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Research Article

Effect of Nozzle Angle and Silt Parameters on Erosion and Performance of Turgo Impulse Turbine

Sourabh Khurana[a], Varun[b] and Anoop Kumar[b]

[a]School of Engineering and Technology, Shoolini University, Bajhol (Solan) – 173212 (HP)
[b]Department of Mechanical Engineering, National Institute of Technology, Hamirpur – 177005 (HP)

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Abstract

In the present study, an experimental work has been carried out to study the effect of nozzle angle, silt parameters and operating parameters on erosive wear as well as on performance of Turgo impulse turbine in actual flow conditions. Silt particles passing through hydro turbine components cause erosion to the surface come in contact. Silt size, concentration, velocity of flow, properties of materials and operating hours of turbine play a vital role in the damage of hydro turbine components. After investigation it has been found that nozzle angle, silt parameters and operating parameters affects the performance of Turgo turbine as well as increases wear rate.

Keywords: *Nozzle angle, Erosive wear, Efficiency loss, Turgo Turbine, jet velocity.*

1. Introduction

Turgo turbine is a medium head impulse turbine (15 – 300 m) that operates in the head range where Pelton and Francis turbine overlap (Anagnostopoulos and Papantonis, 2007). Turgo turbines can handle higher water flow rates than a Pelton turbine. These turbines are in use for hydropower since 1919(Cobb and Sharp, 2013).Turgo turbines have a flat efficiency curve and provide excellent part load efficiency, so they can be used for large flow rate variations. In Turgo turbines jet strikes the runner plane at an angle of 25° (Koukouvinis, 2011). For efficient operation of hydropower plants these turbines must operate without silt to avoid breakdown of hydro turbines.

Silt erosion is gradual removal of material caused by repeated deformation and cutting actions. It depends upon different parameters such as silt size, concentration, hardness, average velocity of particle, shape of particles, angle of impingement and material properties[6]. This problem is more intensify if silt contains higher percentage of quartz, which is extremely hard (hardness 7 in Moh's scale) (Tong 1981, Singh 1990). The gradual removal of material of turbine and parts due to erosion leads to changes in flow pattern, losses in efficiency in hydro turbines take place (Thapa et al, 2012).Silt erosion is a serious problem in a number of Indian hydropower stations especially located in Himalayan regions (Mann and Arya, 2001).In a study, (Naidu, 2004) reported that about 22 large hydropower stations in India are facing silting problem. These power stations have been classified into three categories based on quantum of damage as; (i) category A – indicates intensive damage and needs renovation every year, (ii) category B – indicates substantially high damage and needs renovation in every 3 years and (iii) category C – indicates considerable damage and needs special efforts and resources after 15–20 years.

The hydraulic turbine components which are affected by silt erosion are blades, buckets, nozzle and needle in case of impulse turbines and faceplates, guide vanes, runner blades in case of Francis turbine.

There are two modes of erosive wear, called the ductile mode of erosive wear (at moderate particle speeds) and the brittle mode of erosive wear. The ductile mode of erosive wear depends on tangential movement of the impingement particle across the eroded surface. This tangential movement is favored by a very small angle of impingement as opposed to normal impact. However, the angle of impingement is zero, there will be no kinetic energy of impact between particle and worn surface to initiate indentation by the particle and chip formation. A maximum in the ductile mode of erosive wear is usually found close to an angle of 30° which represents a compromise between the requirements of tangential particle movement and impact energy. For the brittle mode of erosive wear, the maximum in erosive wear occur around 90° (Neopane, 2010).

Khosrowpanah et al. (1988) experimentally studied the performance of cross flow turbine by varying the number of blades, runner diameter and nozzle entry arc under flow/head variations. The authors have concluded that maximum efficiency of the cross flow turbine at any flow / head combination increases by increasing the nozzle entry arc from 58° to 90° but by reducing aspect ratio (D_1/B) of

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* Corresponding author's Email: sourabhnith09@gmail.com

runner from 2.0 to 1.0 and the efficiency reduces upto 20%.

