# Fuzzy Logic Modeling of Heat Transfer in a double Pipe Heat Exchanger with Wavy (Corrugated) Twisted Tape Inserts

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## Abstract
Fuzzy logic is a method which can be used to model the experiments, and it has been introduced for the first time in 1965 by Zadeh. The present work represents the use of fuzzy logic to model and predict the experimental results of heat transfer in a double Pipe Heat Exchanger with Wavy (Corrugated) Twisted Tape Inserts. The tape consists of the corrugations and the twisting with various twist ratios (TR=10.7, 8.5, 7.1). The length, width and thickness of twisted tape were 1 m, 14 mm and 2 mm respectively. The Reynolds number is varied from 5000 to 17000. The friction factor is varied from 0.03840 to 0.07241. The Nusselt number is varied from 69.13 to 266.18. Here the results with various twist ratios tapes were compared with results with plain tube. The experimental results showed that the maximum heat transfer was obtained with twisted tape with TR – 7.1. The Nusselt number increased by 172 % and friction factor value increased by 32.11% as compared to the smooth tube values. For Fuzzy Logic system the twist ratio, temperature and Reynolds Numbers were used as input functions and friction factor and Nusselt number were used as output functions. It is found that a fuzzy inference system named Mamdani is a powerful instrument for predicting the experiments due to its low error.

***Keywords* –**Heat transfer, double pipe heat exchanger, wavy twisted tape, fuzzy logic, Mamdani inference system turbulent, and pressure drop, friction factor,

## Introduction
In heat exchanger, at different temperatures, the heat is transferred between two or more fluids. The use of heat exchangers are in various industrial processes for heating and cooling applications such as air conditioning and refrigeration systems, heat recovery processes etc. The major challenge in designing a heat exchanger is to make the equipment more compact and achieve a high heat transfer rate using minimum pumping power. Fuzzy logic is a method which can be used to model the experiments. Modeling of experiments can be helpful to reduce its costs. By using the models, we can predict results of experiments, which have not performed, or are not possible to perform due to some restrictions. In this study, the fuzzy logic methodology has been used in order to model and predict the experimental results. A simple fuzzy consists from four major parts: Fuzzification interface, Fuzzy rule base, Fuzzy inference engine, and defuzzification interface. The fuzzy logic system is useful in following ways,

1) Define the control objectives and criteria: The main objective of heat transfer enhancement depends upon Re, Temperature, and friction factor
2) Determine the input and output relationships and choose a minimum number of variables for input to the FL engine. Input to the system is Temperature, Reynolds number and Output is the Nusselt number, Friction factor
3) Using the rule-based structure of FL, break the control problem down into a series of IF X AND Y THEN Z rules that define the desired system output response for given system input conditions. The number and complexity of rules depends on the number of input parameters that are to be processed and the number fuzzy variables associated with each parameter. If possible, use at least one variable and its time derivative.
4) Create FL membership functions that define the meaning (values) of Input/Output terms used in the rules.

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5) Test the system, evaluate the results, tune the rules and membership functions, and retest until satisfactory results are obtained Linguistic variables are used to represent an FL system's operating parameters. The rule matrix is a simple graphical tool for mapping the FL control system rules. It accommodates two input variables and expresses their logical product (AND) as one output response variable. To use, define the system using plain-English rules based upon the inputs, decide appropriate output response conclusions, and load these into the rule matrix.

