Proceedings of 8th IOE Graduate Conference
Peer Reviewed
ISSN: 2350-8914 (Online), 2350-8906 (Print)
Year: 2020 Month: June Volume: 8

Sand Erosion in Francis Turbine- A Case Study of Middle Marsyandi Hydropower Station

Prabesh Raj Devkota [a], Laxman Poudel [b], Atmesh Poudyal [c], Nipesh Regmi [d], Dadiram Dahal [e]

[a, b, c, d] *Department of Mechanical Engineering, Pulchowk Campus, IOE, TU, Nepal*
[e] *Department of Mechanical Engineering, Kathmandu University, Nepal*
Corresponding Email: [a] Neaprabesh@gmail.com, [b] Laxman@ioe.edu.np, [c] Atmeshpoudyal@gmail.com, [d] Regmi.nipesh@pcampus.edu.np, [e] Dadi.dahal@ku.edu.np

Abstract

Middle Marsyandi hydropower station (MMHPS) is situated in Siundibar, Lamjung and has an installed capacity of 70 MW. Sand erosion is one of the major problems faced by the station. Due to substantial presence of sand in the Marsyangdi river, the Francis Runner and other turbine components of the station undergo surface erosion specially in the rainy season during the months of June, July and August. The Turbine components are dismantled and replaced with repaired ones once every two years of continuous operation. During this overhauling process it was found that the components were eroded substantially due to which the station has to bear a huge financial burden for rectifying the defects caused by the erosion in addition to the loss of energy generation during the overhauling period. Hence it seems necessary to predict the erosion prone areas in the turbine components as well as to identify the suitable type and techniques of surface coating. In this study the prediction of erosion prone areas at full guide vane opening is done using the ANSYS CFX simulation software. The Erosion analysis is categorized as qualitative and quantitative analysis. The qualitative results from both simulation and site data analysis visit are of similar pattern in which the inlet (leading) and outlet edges of the blade were found to be mostly eroded. The erosion in the leading edge seemed to be due to direct impact of silt laden water emerging from the guide vanes and that of the outlet edge seemed to be due to high outlet velocity and pressure drop as well as the sharp curvature in blade profile. The quantitative measurement was performed in the site and reduction in the blade thickness was measured.

Keywords

Coatings, Erosion, Overhauling, Turbine

1. Introduction

Middle Marsyandi hydropower station is situated in Siudibar, Lamjung with installed capacity of 70 MW and is a peak run-off river type scheme with daily pondage for five hours and annual designed generation of 398 GWh.The power house and headwork's of MMHPS are located at a distance of 27 Km and 34 km from Dumre. The dam site is situated on between Udipur and Chiti. The scope of Francis turbine is broad in small and large hydropower plants. It is due to the geographical structure and head available. Nepalese river contains a bulk amount of sediment especially in rainy season[1]. Due to the presence of sediment particles, there will be wear and tear in turbine and its components. Sediment wear is defined as the loss of material due to contact between sediment particle and solid material. The salient feature of MMHPS are as follows:

Table 1: Salient feature of MMHPS

Type	Run off river with daily pondage of 5 hours peaking
Location	Phalia sanghu(Headworks), siudibar(Powerhouse)
Installed capacity	70 MW
Average annual generation	398 GWh
Max gross head/net head	110/98 m
Catchment area	2729 km^2
Turbine Number and types	Two Francis, vertical shaft
Rated output	35.9MW
Rated speed	333.33 RPM

