SOFTWARE MODELLING OF EXPERIMENTALLY MEASURED PARSHALL FLUMES FOR EVALUATING AERATION PERFORMANCE

Abstract

The Parshall flume was designed primarily to monitor the discharge rate in various irrigation channels, dam discharge, municipal sewer flow rate, industrial wastewater discharge, and many other applications, such as indirect measurement of landfill leachate, whereas its secondary use is to aid in increasing the amount of oxygen in a channel. Aeration is the process through which oxygen is exchanged between water and air. A Parshall flume was designed with a converging part, a diverging outflow, and a flat floor, known as a throat with upward slope sections and a downward sloping floor. The main merits of a Parshall flume are its self-cleaning capability, relatively low head loss compared to other open channel hydraulic structures, high self-cleaning capability, and the ability to sustain comparatively high degrees of submergence without impacting the rate of flow. The famous, simple, and original equation of the Parshall flume contains the biggest shortcoming of not considering spatial and temporal variation which leads to insufficient findings and poor maintenance. The modification of the Parshall flume equation depending on climatic and design parameters is important and may be done successfully and efficiently utilizing software modelling. Many researchers have employed various software modelling techniques to improve the computation speed, accuracy, and precision of measurements in the Parshall flume. The main focus of this study is to determine various software modelling techniques used for the measurement of aeration in the Parshall fume and improvement in the Parshall flume equation

Keywords: Parshall Flumes, Aeration.

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I. INTRODUCTION

A rational and cost-effective water measurement system gives us improved opportunities for precise accounting of various water utilities. It enables us to optimize the supply of water from multiple water resources. The main hydraulic device for calculating the flow rate in open channels and non-full pipes is a Parshall flume [1]. In comparison to other hydraulic structures, its design and installation in a channel is simple. Due to its numerous applications in sewage treatment facilities, wastewater treatment plants, cleaning industries, mine discharge, irrigation canals, and dam outlets, it is a flexible device. Flumes have merits over weirs for a number of reasons, including their relative ease of maintenance, low head loss, and emerging self-cleaning property.

The Parshall flume has three sections: a narrowing beginning part, a middle section with an upward-sloping throat, and a widening diverging ending section (Figure 1). The Parshall Flume's covering wings accelerate the flow, which is followed by a drop in the floor at the throat and a deceleration in the wings that are diverging.

Figure 1: Photographic View of Small Parshall Flume

The general geometrical dimensions of the Parshall flume as shown in (Figure 2).

- W- Throat width of Parshall flume
- K- Sill Height of Parshall Flume.
- F- Length of throat section.
- C- Width at the entrance of the converging section.
- D-Width at the end of the diverging section.
- E-Length of converging wing.
- F-Length of diverging wing.

