REPORT

CEN – 300 PRACTICAL PROBLEM

STUDY ON AERATION IN MONTANA FLUME

SUPERVISOR

Prof. K.S. Hari Prasad

MEMBERS

Bokka Sudha Sri (21113040)

Garima Mandli (21113048)

Gautam Kumar (21113052)

Goli Gayathri (21113053)

Pravas Mishra (21113111)

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- E_{20} = Aeration efficiency at 20°c water temperature
- E = Aeration efficiency at actual water temperature
- H_a = Flow depth
- F_r = Froude number
- R_e = Reynolds number
- DO = Dissolved oxygen
- q = Discharge per unit width
- W = Throat width
- D = Upstream entrance width
- A = Sidewall length
- B = Length of flume
- E = Depth of flume
- Cs = saturation concentration
- a = specific surface area or the ratio of total bubble surface area to total air-water mixture volume
- Cd = concentration of gas in downstream
- Cu= concentration of gas in upstream
- t = bubble residence time
- E =the aeration efficiency at actual water temperature;
- E20 =the aeration efficiency for 20°C
- f =the exponent given by Gulliver et al.

1.Introduction

Aeration involves bringing air and water into contact so that the water absorbs oxygen. In flumes, circulation between the water and air systems entrains air into the water. The principle of aeration is based on the idea that all systems aspire to balance. Turbulence generated downstream during flow through the flume is what causes aeration. The oxygen content of air and water is determined by measuring the amount of dissolved oxygen, which indicates the water's quality. Both humans and aquatic creatures require DO to exist in water. DO eliminates minerals, dissolved gases, and dissolved organic materials from the water.

1.1 Two-Film Theory (Lewis and Whitman, 1924)

The phenomenon of aeration in flumes is elucidated by postulating the presence of two immobile films, one consisting of gas and the other of liquid, which form an interface. Originating from the seminal work of Lewis and Whitman in 1924, known as the two-film theory, this concept is grounded in scientific principles describing the interaction between gases and liquids. Upon contact, gas-liquid interfaces manifest as distinct layers, delineating between bulk phases and facilitating gas transfer through molecular diffusion. Molecular diffusion, characterized by the random motion of molecules, mediates the movement of gas components from regions of higher concentration to lower concentration. The two-film theory remains the predominant framework for explaining gas transfer mechanisms in water, wherein the thickness of these films, particularly under laminar flow conditions, is contingent upon the degree of turbulence present in both water and air. Enhanced gas transfer efficacy necessitates a thinner film, thereby increasing the velocity of gas transport across the interface. Moreover, in cases where the liquid is supersaturated relative to the gas, gas molecules exhibit reverse movement dynamics.

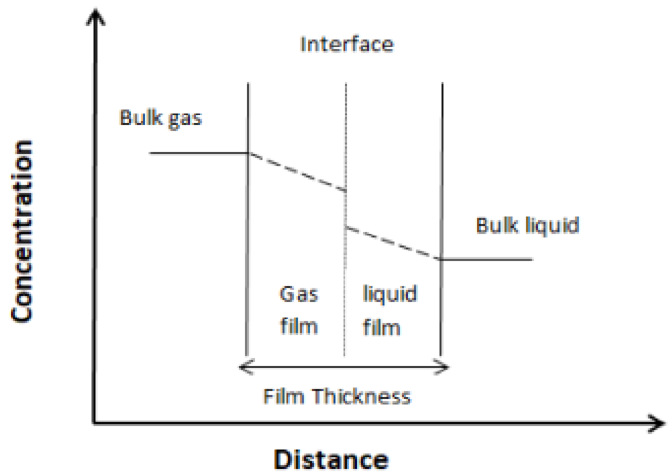


Figure 1 Schematic representation of two film theory

1.2 Factors Influencing Aeration Efficiency

1.2.1 Water Temperature

Water temperature significantly influences aeration efficiency, particularly by modulating the dissolved oxygen (DO) levels. Variations in temperature impact the density and solubility of gases in water. The standard reporting of DO at 20 degrees Celsius serves as a reference point for temperature corrections applied to deviations from this standard, affecting aeration dynamics.

1.2.2 Water Quality

Water quality plays a pivotal role in aeration efficacy, as it can deteriorate due to various contaminants such as dissolved solids, suspended particles, and organic/inorganic matter. These impurities not only hinder the aeration process but also alter the hydrodynamic characteristics of water, potentially leading to a reduction in surface tension and affecting gas transfer dynamics.