Sand induced wear is one of the serious issues for run-off-the-river power plants in snow fed rivers of Nepal. Thermodynamic measurements carried out for a turbine in Jhimruk Hydroelectric Center (JHC) showed a substantial decrease in efficiency due to sediment erosion[2].Nepalese rivers consist huge amounts of sediment and machinery at existing hydropower plants has been adversely affected by these huge sediment contents [1].Sand particles are of hard and soft type which depends upon the parent material and the way it ignites and decomposes and greater the quantity of sand greater will be the erosion impact [3]. Looking at the mineralogical distribution, the content of quartz and feldspar are more in Nepalese rivers. The mineralogical distribution done at JHC found that sediment contains 60-65 percentage of quartz and 20-25 percentage of feldspar with Mohr's hardness of 6-7[4].It was observed that quartz is the most dominating content available having high eroding value followed by feldspar, mica and other minerals[3].Looking at the particle size diameter it was found that 90 percentage of the particles entering the turbine are below 0.1mm in diameter and the mean diameter entering the turbines are 0.025 in JHC[4].The suspended sediment concentration during peak monsoon ranges from 2000-6000 ppm and reaches up to 60,000 ppm[2].As a resulting effect, it creates alteration and changes in blade profile,fatigue and damage, increased vibration,inefficient operation,noise and final breakdown of turbine components[5].The gradual removal of base material changes the profile of the turbine blades and other components and also weakens the structure causing loss of hydraulic efficiency,which in turn results in loss of energy production and also leads to plant shut down for repair and maintenance incurring additional costs[6].Haramain,G.A performed the analysis of silt concentration,particle size distribution and measurement of eroded thickness of runner blade from different sites and concluded that the presence of minerals such as quartz and feldspar possesses problems for hydropower plants with cases of Uri HPS and Dulhasti HPS having average erosion rates of 5mm in four years and 4.55 mm per year respectively[7].Kang, M.W performed the Numerical analysis to predict the erosion of Francis turbine with different operating conditions at best efficiency and full load conditions and concluded that most of the erosion pattern occurred near the outlet side of the runner due to high relative velocity for both operating conditions[8].

2. Research methodology

Different steps that are involved in the study of Sand Erosion in Francis Turbine are listed as follows:

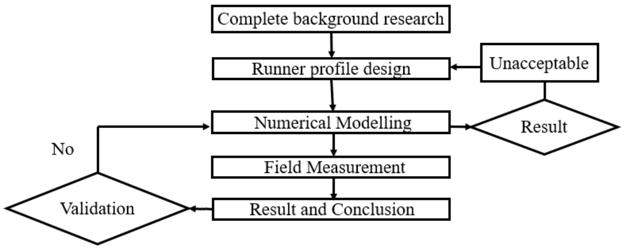

Figure 1: Different steps involved in case study of sand erosion in Francis turbine

3. Calculations

3.1 Sediment data collection

The primary data required for the validation of results was collected from MMHPS. The months June, July and August having the peak sediment concentration were taken into consideration and all data is of the year 2019.

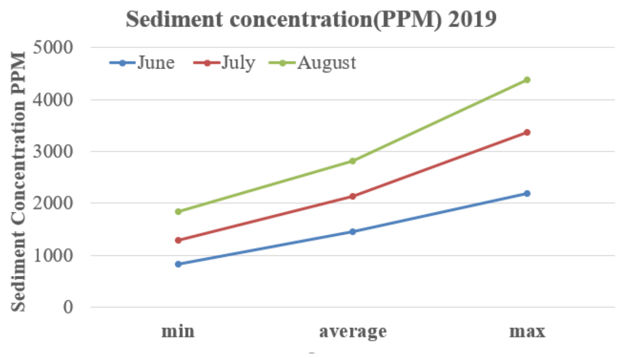

Figure 2: Sediment concentration of year 2019

3.2 Numerical analysis

Following are the different steps involved in numerical modeling section.

3.2.1 Francis turbine ing

The model for this analysis was generated from the actual CAD drawing from MMHPS. The runner drawings were traced in AutoCAD and converted into csv file which was the input file for Bladegen feature of ANSYS. After that the blade angle (i.e. beta angle) distribution (taken from the drawings) and blade thickness (measured at site) were input into Bladegen.

Subsequently the model was transferred to Tubrogrid for mesh generation.

