ESTIMATION OF PRESSURE DROP FOR FLOW OF CMC IN AQUEOUS SOLUTION USING ARTIFICIAL NEURAL NETWORK

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ABSTRACTs

Estimation of behavior of Non-Newtonian fluids is a complex phenomenon & conventional models have deviated & shown non consistency. Present work has addressed to the problem of pressure drop estimation for flow of CMC-water solution having different concentrations in a pipeline. Experimental runs are conducted & the data generated is divided into two parts; one for developing the model& another for testing .Two Artificial Neural Network models S1 & C1 are developed having RMSE values for training data set of 0.021 & 0.013 respectively. The corresponding values for test data set are 0.035 & 0.08. The claim of high accuracy is substantiated further & the percentage relative error values are within ±10% for training data set & around ±20% for test data set for both the models. Thus the present work has successfully demonstrated the potential that need to be further explored in development of ANN models for predicting behavior of Non-Newtonian fluids.

KEYWORDS: *Artificial Neural Network, CMC-Water Solution, Pressure Drop Estimation, Non-Newtonian Fluid*.

I. INTRODUCTION

A fluid is defined as a substance that deforms continuously under the action of shear stress. When a fluid is at rest, there can be no shear stresses. Fluids are broadly classified as Newtonian & Non-Newtonian fluids. Newtonian fluids are those having a constant viscosity that is dependent on temperature but independent of the applied shear rate & the curve of stress versus strain rate is linear and passes through origin. Air, water, honey etc. are the examples following in this category. In a Non-Newtonian fluid, the relation between the shear stress and the shear rate is different, and can even be time-dependent. Therefore a constant coefficient of viscosity cannot be defined. Examples of substances exhibiting Non-Newtonian fluid behaviour are beer, animal waste slurries from cattle farms, biological fluids such as blood, saliva, bitumen, cement paste & slurries, chocolates, coal slurries, cosmetics & personal care products like lotion & creams, shampoos, toothpaste. Dairy products & dairy waste streams like cheese, butter, fresh cream, yogurt, whey, drilling mud, food stuffs that include purees, sauces, jams, ice creams, egg white, bread mixes. Greases & lubricating oils, molten lava & magmas, paints, polishes & varnishes, paper & pulp suspensions, peat & lignite slurries, polymer melts & solutions, reinforced plastics & rubber, printing colours & inks, pharmaceutical products, sewages sludge, wet beach sand, waxy crude oils, etc, also fall in the category of Non-Newtonian fluids[1].

Carboxymethyl cellulose (CMC) has wide application in industries & is a Non-Newtonian fluid. CMC has its innumerable application in oil & gas drilling, textile, printing & dyeing industries, paper industry, daily chemical industry, ceramic industry, construction industry, food industry, mining floatation industry, etc.

Artificial neural network (ANN) has been emerging as a powerful tool for predicting values which have practically importance. The base of artificial neural network is biological neural network. ANN is a black box modelling tool whose working principle is similar to a Biological Neural Network. It consists of input, hidden & output layers. Input & output layer consist a definite number of neurons that depends on the number of variable to be correlated, where as there could be any number of hidden layers with appropriate numbers of neurons depending upon the complexity of the modelling process.

There are several types of the arrangement of the neurons with each other & error back propagation is most common for chemical processes. In this architecture, every node in every layer is connected to all the nodes in the succeeding layers by means of the connectionist constants, also called as weights. The output from each neuron in the input layer is altered by a multiplication factor or weight and every node in the next layer receives the summation of the product of the outputs of the nodes from the preceding layer. The resulting signal received by the node is further transformed by using functions like sigmoid function & the resulting signal acts as an input for the nodes in the next layer. The power of EBP is in its training & the algorithm suggested by Rummelhart [17] is popular among workers.

The paper is presented in sections, starting with the introduction to non Newtonian fluids with special reference to CMC-water solution & Artificial Neural Network (ANN). The next section takes a stock of the related papers published, followed by discussing the details of experimental setup & topology of ANN models developed. The accuracy of the prediction of ANN models developed is compared at length in result & discussion section. The paper concludes with highlighting the findings of the present work & indicating the possible areas for further work that need to be explored.

II. LITERATURE SURVEY

In last few years, CMC were used as Non-Newtonian fluids by researchers for various studies. F.T.Pinho [2] et al, studied the pressure drop of shear thinning in laminar flow across a sudden expansion. Bart C.H. Venneker [3] et al studied about the turbulent flow of shear thinning fluid in stirred tank. Diego Gomez-Diaz & Jose M. Navaza [4] studied the apparent viscosity & the influence of shear rate on different polymer concentration in aqueous solution of CMC, & also the effect of temperature on rheological behaviour. He has reported that the behaviour parameter, n, decreased when CMC concentration increased.

Determination of total head loss & friction factor corresponding to pressure drop& loss coefficient caused by fittings & valves, using CMC aqueous solution was studied by Adelson Balizario Leal S [5] et al. F.T.Pinho & J.H.Whitelaw [6] had well discussed about the delay in transition from laminar to turbulent flow caused by shear thinning, where experiment were carried out by using CMC. Shankar .P, Himanshu Vyas, Kalaichelvi .P and Muthamizhi.K [7] studied mixing characteristics of 0.5%CMC in double jet mixer. Vesna Hegeduš, Zoran Herceg and Suzana Rimac [8] studied Rheological Properties of CMC and Whey Model Solutions before and after Freezing. A. Bombac, M. zumer, and I. Zun [9] reported about their findings on Power Consumption in Mixing and Aerating of Shear Thinning Fluid (CMC) in a Stirred Vessel.

