# Modeling of the free convection heat transfer from an isothermal horizontal cylinder in a vertical channel via the fuzzy logic

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**ABSTRACT**

In this paper fuzzy logic has been used to model and predict the experimental results of free convection heat transfer from an isothermal horizontal cylinder confined between two adiabatic walls. Experiments included vertical position of the cylinder ranging from 0 to 5 cylinder diameter. Also, Rayleigh number based on the cylinder diameter varied from $3.5 \times 10^3$ to $1.4 \times 10^4$. Experimental results showed that, at each Rayleigh number there exists an optimum vertical position for the cylinder which maximizes the Nusselt number. The value of the optimum vertical position increases as the Rayleigh number increases. A fuzzy inference system named Mamdani was used to expect the output membership functions to be fuzzy sets. It has been shown that fuzzy logic is a powerful instrument for predicting the experiments due to its low error. The average error of fuzzy prediction with respect to experimental data was found to be 0.1% for this study.

Keywords: Free convection; Horizontal cylinder; Mach-Zehnder Interferometer; Vertical channel; Fuzzy logic

## 1. INTRODUCTION

### 1.1. FREE CONVECTION FROM A CONFINED CYLINDER

Free convection heat transfer from an isothermal cylinder is an important field of heat transfer study. Some of its engineering applications are heat exchangers, solar collectors, electronic component, refrigerator condensers, etc. The effect of confining walls on the heat transfer coefficient from circular cylinder has been studied by some researchers. Free convection from a confined cylinder has been studied experimentally and numerically by many researchers [1–6]. Recently, Yousefi et al. [7] have studied the free convection from an isothermal horizontal cylinder in a vertical channel. The aim of that paper was to investigate the effect of vertical position of the cylinder on free convection heat transfer from the confined cylinder. They found that, at each Rayleigh number there exists an optimum vertical position for the cylinder which

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maximizes the Nusselt number. The main focus of the present study is to utilize fuzzy logic to model the free convection heat transfer from the confined horizontal cylinder. The experiments have been carried out using a Mach–Zehnder interferometer. The diameter of cylinder is 19.5 mm. The walls spacing was kept constant to 1.5 cylinder diameter. The walls dimensions are 360 × 8 × 195 mm. A schematic representation of the problem is shown in figure 1. The cylinder diameter *D*, the height of the walls *H*, the walls spacing *W*, and distance between the center of cylinder and bottom of the walls *Y* are represented in this figure.

## 1.2. FUZZY LOGIC

Fuzzy logic is a method which can be used to model the experiments, and it was introduced for the first time in 1965 by Zadeh [8]. Modeling of experiments can be helpful to reduce its costs. By using the models, we can predict results of experiments which have not been performed or are not possible to be performed 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 logic as it can be seen from figure 2 consists of four major parts: Fuzzification interface, Fuzzy rule base, Fuzzy inference engine, and defuzzification interface. A fuzzification operator has the effect of transforming crisp data into fuzzy sets. A fuzzy rule represents a fuzzy relation between two fuzzy sets. It takes a form such as; *if x is A then y is B*. Each fuzzy set is characterized by suitable membership functions. A fuzzy rule base contains a set of fuzzy rules, where each rule may have multiple inputs and multiple outputs. Fuzzy inferencing can be realized by utilizing a set of fuzzy operations. The defuzzification interface mixes and converts fuzzy membership functions into significant numerical outputs. Depending on the types of inference operations upon if-then rules, three types of fuzzy inference systems have been widely employed in various applications: Mamdani fuzzy models [9], Sugeno fuzzy models [10], and Tsukamoto fuzzy models [11]. The difference between these models is related to consequents of their fuzzy rules. Other properties of these

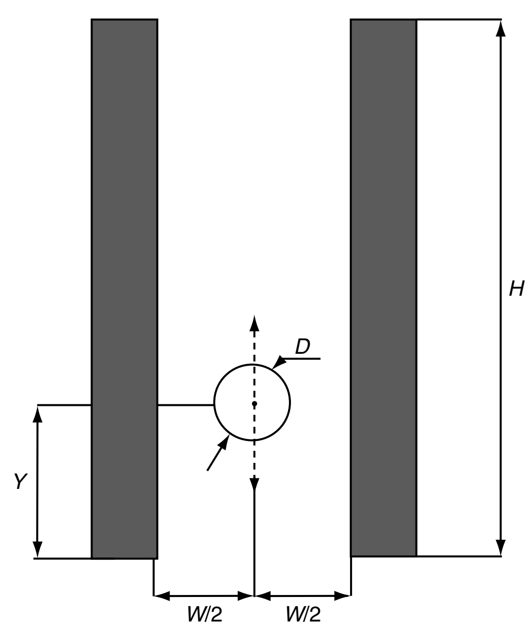


Figure 1 Schematic of the problem.