1.2.3 DO Deficit

The disparity between saturated DO levels and actual DO concentration in water, termed as the DO deficit, is crucial for understanding gas exchange dynamics at the air-water interface. The system tends to attain equilibrium through the transfer of gases, wherein a DO deficit prompts the movement of oxygen between air and water phases to achieve balance.

1.2.4 Pressure

Pressure plays a significant role in determining the solubility of gases, particularly oxygen, in water. The oxygen solubility is directly proportional to the pressure the surrounding air exerts. Consequently, variations in atmospheric pressure influence the amount of oxygen that can dissolve into water, necessitating adjustments in aeration strategies to maintain optimal oxygen levels.

1.3 Applications of Aeration

1.3.1 Wastewater Treatment Plants

Aeration is integral to wastewater treatment processes, where oxygen infusion facilitates aerobic bacteria breakdown of organic matter. This promotes the growth of bacteria responsible for pollutant degradation, leading to more efficient wastewater purification.

1.3.2 Aquaculture

Aeration is vital in maintaining optimal oxygen levels in aquaculture systems, including fish farms and shrimp ponds. Aeration supports aquatic organisms' healthy growth and development by ensuring adequate oxygenation and promoting sustainable aquaculture practices.

1.3.3 Pond Management

Aeration is employed to manage lakes and ponds and mitigate stagnant water conditions. By circulating and oxygenating the water, aeration helps maintain ecological balance and biodiversity, thus contributing to the overall health of aquatic ecosystems.

1.3.4 Water Reservoirs and Tanks

Aeration is utilized in water reservoirs and storage tanks to maintain uniform oxygen distribution. By reducing stratification and promoting gas exchange, aeration minimizes the risk of water quality degradation and mitigates unpleasant odors, ensuring the integrity of stored water resources.

2. MONTANA FLUME

The Montana flume is a modification of the widely used Parshall flume. The flume takes the shape of a Parshall flume but omits the throat and the discharge sections, leaving only the flat-floored convergent section. A Montana flume is a restricting structure that accelerates flow by contracting parallel side walls. Lacking the throat and discharge sections, flow spills directly out of the end of the flume. The contraction and spilling discharge accelerate the flow from a slow subcritical state to a supercritical one.

Montana flumes are accurate in measuring water flow, inexpensive, and easy to maintain as they can clean themselves of silt and sand. They are made of Aluminium, fiberglass, Galvanized stainless steel, and timber.

Unlike Parshall flumes, the Montana flumes are only for those applications where flow-free falls out of the end of the flume. Both the flumes use the same discharge equations. Montana flumes require less installation space and cost less than full-length Parshall flumes.

Montana flumes have many applications, such as industrial discharge monitoring, dam seepage, watershed monitoring, irrigation canals, sewage treatment plants, edge-of-field runoff, stream gauging, spring discharge measurement, mine discharge, etc.

The view of the typical model is shown in Figure 2.1 and Figure 2.2, and a photographic view of the flow in the flume is shown in Figure 2.3 and Figure 2.4.

Figure 2.1

Figure 2.2

Figure 2.3

Figure 2.4

2.1 Experimental Setup and Methodology

2.1.1 Materials and Instruments

- Perspex Aeration cum storage tank
- Tilting prismatic rectangular channel
- Point gauge
- Montana flume models
- Sodium sulfite= 7.9 mg/m3 to drop DO by 1 ppm, cobaltous chloride=3.3 g/m3 (catalyst).
- DO meter

2.1.2 Experimental Setup

The experiment was conducted using a prismatic rectangular channel of 0.25 m width, 0.30 m height, and 4 m length flume in which Montana flume is fixed, shown in figure 1.3 and figure 2.4. The Montana flumes used in this study are made of timber constructed in an institute workshop. The construction of the modified Montana flume was challenging, as we had to build a model of such dimension that could be fixed in the channel. So, Modified Montana flumes were constructed by keeping the converging angle constant, i.e., 78.560, which was decided after analyzing standard Montana flumes. The dimensions of the Montana flumes and modified Montana flumes are given in Table 3.1. The.1. A re-circulated closed device has been provided to the channel, which continuously feeds the channel through redrawing water from the aeration tank. The motor pump has been attached with a regulating valve to control discharge and was connected to the pipe supplying the head tank. A point gauge measures water depth in the flume at a 2/3rd distance from the throat in the upstream direction. The flow was gradually allowed to become stabilized before measuring the depth of flow to ensure a minimum error.

