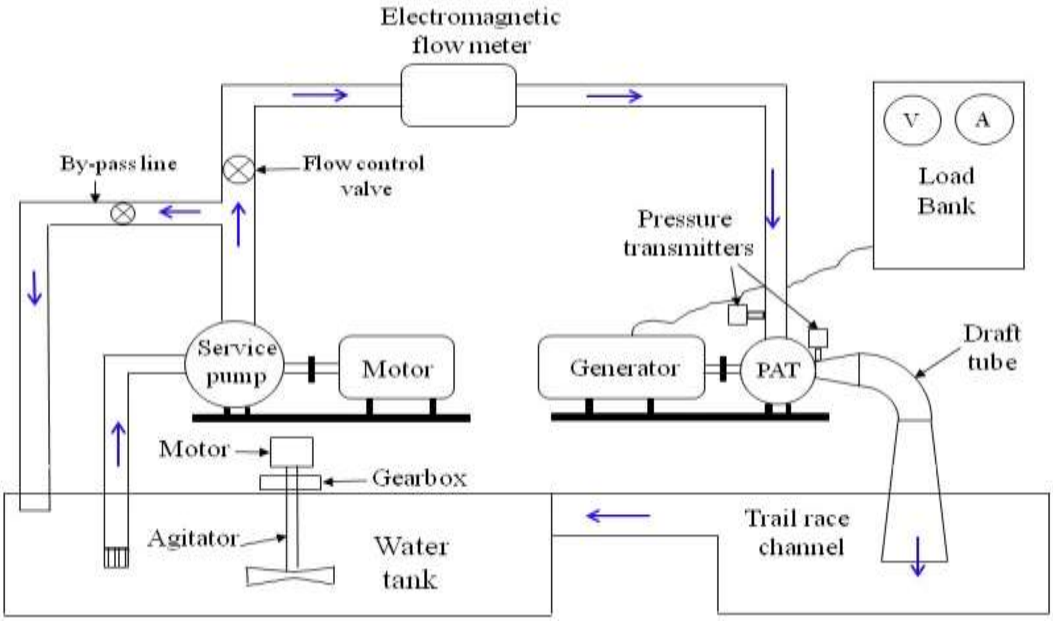


Fig.1 Schematic diagram of experimental setup

Centrifugal pump with backward curved vane was used as PAT. As flow was reversed, inlet and outlet were interchanged in turbine mode and it worked as a forward curved vane. Material selected of the impeller was SS304. Underground water tank having dimensions 2500 mm × 2000 mm ×1500 mm was used to store the water and for mixing of required amount of silt. A centrifugal pump was installed to create required hydraulic input to PAT under desired conditions. For the discharge, pressure and speed measurements electromagnetic flow meter, pressure transmitters and speed sensor were provided. More technical details about the setup are given in Jain et al. [13].

Fig. 2. Photograph of experimental setup [13] **Fig. 3.** Agitator [15]

When silt was mixed the water, it got settled at bottom of the tank due to its higher density. To prevent this and to ascertain the thorough mixing of water and silt, agitator system was designed according to procedure given by Coker [14] and installed in the water tank. The photograph of agitator along with gear box is shown in Fig.3 and the detailed design of agitator is given in Makwana [15]. The agitator was connected with the 1.5 hp motor and operated continuously during the whole period of experimentation to ensure uniform mixture of water and silt. Water-silt mixture from PAT outlet was disposed to the underground water tank through a draft tube. A generator was mounted directly on the impeller shaft and connected to the load bank to apply electrical load.

III. Silt Preperation And Mixing

Fig. 4. Sieve shaker

Silt was collected from the Sabarmati River, Ahmedabad. Silt size and silt concentration were the main factors considered in this silt erosion study. From the literature review, it was found that most of the researchers have done silt erosion studies in the hydraulic machines with silt sizes ranges from 100 to 1000 micron with the concentrations of 5000 to 10000 ppm by mass[10]. After the silt collection, it was segregated in the sieve shaker in the sizes 700 to 1000 micron as shown in Fig. 4. After silt segregation, to avoid error in the mass calculation, silt was heated in the hot air oven at 80°C for 2 hours to remove the moisture. 7000 liters of water was filled in the tank. The amount of silt required will be calculated using following expression:

Silt required = % of silt by mass × amount of water in the tank (1)

Concentrations used for the experiments were 5000 ppm, 7500 ppm and 10000 ppm and accordingly silt required was 35 kg, 52.5 kg and 70 kg respectively. For experiments with particular concentration, required amount of silt was added in the underground tank**.**

IV. Methodology

At first, experiments were performed with clean water at 1400 rpm with SS304 impeller. Various non-dimensional terms were obtained to get performance curves.