The aim of the present study is to analyze the effect of nozzle angle and silt parameters on the performance as well as on the erosion of Turgo impulse turbine.

1.1 Literature Review

The fundamental equation of erosion is (Bitter 1963) had proposed two fundamental erosion models for ductile and brittle materials. (Truscott 1972) presented a literature survey on abrasive wear of hydraulic machinery and observed that most often quoted expression for erosion is;

$$Erosion \propto (velocity)^n$$

The simplest and general form of erosion is, Erosion = f (operating conditions, properties of particles, properties of base materials). Generally, this expression is given as a function of velocity, material hardness, particle size, and concentration.

Krause and Grein (1996) stated the abrasion rate on conventional steel Pelton runner made of X5CrNi 13/4 which was expressed by the expression:

$$\delta = PQCV^{3.4} f(D_{50})$$

Thapa (2004) used jet type test rig to conduct erosion tests on different types of turbine steel. Tests are carried out at different impingement angle at velocity of about 55 m/s and concentration about 280 ppm. The author has given the empirical relation for 16Cr5Ni turbine material for erosion rate which is the most widely used turbine material.

$$y = 6E - 5x^{3.13} [mg/kg]$$

Where y is the loss of material of eroding particle striking the surface (mg/kg) and x is the velocity (m/s) of eroding particles impinging at the angle of 45^{o}

Padhy and Saini have developed a correlation for normalized erosive wear rate for Pelton runner by considering Silt concentration 5000-10000 ppm, Silt size = 90- 355 µm, Jet velocity = 26.61-29.75 m/s as:

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

In another study (Padhy and Saini,) have developed a correlation for estimating percentage efficiency loss for Pelton turbine runner as:

$$\eta_{\%} = 2.43 \times 10^{-10} (s)^{0.099} (c)^{0.93} (v)^{3.40} (t)^{0.75}$$

Thapa et al (2012) have developed empirical relation for erosion rate and loss in efficiency by taking silt concentration = 0.5 kg/m^3 , size of silt particles = 0.025 mm, shape of abrasive particle = 1, hardness of abrasive particle= 0.83for Francis turbine as:

$$E_r = C \cdot K_{hardness} \cdot K_{shape} \cdot K_m \cdot K_f \cdot a \cdot (size)^b \quad [mm/year]$$

$$\eta_r = a \cdot (erosion)^b \quad [\%/year]$$

2.Experimental set up and procedure

Experimental set up of Turgo impulse turbine of 1.2 kW capacity is shown in Fig. 1.has been fabricated and used in the present study. Main characteristics of turbine are given in Table 1. Blades of Turgo impulse turbine were made of brass so that to get considerable amount of erosion in a short period of time. The weight of each blade was 202 g. A 5 mm thick transparent acrylic casing has been provided which allows water behaviour to be observed easily over turbines. 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 concentration 3000 ppm, and the other tank was used to measure discharge using rectangular notch. Size of silt was measured with the help of sieves of different sizes 100, 200,300 and 370 µm .A stirrer was attached to operate continuously during experiment so as to supply uniform mixture of silt and water to the turbine. In order to prepare silt water mixture which is having various concentrations, required quantity of silt was added to a known volume of water in the tank. Head and flow to the turbine during the experiments were kept constants. 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 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.

Table 1: Main Characteristics of Turgo Impulse Turbine

S. No.	Parameter	Values
1	Runner Pitch diameter	216 mm
2	Rotation speed	1108 rpm
3	Flow rate	2.96×10^{-3} m^3/s
4	Nozzle Diameter	12.5 mm
5	Blades	19
6	Mechanic Power	1.2 kW
7	Blade Material	Brass

A generator was directly coupled with the turbine runner shaft to generate electricity as output and by considering efficiency of generator output of turbine was determine. 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 0.1 mg. Experimental study has been carried out in two steps, at the start Monoblock was used to draw clean water for different heads from the storage tank and supplied it to the turbine to estimate efficiency of the turbine. In second step, the effect of silt parameters on erosive wear and performance has been investigated. The experiments were conducted for fixed values of jet velocity, operating time and concentration values of 28.81 m/s, 2 hours and 3000 ppm respectively. A total number of 12 sets of readings were recorded for the purpose to evaluate erosion characteristics and efficiency loss. The nozzle angles used for experimental work were 20°, 25° and 30°.