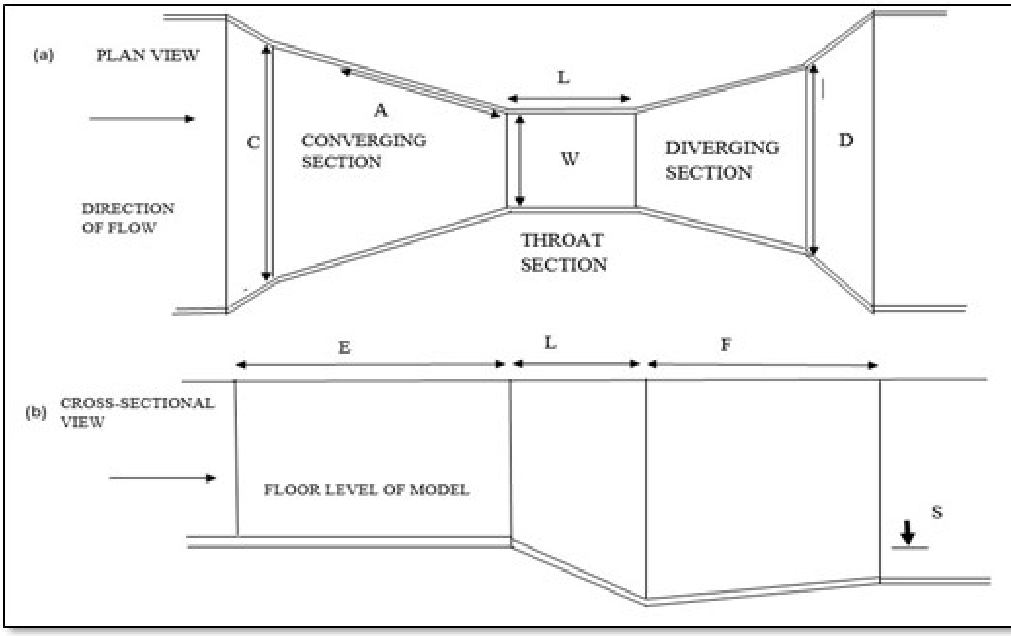

Figure 2: General Layout of Parshall Flume (A) Plan View, (B) Cross-Section View

The Parshall flume is beneficial as an oxygen ejecting device (aeration device) in a variety of irrigation, wastewater, and ecosystem applications as it increases the dissolved oxygen level of surface waters which is an important indicator of human water quality as well as aquatic plant and animal environmental life sustainability [2]. As in the case of dams, the reservoir takes up more space and is larger, but the oxygen concentration there is low because there isn't much turbulence results in endangering aquatic life [3]. According to the established norm, the needed oxygen content for populations of warm- and cold-water fish should both not be less than 4.0 mg/similar to these instances, the Parshall flumes play a vital role in flow measurement and increase aeration.

1. **Mechanism of Aeration:** Aeration is a physical process that transfers oxygen or absorbs oxygen from the environment in order to replace the depleted oxygen. It occurs in the Parshall flume with the help of a hydraulic jump. In the Parshall flume, flow accelerates in the converging wing and experiences a sudden drop in the throat section, and then flow deaccelerates in diverging section. A hydraulic jump happens in the downstream section. The change from subcritical to critical flow occurs in the throat section of Parshall Flume and the transition from supercritical to subcritical flow occurs at the downstream side of the flume. A hydraulic jump that takes place in a small Parshall flume is shown in (Figure 3)

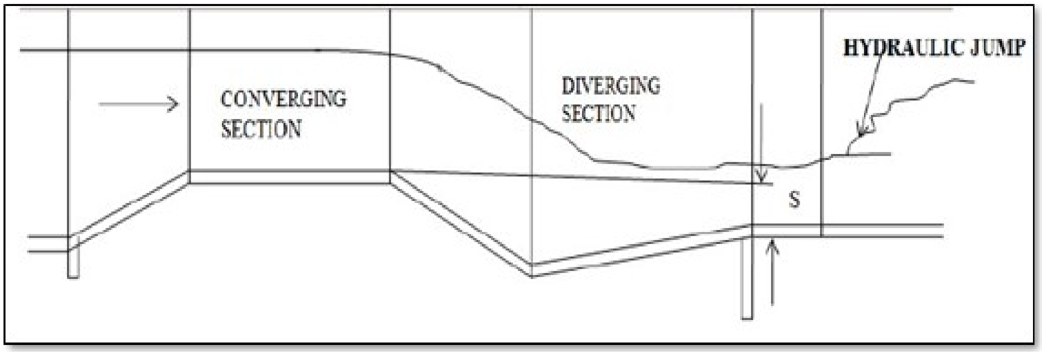

Figure 3: Parshall Flume with Hydraulic Jump

2. **History of Parshall Flume:** Earlier weir was one of the devices used to measure irrigation water. If properly maintained, a weir can measure the flow accurately. However, using it to quantify water flow presented challenges due to large head losses and debris clogging weirs [4]. To solve these issues, another device called the rating flume (venturi flume) was developed [4]. A venturi flume is a straightforward hydraulic structure that typically consists of a converging segment, a throat, and a diverging section [5]. The famous researcher V. M. Cone suggested that altering the venturi flume's specification might be crucial and necessary for improving measurement accuracy to Parshall. Then over a number of decades of his life, Parshall conducted considerable and serious research. The current flume was created by Parshall and then its application was broadened in the agriculture field (Figure 4). He created a Parshall flume as shown in with an upstream converging part, a downstream diverging exit section, a flat throat with a defined width, a floor with a downward slope, and a section with an upward slope in between [6,7]. Dr. Parshall submitted a patent application for his novel "Parshall Flume" six years after his work on the topic of the development of a "modified venturi flume" began. After the development of modified venturi flumes, these were installed in various irrigation systems all across America [8]. The "Venturi Flume" was redesignated as the "Parshall measuring Flume" by the ASCE Irrigation Hydraulics Committee in 1929.