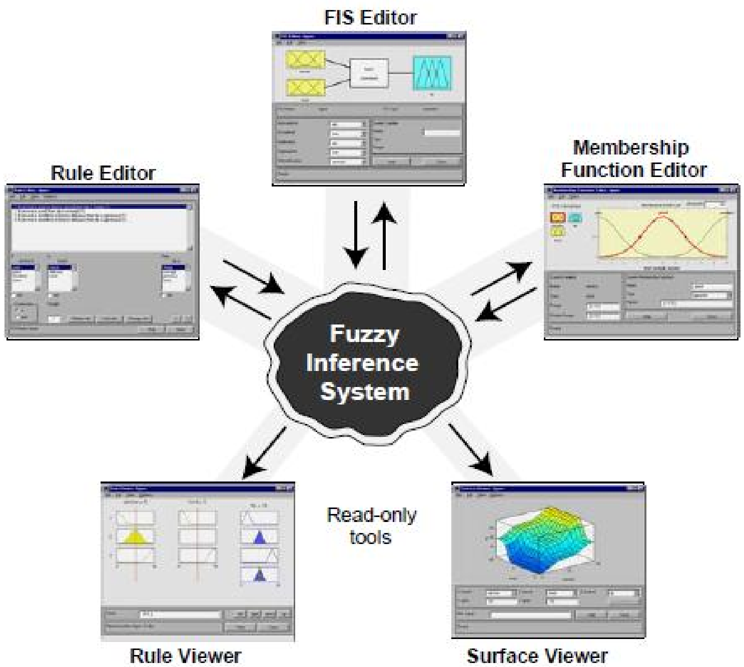
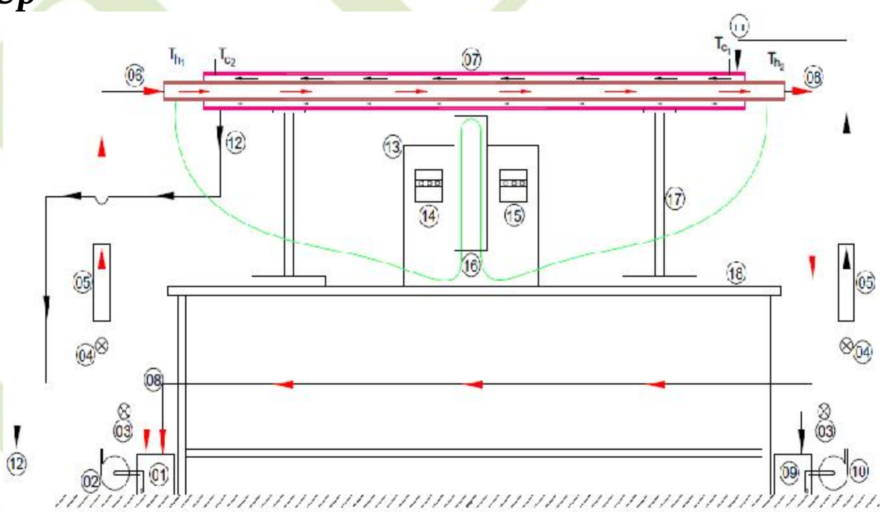



Fig.1 Performance of a simple fuzzy model

## *Experimental Set-Up*



| | | | | | |
|---|---|---|---|---|---|
| 01 | Hot water tank | 07 | Test Section | 13 | Control pannel |
| 02 | Hot water pump | 08 | Hot water outlet | 14 | Temperature Indicator |
| 03 | By pass valve | 09 | Cold water tank | 15 | Temperature controller |
| 04 | Flow control valve | 10 | Cold water pump | 16 | Inverted U-tube manometer |
| 05 | Rotameter | 11 | Cold water inlet | 17 | Stand |
| 06 | Hot water inlet | 12 | Cold water outlet | 18 | Table |

Fig. 2 The schematic diagram of experimentation

The experimental set up and the various measuring devices were shown in figure. In the experiment, initially the water tank was filled with cold water and maintained its temperature up to 80 0C by using water heater. Then, this hot water was flowed through the rota meter by opening the flow control valve with help of hot water pump and through the inner pipe of heat exchanger. The cold water from the cold water tank was allowed to enter the heat exchanger through rota meter by flow control valve & cold water pump. Adjust the flow rate of cold water at 100 LPH and made it constant during whole experiment. The flow rate of hot water was adjusted at 300 LPH and kept it constant. When the steady state was reached, the temperatures of the inlet and outlet of the cold and the hot waters were recorded and pressure drop across the test tube was measured for plain tube without inserts. Thereafter repeat same procedure with wavy twisted tapes having twist ratio (TR=10.7, 8.5, 7.1) for various flow rates of hot water like 400, 500, 600, 700, 800, 850, 900 & 950 LPH. The figure 3a, 3b, 3c shows the wavy tape inserts with twist ratio 10.7, 8.5, 7.1 respectively.