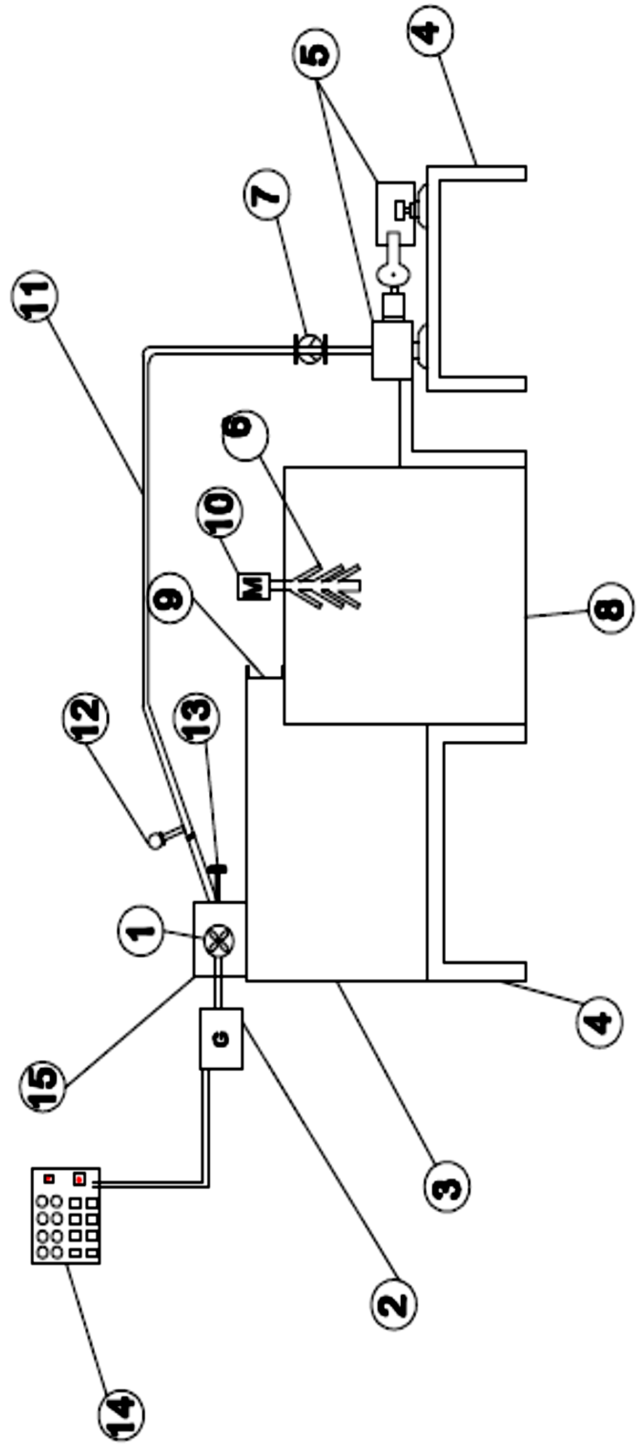
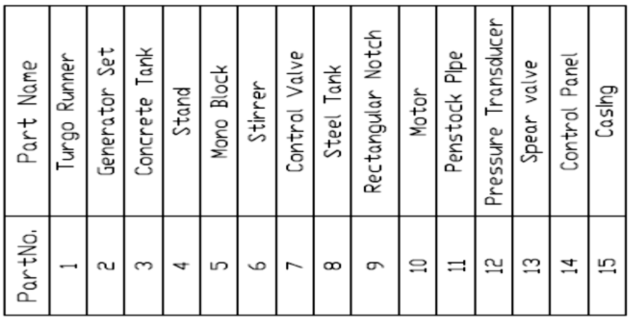


Fig. 1: Schematic of experimental setup



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

3. Range of Parameters

Effect of parameters such as; silt size, silt concentration, operating hour, nozzle angle and jet velocity were investigated under the present study. 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). Range of parameters used for present study is given in Table 2. Silt was dried under sun and then sieve was used to measure the silt size.

