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Experimental Examined of Effect of Silt Erosion on Overall Performance of Pelton Turbine Buckets

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***Abstract*— Silt particles exhibit in waterway causes erosion in various segments of hydraulic turbines which interacts with it. The intensity of erosion relies on silt size, silt concentration, stream velocity, properties of silt materials and working hours of turbine. Because of increment in sediment content erosion increases which decreases the productivity of the turbine. This causes colossal financial misfortune to the nations. In this present work the impact of residue size, sediment concentration, flow velocity and working hours of turbine on execution of Pelton turbine under genuine flow conditions has been ascertained experimentally. It has been found that sediment parameters and working parameters are in charge of diminishment in proficiency of Pelton turbine. Erosive wear prompts to productivity lessening up to 1.81% therefore resulting in loss of power generation. In view of results, correlation of performance are established in term of Jet velocity, time, size and silt concentration can be used to predict the values of performance parameters with considerably good accuracy.**

Keywords- Silt size; Silt concentration; Stream velocity; Efficiency loss; correlation

Nomenclature

C	Silt concentration (ppm)
C_w	Fraction of solid by weight (ppm)
D_{50}	Mean silt size (µm)
H	Head (m)
K_f	Factor that relates abrasion to water flow around each component
P	Constant
P_0	Electrical power output (kW)
Q	Quartz content
S	Silt size (µm)
t	Operating time (hour)
V	Jet velocity (m/s)
v	Relative velocity of water
δ	Erosive wear rate (Kg/ year)
η_g	Generator efficiency
η_m	Turbine peak efficiency with sediment laden flow
η_w	Turbine peak efficiency with clean water
a, b	Empirical constants

I. Introduction

Silt present in flowing river water is one of the major concerns that shorten the life of hydro turbines. Due to silt, debasement of components of hydro turbines takes place. The debasement of the components causes reduction in performance of hydro turbines. Performance of hydro turbines such as efficiency not only decreases due to silt but it is a major concern for turbine manufacturers. Due to silt erosion in hydro turbines take place and the problem is more exasperate when silt contains high percentage of quartz, which is exceedingly hard having hardness of 7 on Mohr's scale [1-3].

During monsoon season, the problem become even more intricate as concentration level of silt suddenly enrich which cause extensive damage to turbine components due to erosion [4-5]. India is also facing erosion problem due to silt carried by Himalayan Rivers as a result patronize shutdown of hydropower stations take place. The problem due to silt is not limited to Indian hydro power plants only, Nepal and South America hydro power stations are also facing silt erosion problem which cause immense economic loss [6-7]. Erosion or erosive wear damage is considered as gradual removal of material caused by impact of solid or liquid particle on solid surface [8-9]. Silt present in flowing water induce erosion in hydro turbine components which leads to reduction in efficiency of turbine, change in flow pattern and at last hydro turbine breaks. Previous investigation has shown that in case of Impulse turbines the components which are more prone due to silt are buckets, nozzle, blades, and needle. Erosion intensity of hydro turbines is directly proportional to silt shape, silt size, silt concentration, hardness of silt, if the particle shape is angular and sharp they produce high erosion as compared to round shape silt particles and if size of silt particles are above 200 µm they cause high erosion as compare to fine silt particles. Investigation of silt erosion in hydro turbines is always a challenging task in actual flow conditions. Most of the previous studies were conducted on small test rigs experimentally to identify the effect of silt on erosion and performance of hydro turbines [10, 11-16]. Now a days Computational Fluid Dynamics (CFD) software and computer based programming has been used to investigate the erosion pattern and optimize the design of hydro turbines [17-21].

The fundamental reason of erosion in hydro turbine parts is the mix of high concentration of sediment with a higher rate of quartz substance in water which is a great degree hard material [22-23].