## *Specifications of inserts*

Fig. 3a Wavy corrugated twisted tape with TR – 10.7

Fig. 3b Wavy corrugated twisted tape with TR – 8.5

Fig. 3c Wavy corrugated twisted tape with TR – 7.1

Specifications:

1. Material = Copper
2. Width of twisted tape (W) = 14 mm
3. Twist ratio (TR) = 10.7, 8.5, 7.1.
4. Length of insert = 1000 mm
5. Thickness of inserts = 2 mm
6. Wave-width (WW) = 10 mm
7. Depth of wave = 10 mm

## Data Reduction

1. The Properties of hot water and cold water are calculated at their bulk mean temperature,

$$T_{bh} = \frac{T_{h1} + T_{h2}}{2}, \qquad T_{bc} = \frac{T_{c1} + T_{c2}}{2}$$

$T_{bh}$ and $T_{bc}$ are bulk mean temperature of hot & cold water. $T_{h1}$ & $T_{h2}$ and $T_{c1}$ & $T_{c2}$ are inlet and outlet temperature of hot & cold water respectively.

2. Hot water heat transfer rate,
$Q_h = m_h \times C_{ph} \times (T_{h1}-T_{h2})$

3. Cold water heat transfer rate,
$Q_c = m_c \times C_{pc} \times (T_{c2}-T_{c1})$

4. An average heat transfer rate can be written as,

$$Q_{avg.} = \frac{Q_h + Q_C}{2}$$

$$Q_{avg.} = U \times As \times \Delta Tm$$

$$\Delta T_m = \frac{(\Delta T_1 - \Delta T_2)}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)}$$

$\Delta T_1 = T_{h1} - T_{c2}$
$\Delta T_2 = T_{h2} - T_{c1}$

As , U & ΔTm is the surface area of tube, overall heat transfer coefficient & Logarithmic mean temperature difference respectively.

5. Nusselt Number of cold water flowing through the annular space is given by,
$Nu_o = 0.023(R_{eo})^{0.8} (P_r)^{0.3}$

6.Heat transfer coefficient ($h_0$) of cold water flowing through the annular space is given by,

$$Nu_o = \frac{h_o D_h}{K}$$

7. Heat transfer coefficient of hot water ($h_i$), $\frac{1}{U} = \frac{1}{h_i} + \frac{1}{h_o}$

8. Nusselt Number (Experimental) of hot water flowing through the tube, $Nu_i = \frac{h_i d_i}{K}$

9. Theoretical Nusselt Number of hot water flowing through the tube is given by (Dittus Boelter equation).
$Nu_i = 0.023(R_{ei})^{0.8} (P_r)^{0.3}$

10. Experimental Friction Factor is calculated by,

$$f = \frac{2gd_i h}{LU_i^2}$$

11. Theoretical Friction Factor f can be written as,

$$f = 0.0055 \times \left(1 + \left(50 + \left(\frac{10^6}{\mathrm{Re}_i}\right)\right)^{0.33}\right)$$

## Result and discussion

After the experimental study, the results were compared with the correlation of Dittus and Boelter for Nusselt number & John Nikuradse for friction factor.