Several applications of ANN in modelling of various processes is reported in literature. Study o Pawan P Singh & Vinod K Jindal [10] made the comparison of the viscometric characterization of selected foods, consist CMC as one of the item, based on tube & rotational viscometers for estimating pressure drop & also made neurals networks for estimating pressure drop. Artificial neural network application for model in calculation of pressure drop of nanofluid was made by Mahmoud S. Youssef, Ayman A. Aly, and El-Shafei B. Zeidan [11]. Nirjhar Bar & Sudip Kumar Das [12] used multilayer perceptron for pressure drop prediction for flow of Gas-Non-Newtonian liquid. ANN is used to detect leak in pipelines [13]. ANN is also used for the estimation of pressure drop of packed column [14]. Work has done for Optimizing topology in developing artificial neural network model for estimation of hydrodynamics of packed column [15]. S.L. Pandharipande with his co-workers has utilized the power of Artificial Neural Network for Estimation of Composition of a Ternary Liquid Mixture with its Physical Properties such as Refractive Index, pH and Conductivity [18], for Modeling of Equilibrium Relationship for Partially Miscible Liquid-Liquid Ternary System [19] and for Modeling of Packed Bed Using Artificial Neural Network [20].

III. MATERIALS & METHODS

Experimental runs are conducted & the generated data is divided into two parts. One part is called as training data set & is used in developing ANN models. The other data set is called as test data set & is used in validating the model developed.

Two ANN models are developed to predict output parameters i.e. head loss & pressure drop. These developed models are then compared based on their predicted results for future application. Water is Newtonian fluid whereas addition of CMC in water diverts behaviour of system to Non-Newtonian.

- Figure 1 shows the schematic of the experimental setup. It consists of a reservoir tank, with 60 liters capacity, a centrifugal pump of 1HP & 9 feet long experimental acrylic pipe having 25 mm diameter.
- CMC solution of concentrations 0.192%, 0.29%, 0.392%, 0.492%, & 0.592% by wt are prepared by weighing CMC powder using electronic weighing balance & then vigorously mixing it in known amount of water to make the desired concentration.
- Experiments are performed by pumping homogenous solution into the pipe & noting pressure drops for varying flow rates conditions.
- Pressure drops are measured by using an inverted manometer, whose limbs are 3 feet apart & flow rates are measured by weighing the solution collected for known interval of time.

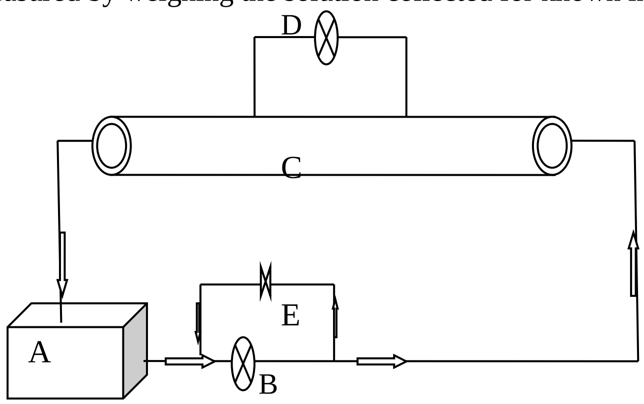

Figure 1: Schematic of the Experimental set up

A→ storage tank; B→ centrifugal pump; C→ acrylic pipe of diameter 25mm;D→ inverted U tube manometer, whose limbs are 1m apart; E→ valve to control flow rate.

The data generated is divided in two parts; one part containing 42 data points as training set and the other with 9 data points as test set. Two ANN models S1 & C1 having different topologies are developed using elite-ANN© [16].The graphs are plotted for the comparison of actual & predicted values for output parameters i.e. head loss and pressure drop for the training & test data set for these ANN models

The topology of the ANN models S1 & C1developed in the present work is given in table 1.

Table 1. Neural network topology for ANN models

Name of ANN models	Numbers of neurons					Data points		RMSE		Iterations
	Input layer	1st hidden layer	2nd hidden layer	3rd hidden layer	Output layer	Training data set	Test data set	Training data set	Test data set	
S1	2	0	5	5	2	42	9	0.021	0.035	50000
C1	2	10	10	10	2	42	9	0.013	0.08	50000

The architecture of ANN topology for ANN models S1 & C1are shown in figure number 2.