II. Literature Review

Bajracharya et al. [24] researched relationship to anticipate erosion wear rate and size of molecule for various quartz content as:

$$Erosion\ rate \propto a\,(size)^b\ \text{[Kg /year]} \quad (1)$$

They have also developed correlation between efficiency reduction and erosion rate as:

$$Efficiency\ reduction \propto a\,(erosion\ rate)^b \quad (2)$$
$$a = 0.1522\ and\ b = 1.6946$$

Takgi et al. [25] conducted performance test hydraulically on Francis turbine model with silty water and observed that maximum efficiency decreases in direct proportion to increase in solid concentration. The efficiency reduction was given by:

$$\eta_m = (1 - 0.085\,C_w)\eta_w \quad (3)$$

Tsuguo [26] established a correlation of basic parameters which are responsible for erosion of turbines and the data was collected from 18 hydropower plants of 8 years. He predicted correlation to estimate turbine erosion as:

$$W = \gamma . C^x . a^y . K_s . K_h . K_r V^m \quad (4)$$

Anant and Arun [27] reported a case study of Chilla hydropower plant (4×36 MW) in Himalayan river in India. In this hydropower plant four Kaplan vertical shafts turbines were used having 32.5 m designed head. They have presented a simple method to investigate erosion in blade, runner chamber and draft tube cone of Kaplan turbine. During the study they have observed that due to sediment parameters outer trailing edge of blade and runner chamber were most affected parts due to erosion.

Chattopadhyay [28] experimentally tested the commonly used turbine runner material in order to investigate the slurry erosion characteristic of AISI 316 L, 15 wt % Cr-15 wt % Mn stainless steel and cast ferritic stainless steel CA6NM with stellite powder alloy applied as overlay. The samples used in the experiment were of rectangular cross-section of size 65 mm × 14 mm × 20 mm and thick slurry was used as erodent. It was concluded that 15 wt% Cr-15 wt% Mn stainless steel and Stellite powder alloy shows better erosion resistance properties as compared with CA6NM steel.

Krause and Grein [29] proposed the equation by conducting model tests Pelton runner made of X5CrNi 13/4 to find the abrasion rate and can be predicted as:

$$\delta = P\,Q\,C\,V^{3.4}\ f(D_{50}) \quad (5)$$

The equation presented above can be used for components made of above said material.

Khurana et al. [30] have developed correlation by conducting experiments to estimate the percentage efficiency loss of Turgo impulse turbine in actual flow conditions as a function of silt size, silt concentration, jet velocity and operating hours of turbine as follows:

$$W = 2.93 \times 10^{-8} S^{0.212} C^{1.113} V^{1.409} t^{0.737} \quad (6)$$

Padhy and Saini [31] experimentally studied the effect of silt size, silt concentration, jet velocity and operating hours of Pelton turbine on efficiency loss of 16 buckets in actual flow conditions. They found a good agreement between experimental data and calculated data for percentage efficiency loss. The developed correlation was obtained as:

$$\eta_{\%} = 2.43 \times 10^{-10} (S)^{0.099} (C)^{0.93} (V)^{3.40} (t)^{0.75} \quad (7)$$

It has been observed from the Literature survey that most of the reported work was conducted on small test rigs to investigate the effect of silt on erosion of hydro turbines. Some experimental study has been conducted in actual flow conditions on Turgo impulse turbine and Pelton turbine and in both the cases the material of blades / buckets was brass. In the present study the material of buckets is Aluminium and experiment was conducted on small scale Pelton turbine in actual flow conditions. Using the experimental data a correlation has been developed to study the effect of silt erosion on performance of Pelton turbine.