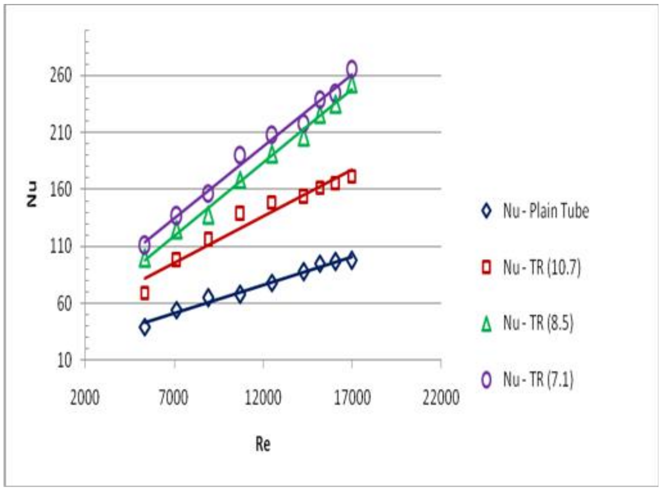



Fig. 5a Nu Vs Re

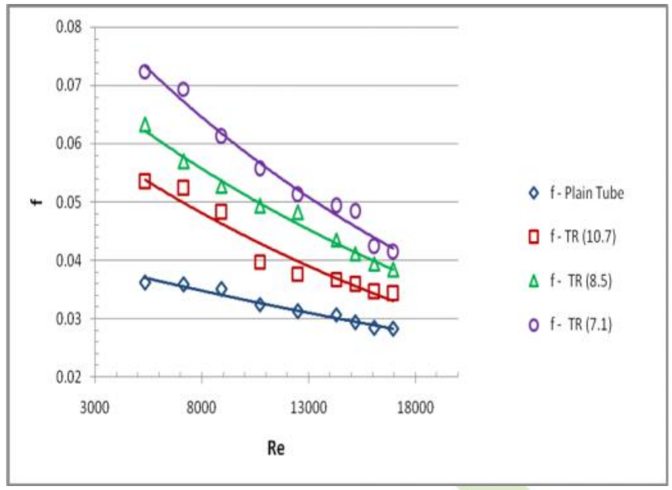



Fig. 5b F Vs Re

Fig.5a shows the variation of Nusselt number with Reynolds number at various twist ratios (TR=10.7, 8.5, 7.1). This figure indicates that the Nusselt number is directly proportional to Reynolds number. Therefore heat transfer rate is more with higher Reynolds number. Here Nusselt number is more for the twisted tape with lesser twist ratio (TR – 7.1) for particular Reynolds number compared with other twisted tapes. So highest heat transfer rate was obtained for lesser twist ratio. Fig.5b shows the variation of friction factor with Reynolds number. It was found that the friction factor become greater as the twist ratio decreased. The value of friction factor is more for the wavy twisted tape insert having twist ratio 7.1 as compared with other inserts.

## *Fuzzy Logic Modelling*

The purpose of this Fuzzy logic is to consider the effect of main factors, Reynolds number, twist ratios and the temperature. For the operation of Fuzzy Logic system, the input and output variables were selected for their levels. Reynolds number (Re) in 3 levels ranging from 5000 to 17000, temperature in three levels from 35° c to 51°c, Number of twists from 07 to 11 as input variables and friction factor and Nusselt No and friction factor as output variable were chosen. The Mamdani inference system used in this study is shown in Fig.6a. Fig. 6b, 6c and 6d shows membership functions for input variables, i.e. TR, Re and Temp. The membership functions of friction factor and Nusslet No. are brought in Fig.6e & 6f. Some parts of rules, which were chosen for the fuzzy model, are shown in Fig 6g & Fig. 6h. The three dimensional graphs which shows the relations between I.P. Variable Re, TR with output variable f and I.P. Variable Re, TR with output variable Nu are shown in Fig. 6i & 6j. Therefore experimental results are modeled by fuzzy interference system, which shows that, the fuzzy logic is a reliable method to model & predict the heat transfer. According to fuzzy logic, with increasing Reynolds number, the Nusselt number increases.