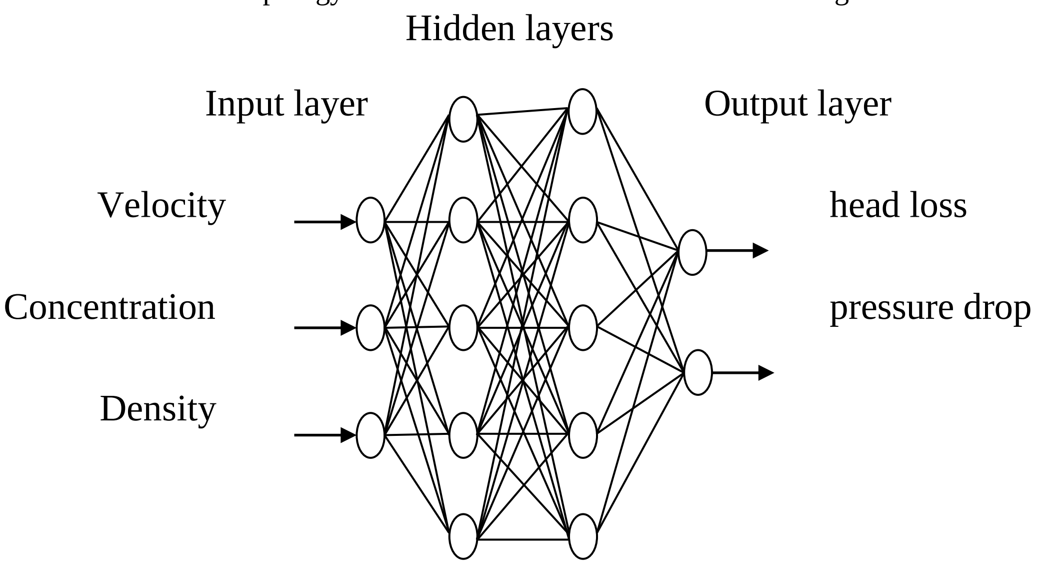

Figure 2. Neural network architecture

IV. OBSERVATIONS

Figures 3 & 4 shows the comparison of actual & predicted values of head loss & pressure drop for training data set using ANN model S1.

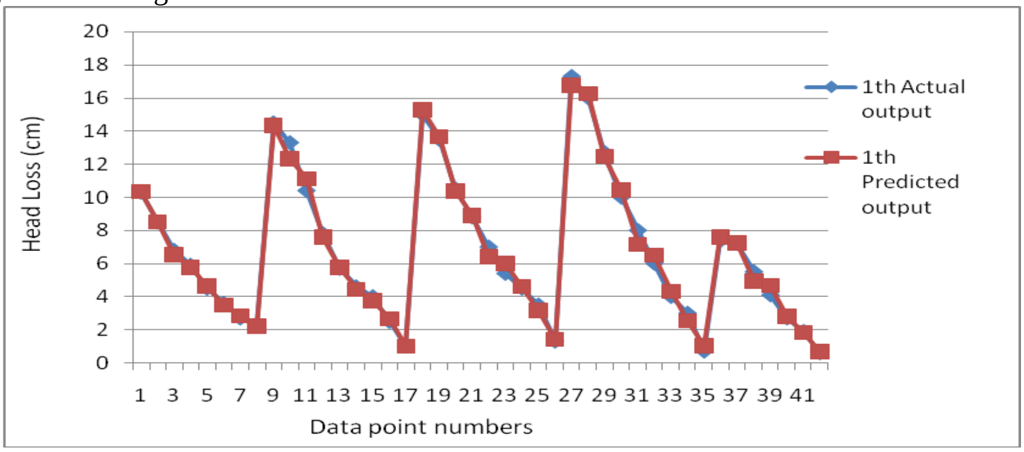

Fig 3: Comparison of actual and predicted values of head loss for training data set using ANN model S1

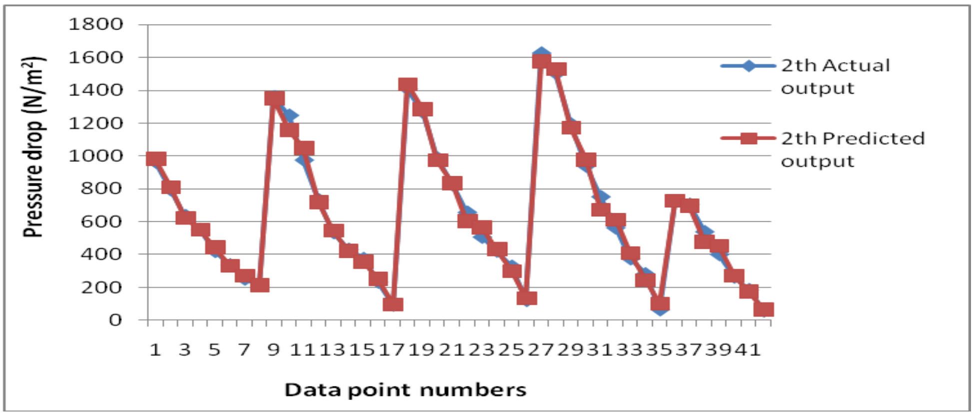

Fig 4: Comparison of actual & predicted values of pressure drop for training data set using ANN model S1

Figures 5 & 6 shows the comparison of actual & predicted values of head loss & pressure drop for test data set using ANN model S1.

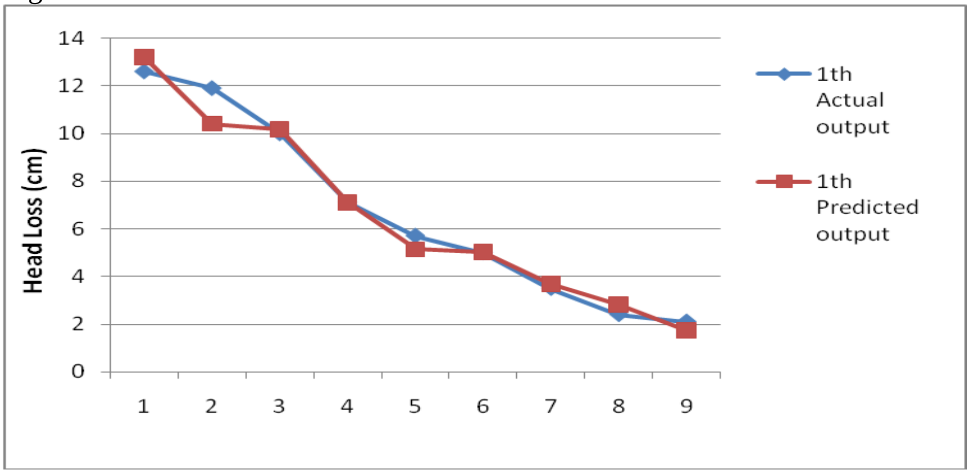

Fig 5: Comparison of actual & predicted values of head loss for test data set using ANN model S1

