Effect of Silt Size, Concentration on Erosion of Turgo Turbine Blades

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Abstract: An experimental investigation in actual flow conditions has been carried out to study the effect of silt size, concentration, jet velocity, operating hours and nozzle angle on erosive wear of Turgo impulse turbine blades. Experiments have shown that maximum erosion occurs at nozzle angle of 20° for silt size 370 µm and silt concentration of 12000 ppm. During the experiments it has been observed that erosive wear depends on silt size, silt concentration, nozzle angle and operating hours of turbine. A correlation has also been developed as a function of silt size, silt concentration, operating hours of turbine and nozzle angle.

Key words: Silt size, silt concentration, correlation, nozzle angle, normalized wear

Nomenclature

C	silt concentration (ppm)
S	silt particle size (µm)
V	velocity of flow (m/s)
t	operating time (hour)
W	normalized wear (g/g)
H	head (m)
v	relative velocity of water
V	particle velocity (m/s)
α	nozzle angle (unit in radians?)
δ	erosive wear rate (mm/h)
P	a constant
n	exponent of velocity
ε	deformation factor
E_r	efficiency reduction

Introduction

Silt erosion is result of mechanical wear of components due to dynamic action of silt flowing along with water impacting against a solid surface. A number of factors can influence the process of silt erosion such as, silt size, silt concentration, shape of erodent, and hardness of erodent, velocity, operating time, impingement angle and properties of the base material. The silt laden water passing through turbine not only erodes the turbine components but also reduces its efficiency. The main turbine parts which are affected due to silt are buckets, blades, nozzle and needle in case of impulse turbines, while for reaction turbines guide vanes, faceplates, runner blades and seal rings are the most affected parts (Padhy and Saini 2009; Thapa et al. 2012).

Silt erosion in hydraulic turbines is a major problem in most of the hydroelectric projects around the world especially for those situated in Himalayan and in the north eastern region in India (Goyal et al; 2012). Himalayan rivers contain very high sediment concentration during the monsoon season. Major components of this sediment are hard abrasive sand and silt which rigorously damage the turbine components. Due to increase in concentration of silt particles in water during monsoon season causes the underwater components in hydropower plants, particularly turbine parts to erode which drastically reduces overall efficiency of turbines, changes in flow patterns, vibrations and finally breakdown of hydro turbines.

Erosive wear of hydro turbine blades is a complex phenomenon which depends upon different parameters such as silt concentration, silt size, velocity of flow and impingement angle (Padhy and Saini 2011; Eltvik 2009).

The aim of the present study is to analyze the effect of nozzle angle, silt parameters and operating hours on the erosion of Turgo impulse turbine.

Literature Review

The impingement angle is defined as the angle between the eroded surface and the trajectory of the particle just before the impact. If the particles are moving parallel to the surface, impingement angle is almost 0° and hence minor erosion take place. When particles are moving normal to the surface the impingement angle is 90°. Ductile and brittle material show different erosion behavior against impingement angles. In case of ductile materials maximum erosion rate is observed between 10 ° to 30 °, whereas lower erosion rate is observed at normal impact. While for brittle materials the erosion rate increases as the angle of impingement increases and is highest at normal impingement (Thapa 2004).

Pool et al. (1986) conducted experimental study of polymer composite materials on erosion wear tester. The authors concluded that maximum erosion for ductile material occurred at about 20° and for brittle materials maximum erosion occurred at 90°.

Krause and Grein (1996) proposed the abrasion rate for silt size = 40-70 µm and sand containing 99% quartz for Pelton runner made of X5CrNi 13/4 as:

$$\delta = P\,Q\,C\,V^{3.4} f(D_{50}) \qquad (1)$$

Bajracharya et al. (2008) conducted field survey of 22MW Chilime Hydropower Plant (CHP) located in Nepal and established erosive wear rate of spear and efficiency reduction relationship for Pelton turbine as:

$$Erosion\ wear\ rate \propto a(size)^{b} \qquad (2)$$

Where erosive wear rate is in Kg/year, and
a= 351.35, b= 1.4976, for quartz content of 38%
a = 1199.8, b= 1.8025, for quartz content of 60%
a= 1482.1, b= 1.8125 for quartz content of 80%.