III. EXPERIMENTAL STUDY

A new test apparatus has been designed and fabricated in order to investigate the performance of Pelton turbine under silty water. The test set up has been made at Shoolini University Solan, India. For the present extensive experimental study runner was designed for 1 kW power output as shown in Figure 1. In the present rigorous study the runner of Pelton was made of Aluminum so that it can erode in short time. Pelton Runner has 20 numbers of buckets and the pitch circle diameter of runner is 145 mm. The weight of each bucket is around 115 g. For the present analysis Auto Cad software version 2015 was used to prepare drawings of buckets and runner as shown in Figure 2. In this experimental work two tanks were made (650 mm × 520 mm × 800 mm). At begin, the principal tank was utilized to store water and to course sediment water blend to the runner of Pelton turbine of various residue focuses. The second tank was utilized to gauge the release by utilizing rectangular notch. In the trial a stirrer was utilized ceaselessly in order to supply a uniform blend of sediment water to turbine runner. A penstock pipe having 70 mm external width and 3 mm thickness was utilized for providing water to the turbine runner.

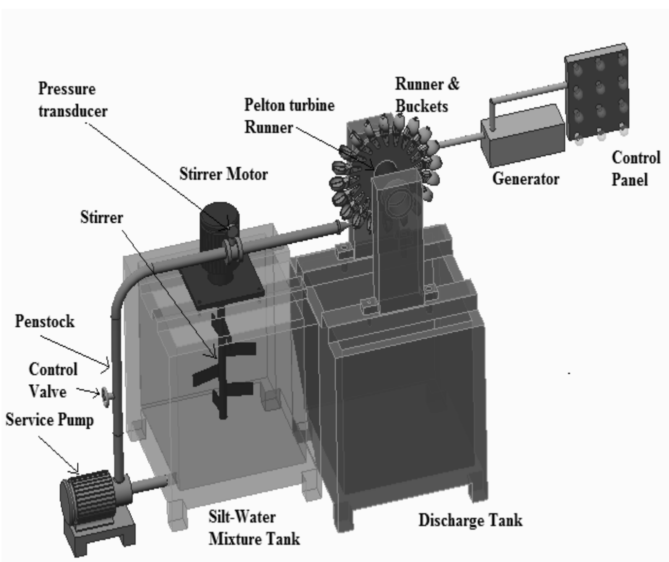

Figure 1. Schematic of Experimental Setup

A monoblock having 40 m evaluated head and a release limit of 9 l/s was utilized to make hydro potential. An advanced weight transducer of Yokogawa make having scope of 0.5 kPa to 14 MPa and having precision ± 0.065 % was fitted with penstock pipe to quantify the net head at channel of Pelton turbine. A generator was specifically coupled to the turbine shaft. Electric knobs of various wattage were utilized as resistive load. The electric load was measured to decide the yield of the turbine. The weight reduction of Pelton containers were measured prior and then afterward experimentation with the assistance of electronic weight adjust having slightest tally of 0.1 mg. Distinctive sorts of sifters of 90, 150, 300 and 450 microns were utilized so that evaluating of residue should be possible.