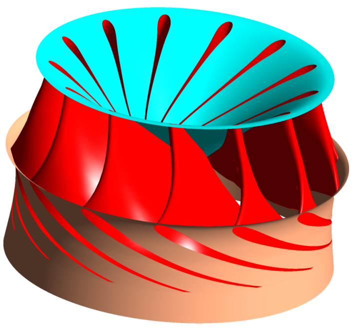

Figure 3: Runner profile of MMHPS designed in Bladegen

3.2.2 Mesh generation

For the generation of mesh ATM optimized featured in ANSYS Turbo Grid was used. An O grid tropology was used to have controlled transition to the inflation layer.

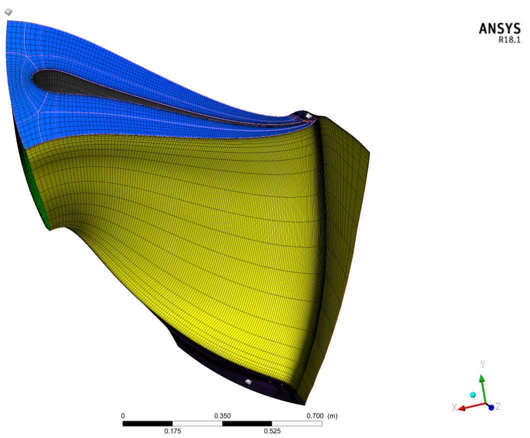

Figure 4: Mesh generation of blade domain in Turbo grid

3.2.3 Mesh independence test

Mesh independence test was carried out for different mesh using the target mesh size of coarse, medium and fine mesh. The y+ method was used using Reynold's number of 1,000,000 for near wall elements. After the mesh independence analysis, 0.61 millions elements were chosen for analysis.

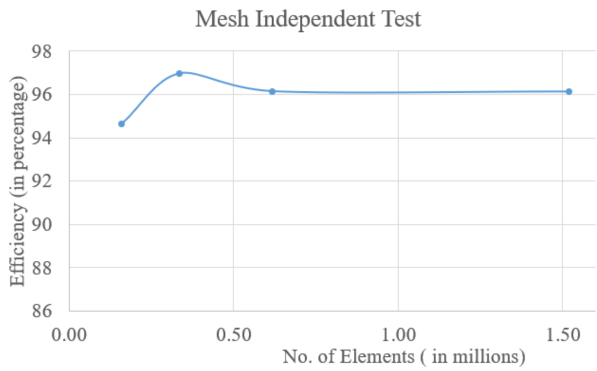

Figure 5: Mesh independence test for blade profile

3.2.4 Erosion model

Tabakoff's model gives the erosion rate as the eroded wall material divided by the mass of the particles.

3.2.5 Parameters investigated

These are the parameters used during the flow analysis in ANSYS CFX.

Table 2: Parameters investigated in simulation analysis

Boundary conditions:
Analysis type: Steady State Analysis
Fluid and particle Definition: Water, Quartz
Reference pressure: 1 atm
Erosion model: Tabakoff erosion model
Eroding material: Quartz
Average diameter of quartz: 0.1 mm
Shape factor: off
Turbulence model: SST model
Drag force: Schiller Naumann
Volume flow rate:40 m^3/sec (full opening),
Flow direction: Cylindrical Components for sand also
Number of Position: 5000
Mass flow rate of quartz: 0.5 kg/s
Convergence Criterion: 0.0001 residual
Wall function: automatic

3.2.6 Simulation analysis

The figure shows the erosion pattern of the MMHPS runner of. It can be observed that the inlet and outlet sides of the blade, specially the leading and trailing edges are highly eroded.