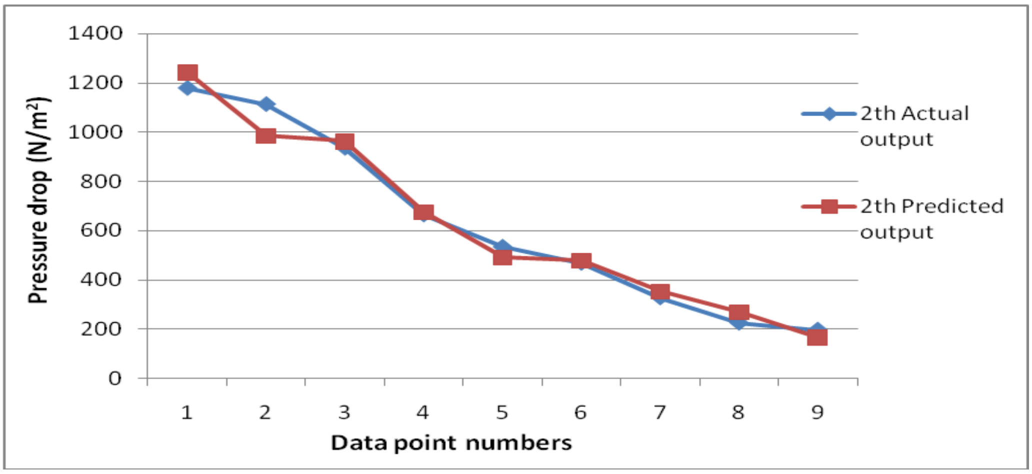

Fig 6: Comparison of actual & predicted values of pressure drop for test data set using ANN model S1

It is observed from the graphs that the predicted values are fairly close to the actual values. Similar graphs are obtained for comparison of actual & predicted values for training & test data set using ANN model C1.

Figures 7 & 8 shows the comparison of actual & predicted values of head loss & pressure drop respectively for training data set using ANN model C1.Similarly figure 9 & 10 shows the comparison of actual & predicted values of head loss & pressure drop for test data set using ANN model C1 respectively.

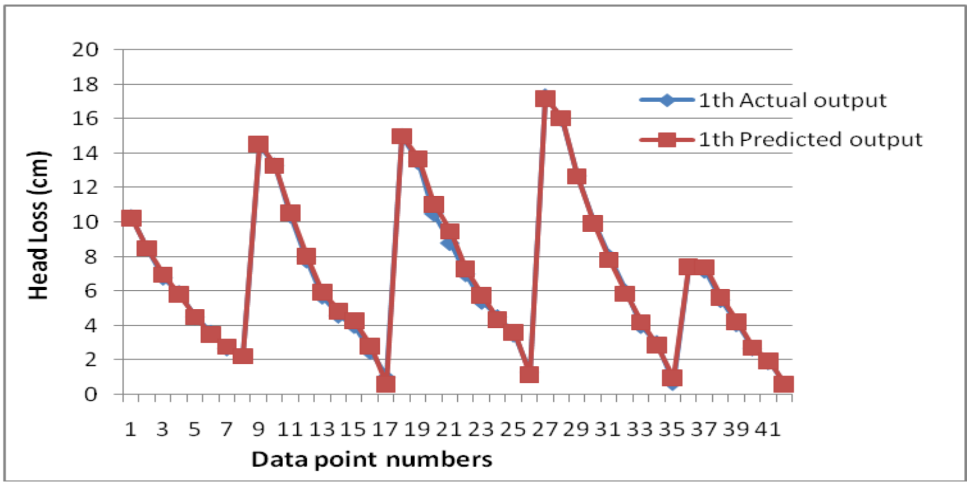

Fig 7: Comparison of actual & predicted values of head loss for training data set using ANN model C1

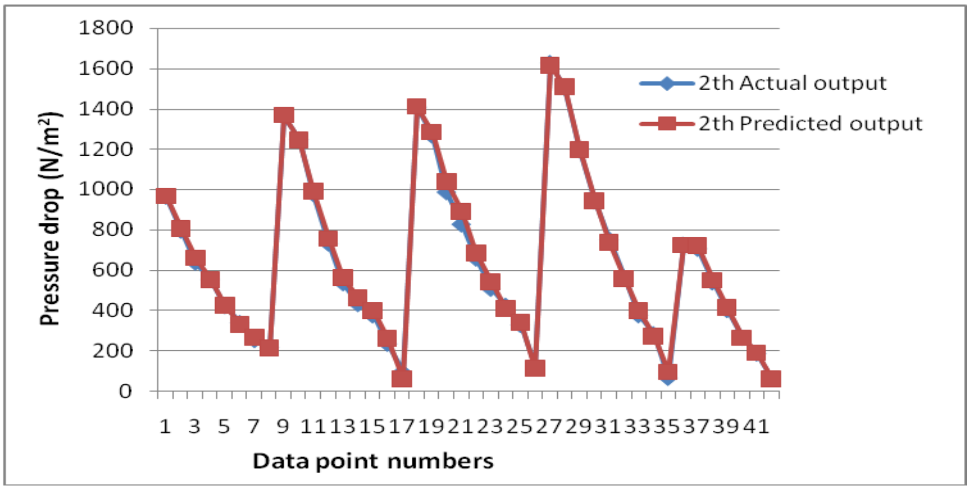

Fig 8: Comparison of actual & predicted values of pressure drop for training data set using ANN model C1