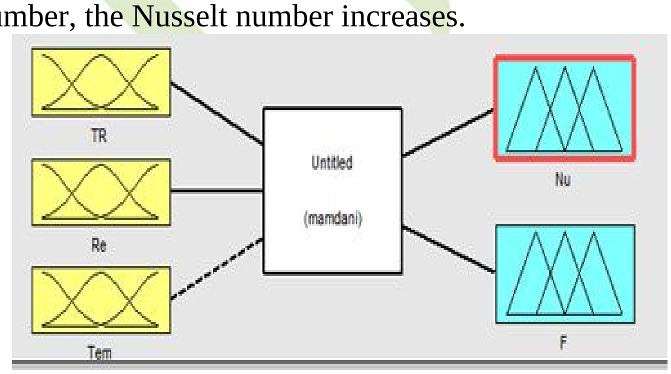



Fig. 6a Mamdani inference system

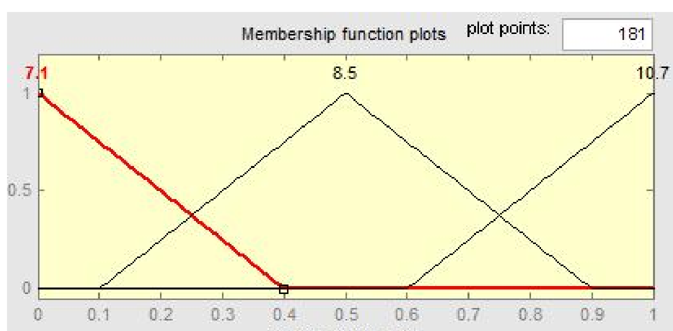



Fig. 6b Membership functions for TR

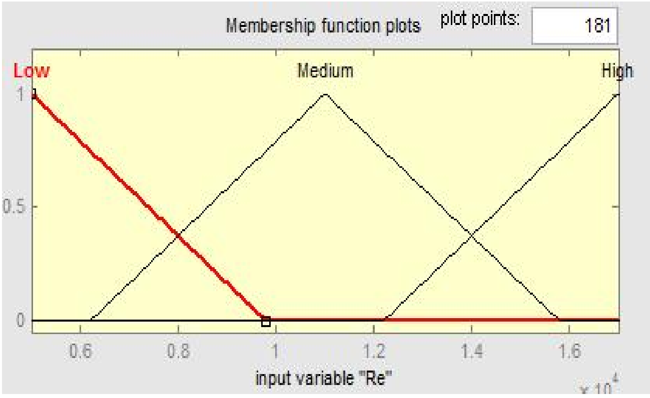



Fig. 6c Membership functions for Re

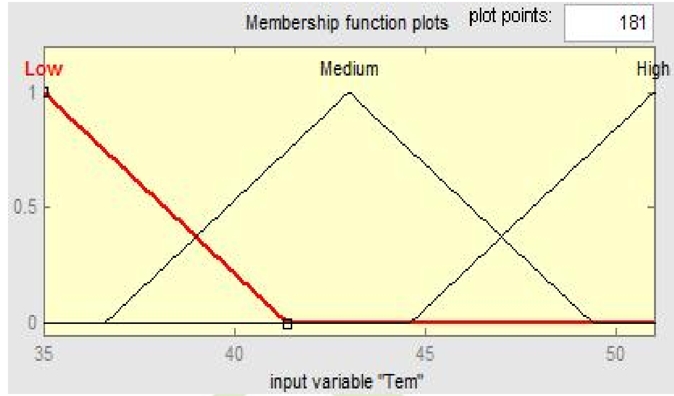



Fig. 6d Membership functions for Tem.