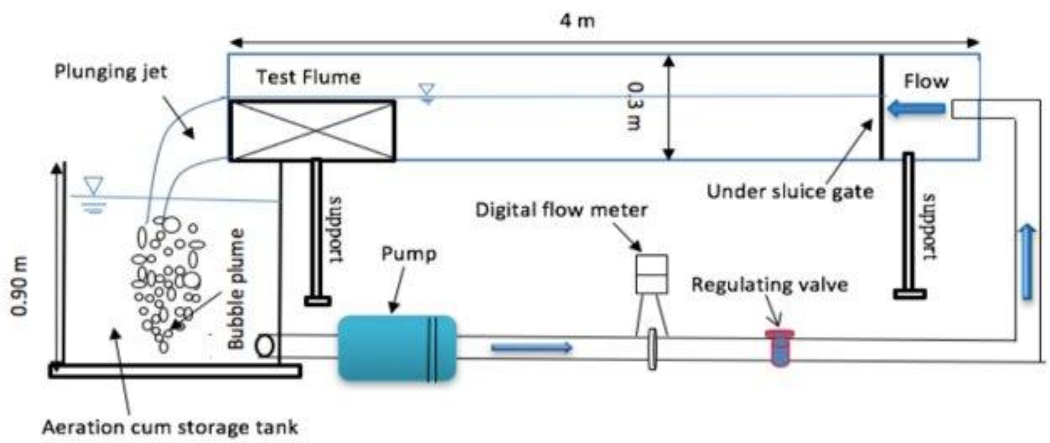


Figure 2.5 Schematic diagram of sideview of the experiment setup

2.2 Methodology

The aeration tank was filled with tap water, and an estimated quantity of sodium sulfite and cobalt chloride as catalysts was added to deoxygenate water and bring the DO content of water to 1-2ppm so that the DO content doesn't reach a saturation level during the aeration process. A water sample measured the water's initial dissolved oxygen content. The channel could run for 90 seconds (about one and a half minutes), and the water samples at the upstream and downstream sections of the flume were collected and measured for dissolved oxygen content using a DO meter. The flow depth is measured using a point gauge at 2/3 length (POM) from the throat in the upstream direction. This procedure was repeated for different flows in all flumes. The aeration efficiency at 20°C is calculated using equations 4, 5, and 6.

2.3 **Experimental Observations**

A total of six Montana flumes were constructed, including two standard Montana flumes and four modified Montana flumes. In the lab, we experimented with one of the Montana Flumes while other data points were taken from the literature.

The two-film theory of mass transfer, initially suggested by Lewis and Whitman in 1924, acknowledged that gas masses transfer from one to another through an interface by turbulence and eddy diffusion. Considering this theory, an oxygen mass transfer equation was developed.

The mass transfer rate of oxygen to the water is proportional to the difference between existing and saturation concentrations.

$$dC/dt = K_L\, A/V\, (Cs - C) \tag{1.}$$

$$dC/dt = K_L\, a\, (Cs - C) \tag{2.}$$

Where Cs = saturation concentration

a = specific surface area or the ratio of total bubble surface area to total air-water mixture volume.

For simplicity, it is assumed that the product $K_L a$ remains constant over a hydraulic structure.

Then, Eq. (2.) is integrated with respect to the residence time of the entrained bubble, which gives a deficit ratio (r).

$$r = (Cs - Cu)/(Cs - Cd) = e^{K_L at} \tag{3.}$$

Where Cd = concentration of gas in downstream

Cu= concentration of gas in upstream

t = bubble residence time

Eq. (3.) can be expressed as aeration efficiency, E

$$E = (Cd - Cu)/(Cs - Cu) = 1 - (1/r) = 1 - e^{-K_L at} \tag{4.}$$

Eq. (4.) is aeration efficiency at actual temperature, and correction is applied to report it at a reference temperature of 20°C. The equation given by Gulliver et al. (1990) is most widely used to account for the effect of temperature on the aeration process.

$$(1-E20) = (1-E)^{1/f} \tag{5.}$$

Where E is the aeration efficiency at actual water temperature;

E20 is the aeration efficiency for 20°C, and

f is the exponent given by Gulliver et al. (1990) described as:

$$f = 1+0.02103(T-20) + 8.261 \times 10^{-5}(T-20)^2 \tag{6.}$$

We calculated E_{20} with the above equation from the data collected in the experiment.