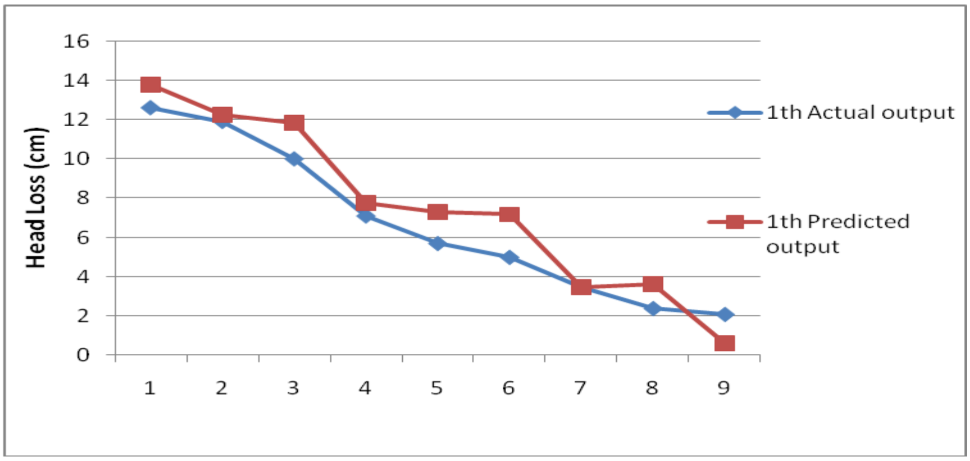

Fig 9: Comparison of actual & predicted values of head loss for test data set using ANN model C1.

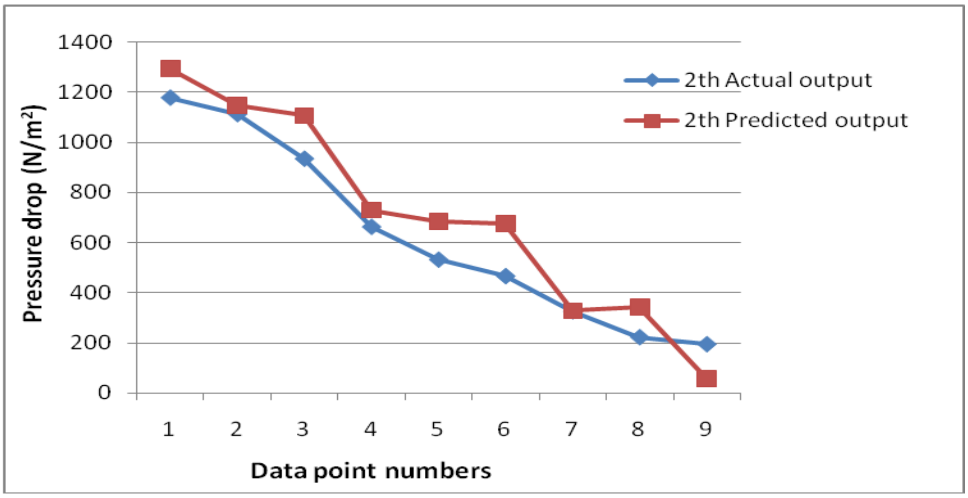

Fig 10: Comparison of actual & predicted values of pressure drop for test data set using ANN model C1.

Graphs obtained for training & test data set by ANN model C1 also give fairly close predicted values for head loss & pressure drop compared with the actual values. Hence it is felt necessary to compare predicted values of S1 & C1.

V. RESULTS AND DISCUSSIONS

The accuracy of prediction of ANN models is checked by estimating percentage relative error as
%E= [(Actual values - Predicted values)/Actual values]*100
The distribution of % relative error for data points for ANN model S1 & C1.

Table 2. Distribution of % relative error

Name of ANN model		% Relative error =[(Actual value –Predicted value)/ Actual value]× 100			
		Parameters	0 to ±10	±10 to ±20	>±20
S1	Training data points 42	Head loss	34	7	1
		Pressure drop	36	5	1
	Test data points 9	Head loss	6	3	0
		Pressure drop	6	3	0
C1	Training data points 42	Head loss	40	1	2
		Pressure drop	40	1	2
	Test data points 9	Head loss	2	3	4
		Pressure drop	2	3	4

Figures 11 & 12 shows the percentage relative error for head loss & pressure drop for training data set using ANN model S1 respectively.