Figure 4: Parshall Flume in Water Drainage Work
(Source: https://tracomfrp.com/parshall-flumes-work)

II. AERATION EFFICIENCY EQUATION

Numerous researchers have worked on calculating the aeration efficiency of hydraulic structures such as weirs [9,10], baffled chutes [11,12,13], and stepped channels [14,15,16]. They calculated the change in the rate of dissolved oxygen (O2) with respect to time (t) by using the below equation (1);

$$\frac{\mathrm{dC}}{\mathrm{dt}} = K1\left(\frac{A}{V}(\mathrm{CS} - \mathrm{CU})\right) \tag{1}$$

Where, CU is dissolved oxygen ($O2$) concentration, Kl is the liquid film coefficient for oxygen transfer; A represents surface area (A) associated with the volume (V); on which aeration processes occur, Cs = constant saturation concentration with respect to water temperature; and t represents time taken (s)

Let us assume that, the saturation coefficient (CS) is constant with respect to time, and the oxygen transfer efficiency (aeration efficiency), E calculated as given below [17] equation (2);

$$E = \frac{\mathrm{Cd} - \mathrm{Cu}}{\mathrm{CS} - \mathrm{Cu}} = 1 - \frac{1}{\mathrm{R}} \tag{2}$$

Where,u and d subscripts indicate upstream and downstream of measu,rement locations and R indicate oxygen deficit ratio, $\left(\frac{\mathrm{CS} - CU}{\mathrm{CS} - \mathrm{C}d}\right)$

When the aeration efficiency valve should be set to 1, entire oxygen transfer (full aeration) occurs, however there is no oxygen transfer when E =0. By using a standard chart or experimental equations provided by prior researchers, the value of Cs can be determined. The value of Cs depends on both air temperature and water salinity.

Factors Affecting Aeration Efficiency (Oxygen Transfer Efficiency): Aeration efficiency in a hydraulic system is highly dependent on flow rate, oxygen deficiency, tail water depth, and water quality and temperature.

1. **Temperature of Water (T):** The temperature of the water has the biggest impact on aeration efficiency. It was held constant while the experiment was being conducted. The temperature correction factor is important for calculation accurate aeration efficiency [18]. Gulliver et al. (1990) developed the following relationship using various theories [19,20];

$$1\text{-}E_{20} = (1\text{-}E)^{1/f} \tag{3}$$

Where, E is the oxygen transfer efficiency of tape water at room temperature, E20 is the oxygen transfer efficiency for 20oC,f is the aeration exponent which is calculated by below formula,

$$f=1+2.1*10^{-2}(T-20)+8.25*10^{-5}(T-20)^2$$

2. **Flow Rate:** The Modified Small Parshall Flume's aeration efficiency rises as the flow rate rises, whereas the weir aeration efficiency falls. Aeration efficiency has a direct relationship with discharge.

3. **Tail Water Depth:** In the case of weir aeration, aeration efficiency typically increases with an increase in tail water depth. The tail water depth for a weir should be 0.6 times the drop height for best aeration efficiency [21]. In the case of the Modified Small Parshall Flume, the tail water depth has an inverse relationship with the aeration efficiency.

4. **Water Quality:** The presence of organic substance, suspended solids & dissolved impurities result in deterioration of quality of water. It alters the rate of aeration & affect the hydrodynamic characteristics of the flow.