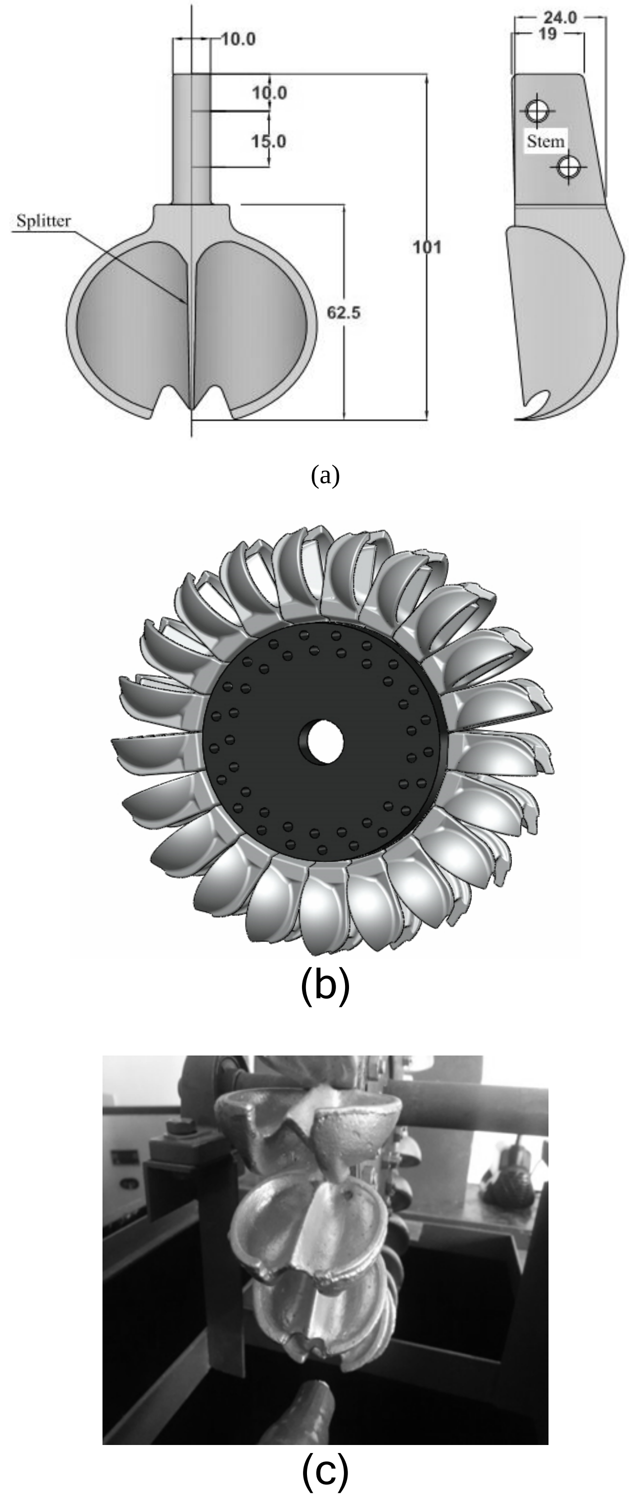

Figure 2. Design details of Pelton turbine blades and runner

Before starting the experiment, a trial test was conducted to verify the proper functioning of the whole set up. Proper functioning of all the instruments was also verified. Initially service pump drew water from the storage tank and supplied it to the turbine. Water from the turbine was allowed to flow through second fitted with rectangular notch for discharge measurement. The height of water over the crest of the notch was recorded by a pointer gauge and the discharge of the pump corresponding to each head was determined. The calculation of discharge will be made based on the height of water flowing above the crest (h).

Residue was dried in the daylight for 3-4 days and sifters of various sizes were utilized to strainer the sand before blending with water.

A. Turbine efficiency

The turbine efficiency has been proposed as;

$$\eta_t = \frac{P_0}{P_i \times \eta_g} \times 100 \qquad (8)$$

Pi is the input power available can be expressed as:

$$P_i = \rho\, g\, Q\, H \qquad (9)$$

The input power was examined in terms of head and discharge to calculate efficiency of turbine. For measuring output power through a generator electricity was generating. A control board is given a voltmeter, wattmeter (minimum tally1W) was associated with generator and electric knobs were utilized as load. Control yield from generator was recorded by the wattmeter and proficiency of generator was taken as78%. The misfortune in effectiveness was figured by contrasting the proficiency got and clean water.

From trial perspective rate productivity misfortune increments with increment in residue focus, sediment measure, time of operation and fly speed. Control yield diminished with misfortune in edge mass moreover. So a relationship was gotten for effectiveness misfortune as an element of residue focus, sediment estimate, fly speed and working time.

B. Parameters Investigated

In this present experimental work silt size, silt concentration, jet velocity and operating hours were investigated parameters. For this, sample of silt was collected from Chamera lake , Chamba (HP, India) in which the silt concentration during monsoon season was around 20000 ppm and the average quartz content was found to be around 80%. Silt was dried in the sunlight for 3-4 days and sieves of different sizes were used to sieve the sand before mixing with water.