Flow number (ϕ) represents non-dimensional discharge and calculated as follows:

$$\phi = \frac{Q}{nD^3} \tag{2}$$

Where Q is the discharge to the PAT (m^3/s), n is the rotational speed of impeller (rps), and D is the diameter of pipe (m).

Power number (π) represents non-dimensional output power and calculated as follows:

$$\pi = \frac{P_{out}}{\rho n^3 D^5} \tag{3}$$

$$P_{out} = VI + I_f^2 R \tag{4}$$

Where P_{out} is the output power (watt), ρ is the density of water (kg/m^3), V is the output voltage across the load (volts), I is the current flowing through the load (amperes), I_f is the field current (amperes), and R is the field resistance.

Head number (Ψ) represents non-dimensional head working across PAT and calculated as follows:

$$\psi = \frac{gH}{n^2 D^2} \tag{5}$$

Where g is the gravitational field, and H is the total head consisting of pressure head, velocity head and datum head (m of H_2O).

Overall efficiency of the system was calculated by following expression:

$$\eta_o = \frac{P_{out}}{P_{in}} \qquad (6)$$

Where η_o is the overall efficiency, and P_{in} is the input power (watt).
PAT efficiency (η_{PAT}) was calculated by following expression:

$$\eta_{PAT} = \frac{\eta_o}{\eta_g} \qquad (7)$$

Where η_g is the generator efficiency.

After performing experiments with clean water, silt of size 700 micron to 1000 micron was added to the underground water tank. To identify the major impact areas on the impeller, thin layer of black paint was applied. This coating was easily erodible, so setup was run for 18 hours to identify erosion spots at various areas on the impeller. From the visual inspection, some spots were found on the impeller hub, shroud and blades as shown in Fig. 5(a).

Fig. 5(a) Silt erosion impact areas[16]

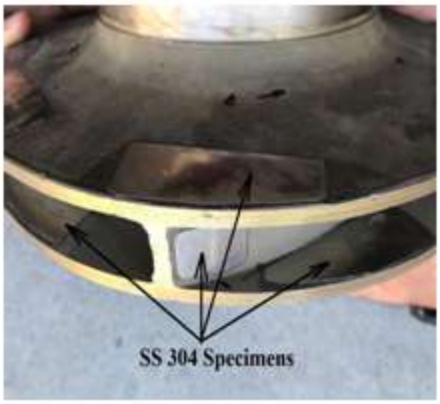


Fig. 5(b) Impeller with SS304 specimens

Specimens were prepared from the SS304 sheet of thickness 0.25 mm and glued to the impeller at eroded areas as shown in Fig. 5(b). Specimen material was chosen same as the impeller material to get the exact idea about the erosion of impeller. Adhesive LOCTITE 495 and for the removal of specimens LOCTITE Chisel Paint Stripper were used.

Experiments were performed with silt concentrations 0.5%, 0.75% and 1% by mass for time steps 18 hours, 36 hours and 56 hours. Impeller weight was 7825.50 gm before the experiment. Weighing machine with an accuracy of 1 mg or 10 mg with capacity 8000 gm was very difficult to find out. Therefore, for each experiments, weight of specimens were noted at the beginning and after the time intervals 18 hours, 36 hours and 56 hours. Weighing machine of accuracy of 1 mg and capacity 210 gm was used for measurements. From those readings relative mass loss and wear rate of specimens were calculated. Percentage change in roughness of specimen was measured with roughness tester at each time step. Performance curves were generated and compared with the performance curves which are obtained with clean water.

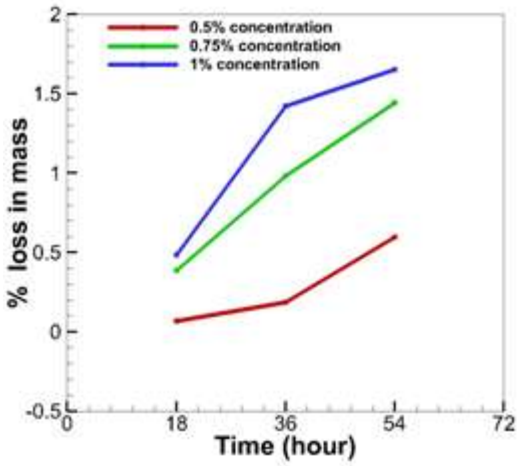
V. Results And Discussion

5.1 Loss in mass

As Concentration increases loss in mass increases with time. Fig. 6 shows relation of % loss in mass at different concentrations with time which gives better analysis of wear rate.