1. Erosion pattern in Runner

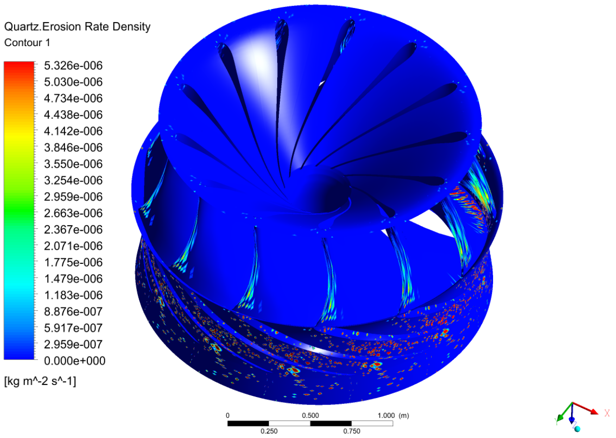

Figure 6: Erosion in runner

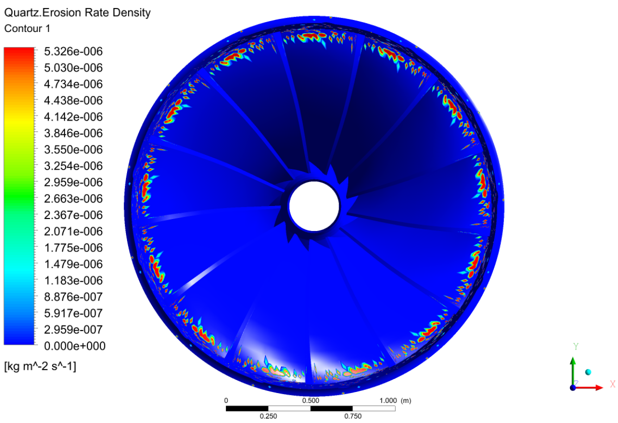

Figure 7: Erosion in runner outlet

2. Erosion pattern in the inlet side (leading edge) of blade

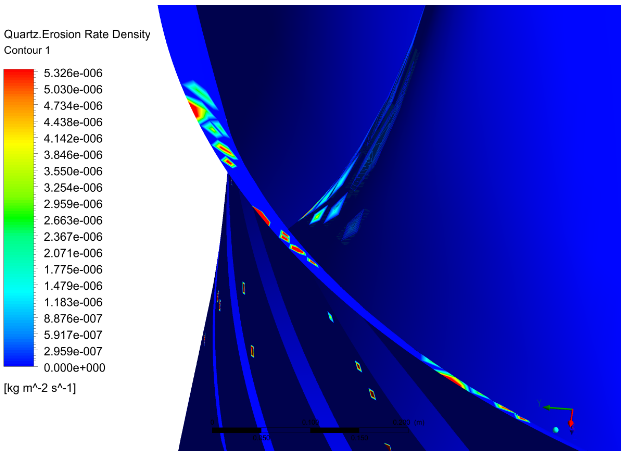

Figure 8: Erosion pattern in inlet side of runner

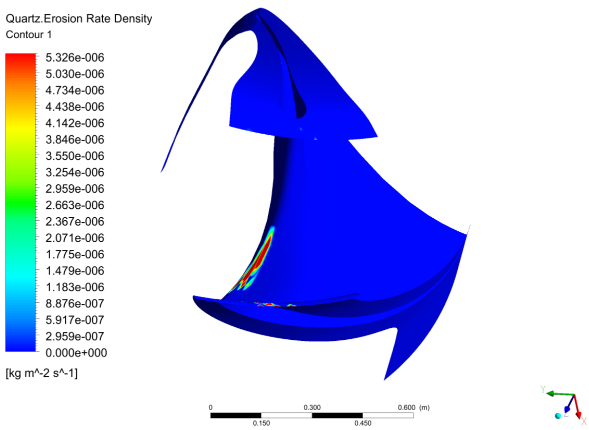

Figure 9: Erosion pattern in inlet side of blade

3. Erosion on the surface and outlet of the blade

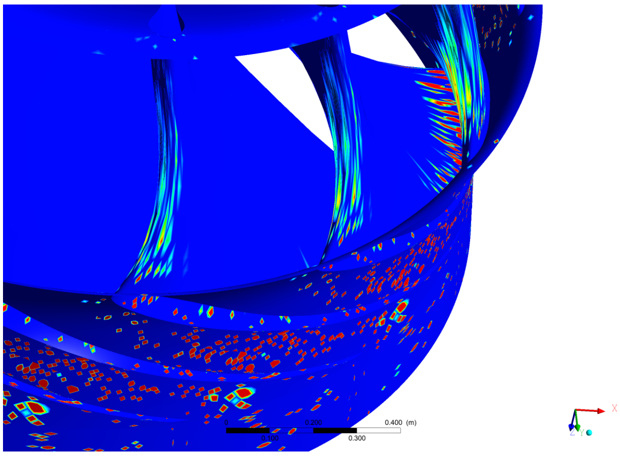

Figure 10: Erosion pattern in blade surface and outlet of runner

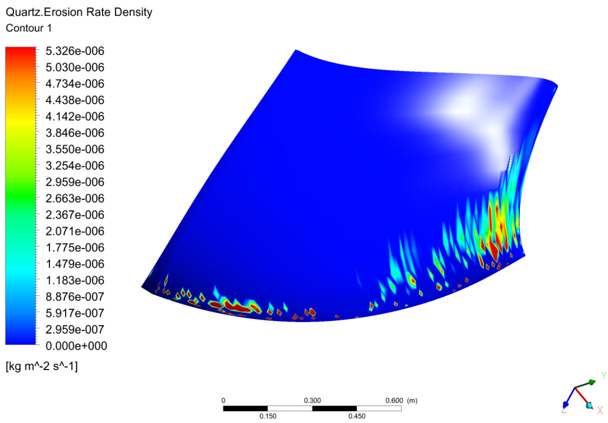

Figure 11: Erosion pattern in outlet side of blade

3.3 Field measurement

The measurement was performed at MMHPS during the turbine unit overhauling of 2018/2019. Different tools and techniques were used for the measurement. Transparent Paper and pencil was used for tracing the eroded area of blades and results seemed more accurate by this method. The depth of eroded gaps at different points was measured using Vernier Caliper with the least count of 0.02 mm and the average depth was calculated. Similar method was used on the outlet side. The loss of blade material and coating were traced on the paper and calculations were done assuming different small rectangular sections to determine the eroded area. The loss of blade thickness was calculated by subtracting the measured thickness from the original thickness. The erosion analysis portion has been divided into two categories: Qualitative and Quantitative.

3.3.1 Qualitative analysis

In qualitative analysis, the erosion prone area was determined by taking photographs of the dismantled runner during overhauling and most amount of erosion was seen on the Inlet (leading edge) and outlet sides of the blade.

1. Erosion on the inlet (leading edge) side