IV. RESULTS AND DISCUSSIONS

Figure 3 shows percentage efficiency loss with silt concentration for different silt size at constant jet velocity (26.449 m/s). The experiments were conducted for a period of eight hours. It is observed that percentage efficiency loss of turbine increases with increase in concentration for all sizes of silt. The maximum efficiency loss varied from 0.29 % to 1.81% at the highest concentration of 8000 ppm due to erosive wear by quartz containing silt. The maximum loss of efficiency was observed for largest particle size of 450 µm.

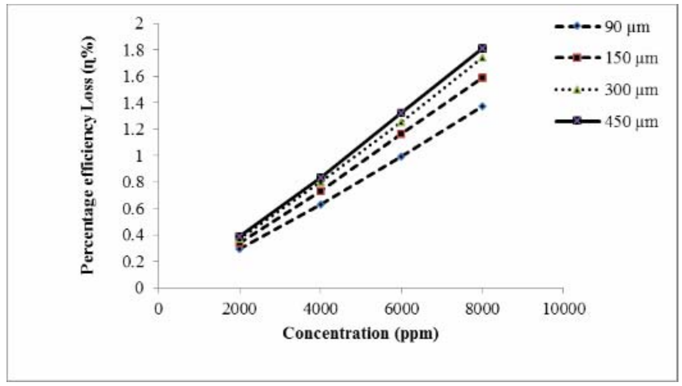

Figure 3. Percentage efficiency loss versus silt concentration

Figure 4 shows variation in percentage efficiency loss with particle size for different values of silt concentration for eight hours of operation at a jet velocity of $28.81\ m/s$. Percentage efficiency loss increased linearly with increasing silt size. It is observed that when particle size is $90\ \mu m$ the value of efficiency loss is 0.29 for low concentration$(2000\ ppm)$, the loss in efficiency is 1.77 for silt size$450\ \mu m$.

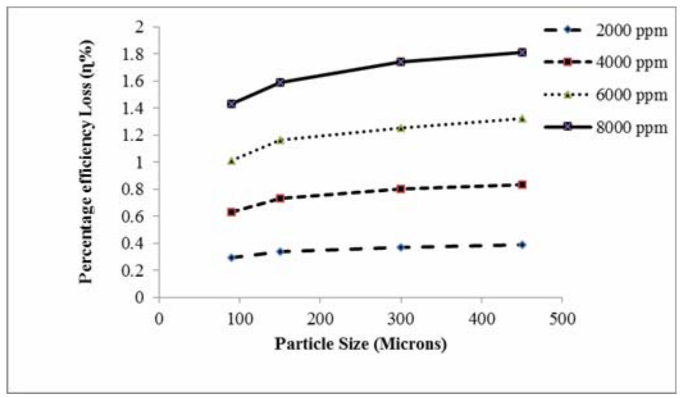

Figure 4. Percentage efficiency loss versus silt size

However, with increase in concentration significant loss in percentage efficiency $(up\ to\ 1.81\%)$ is observed and even smaller particles $(100\ \mu m)$ are very harmful. Power output of turbine decreased with increase in mass loss of blade (Figure 5). The rate of power loss is more initially but stabilizes at higher mass loss. Similar trend was observed for variation in turbine efficiency with loss of mass of turbine, Figure 6. Variation in percentage efficiency loss with percentage mass loss of the blade is shown in Figure 7. As percentage of mass loss increased percentage efficiency loss increased significantly. It can be observed that about 1.81% efficiency loss occurred against a blade mass loss of 0.5%.

