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Prediction of Air-Water Two-Phase Frictional Pressure Drop Using Artificial Neural Network

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Abstract**—**The present paper discusses the prediction of gas-liquid two-phase frictional pressure drop in a 2.12 mm horizontal circular minichannel using Artificial Neural Network (ANN). The experimental results are obtained with air as gas phase and water as liquid phase. The superficial gas velocity is kept in the range of 0.0236 m/s to 0.4722 m/s while the values of 0.0944 m/s, 0.1416 m/s and 0.1889 m/s are considered for superficial liquid velocity. The experimental results are predicted using different Artificial Neural Network (ANN) models. Networks used for prediction are radial basis, generalised regression, linear layer, cascade forward back propagation, feed forward back propagation, feed forward distributed time delay, layer recurrent, and Elman back propagation. Transfer functions used for networks are Linear (PURELIN), Logistic sigmoid (LOGSIG), tangent sigmoid (TANSIG) and Gaussian RBF. Combination of networks and transfer functions give different possible neural network models. These models are compared for Mean Absolute Relative Deviation (MARD) and Mean Relative Deviation (MRD) to identify the best predictive model of ANN.

Keywords**—**Minichannel, Two-Phase Flow, Frictional Pressure Drop, ANN, MARD, MRD.

I. Introduction

RELIABLE assessment of two-phase frictional pressure drop becomes instrumental in compact heat exchangers which have small flow passages of the order of 1-2 mm. These exchangers are used in space applications, microelectronic cooling systems, small refrigeration systems, chemical plants, nuclear reactors etc. [1]. Estimation of two-phase pressure drop in conventional size channel is still a challenge [2]. Hence, it is essential to carry out systematic analysis of frictional pressure drop for single phase and two-phase flow through such small passages, i.e., microscale channels. The experimental work has been extensively carried out for thermo-hydrodynamics of continuous Taylor bubble flow through minichannel [3]. The present work is an extension of the reported work of Mehta and Banerjee using ANN techniques [3]. ANN is widely used for the qualitative and quantitative analysis of two-phase flow data. The possibility of using a neural network based techniques to identify gas-liquid two-phase flow pattern (qualitative analysis) is reported by [4] and obtained better prediction accuracy with Radial Basic Function (RBF) network. The aim of the present paper is to suggest the suitable ANN model for the prediction of air-water two-phase frictional pressure drop (quantitative analysis) based on the experimental data obtained on 2.12 mm horizontal circular minichannel.

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II. Experimental Analysis

The detailed experimental procedure for frictional pressure drop and its comparative assessment with separated flow models are reported by Mehta and Banerjee [3]. The frictional pressure drop is measured experimentally using HTC make PM-6205 series digital manometer. In-situ calibration for frictional pressure drop is carried for single phase flow through minichannel. The mean relative deviation between theoretical and experimental pressure drop is observed to be in the error range of ±2.5% for air and ±2.66% for water. Two-phase frictional pressure drop is measured for different values of inlet flow rates of gas and liquid phase. Based on the experimental data, the functional relationship between two-phase frictional pressure drop as function of superficial gas and liquid velocities are shown in Fig. 1. The frictional pressure drop is observed to increase with increase in superficial gas and liquid velocity. This can be explained by the fact that an increase in superficial gas velocity causes higher production of gas bubbles which in turn increases the true liquid velocity due to a decrease in the liquid holdup [5].

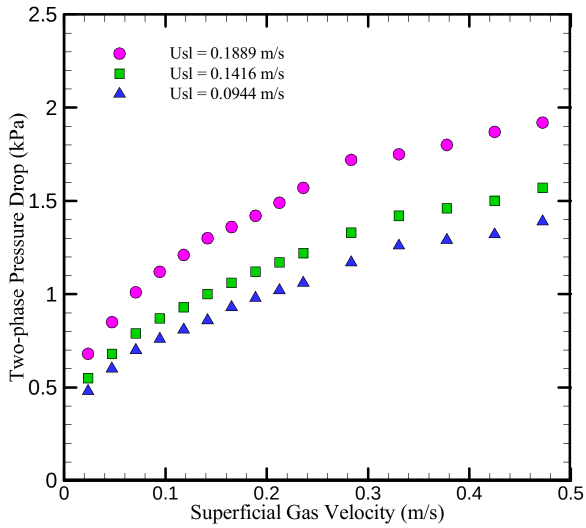

Fig. 1 Experimental two-phase pressure drop versus superficial gas and liquid velocities