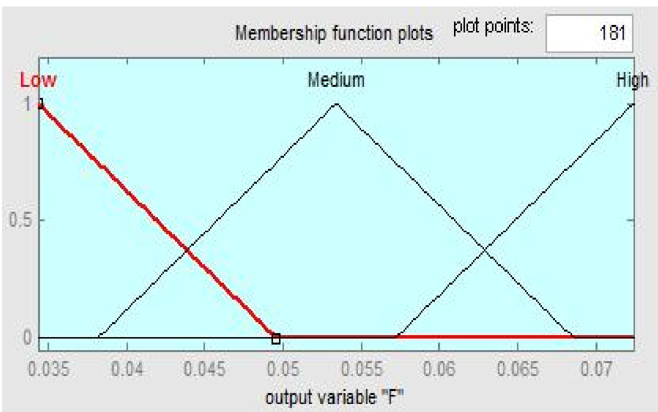



Fig. 6e Membership functions for friction factor

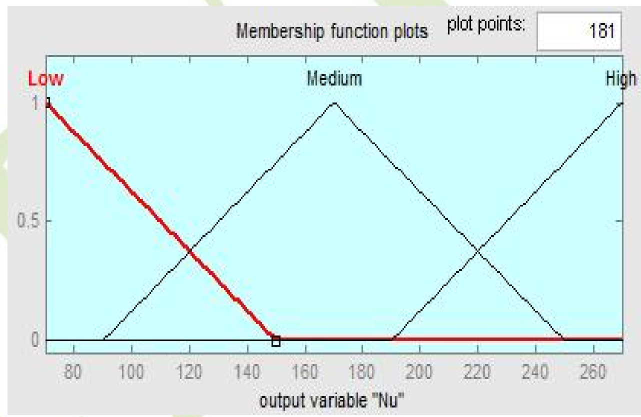



Fig. 6f Membership functions for Nusselt No

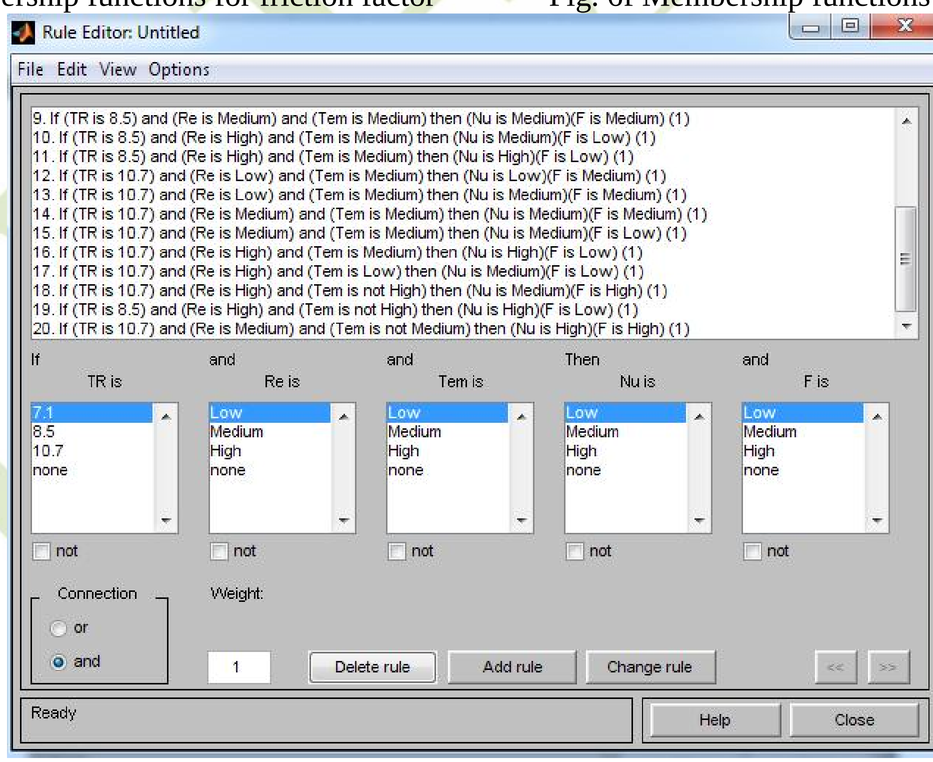



Fig. 6g Rule Editor Window

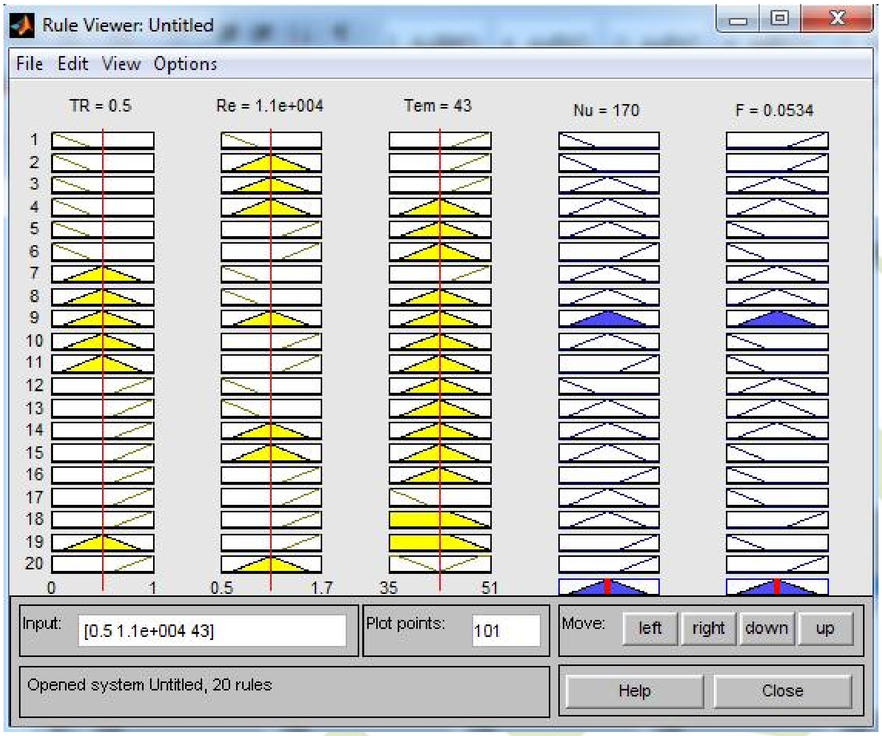



Fig. 6h Rule Viewer Window

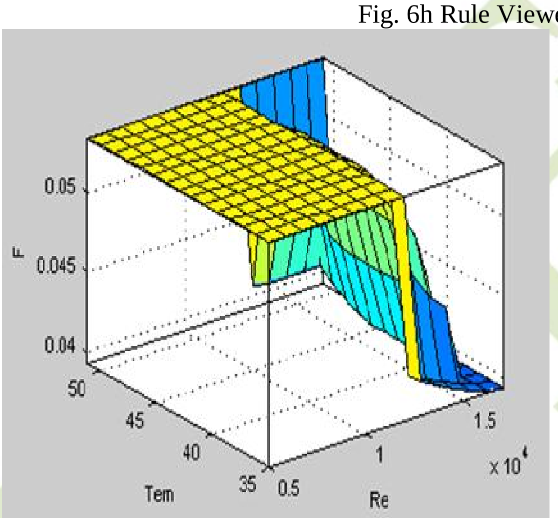



Fig. 6i I.P. Variable Re, Tem with output variable f

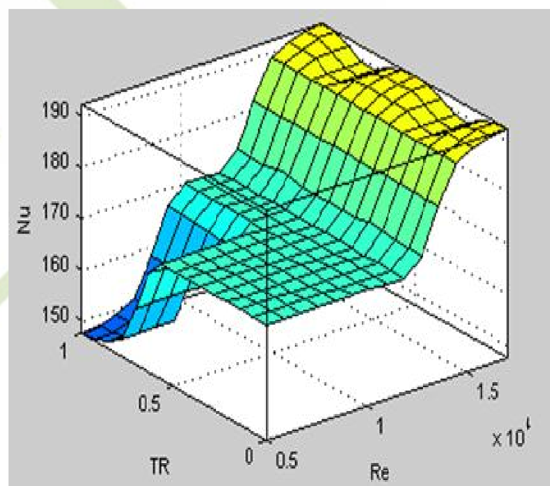



Fig. 6j I.P. Variable Re, TR with output variable Nu

## *Conclusion*

The highest heat transfer rate was achieved for twist ratio 7.1. In comparison with plain tube all wavy twisted tape inserts would significantly enhance the heat transfer rate. The more twist increased the heat transfer and decreased the friction factor. From this experimental study the results can be concluded as follows, The Nusselt number for wavy twisted tape insert with twist ratio 10.7, 8.5 and 7.1 was found to be 75.75 %, 157 % and 172 % respectively and the Friction factor is increased approximately by 9.4 %, 22.44 % and 32.11 % with twist ratio 10.7, 8.5 and 7.1 respectively. The Fuzzy logic is an effective method for the prediction of results due to its high accuracy so that it can be used to model the experiments precisely.

## *Nomenclatures*

| | | | |
|---|---|---|---|
| As | Lateral surface area of tube, $m^2$ | Re | Reynolds number |
| Cp | Specific heat, J/Kg K | V | Mean velocity of water |
| f | Friction factor | L | Length of inner tube |
| h | Heat transfer coefficient, $W/m^2K$ | ν | Kinematic viscosity of water |
| k | Thermal conductivity, W/mK | ρ | Density of water |
| Nu | Nusselt number | Pr | Prandle number |
| ΔP | Prassure drop | I.P | Input put |
| TR | Twist Ratio | FL | Fuzzy logic |

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