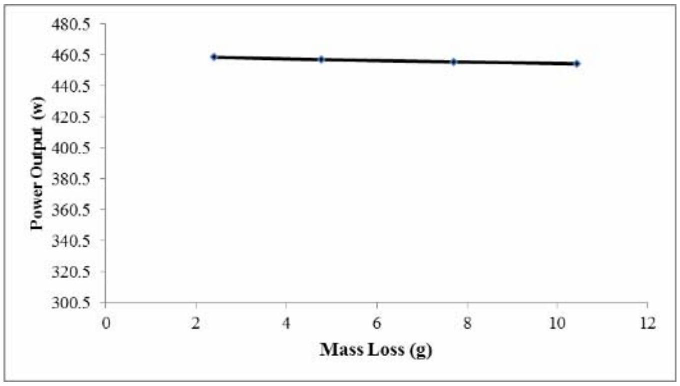

Figure.5. Power output of turbine versus mass loss

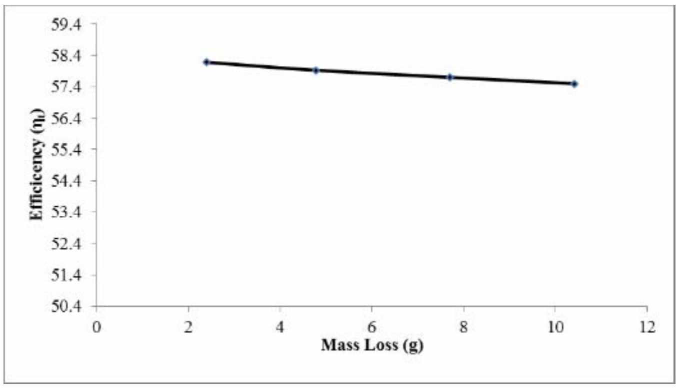

Figure 6. Turbine efficiency versus bucket mass loss

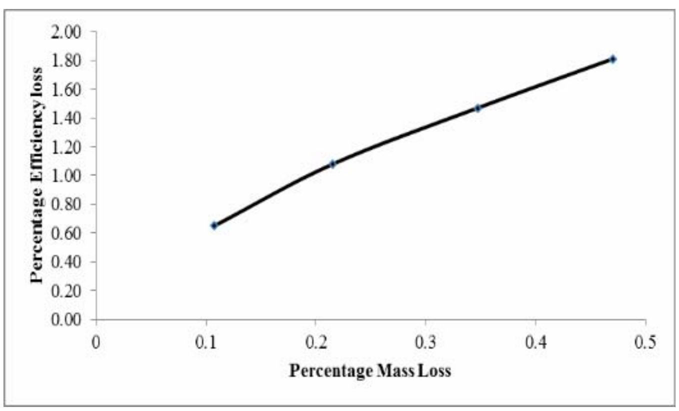

Figure 7. Percentage efficiency loss versus percentage mass loss of turbine

Figure 8 presents data of percentage efficiency loss with jet velocity for constant silt concentration of $8000\ ppm$ and silt size $450\ \mu m$. As jet velocity is increased from $27.3\ to\ 27.35\ m/s$ percentage efficiency loss increased to 0.40%.

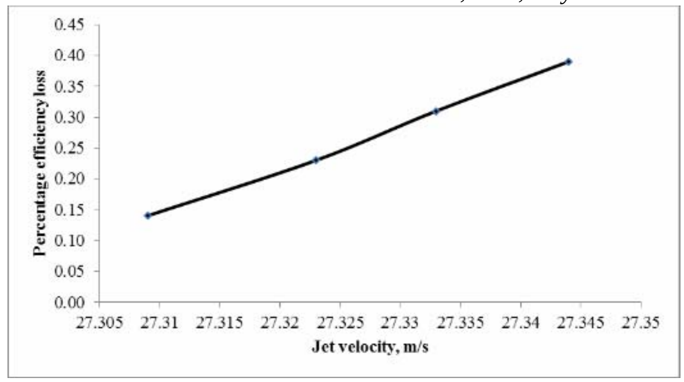

Figure 8. Percentage efficiency loss versus jet velocity

V. CORRELATION DEVELOPMENT

In this paper experimental study and development of correlation has been performed for efficiency loss of Pelton turbine due to erosion created by silt water. It has been observed that efficiency loss is strongly dependent on silt particle size, silt concentration, jet velocity and operating hours. Hence a need was felt to develop a correlation using experimental data for efficiency as a function of silt size (S), silt concentration (C), jet velocity (V) and operating time (t). To find the effect of silt size on efficiency loss a plot for efficiency loss versus silt size was plotted and a power law line was fitted to obtain the relation as (Figure 9):

$$\eta_{\%} = A_0 S^{0.166} \qquad (10)$$

where S is silt size and A0 is a constant whose value depends upon the other factors i.e. C, V and t.