III. ANN Modelling of Two Phase Flow

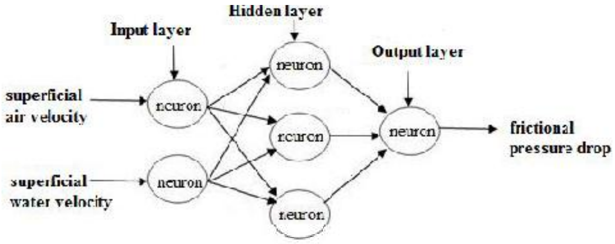

Fig. 2 Basic ANN model

Artificial neural network is model developed based on human brain. The basic element or unit of human brain is known as neuron. It is a basic information-processing unit. Each neuron has simple configuration. But complex connectivity of all neurons create tremendous processing power. Grouping of neurons are done by creating layers. Each layer contains number of neurons. One layer is connected to another layer. According to connections between layers, different types of neural networks possible like as Radial basis, Generalised regression, Linear layer, Cascade forward back propagation, Feed forward back propagation, Feed forward distributed time delay, Layer recurrent, and Elman back propagation. Generally, all networks contain three types of layers – input layer, hidden layer and output layer. Neurons of input layer receive the data from real world. The superficial gas velocity and superficial liquid velocity are considered as input as shown in Fig. 2. The output layer passes signal to the outside user. Air-water two-phase frictional pressure drop is considered as output parameter. Many hidden layers exist between output layer and input layer. Hidden layer or internal layer consists of many neurons which are connected in different patterns. Input layer supplies signal to the hidden layer. Neurons in hidden layer perform their functions and arithmetic calculation. Hidden layer sends their signal to output layer neurons. Output layer compare output signal with original targeted value till the output signal does not match with target signal. Neural Network tool is used for designing, implementing, visualizing, simulating, complex analysis, pattern recognition, identification, classification, control systems and nonlinear system identification.

The aim of the present paper is to suggest the suitable ANN model that can predict air-water two-phase frictional pressure drop in line with the experimentally obtained data.

IV. MATLAB Algorithm

The procedure to predict air-water two-phase frictional pressure drop using ANN modeling is summarized as follows:

1. *Data Collection:* Frictional pressure drop is measured with digital manometer for different air and water superficial velocities.
2. *Build the Network:* Divide experimental data as input, target and test data. Select the network and set input data, target data, number of neurons, transfer function, training function, number of hidden layers etc.
3. *Train the Network:* The training of network involves the adjustment of associated weights such that the predicted outputs close to the target output of the network. In the present case, 89 percentage data are used for training the network.
4. *Test the Network:* The modelled network is tested to predict the performance of the developed ANN model. Here, unseen data (11%) are exposed to model for testing.

V. Result and Discussion

Radial basis, Generalised regression, Linear layer, Cascade forward back propagation, Feed forward back propagation, Feed forward distributed time delay, Layer recurrent, and Elman back propagation networks are considered for study. Transfer functions used for networks are Linear (PURELIN), Logistic sigmoid (LOGSIG), Hyperbolic tangent sigmoid (TANSIG) and Gaussian RBF. Combination of networks and transfer functions give different possible models as shown in Table I. 45 experimental data are obtained for gas-liquid two-phase frictional pressure drop in a 2.12 mm horizontal circular mini-channel. For modeling, the whole dataset has been divided into 89% and 11%. That means 89% data has considered for training and remaining 11% data has selected for validation of the model. The channel diameter as 2.12 mm and its orientation as horizontal keep constant. The superficial gas velocity and superficial liquid velocity are considered as input parameters while air-water two-phase frictional pressure drop are predicted as output parameter. The Training function and Adaption learning function are based on gradient descent algorithm. Total number of layer is two. Number of neuron considered is 10. Learning rate is considered as 0.01. Matlab R2011b has been used. The predicted results are compared based on the Mean Relative Deviation (MRD) and Mean Absolute Relative Deviation (MARD) which is defined as:

$$M = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{P(i)_p - P(i)_{ex}}{P(i)_{ex}}\right) \quad (1)$$

$$M = \frac{1}{N}\sum_{i-1}^{N}\left|\frac{P(i)_p - P(i)_{ex}}{P(i)_{ex}}\right| \quad (2)$$