III. FUNDAMENTAL APPROACH EMPLOYED IN THE ASSESSMENT OF THE AERATION PERFORMANCE OF PARSHALL FLUME

The experimental tests were carried out in a hydraulic laboratory or field condition with a lot of care. In laboratory conditions, the experiments are performed in straight rectangular rigid steel tilting flume with a centrifugal pump which can provide measurable discharge with respect to time. The water enters the flume through the head box. The upstream section of the flume is provided with a metallic screen which helps in damping the turbulence if any occur in the flow of water. To control discharge, a regulating valve was provided near the motor pump. The motor pump was attached to the pipe feeding the head tank. A rectangular flume was provided with the closed recirculating device. At delivery pipe of the centrifugal pump should be calibrated using an orifice meter in the flume. The water head in the flume was measured by a digital pointer gauge with approximately 0.01mm accuracy. The modified Parshall flume was installed in the middle of the flume and it was ensured that there would not be any leakage of water. The flow was slowly allowed to be stable before taking a reading in order to reduce the errors.

Dissolved Oxygen (DO) concentration was measured twice for every single experiment, before and after the run of flow through the Parshall flume for both laboratory or field conditions. Initially, the concentration of dissolved oxygen was reduced below 2ppm in the storage tank with the addition of an adequate quantity of anhydrous sodium sulphate & cobalt chloride salts. After this initial dissolved oxygen concentration was calibrated. This step was repeated again if the concentration of dissolved oxygen was not reduced below 2ppm.After this centrifugal pump of capacity 6l/s was started at fixed discharge (m3/s) & fixed time (s). Then other sample was collected for calibration of dissolved oxygen. The calibration of oxygen quantity can be done using laboratory method (Modified winkler method) or BOD equipment.

After performing experiments and taking calculating aeration (E20) then different software modelling techniques are implied for understanding the behaviour difference with respect to climatic and dimensional parameters. The whole procedure shown below (Figure 5).

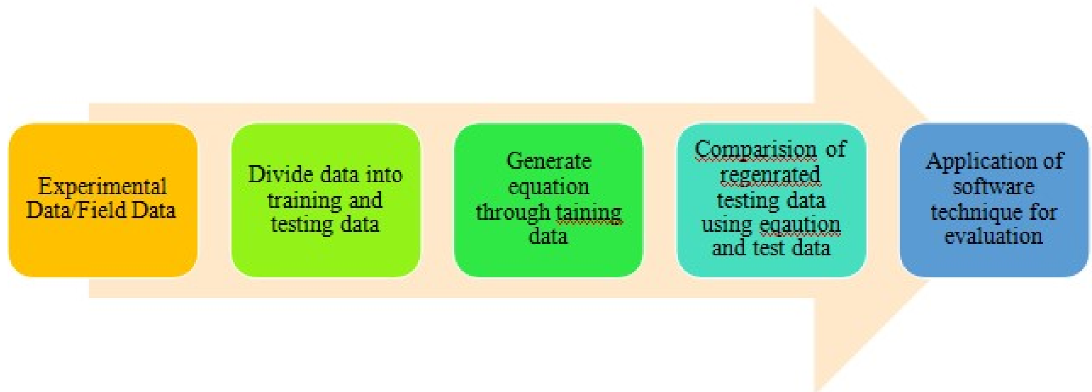

Figure 5: Methodology used in Software Modeling

IV. AERATION EFFICIENCY OF PARSHALL FLUME USING SOFTWARE MODELLING

The software modelling is a method of data analysis that gives computers the capacity to learn things the same way people and other animals learn things naturally. This involves the use of computational methods by machine learning algorithms to extract insights directly from data, without the need for a pre-established equation to act as a model. The algorithm modifies itself to improve its efficacy as the number of examples available for learning increases. On the other hand, deep learning is a unique form of machine learning. An overview of the numerous software modelling techniques used to evaluate the Parshall flume's performance using machine-based methodologies.

1. **Gaussian Processes (GP):** The GP is a technique used in many branches of science and engineering to optimize an unknown function. Non-parametric probabilistic models, like GP, are suggested to enhance modelling performance while tackling related issues [22]. The GP approach was first introduced in curve fitting [23]. Many learning algorithms have been devised in GP [24,25], and GP has been employed in a variety of applications [26]. The evaluations of output variance were calculated in GP models. The GP model can be described as a Gaussian process (GP) with Radial basis function (RBF) Kernel and GP with Person VII Universal Kernel (PUK) from the perspective of a neural network. These results are displayed as a mean and a covariance function. Some researchers used GP with RBF, Linear progression (LP) and GP with PUK for evaluating aeration efficiency of Parshall flume [27] and other hydraulic structures [28,29,30] and found better results with GP software modelling.