The relation between erosion rate and efficiency reduction was expressed as:

$$E_r \propto a(erosion rate)^b \quad (3)$$

Where a = 0.1522 and b = 1.6946

Padhy and Saini (2009) have developed correlation for wear rate for Pelton turbine buckets as a function of silt concentration (5000-10000 ppm), silt size (below 90µm to 355 µm), Jet velocity (26.61 m/s to 29.75 m/s) and operating time = 8 h as:

$$W = 4.02 \times 10^{-12} (s)^{0.0567} (c)^{1.2267} (v)^{3.79} (t) \quad (4)$$

Range of Parameters

In the present investigation effect of five parameters such as: silt size, silt concentration, jet velocity, nozzle angle and operating hour were investigated. Sample of silt was collected from Beas River (India) near Pandoh Dam in which silt concentration during monsoon season found to be around 34,400 ppm (Awasthi 2001). Silt was dried under sun and then sieved to different sizes before mixing with water. Range of parameters used for present study is given Table 1.

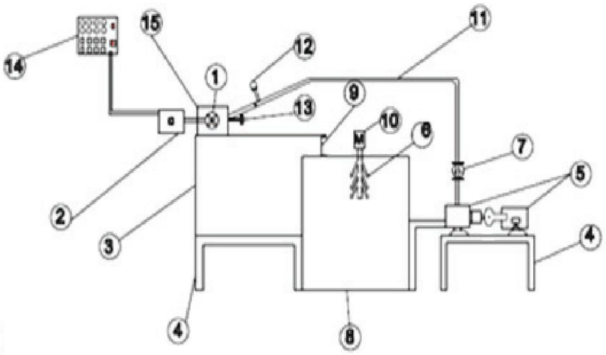
S. No.	Parameters	Range of parameters
1	Silt size	370, 300, 200,100 µm
2	Silt concentration	3000, 6000, 9000,12000 ppm
3	Jet velocity	28.81 m/s
4	Operating time	4 h run for each set
5	Nozzle angle	20°, 25° and 30°

Table 1. Range of Parameters

Experimental set up and procedure

An experimental set up of small scale model of Turgo impulse turbine of capacity 1.2 kW was designed and fabricated to study the effect of silt size, silt concentration, jet velocity, operating hours of turbine and nozzle angle on erosion of Turgo turbine blades. Figure 1 shows a schematic arrangement of test setup. Blades of Turgo turbine were made of brass to get considerable amount of erosion in short time. The weight of each blade was approximately 202 g. The Turgo turbine runner with pitch circle diameter of 216 mm is mounted with 19 blades. Two tanks (680 mm × 530 mm × 810 mm) were fabricated for experimentation work. The first tank was used to store water and to prepare silt water mixture of different concentrations and the other tank was used to measure discharge using rectangular notch. A stirrer was attached to operate continuously during experiment so as to supply uniform mixture of silt and water to the turbine. A penstock pipe having 71 mm outer diameter and 3 mm thickness was used for supplying water to the turbine. Water has been supplied by a 7.5 HP monoblock centrifugal pump of Kirloskar having 45 m rated head and discharge capacity of 5.5 l/s. A spear valve was used at the end of penstock pipe with nozzle having diameter 12.5 mm to regulate the discharge. Water from the turbine outlet flows through the discharge tank and then discharged to the storage tank. A control valve was used at the delivery side to maintain required head of water at every time. The head of water was measured by a digital pressure transducer and it was mounted on the penstock pipe at the inlet of turbine. Shaft of the runner was directly coupled with the generator shaft. A resistive load was connected to the generator through control panel. The control panel consisted of wattmeter, a voltmeter and load in the form of electric bulbs of different ratings. The electric load was measured to determine the output. Weight loss of blades was measured by using an electronic weight balance having least count of 0.1mg. Grading of different size of silt was done with the help of sieves of different size ranges of 100 µm, 200 µm, 300 µm and 370 µm.

A stirrer was continuously rotated during the experiments with a motor in the middle of the tank to provide uniform mixture of silt and water. Head and flow to the turbine during the experiments were kept constant. The experiments were conducted for fixed value of jet velocity of 28.81 m/s respectively. Erosion is measured in terms of mg with the help of electronic balance having least count of 0.1 mg. The nozzle angles used for experimental work were 20°, 25° and 30°. Head and flow to the turbine during the experiments kept constants. The Blades from runner after every 2 h were dismantled and they were cleaned with soft cloth and then weight loss of each blade after 2 h were measured.