Dissolved oxygen at Upstream (mg/l)	Dissolved oxygen at Downstream (mg/l)	Temperature (°C)	E_{20}	Position of Montana Flume Model
2.62	3.33	26.2	0.129	Center of the channel
2.82	3.42	26.2	0.114	Center of the channel
2.43	3.4	25.76	0.169	End of the channel
2.56	3.38	25.76	0.146	End of the channel

3. Machine-Learning-Models

3.1 Multi-Linear Regression

This model assumes a linear relationship between the independent and target variables (aeration efficiency). It's a simple and interpretable model.

Usage: Fit a linear regression model using airflow rate, water temperature, dissolved oxygen levels, pH, etc.

3.2 Random Forest

Random Forest is an ensemble learning method based on decision trees. It's robust enough to overfit and can capture non-linear relationships.

Usage: Train a Random Forest Regression model using the same features as linear regression. Random Forests can automatically handle feature selection and numerical and categorical data.

3.3 K-nearest Neighbors (KNN)

KNN is a simple and intuitive algorithm that makes predictions based on most k-nearest data points.

Usage: Train a KNN Regression model using features similar to previous models. KNN can be sensitive to the choice of distance metric and the number of neighbors.

3.4 Feedforward Neural Network (FNN)

A basic form of artificial neural network is one where information flows in one direction, from input to output. It's versatile and can capture complex relationships.

Usage: Design and train a feedforward neural network with multiple hidden layers. To prevent overfitting, utilize activation functions like ReLU (Rectified Linear Unit) and consider techniques like dropout regularization.

3.5 Multi Non-Linear Regression

This regression model allows for non-linear relationships between the independent and dependent variables.

Usage: Use methods like polynomial or kernel regression to capture non-linear relationships. This could be especially useful if you suspect the relationship between variables and aeration efficiency isn't strictly linear.

3.6 Layer Recurrent Neural Network (LRNN)

A type of recurrent neural network (RNN) where the information flows from input to output and from one layer to another.

Usage: Design and train a Layer Recurrent Neural Network. This type of network can capture temporal dependencies in the data, which might be relevant if time-series data or sequences of events influence aeration efficiency.

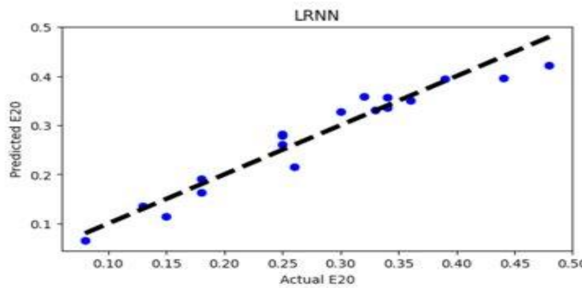
3.7 Recurrent Neural Network (RNN)

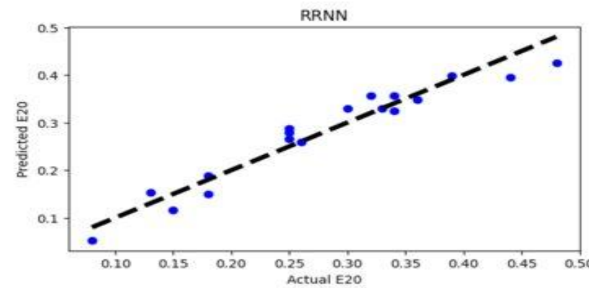
RNNs are designed to work with sequence data, allowing them to capture temporal dependencies.

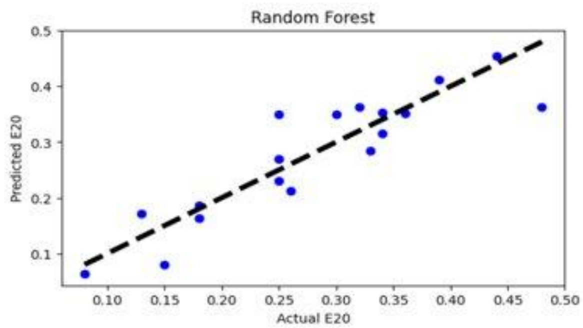
Usage: Train an RNN to predict aeration efficiency, mainly if your data includes time-series information or sequences of events. LSTM (Long Short-Term Memory) or GRU (Gated Recurrent Unit) architectures can be particularly effective here.