It is concluded that radial basis (exact fit) neural network with Gaussian RBF give minimum MARD as shown in Fig. 3 and minimum MRD as tabulated in Table I among all models. Radial basis (exact fit) neural network with Gaussian RBF transfer function model takes default spread constant value as 1. The work is further extended to study the effect of spread constant in radial basis (exact fit) with Gaussian RBF to optimize the spread constant which can predict the two-phase frictional pressure drop with minimum MARD and MRD. It is better to choose the spread constant of RBF larger than the distance between adjacent input vectors in order to get good generalization [6]. Spread constant is varied in the range of 0.1 to 2.5. Mean Absolute Relative Deviation (MARD) obtained for different spread constant in Radial basis (exact fit) neural network with Gaussian RBF model is plotted in Fig. 4. MRD for different spread constant are tabulated in Table II. Spread constant 0.19 is found to have least Mean Absolute Relative Deviation (MARD) and Mean Relative Deviation (MRD). MARD is estimated to be less than 0.1% with spread constant of 0.19. The experimental value of frictional pressure drop plotted against the predicted value for spread constant of 0.19 is plotted in Fig. 5 and close agreement is observed.

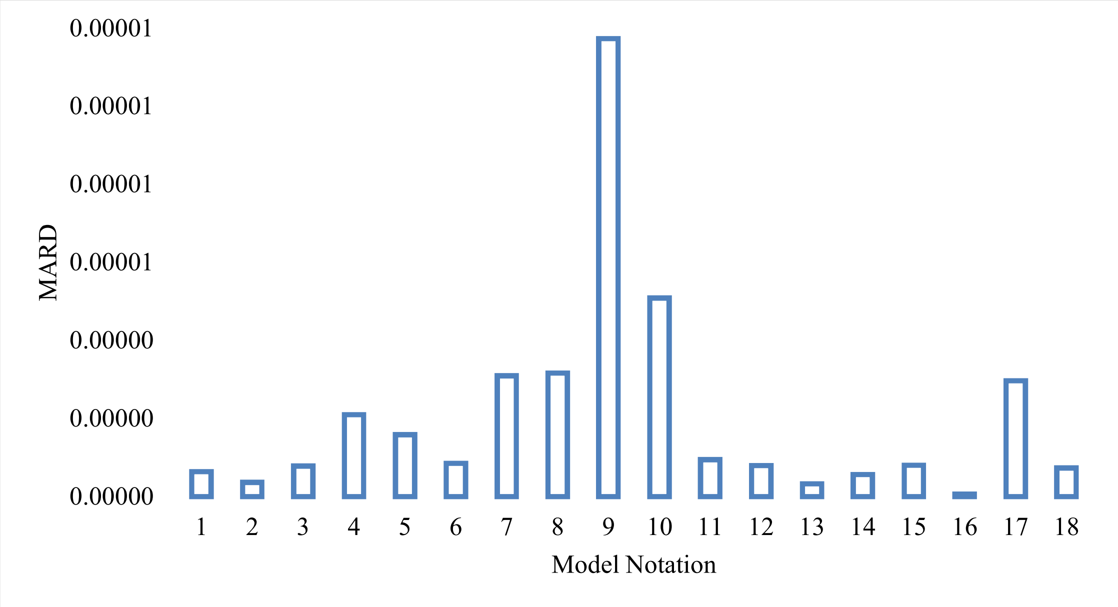

Fig. 3 Comparison between different networks by MARD

TABLE I
COMPARISON BETWEEN DIFFERENT NETWORKS BY MRD

Neural Network	Transfer Function	Models Notation	MRD
CASCADE FORWARD BACK PROPAGATION	TANSIG	1	0.01054
	LOGSIG	2	0.00366
	PURELIN	3	0.01249
FEED FORWARD BACK-PROPAGATION	TANSIG	4	-0.06245
	LOGSIG	5	-0.03936
	PURELIN	6	-0.00533
FEED FORWARD DISTRIBUTED TIME DELAY	TANSIG	7	-0.13899
	LOGSIG	8	0.15937
	PURELIN	9	-1.16180
LAYER RECURRENT	TANSIG	10	0.44589
	LOGSIG	11	0.02499
	PURELIN	12	0.02608
ELMAN BACK PROP	TANSIG	13	0.01247
	LOGSIG	14	0.01375
	PURELIN	15	0.00512
RADIAL BASIS (EXACT FIT)	**GAUSSIAN RBF**	**16**	**0.00010**
GENERALISED REGRESSION	GAUSSIAN RBF	17	0.10621
LINEAR LAYER(DESIGN)	PURELIN	18	0.00454