In the next step $\frac{\eta_{\%}}{S^{0.166}}$ was plotted against C (concentration) in (Figure 10) and a relation was obtained as below;

$$\frac{\eta_{\%}}{S^{0.166}} = B_0 C^{1.1223} \qquad (11)$$

In this relation, B_0 is constant whose value depends on remaining factors i.e. V and t.

So, again a graph was plotted between $\frac{\eta_{\%}}{S^{0.166}C^{1.1223}}$ versus V (jet velocity) is shown in (Figure 11). From the figure following relation was obtained:

$$\frac{\eta_{\%}}{S^{0.166}C^{1.1223}} = C_0 V^{2.413} \qquad (12)$$

C_0 is a constant which depends upon time t.

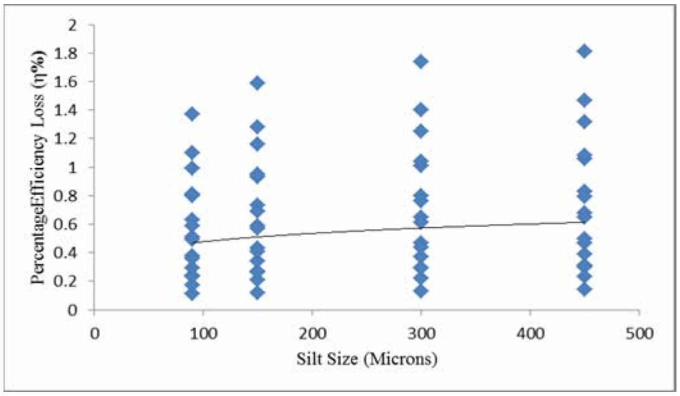

Fig.9. Plot of percentage efficiency loss versus silt size

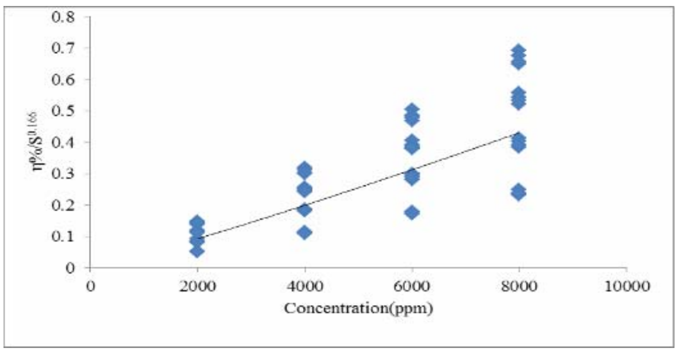

Figure 10. Plot of $\dfrac{\eta_{\%}}{S^{0.166}}$ versus concentration (ppm)

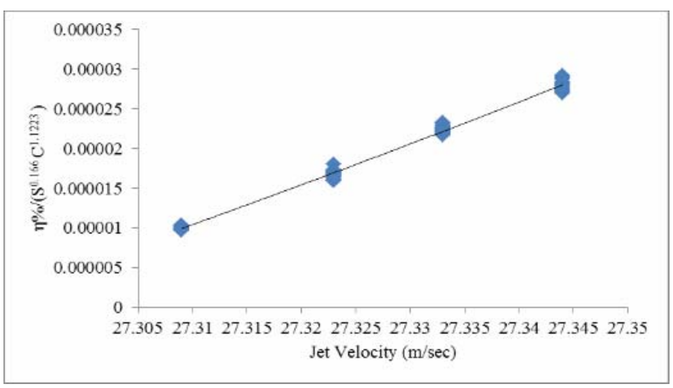

Figure 11. Plot of $\dfrac{\eta_{\%}}{S^{0.166}C^{1.1223}}$ versus jet velocity

Finally a graph was plotted between $\dfrac{\eta_{\%}}{S^{0.166}C^{1.1223}V^{2.413}}$ versus time (Figure 12) and the relation obtained is written as below:

$$\frac{\eta_{\%}}{S^{0.166}C^{1.1223}V^{2.413}} = 1.752\times10^{-9}t^{0.699} \qquad (13)$$

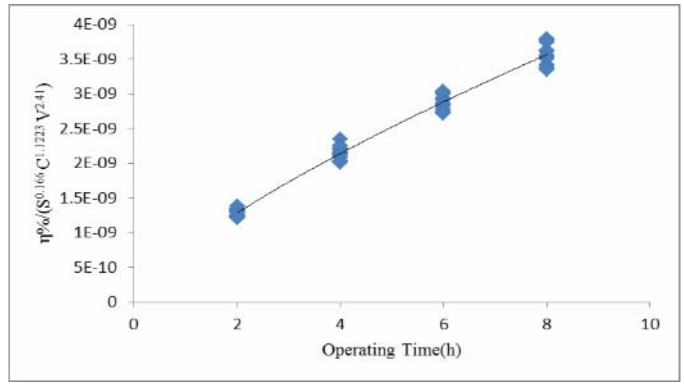

Figure 12. Plot of $\dfrac{\eta_{\%}}{S^{0.166}C^{1.1223}V^{2.413}}$ versus operating time

By rearranging equation (13) the final equation for percentage efficiency loss can be written as:

$$\eta_{\%} = 1.752\times10^{-9}(S)^{0.166}(C)^{1.1223}(V)^{2.413}(t)^{0.699} \qquad (14)$$

Figure 13 shows the comparison of the experimental data of percentage efficiency loss and the values obtained from the developed correlation. A good agreement is observed with average absolute percentage deviation between the experimental data and calculated values of percentage efficiency loss found to be within ± 8.2%.

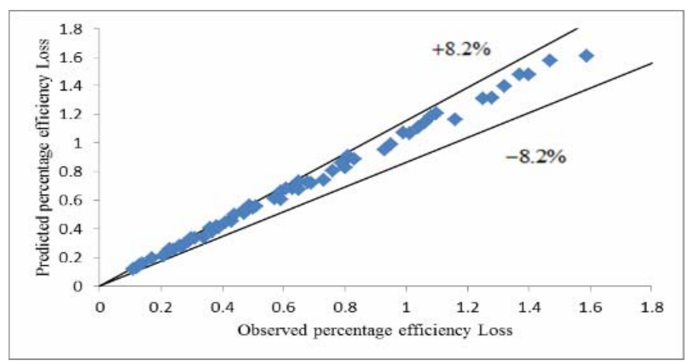

Figure 13. Comparison of observed percentage efficiency loss and predicted percentage efficiency loss

VI. CONCLUSION

In this present test work focus has been to examine the impact of sediment erosion on performance of Pelton turbine. Sediment erosion in hydro turbines is an intricate phenomenon; the segments that interact with the stream are influenced by erosion. Because of sediment disintegration material is expelled from the turbine parts. This results in loss in proficiency of hydro turbines which causes enormous financial misfortune to the country. From the exploratory review taking after conclusions have been made:

- Turbine control yield diminishes when loss of bucket mass enhances.

• Efficiency of turbine reductions essentially when mass loss of buckets happens.

• Rate of percentage effectiveness loss fluctuates from $0.65\ to\ 1.81$.

• Correlation of performance are developed in term of jet velocity, time, size and silt concentration can be used to predict the values of performance parameters with considerably good accuracy.

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