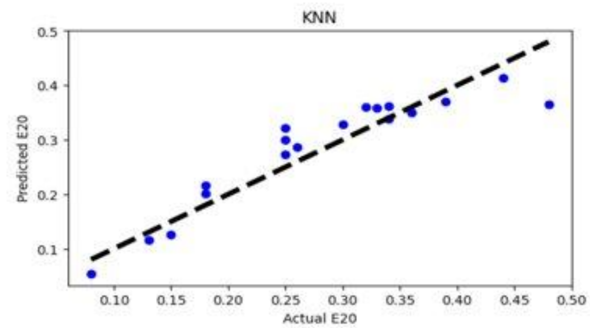
Each of these models has its strengths and weaknesses, and their effectiveness can vary depending on the characteristics of your data. It's often a good idea to experiment with multiple models and evaluate their performance to determine the best approach. Determination of which model works best for the dataset and prediction task by experimenting with these models and assessing their performance is done using metrics like Mean Absolute Error (MAE), Mean Squared Error (MSE), or R-squared. It's often a good idea to try different models and ensemble methods to leverage the strengths of each and improve overall performance.

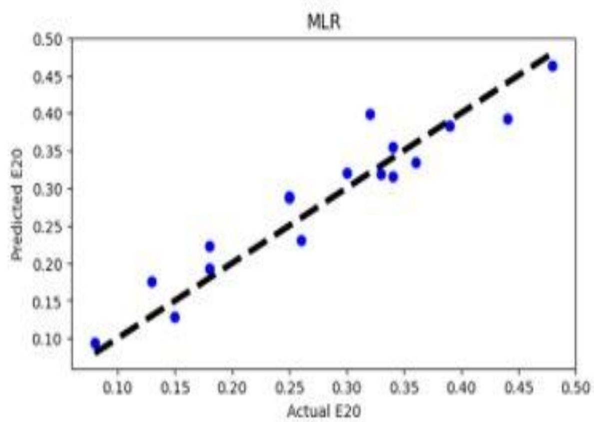
4 . Non-Dimensional data predictions:

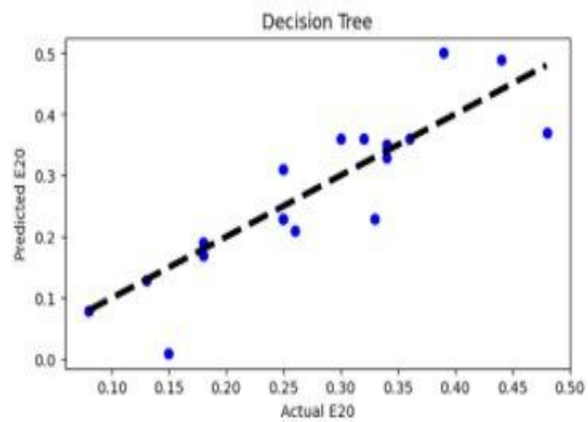


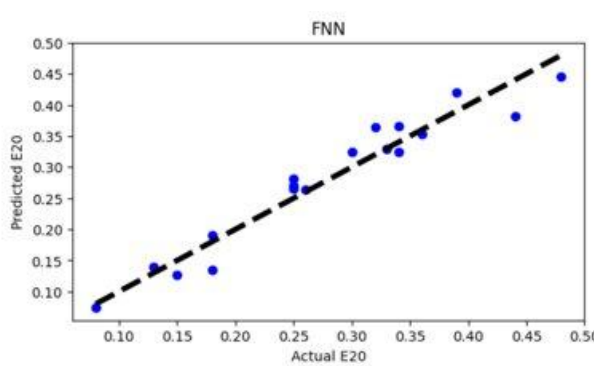


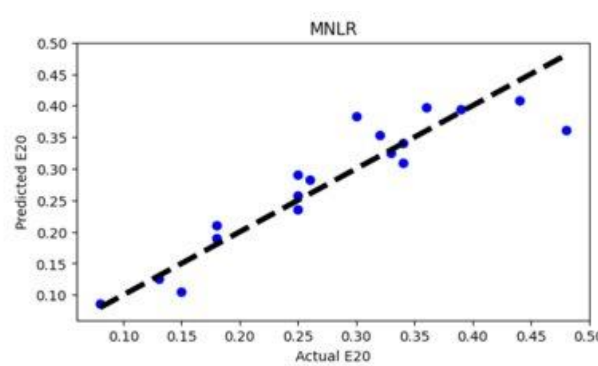








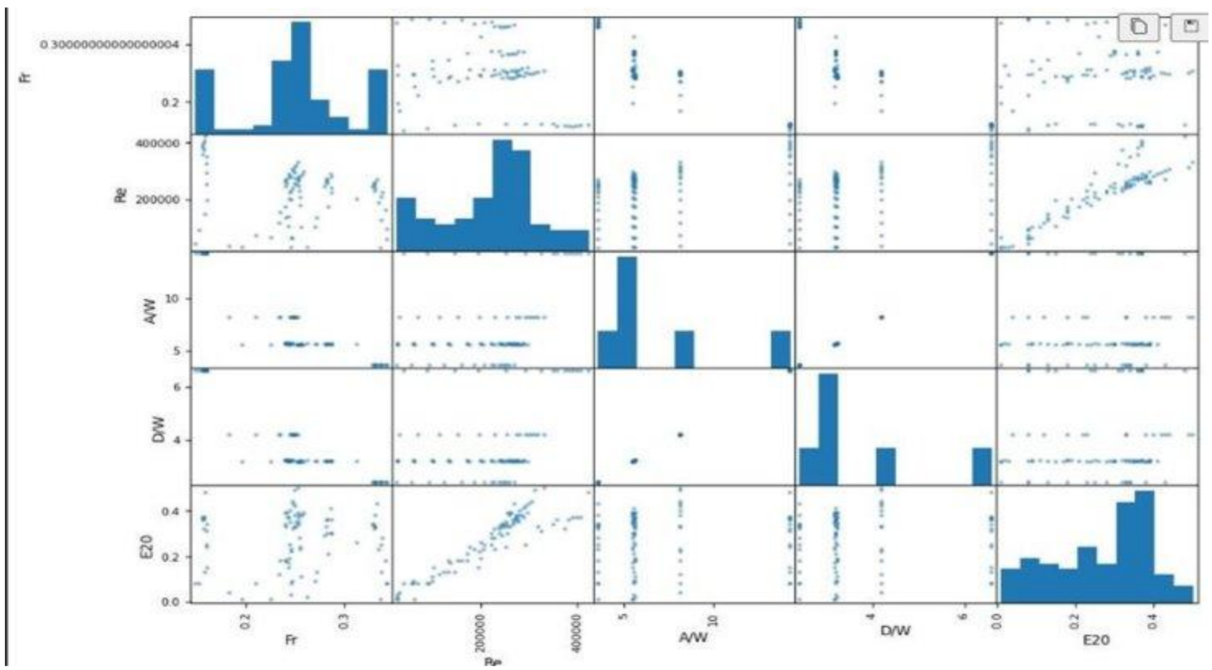




5. Correlation for non-dimensional data:

Aeration Efficiency (E_{20})	1.000000
Reynold number (R_e)	0.912209
The ratio of the depth of the flow to throat width(D/W)	0.090177
The ratio of sidewall length to throat width(A/W)	0.090529
The ratio of the depth of the flow to throat width(D/W)	0.090177
Froude number (F_r)	0.014326

5.1 Correlation Graph:



6. Result

LRNN (layer recurrent neural network) gave the most accurate results, showing the highest R2 Score and lowest RMSE. R is the Determination coefficient, and RMSE is the root mean square error.

The Determination coefficient is the statistical measure of the strength of the relationship between two dependent variables. Close to 1 for a direct solid relationship, close to -1 for a strong inverse relationship, and close to 0 for no relationship. In the context of model output, it can be used to evaluate how well the predicted values from the model align with actual values.

Root mean square error measures the difference between actual and predicted values from the model. It can be calculated manually by taking the square root of the mean of the squared difference between the actual and the predicted values.

7. CONCLUSION

- For the same discharge, temperature, pressure, and geometry of the Montana flume, aeration efficiency is higher when placing the flume at the channel's end than at the channel's center because of the vertical fall present at the end.
- The aeration efficiency of a flume having a considerable throat length is higher than that of a smaller one, and it is because of an increase in contact time for more air-water interaction that ultimately enhances the overall efficiency.
- As per sensitivity analysis, Reynolds's number is the most dependent or sensitive variable in predicting the aeration efficiency of the Montana flume as it shows a high correlation, whereas Froud's number is the least. One of the possible reasons for this is that Froud's number primarily affects the flow characteristics related to gravity effects rather than turbulence level. In contrast, Reynolds number directly affects the turbulence of flow.

8. References

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