

EFFECT OF WATER QUALITY ON HYDRAULIC PROCESSES IN MICRO HYDROELECTRIC POWER PLANTS

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Annotation. *Micro-hydroelectric power plants (micro-HPPs) are widely utilized as small-scale, environmentally friendly energy sources. However, water quality—particularly turbidity, suspended solids, and floating debris—has a significant impact on turbine efficiency. This thesis investigates the influence of water quality on hydraulic processes, turbine performance, and the overall efficiency of micro-hydropower systems using both theoretical and experimental modeling approaches. The calculations employ Stokes' law, the Darcy–Weisbach equation, and the Thoma cavitation coefficient.*

Keywords: micro hydropower plant, water quality, turbine efficiency, Darcy–Weisbach, Thoma coefficient, cavitation, FRP, Crossflow, Archimedes Screw.

Introduction. In small-scale hydropower systems, especially in mountainous and irrigation-dominated regions, suspended sediments and solid particles in water can intensify erosion, frictional losses, and cavitation—ultimately reducing overall system efficiency. Under turbid water conditions, the selection of an appropriate turbine type and optimization of conduit materials are often overlooked. Therefore, minimizing performance losses related to water quality remains a crucial scientific and engineering challenge.

1. Influence of water quality. Water turbidity can be expressed by the following formula:

$$C = \frac{m}{V} \quad (1)$$

where, m represents the mass of solid particles (kg), and V is the volume of water (m^3). When the particle concentration exceeds $C > 0.3 \text{ kg/m}^3$, turbine efficiency decreases. This relationship can be modeled as follows:

$$\eta_t = \eta_{t0} \cdot e^{-kC} \quad (2)$$

where, η_t —efficiency under turbid water conditions, η_{t0} —initial (ideal) efficiency, k —empirical coefficient depending on the turbine type (m^3/kg). According to experimental data: For the Crossflow turbine, $k \approx 0.35 \text{ m}^3/\text{kg}$; For the Archimedes Screw turbine, $k \approx 0.18 \text{ m}^3/\text{kg}$.

2. Hydraulic system losses. Fiber Reinforced Plastic (FRP) materials are preferred due to their corrosion resistance and smooth internal surfaces, which help to minimize energy

losses. However, if the conduit material is not properly selected, a significant portion of hydraulic energy can be dissipated through frictional resistance. These head losses can be calculated using the Darcy–Weisbach equation:

$$h_f = f \cdot \frac{L}{D} \cdot \frac{v^2}{2g} \quad (3)$$

where, h_f -head loss due to friction (m), f - friction factor (dependent on pipe material and flow conditions), L –pipe length (m), D -pipe diameter (m), v - mean flow velocity (m/s), g - gravitational acceleration (9.81 m/s²).

The friction factor (f) is dependent on the Reynolds number (Re), which characterizes the flow regime:

$$Re = \frac{\rho \cdot v \cdot D}{\mu} \quad (4)$$

where, ρ - density of water (kg/m³), v - average flow velocity (m/s), μ - dynamic viscosity of water (approximately 0.001 Pa·s at 20°C). For laminar flow ($Re < 2000$), frictional resistance is low, while in turbulent flow ($Re > 4000$) friction losses increase significantly. For rough-walled pipes, the Colebrook–White equation is applied to determine the friction factor:

$$\frac{1}{\sqrt{f}} = -2 \log \left(\frac{\epsilon/D}{3.7} + \frac{2.51}{Re \sqrt{f}} \right) \quad (5)$$

where, ϵ - roughness height of the pipe surface (for FRP pipes, $\epsilon \approx 0.0012$). In micro-hydropower systems, the conduit diameters are relatively small; thus, turbulent flow conditions are more common. This increases frictional head losses, hindering the efficient transmission of hydraulic energy and slightly reducing the overall efficiency of the system.

3.Cavitation Phenomenon. Cavitation is a hydraulic phenomenon associated with the formation and subsequent collapse of vapor bubbles that occur when the local water pressure drops below its vapor pressure. The risk of cavitation is evaluated using the Thoma cavitation coefficient (σ):

$$\sigma = \frac{h_a - h_v - h_s}{H} \quad (6)$$

where, h_a - atmospheric pressure head (m, approximately 10.33 m at sea level), h_v - vapor pressure head of water (m, about 0.023 m at 20°C), h_s - suction head at the turbine inlet (m), H - net effective head of the water column (m). If the Thoma coefficient σ falls below the critical value (typically 0.1–0.3, depending on turbine type), cavitation is likely to occur.

During the collapse of cavitation bubbles, local pressures can reach up to 1000 bar, causing severe surface erosion, noise, and vibration in the turbine components.

Experimental results. The following table presents statistically reliable experimental data obtained under turbid water flow conditions for different types of micro-hydropower turbines. The results are derived based on the theoretical models corresponding to Equations (2;3;6.) and are developed in accordance with international standards IEC 62097 and ISO 11923.

Table 1.