Table 2: Range of parameters investigated

S. No.	Parameters	Range
1.	Silt size	100,200,300,370 µm
2.	Silt concentration	3000,6000,9000 ppm
3.	Jet Velocity	28.81m/s
4.	Operating Time	2 h
5.	Nozzle angle	20°, 25°, 30°

4.Turbine efficiency

To calculate the efficiency of Turgo impulse turbine input in terms of head and discharge was calculated. Power output was measured with the help of wattmeter. A control panel was connected to the generator to record the power generation from the generator. Control panel consisted of a voltmeter, a wattmeter having least count of 1W and electric bulbs were used as load. Discharge was calculated with the help of rectangular notch. A pointer gauge was used to measure the height of water over the notch. During experiments input to the turbine was maintained constant by keeping head and flow as constant to the turbine. Turbine input was calculated from eq(n) 1.

$$P_i = \rho g Q H \tag{1}$$

The efficiency of turbine was calculated from eq(n) 2.

$$\eta_t = \frac{P_0}{\rho g Q H \times \eta_g} \times 100 \tag{2}$$

5. Results and Discussions

Effect of nozzle angle on normalized wear (loss of weight/original weight) of blades with operating time has been presented in Fig. 2, 3 and 4 for fixed value of jet velocity, concentration and operating hour. It has been observed from these figures that maximum erosion occurs at 20° nozzle angle. This feature is typical for ductile material (Lin et al. 2001). In this case material is removed by micro cutting as a result of oblique shear force thus increases erosion rate. The amount of erosion is less at 25° nozzle angle due to increase in angle of oblique shear force due to which cutting action gradually converts into impact erosion and for further increase in angle pure impact erosion will take place and erosion rate increases considerably at angle of 30°.

Effect of nozzle angle on percentage efficiency loss of blades with operating time has been presented in Fig. 5,6 and 7 for fixed value of silt size, silt concentration, jet velocity and operating time. From these figures it can be noticed that at nozzle angle of 20°, percentage efficiency loss was found to be maximum about 1.6% for nozzle angle of 20°. Rate of percentage efficiency loss was found to be significant in this case. This shows that rate of percentage efficiency loss is significant for smaller nozzle angle. However, rate of percentage efficiency loss was found to be maximum 1.4 % for nozzle angle 25° and 1.5% for nozzle angle 30°, due to increase in wear rate at this angle.

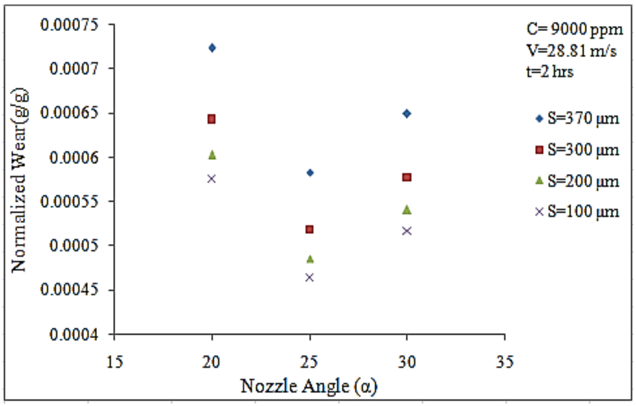


Fig. 2. Effect of nozzle angle on normalized wear for different silt sizes but fixed value of concentration (9000), jet velocity and operating time.