   Due to the direct impact of high velocity water emerging from guide vane openings, there was substantial erosion on the inlet (leading) edge of the blades. A larger amount of material loss was found at the inlet portion as shown in the figure.

Figure 12: erosion on the inlet side of the runner

2. Erosion on the outlet of the blade

   There was a huge amount of coating loss and reduction in blade thickness on the outlets of dismantled runner. It was mainly due to the curved profile of the runner at the outlet. As a result there was a direct impulse action of high velocity water in the blades as well as a huge amount of pressure drop. Consequently, there was the possibility of the problem of Cavitation also. The loss of coating and blade material at the outlet is shown in the following figures.

Figure 13: Tear detection at the outlet portion

Figure 14: Tear detection at the outlet of the blade

3.3.2 Quantitative analysis

The eroded area is multiplied with the depth of erosion to determine the eroded volume. Now multiplying the eroded volume by the density of turbine material (ρ= 7,800 kg/m3) the eroded mass was calculated. A large amount of void gap (material loss) was seen in some of the blades in the inlet. Also, erosions of similar pattern were seen on all thirteen blades. The total eroded mass was calculated from all the blades and the results are shown in the table below.

Table 3: Eroded in the leading edge (inlet part) in all blades

Blade number	Uniform type of erosion (kg)	Local large wear (kg)	Total eroded mass(kg)
1	0.12	0	0.12
2		0.04	0.16
3		0	0.12
4		0	0.12
5		0.02	0.12
6		0	0.12
7		0	0.12
8		0.07	0.19
9		0	0.12
10		0	0.12
11		0	0.12
12		0	0.12
13		0.04	0.16

Total mass eroded in each blade i.e. the sum of erosion at inlet side and outlet side erosion is shown in the table below.