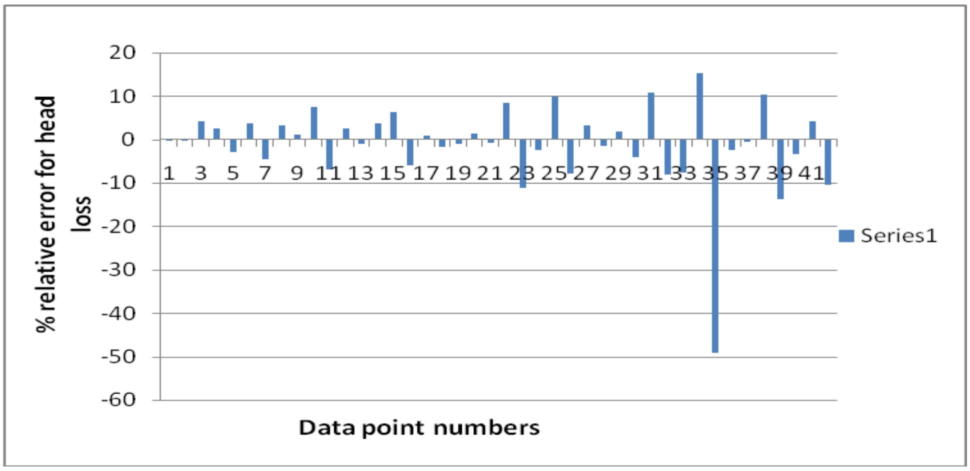

Fig 11: percentage relative error for head loss for training data set using ANN model S1.

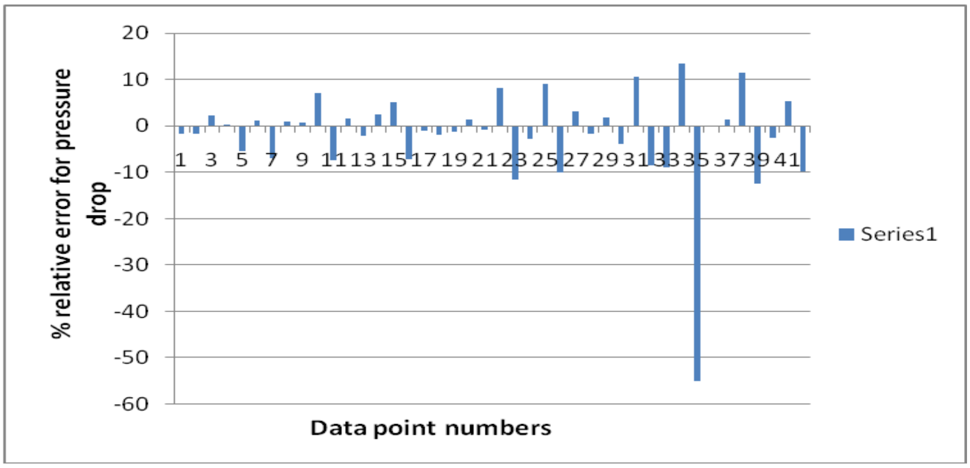

Fig 12: percentage relative error for pressure loss for training data set using ANN model S1.

Figures 13 & 14 shows the percentage relative error for head loss & pressure drop for test data set using ANN model S1respectively.

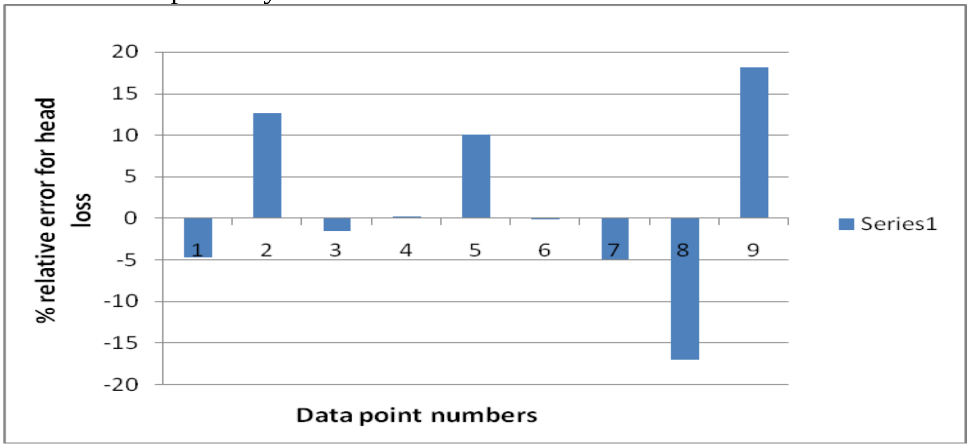

Fig 13: Percentage relative error for head loss for test data set using ANN model S1.

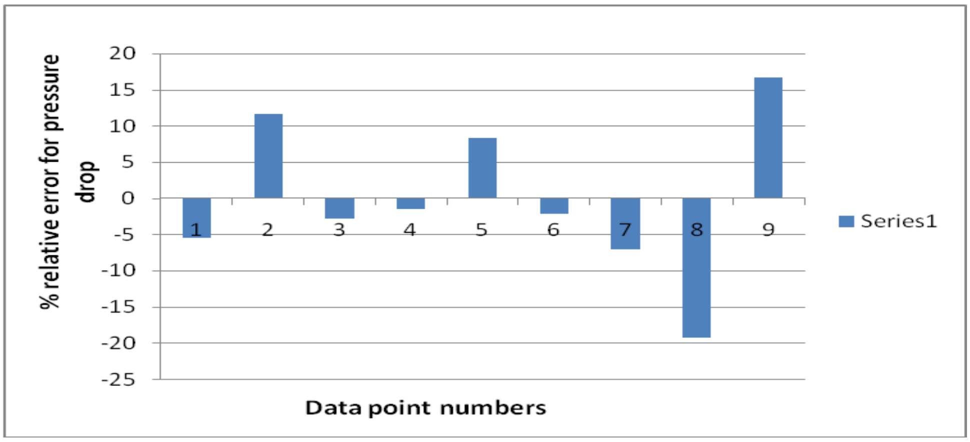

Fig 14: Percentage relative error for pressure drop for test data set using ANN model S1.