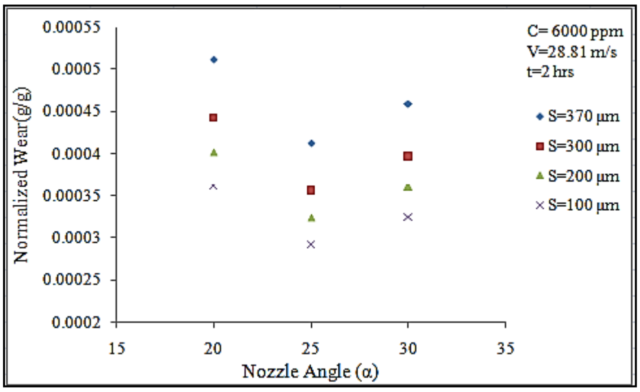


Fig.3. Effect of nozzle angle on normalized wear for different silt sizes but fixed value of concentration (6000), jet velocity and operating time.

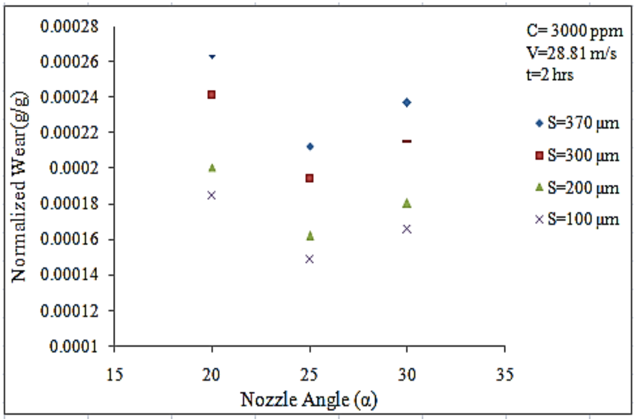


Fig. 4. Effect of nozzle angle on normalized wear for silt concentration (3000) but different silt sizes.

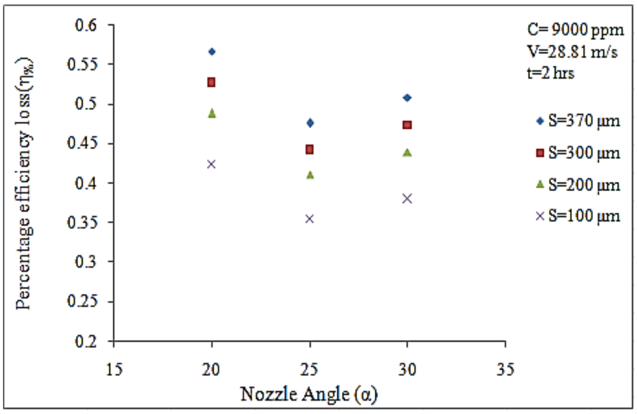


Fig. 5. Effect of nozzle angle on Percentage efficiency loss with fixed value of concentration (9000), jet velocity, operating time but different silt sizes.

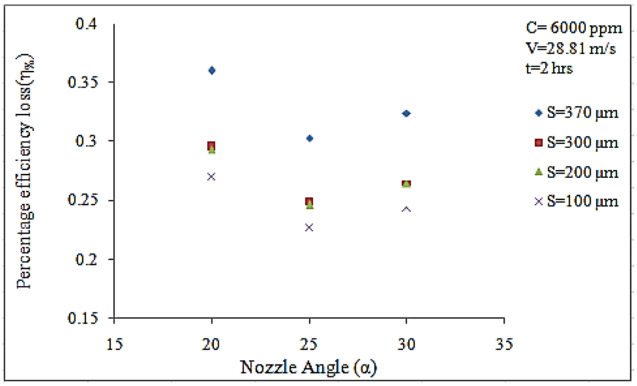


Fig. 6. Effect of nozzle angle on Percentage efficiency loss with fixed value of concentration (6000), jet velocity, operating time but different silt sizes.