Table 4: Total mass eroded of the blade

Blade number	Eroded mass in leading edge Kg	Eroded mass in outlet of the blade Kg	Total eroded mass in each blade Kg
1	0.12	1.49	1.61
2	0.16	2.87	3.03
3	0.12	2.74	2.861
4	0.12	1.36	1.48
5	0.12	1.76	1.88
6	0.12	1.49	1.61
7	0.12	1.40	1.52
8	0.19	0.57	0.76
9	0.12	0.88	1
10	0.12	2.95	3.07
11	0.12	1.08	1.2
12	0.12	1.51	1.63
13	0.16	1.12	1.28

The average loss of thickness of the blade of MMHPS was found 3.646 mm during two years of continuous operation and the average material loss from each blade was found to be 1.630 kg.

Table 5: Thickness loss in each blade

Blade number	Thickness (mm)	Loss in thickness (mm)
1	6.7	3.3
2	5.5	4.5
3	6.65	3.35
4	6.55	3.45
5	4.4	5.6
6	6.5	3.5
7	5.5	4.5
8	7.9	2.1
9	7.6	2.4
10	6.2	3.8
11	5.1	4.9
12	6.9	3.1
13	7.1	2.9
Average	6.353	3.646

4. Result and discussion

The overall results of this research are divided into two sections which are explained below.

4.1 Qualitative result

The qualitative analysis was done by taking photographs of the dismantled runner along with a flow simulation. Results of both show that the inlet side (leading edge) and outlet side are found to be mostly eroded by sediment. The erosion in inlet side was due to the high velocity impact of water emerging from the guide vanes and outlet side erosion was due to the high velocity of flow, pressure drop and curved profile of the runner blade. Following figures show the results for the erosion pattern at full gate opening by both methods. The validation of the CFD result

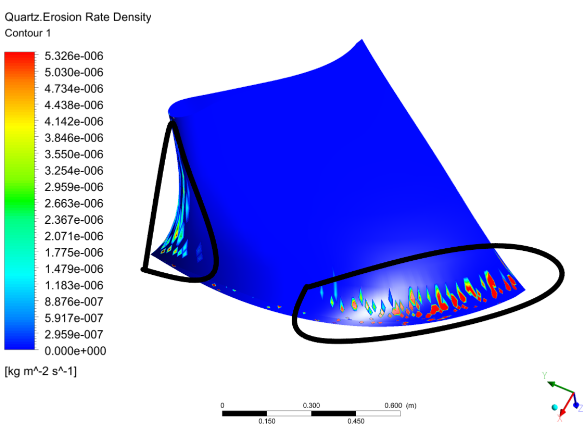

Figure 15: Erosion pattern in the runner blade via simulation

was done by comparing it with the actual findings at site and the qualitative results obtained from the flow simulation was of similar nature as that obtained from the site visit.

Figure 16: Erosion pattern in inlet side of the blade

Figure 17: Erosion pattern in outlet side of the blade

4.2 Quantitative result

The site measurement was also done using different tools and techniques. The Tables 3,4 and 5 show the values of erosion measured in the inlet and outlet sides. The average amount of eroded mass in the inlet side was found to be 0.13kg per blade. The average loss of mass in the outlet side was found to be 1.63 kg per blade. The average loss in blade thickness at the outlet was found to be 3.64 mm per blade for every two years of continuous operation.

5. Conclusion

The simulation analysis was performed and the erosion pattern was obtained and compared with the actual pattern photographed and measured at site. The total amount of eroded mass and the reduction in blade thickness during the period of 2018-2019 were calculated. The runner blades were found to be heavily eroded at the outlet portion as the outlet blade thickness was found to be reduced by 3.646 mm on average during those two years of operation. Few cracks were also seen at the outlet edges. A uniform type of erosion was detected in the inlet side with few cavities in the leading edge and the average material loss at the inlet side was found to be 0.13 kg compared to an average material loss of 1.63 kg at the outlet side. From such a flow simulation the erosion pattern for upcoming years could be predicted in advance using the corresponding sediment data and preventive measures could be taken accordingly. It is recommended that the Runner blades be surface coated using High Velocity Oxy-Acetylene (HVOF) or Soft coating technique specially along the erosion prone zones for longetivity of operation.