Figures 15 & 16 shows the percentage relative error for head loss & pressure drop for training data set. Similarly figures 17 & 18 shows the percentage relative error for head loss & pressure drop using ANN model C1 respectively.

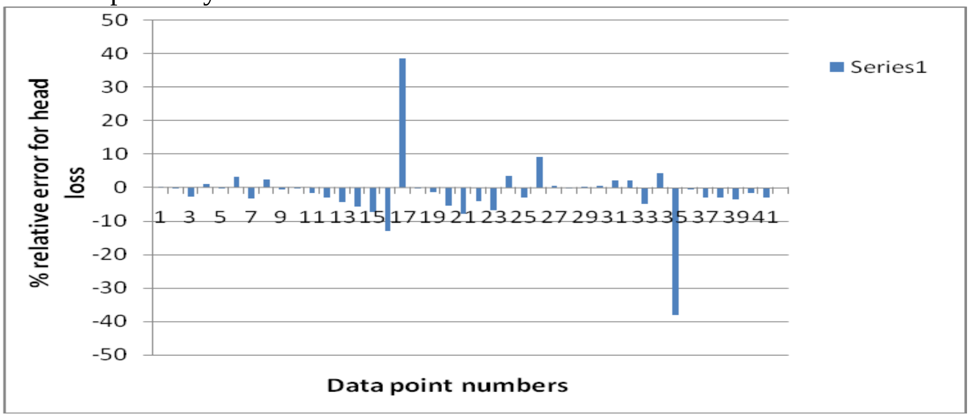

Fig 15: Percentage relative error for head loss for training data set using ANN model C1.

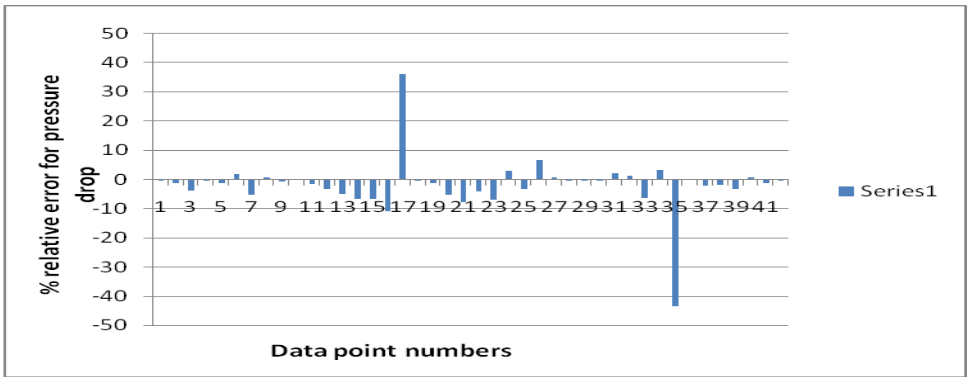

Fig 16: percentage relative error for pressure loss for training data set using ANN model C1.

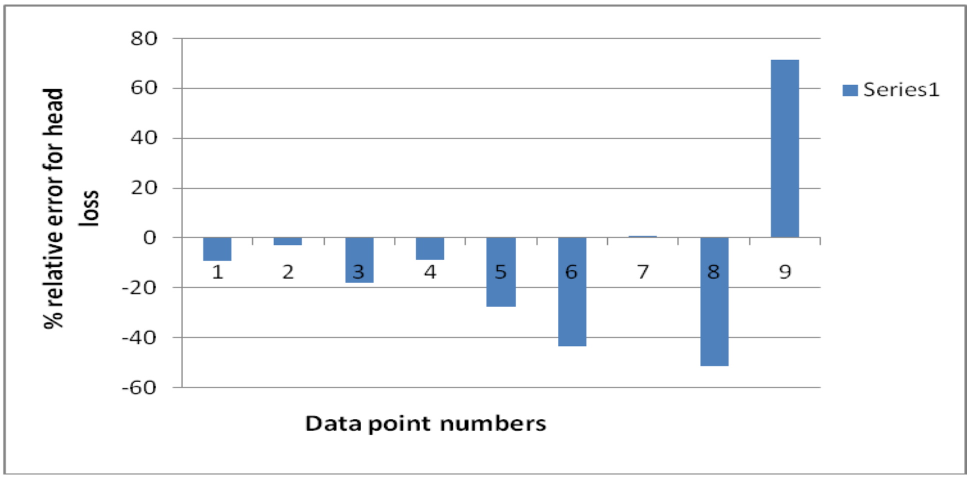

Fig 17: Percentage relative error for head loss for test data set using ANN model C1.