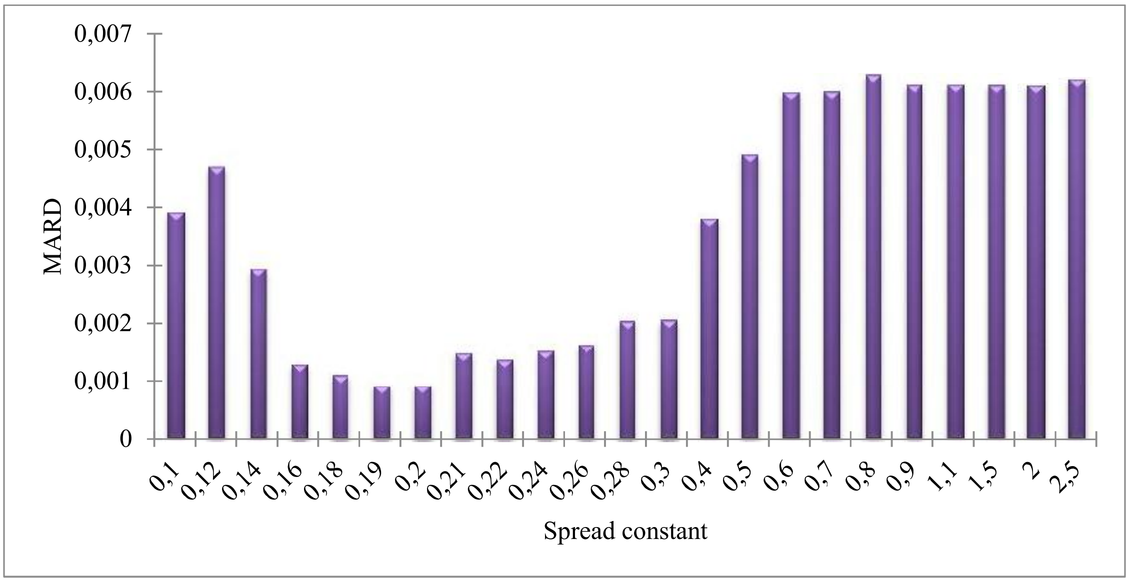

Fig. 4 Comparison of MARD for different spread constant

TABLE II
COMPARISON OF MRD FOR DIFFERENT SPREAD CONSTANT

Spread constant	MRD
0.1	-0.0023102030
0.12	-0.0030507090
0.14	-0.0013273040
0.16	0.0003006090
0.18	0.0001445490
0.19	**-0.0000786839**
0.2	-0.0000795622
0.21	-0.0004155630
0.22	-0.0003122580
0.24	-0.0004621780
0.26	-0.0002601690
0.28	-0.0001820470
0.3	-0.0001985430
0.4	0.0000951576
0.5	-0.0004040710
0.6	0.0000935351
0.7	0.0000800909
0.8	-0.0000273746
0.9	0.0000993017
1.1	0.0001024380
1.5	0.0000675097
2	0.0001414500
2.5	0.0002254730

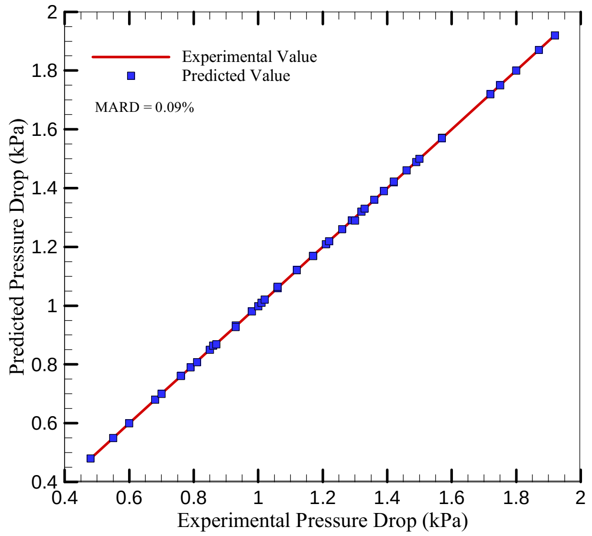

Fig. 5 Experimental pressure drop versus predicted pressure drop for optimize model

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