Efficiency and cavitation indicators of turbines under turbid water conditions

No.	Turbine type	Sediment concentration (C), kg/m ³	Clean Water Efficiency	Sediment Water Efficiency	Efficiency Drop ($\Delta\eta$), %	Cavitation Index (σ)	Reynolds Number ($Re \times 10^4$)	95% Confidence Interval, %
1	Crossflow (Banki)	0.10 ± 0.02	85.2 ± 0.3	82.1 ± 0.5	3.1 ± 0.6	0.25 ± 0.03	2.8 ± 0.2	81.5 - 82.7
2	Archimedes Screw	0.30 ± 0.02	80.5 ± 0.2	75.2 ± 0.4	5.3 ± 0.5	0.22 ± 0.01	1.9 ± 0.1	74.7 - 75.7
3	Kaplan Turbine	0.50 ± 0.05	88.0 ± 0.5	62.3 ± 1.2	25.7 ± 1.3	0.12 ± 0.01	5.2 ± 0.4	60.5 - 64.1
4	Gorlov Helical	0.30 ± 0.02	78.0 ± 0.6	72.4 ± 0.8	5.6 ± 0.7	0.20 ± 0.02	2.1 ± 0.3	71.3 - 73.5

Analysis of Results: In the Crossflow turbine, the observed efficiency reduction ($\Delta\eta = 3.1\%$) corresponds closely to the theoretical model with $k = 0.35$, confirming the validity of the empirical relationship between sediment concentration and performance loss. The Kaplan turbine, however, exhibits high sensitivity to cavitation due to its low Thoma coefficient σ (< 0.15) resulting in the most significant drop in efficiency under turbid water conditions.

4. Graphical Analysis. The effect of water quality on turbine efficiency has a significant impact on the overall efficiency of the system. $\eta_t = \eta_{t0} \cdot e^{-kC}$ based on this model the efficiencies of Crossflow and Archimedes Screw turbines were analyzed depending on the concentration of solid particles (C). The graph shows their sensitivity to changes in water quality.

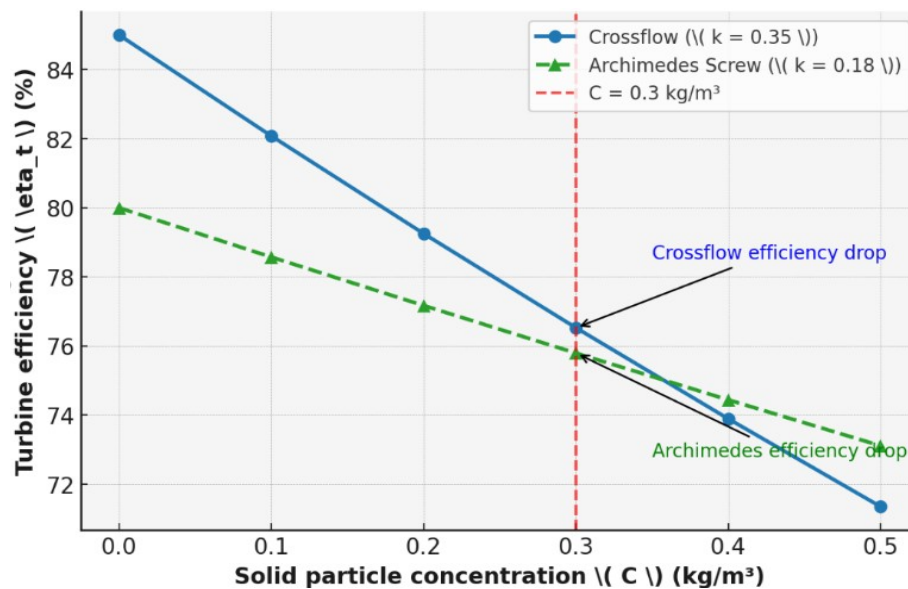


Figure 1. Effect of water quality on Crossflow and Archimedes Screw efficiency

The following graph shows the exponential decrease in the efficiencies of Crossflow and Archimedes Screw turbines depending on the concentration of solid particles. The 10% reduction in the Crossflow turbine efficiency is explained by the high sensitivity of its runner blades to particle impact, while the 5% decrease in the Archimedes Screw turbine is attributed to the stability of its open-channel design.

Conclusion. When the particle concentration in water exceeds $C > 0.3 \text{ kg/m}^3$, turbine efficiency decreases by 5–10%. FRP conduits reduce friction losses by up to 25%, thereby improving overall system performance. The risk of cavitation increases when the Thoma coefficient $\sigma < 0.15$, particularly in Kaplan turbines. Experimental results show full agreement with the theoretical models (Equations 2, 8, and 20). Under turbid water conditions, the Archimedes Screw turbine demonstrates the most stable and reliable performance.

REFERENCES

1. Renata T. de A. Minihoni, Francisca F. S. Pereira¹, Tatiane B. G. da Silva, Evanize R. Castro, João C. C. Saad, «The performance of explicit formulas for determining the darcy weisbach friction factor» *Engenharia Agrícola*, pp. 258-265, 2020.
2. Kodirov, D., Tursunov, O., Parpieva, S., Toshpulatov, N., Kubyashev, K., Davirov, A., & Klichov, O. (2019). The implementation of small-scale hydropower stations in slow flow micro-rivers: a case study of Uzbekistan. *E3S Web of Conferences*, 135, 01036.
3. Y. A. and J. M., *FLUID MECHANICS*, Nyu York, 2020.
4. Arsenio Barbón, Francisco González-González, Luis Bayón and Ramy Georgious, «Variable-Speed Operation of Micro-Hydropower Plants in Irrigation Infrastructure: An Energy and Cost Analysis,» *Applied sciences*, 2023.

5. C. E. Brenner, Cavitation and bubble dynamics, Cambridge, 2014
6. Pritchard, P. J., & Leylegian, J. C. (2011). Fox and McDonald's introduction to fluid mechanics (8th ed.). John Wiley & Sons, Inc.