References

[1] Bhola Thapa, Raju Shrestha, Projjwal Dhakal, and Biraj Singh Thapa. Problems of nepalese hydropower projects due to suspended sediments. *Aquatic Ecosystem Health & Management*, 8(3):251–257, 2005.

[2] Pratik Man Singh Pradhan. Improving sediment handling in the himalayas. *OSH research, Nepal*, pages 1–6, 2004.

[3] L Paudel. Study on sediment characterization and its impact on hydraulic turbine materials. *Dhulikhel: Kathmandu University*, 2013.

[4] Biraj Singh Thapa, Bhola Thapa, and Ole G Dahlhaug. Empirical modelling of sediment erosion in francis turbines. *Energy*, 41(1):386–391, 2012.

[5] Mamata Kumari Padhy and RP Saini. A review on silt erosion in hydro turbines. *Renewable and Sustainable Energy Reviews*, 12(7):1974–1987, 2008.

[6] Adnan Aslam Noon and Man-Hoe Kim. Erosion wear on francis turbine components due to sediment flow. *Wear*, 378:126–135, 2017.

[7] JH Masoodi and GA Harmain. Sediment erosion of francis turbine runners in the himalayan region of india. *The International Journal on Hydropower & Dams*, (1):82–89, 2017.

[8] Min-Woo Kang, Nohyun Park, and Sang-Ho Suh. Numerical study on sediment erosion of francis turbine with different operating conditions and sediment inflow rates. *Procedia Eng*, 157(1):457–464, 2016.

[9] Saroj Gautam, Hari Prasad Neopane, Nirmal Acharya, Sailesh Chitrakar, Biraj Singh Thapa, and Baoshan Zhu. Sediment erosion in low specific speed francis turbines: A case study on effects and causes. *Wear*, 442:203152, 2020.

[10] Ravi Koirala, Bhola Thapa, Hari Prasad Neopane, Baoshan Zhu, and Balendra Chhetry. Sediment erosion in guide vanes of francis turbine: A case study of kaligandaki hydropower plant, nepal. *Wear*, 362:53–60, 2016.

[11] MK Padhy and RP Saini. Study of silt erosion mechanism in pelton turbine buckets. *Energy*, 39(1):286–293, 2012.

[12] Junaid H Masoodi and GA Harmain. A methodology for assessment of erosive wear on a francis turbine runner. *Energy*, 118:644–657, 2017.

[13] Biraj Singh Thapa, Ole Gunnar Dahlhaug, and Bhola Thapa. Sediment erosion in hydro turbines and its effect on the flow around guide vanes of francis turbine. *Renewable and Sustainable Energy Reviews*, 49:1100–1113, 2015.

[14] Biraj Singh Thapa, Ole Gunnar Dahlhaug, and Bhola Thapa. D sediment erosion induced leakage flow from guide vane clearance gap in a francis turbine. *Effects of sediment erosion in guide vanes of Francis turbines*, page 119, 2016.

[15] Md Rakibuzzaman, Hyoung-Ho Kim, Kyungwuk Kim, Sang-Ho Suh, and Kyung Yup Kim. Numerical study of sediment erosion analysis in francis turbine. *Sustainability*, 11(5):1423, 2019.

[16] Anton J Schleiss, Mário J Franca, Carmelo Juez, and Giovanni De Cesare. Reservoir sedimentation. *Journal of Hydraulic Research*, 54(6):595–614, 2016.

[17] Hari Prasad Pandit. *Sediment handling in Himalayan rivers using hydrocyclones*. PhD thesis, 2018.

[18] MB Bishwakarma and H Støle. Real-time sediment monitoring in hydropower plants. *Journal of Hydraulic Research*, 46(2):282–288, 2008.

[19] Biraj Singh Thapa, Bhola Thapa, and Ole Gunnar Dahlhaug. Current research in hydraulic turbines for handling sediments. *Energy*, 47(1):62–69, 2012.