2. **M5P Tree Model:** Numerous experimental studies have highlighted the importance of the M5P model in the management of water resources. The GP and regression approaches have both shown themselves to be superior to the neural network approach in this situation. On their dataset, they used the M5P model tree-based regression technique to get good results [31]. This technique entails creating a linear regression model for each of the compact subspaces created by partitioning the parameter space into subspaces. The Model Tree, which keeps fixed values at its terminal nodes and makes it comparable to a linear function, extends and generalizes the idea of regression trees.

The main and most obvious benefit of using model trees over regression trees is the better compactness of the model trees as compared to the generated regression trees. Model trees' regression function uses fewer variables and allows for more precise decision- making. The M5 algorithm is used for the ongoing study. The M5P seeks to create a model that establishes a relationship between the input variables and the fixed target value of the training dataset. Based on how well these models predict values for hypothetical instances, their predictive ability can be evaluated.

3. **Artificial Neural Network (ANN):** The idea of ANN is inspired from the biological nervous system; however, it leaves out some of the finer biological details. ANNs are large-scale systems that mimic the organization of the human brain by utilizing several parallel processing units linked together. The multilayer backpropagation network (MLP), among the different ANN paradigms, is the most appropriate architecture.

Multiple parallel processing units known as neurons make up ANN networks. The connectivity strengths (S) or weights (W) of each layer within the ANN connect it to the layer below it. Throughout the training, initial weight estimates are continuously modified. In this procedure, all errors are propagated backward by comparing the anticipated output to the actual data. To increase training speed and get around problems like local minima, adaptive learning rates are used. Trial-and-error techniques are used to determine the number of neurons in buried layers. Recently, most researchers have paid attention to the use of the ANN technique. Numerous research studies have been done on the evaluation of aeration of the Parshall flume and other hydraulic structures [32,33,34]. There have been numerous efforts made to determine the ideal ANN parameter values. The choice of these ideal values frequently depends on statistical indicators like the correlation coefficient and root mean square error (RMSE).

4. **Adaptive Neuro-Fuzzy Inference System (ANFIS):** A platform that is flexible and extends its capabilities beyond numerical analysis into multi-domain simulations is offered by MATLAB, a program designed primarily for numerical computing. ANFIS, a computational system based on computer software, works by using different training and testing datasets as inputs to produce useful output results. Gradient descent and the least squares approach are two learning approaches that can be effectively combined to create the hybrid learning approach known as ANFIS. The gradient descent, as an addition to the least squares approach, facilitates the progressive change in the underlying nature of the membership function, which is the key component driving quick training.

As a result, ANFIS frequently produces positive results soon after training begins, especially after the first application of the least square approach. The output is created by joining all of the inputs at the interface layer. The literature has developed a variety of categorization approaches, some of which are based on fuzzy logic. The fuzzy logic approach's key strength is its capacity to handle uncertainty in context. Researchers work to create models that are effective at turning what people see as significant categories into concrete results. Three inputs were used for two different ANFIS models in the software modelling technique used by [32,34] to determine the air entrainment rate of a Parshall flume.

V. CONCLUSION

The understanding of complex patterns among numerous function variables is substantially improved by the use of machine learning techniques, a type of software-driven analysis. This method helps in the development of intricate and ideal equations suited to desired results. A deeper understanding of underlying phenomena is being achieved thanks in large part to the steadily increasing application of machine learning. Different approaches produce different associations, so it is important to carefully choose the best one. For instance, the M5P method outperforms ANFIS when used in the context of Parshall flume analysis. Similar to this, it has been discovered that when dealing with hydraulic systems, the Person VII Universal Kernel (PUK) Gaussian Process (GP) provides somewhat improved results when compared to the Gaussian Process (GP) using the Radial Basis Function (RBF) Kernel in the situation of small Parshall Flume. Utilizing software techniques for the analysis of various aspects of the Parshall flume and other hydraulic structures is important for better, precise, and accurate prediction.

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