Part No.	Part Name
1	Turgo Runner
2	Generator Set
3	Concrete Tank
4	Stand
5	Mono Block
6	Stirrer
7	Control Value
8	Steel Tank
9	Rectangular Notch
10	Motor
11	Penstock pipe
12	Pressure Transducer
13	Spear Valve
14	Control Panel
15	Casting

Figure 1. Schematic of test set up

Uncertainty Analysis

The uncertainty analysis of experimental measurements was carried out on the basis of method proposed by Kline and McClintock (1953). The approach used is discussed as; if a parameter is calculated using certain measured quantities as;

$$R=R\,(x_1, x_2, \text{-----}\ x_n) \tag{5}$$

$$W_R = \left[\left(\frac{\partial R}{\partial x_1}W_1\right)^2 + \left(\frac{\partial R}{\partial x_2}W_2\right)^2 + \dots\dots\dots\dots + \left(\frac{\partial R}{\partial x_n}W_n\right)^2\right] \tag{6}$$

Then uncertainty in measurement of R is given as follows Where W_1, W_2, W_n be the uncertainties in measurement of $x_1, x_2 \ldots x_n$

The maximum uncertainty values of parameters are given below:

- Silt size: 1.41%
- Silt concentration: 0.10%
- Weight of blade: 0.71%

Results and Discussion

From the experimental data plots have been prepared to analyze the effect of nozzle angle, silt parameters and operating hours on normalized wear. Graphs were generated for different values of silt concentration (3000-12000 ppm), silt size (100-370 μm), operating hours of turbine (2, 4 hours) with a fixed value of jet velocity (28.81 m/s). Figures. 2 (a-d), 3 (a-d) shows the variation of normalized wear (loss of weight/original weight) with nozzle angle. In the present study the average value of weight loss was considered because all blades of Turgo turbine were identical.

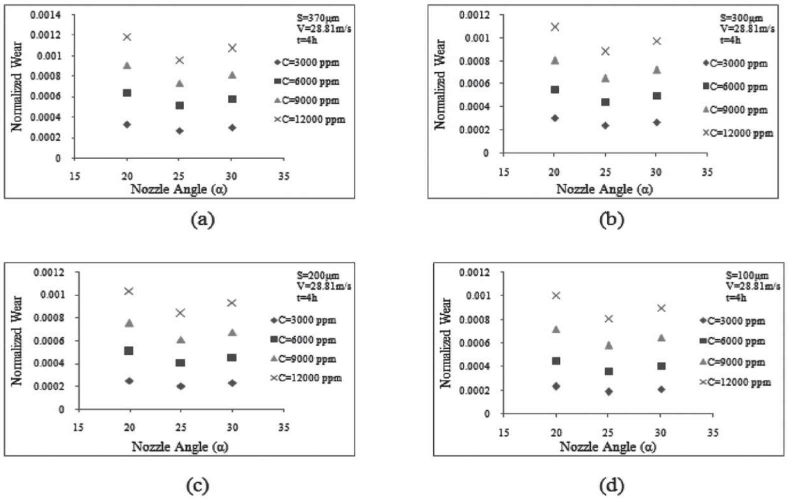


Figure 2.Effect of nozzle angle on normalized wear for different values of silt concentration for operating time = 2h for
(a) Silt size = 370 μm (b) silt size = 300 μm. (c) silt size = 200 μm. (d) silt size = 100 μm