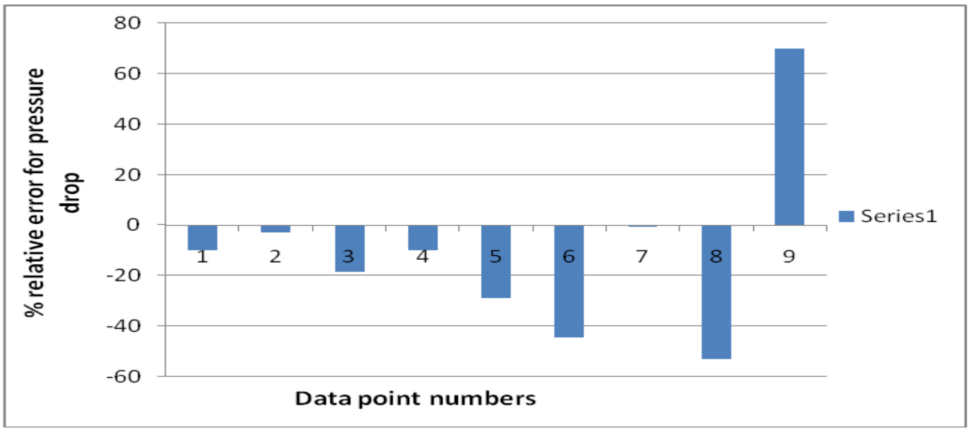

Fig 18: Percentage relative error for pressure drop for test data set using ANN model C1.

Developed ANN models S1 & C1 are then compared for predicted values of head loss & pressure drop with actual values respectively. Figure 19 & 20 shows these comparisons. It can be concluded that predicted values from ANN model S1 are fairly close to actual values & acceptable.

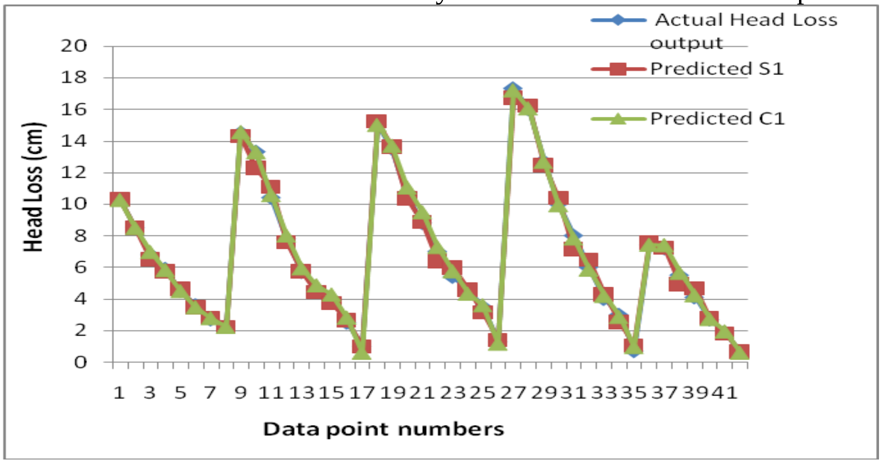

Fig 19: Comparison of actual & predicted values of head loss using ANN models S1 & C1.

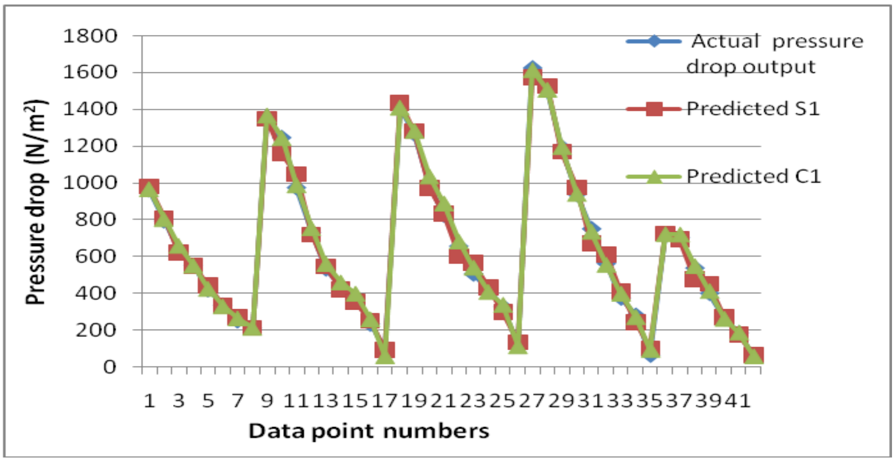

Fig 20: Comparison of actual & predicted values of pressure drop using ANN models S1 & C1.

VI. CONCLUSIONS

Present work has addressed to the problem of modeling of pressure drop estimation of flow of CMC-Water solutions having varying concentrations in a pipe line. Artificial Neural Network has been used as a modelling tool in developing two models S1 & C1 with different topologies. Experimental runs have been conducted & the data generated is divided into two parts having 42 & 9 data points each for training & test data sets. Training data set is used in developing ANN models S1 & C1 having RMSE values of 0.021 & 0.013 respectively. The corresponding values for test data set are 0.035 & 0.08. The claim of accuracy is further substantiated by calculating percent relative error for all the data points for both the ANN models S1 & C1. Based on these values of percent relative error, it can be said that, both the ANN models developed in the present work have very high accuracy & the percent relative error is within ±10% for the training data set. However based on the comparison between the percent relative errors for test data set values, it can be said that ANN model S1 has more accuracy of prediction and most values of test data set are below 10 % error as compared to the ANN model C1 where the deviations are more than ±20 % from actual values. Thus it can be concluded that the present work has successfully developed ANN model S1 having acceptable accuracy levels.

VII. FUTURE SCOPE

Estimation of behaviour of Non-Newtonian fluids is a complex phenomenon & there are many operations in chemical process industries where Non-Newtonian fluids are used. Conventional models have deviated & shown non consistency. It can be said that there is a lot of potential & future scope to explore the application of Artificial Neural Network models in prediction of other behavioural parameters related to the flow of Non-Newtonian fluid.

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