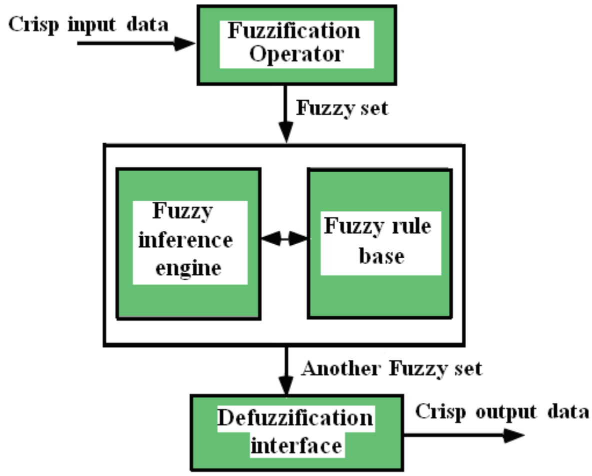


Figure 2 Schematic view of the performance of a simple fuzzy model.

models can be found in references [12]. The fuzzy system which has been used here is Mamdani. After parameters classification, the rules for fuzzy systems must be defined. For example: if Ra is $\alpha$, and $\theta$ is $\beta$, then Nu is $\gamma$. Where $\alpha$, $\beta$, and $\gamma$ are arbitrary parameters.

## 2. EXPERIMENTAL SETUP

### 2.1. INTERFEROMETER

The experimental study was carried out using Mach-Zehnder interferometry (MZI) technique [7]. The interferometer consists of a light source, a micro lens, a pinhole, two doublets, three mirrors and two beam splitters. Figure 3 shows the interferometer setup. Beam splitters $BS_1$ and $BS_2$, along with plane mirrors $M_1$ and $M_2$ constituted the basic MZI. More details about MZI can be found in [13, 14]. The light source which was used is a 10 mW helium–neon laser with $k = 632.8$ nm. All the interferograms were digitized with a "ARTCAM-320P1/200" CCD

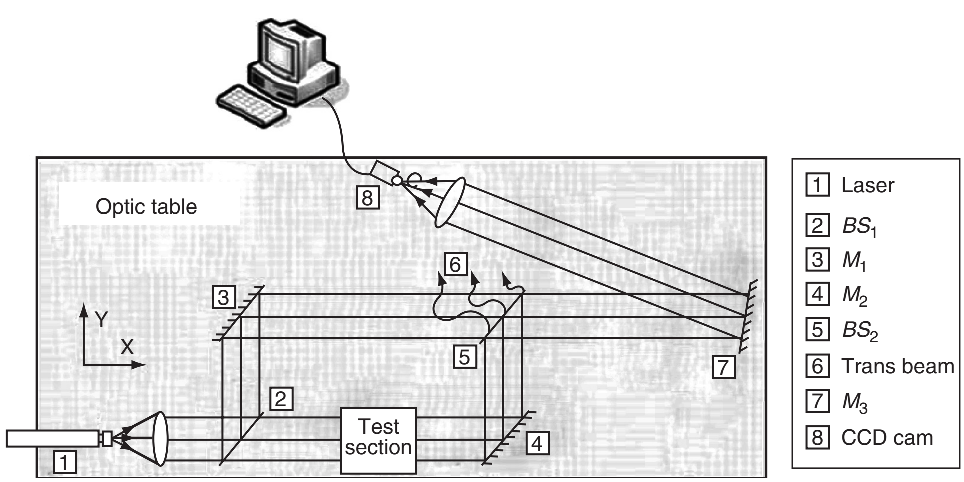


Figure 3 Schematic of (MZI) setup.

camera with 3.2 M pixels. To acquire the interferograms the camera was connected to a PC. Figure 4 shows one of the images which is recorded by the CCD camera. Local Nusselt numbers at each cylinder surface were obtained using infinite fringe mode, where the fringes correspond directly to isotherms in the flow field.