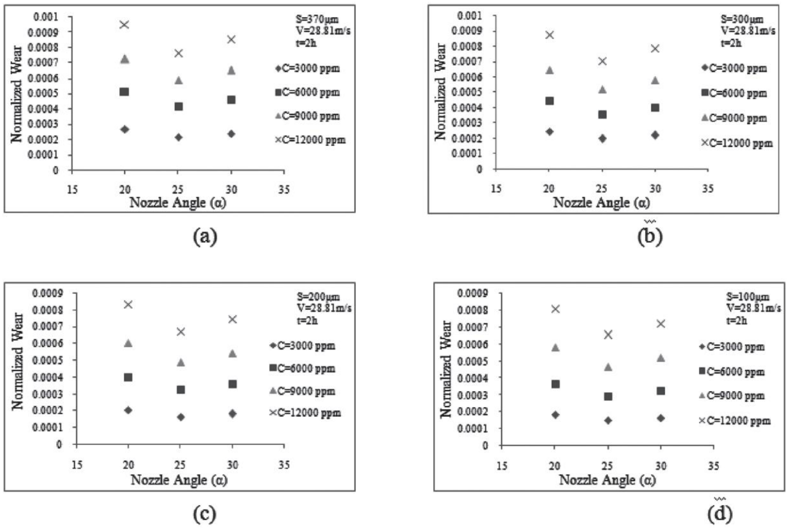


Figure 3. Effect of nozzle angle on normalized wear for different values of silt concentration for operating time = 4h (a) silt size = 370 μm (b) silt size = 300 μm. (c) silt size = 200 μm. (d) silt size = 100 μm.

Figure 3 (a) shows the variation of normalized wear with nozzle angle for various concentrations at fixed value of silt size (370 μm), jet velocity (28.81 m/s) and operating time = 2 h. It can be observed that normalized wear increases with increasing silt concentration for all nozzle angles. For nozzle angle of 20°, normalized wear was found to be about 0.00095 which is having highest value for this nozzle angle for 12000 ppm silt concentration. For nozzle angle of 25° normalized wear was found to be about 0.00076 but for nozzle angle of 30° the value of normalized wear was found to be about 0.00085. So for all values of silt concentration normalized wear is minimum at nozzle angle of 25°.

Figure 4 (a) shows the variation of normalized wear with nozzle angle for various concentrations at fixed value of silt size (370 μm), jet velocity (28.81 m/s) and operating time = 4 h. It can be observed that normalized wear increases with increasing silt concentration for all nozzle angles. For nozzle angle of 20°, normalized wear was found to be about 0.00118 which is the highest value for this nozzle angle and 12000 ppm silt concentration. For nozzle angle of 25° normalized wear was found to be about 0.000956 but for nozzle angle of 30° the value of normalized wear was found to be about 0.00106. So for all values of silt concentration normalized wear is minimum at nozzle angle of 25°.

Development of correlation for normalized wear

An attempt was made to develop a correlation for erosion for Turgo impulse turbine as a function of nozzle angle, silt size, silt concentration, operating time and jet velocity of turbine.

The simplest Equation for erosion can be written as:

$$W = f(C, \alpha, S, t) \qquad (7)$$

It has been found that data of regression deals with the first order. The values of the constant and the exponents for S, C, α and t are 4.28E + 9, 0.194, 0.979, -24.73 and 0.375 respectively.

The final form of correlation for normalized wear is obtained as follows:

$$W = 4.2824\times10^{9}\, S^{0.194} C^{0.979} \alpha^{-24.73} t^{0.375} \qquad (8)$$

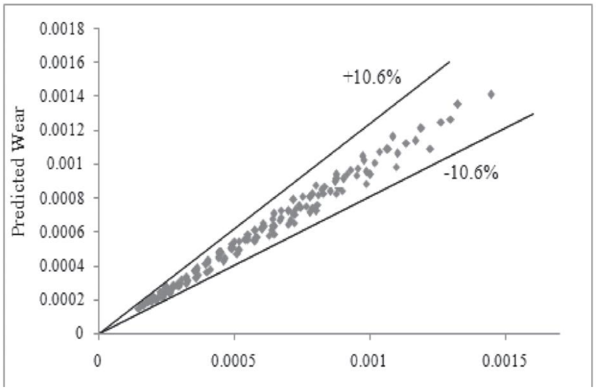


Figure 4. Comparison of actual wear and predicted wear for Turgo Blade

Figure 4. Shows the comparison of experimental data obtained for normalized wear and those obtained from above correlation. The deviation between these two found to be within ±10.6%

Conclusion

Based on experimental investigation it has been observed that silt concentration, silt size, jet velocity, operating hours and nozzle angle of turbine were strong parameters for erosion in Turgo impulse turbine blades. It can be concluded from the figures that as silt concentration and silt size increases normalized wear, but normalized wear is maximum for nozzle angle of 20^{o} and normalized wear has lowest value for 25^{o}. Based on experimental data obtained correlation was developed for normalized wear and percentage efficiency loss a function of silt concentration, silt size and nozzle angle. It has been observed that the developed correlations have found to have good agreement with experimental data.

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