Conclusion

On the basis of experimental investigation it has been found that silt size, silt concentration, jet velocity, operating hours, nozzle angle affects erosion as well as performance of Turgo impulse turbine. It can also be concluded from the experiment that maximum erosion occur at an nozzle angle of 20° and at angle of 25° less erosion take place which is typical behaviour for ductile materials. However, rate of percentage efficiency loss was found to be about 1.6% for nozzle angle of 20°.

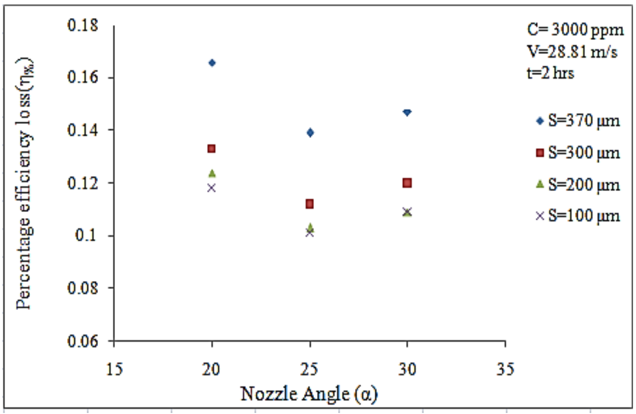


Fig.7. Effect of nozzle angle on Percentage efficiency loss with fixed value of silt concentration(3000), jet velocity, operating time but different silt sizes.

References

Anagnostopoulos J and D Papantonis (2007), Flow modeling and runner design optimization in Turgo water turbines, *World Academy of Science, Engineering and Technology*, 28, pp. 206-211.

Awasthi AK (2001), Desanding for small hydro- An innovative approach. 2nd International conference on silting problems in hydropower plants 26-28 September Bangkok Thailand.

Bitter JGA. (1963). A study of erosion phenomena Part I. *Wear*, 6, pp.5-21.

Bitter JGA. (1963). A Study of erosion phenomena Part II. Wear, 6, pp.169-190.

Cobb, BR. and Sharp, KV (2013). Impulse (Turgo and Pelton) turbine performance characteristics and their impact on pico-hydro installations. *Renewable Energy*, 50, pp. 959-964.

H Neopane, 2010, Sediment erosion of hydro turbines, Ph.D. Thesis *at NTNU.*

Khosrowpanah S, A.A.Fiuzat and M.L.Albertson, 1988, Experimental study of cross flow turbine, *Journal of Hydraulic Engineering*, v. 114, 299-314.

Koukouvinis P, J Anagnostopoulos and D Papantonis, 2011, SPH method used for flow predictions at a Turgo impulse turbine: Comparison with fluent, *World Academy of Science, Engineering and Technology*, v. 79, 659-666.

Krause M. and Grein H. (1996). Abrasion research and prevention. *International Journal of Hydropower and Dams*, 4, pp.17-20.

Lin HC, S.K. Wu and C.H. Yeh, 2001, A comparison of slurry erosion characteristics of TiNi shape memory alloys and SUS304 stainless steel, *Wear*, v.249, 557-65.

Mann BS, Arya Vivek (2001), Abrasive and erosive wear characteristics of plasma nitriding and HVOF coatings:their applications in hydro turbines, *Wear* 249, pp. 354-360.

Naidu BSK. (2004). Silting problem in hydro power plant & their possible solutions India: NPTI.

Padhy MK and Saini RP (2009). Effect of size and concentration of silt particles on erosion of Pelton turbine buckets, *Energy* , 34 pp.1477-83.

Padhy MK and Saini RP (2011). Study of silt erosion on performance of a Pelton turbine. *Energy* 36(1) pp.141-7.

Singh SC, 1990, Operational problems and development of a new runner for silty water, International Water Power and Dam Construction.

Thapa BS, B Thapa and OG Dahlhaug (2012) Empirical modelling of sediment erosion in Francis turbines, *Energy* 41pp. 386-391.

Tong D, 1981, Cavitation and wear on hydraulic machines, International Water Power and Dam Construction.