5.2 Variation in roughness

Roughness tester was used to check roughness before and after each experiments. For each specimen, average roughness was calculated. From that data, surface roughness variation was found out. Fig. 7 shows roughness variation at different concentration with different time period. Roughness increases with increase in concentration with time.



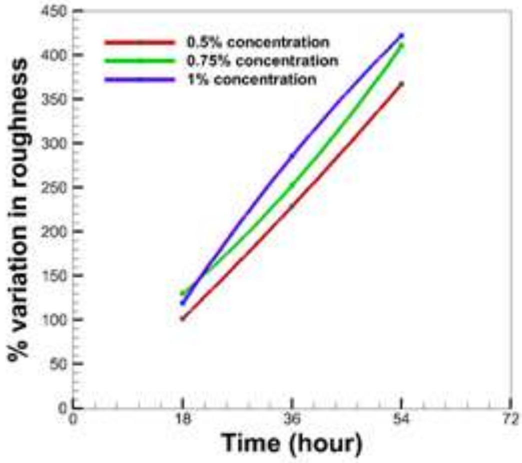


Fig. 6. Comparison curves for % loss in mass **Fig.7.**Comparison of roughness at different concentration

Performance parameters at 1% silt concentration were compared with those obtained from clean water. Fig. 8 shows comparison of performance curves for experiments with silt and without silt. Head was decreased when silt was added to the water. At very small flow rate, power output and efficiency were found to be higher with silt laden water. Then after at any flow rate, efficiency and power output with silty water decreased in its value when compared to clean water conditions.

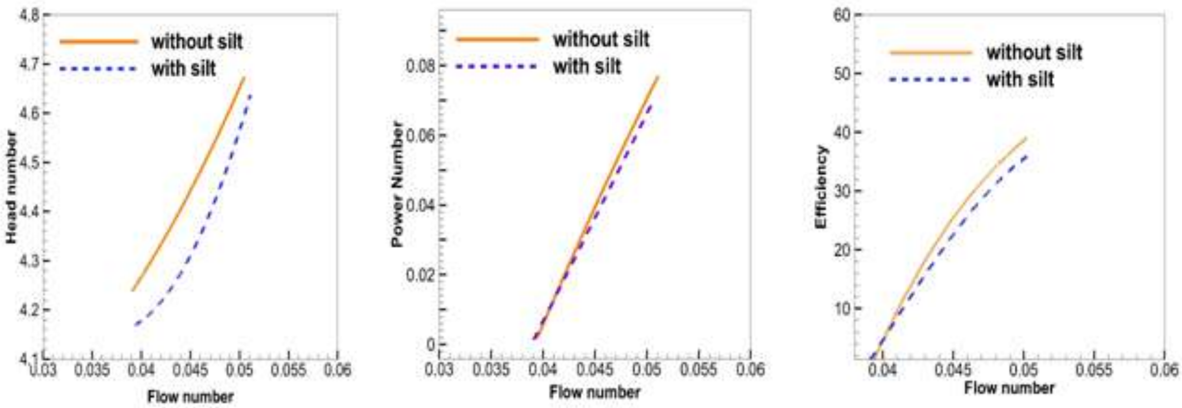


Fig. 8 Comparison of performance parameters with and without silt

5.4 Uncertainty analysis

Errors in primary measurements cause uncertainties in the experimental results. Uncertainty analysis was carried out by the method suggested by Kline and McClintock [17]. Based on that, errors for the investigated parameters were calculated. The maximum percentage errors of discharge, head and efficiency were 1%, 0.70% and 2% respectively.

VI. Conclusion

In the current study, the effects of silt size of 700 to 1000 micron were examined on the performance of PAT at three different concentrations 0.5%. 0.75% and 1% with three time intervals, 18 hours, 36 hours and 54 hours. It was found that the, roughness of specimens as well as wear rate increased with increase in silt concentration and time. Various non-dimensional parameters, flow number (ϕ), head number (Ψ) and power number (π) were found out and performance was analyzed by comparing these parameters for clean water and silty water conditions. The results showed that head was found to be lower under silt laden water as compared to same operating conditions with clean water. Due to silt erosion the power number and efficiency of PAT decreased by 9.60% and 9.81% respectively.

Conflict of interest The authors declare that there is no conflict of interests regarding the publication of this paper.

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