## 2.2. EXPERIMENT TEST SECTION

The details of 19.5 mm diameter aluminum cylinder used in the array [7] with the heating circuit are shown schematically in Figure 5. The length of each cylinder was chosen as 340 mm which causes the induced flow to be two dimensional. Also wooden end caps with

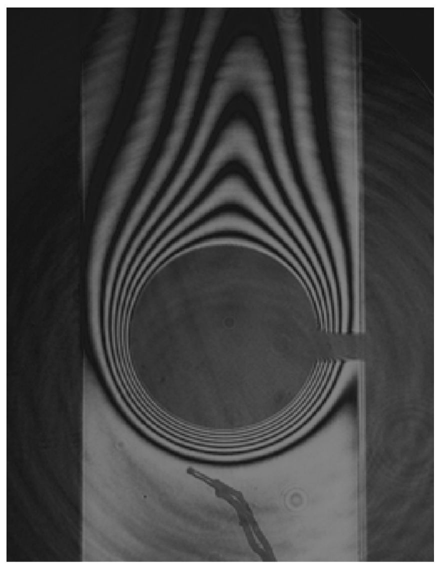

Figure 4 Interferogram of the cylinder for $Ra = 8 \times 10^3$ and $Y/D = 2$ [7].

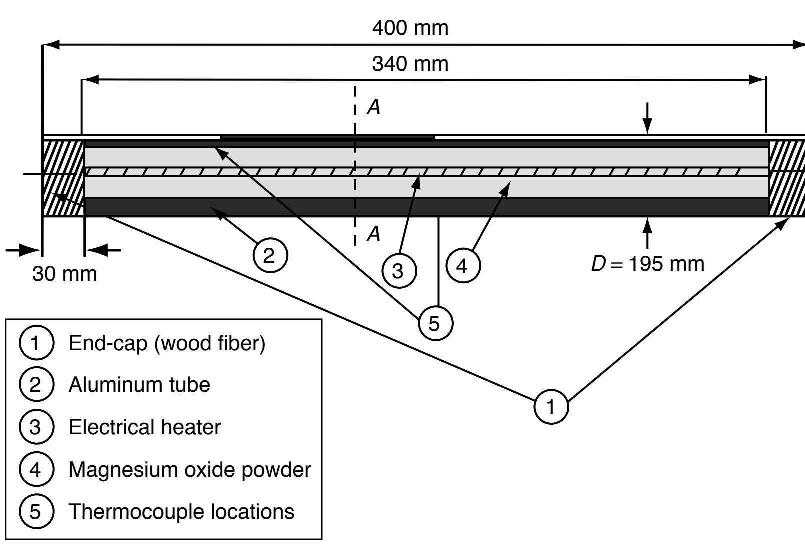


Figure 5 Details of the cylinder used in the experiments [7].

thermal conductivity of 0.05 W/m.K [15] were installed on each cylinder bases to minimize the end effects. The surfaces of the cylinders were highly polished to assure smoothness and the reduction of radiation heat transfer. Cylinders were hollow; therefore electric heaters could be placed inside them and they were filled with magnesium oxide powder. By passing electricity through each heater by a 20V-2A DC power supply and considering relatively thick walled aluminum tubes, constant surface temperature could be achieved. The local surface temperatures of the heated cylinders were recorded via two type *K* thermocouples, embedded axially in the cylinder wall (see Figure 5). Their junctions were 60 mm and 170 mm far from ends. Two other thermocouples of the same type were used to measure the ambient and the reference temperatures for data reduction. All the temperatures were monitored continuously in a PC by a selector switch and a "TESTO 177" four channel data logger.

## 3. RESULTS ANALYSIS AND DISCUSSION

Figure 6 shows the enhancement of the heat transfer from the confined horizontal cylinder with respect to its infinite medium case. The maximum value of increase, which is occurs at the optimum vertical position of the cylinder, is approximately 29%. The aim of this study was to consider the effects of two main factors, Rayleigh number and vertical position of the cylinder on average heat transfer from the horizontal cylinder confined between two adiabatic walls via the use of fuzzy logic. In order to perform fuzzy logic, input and output variables with their levels must be determined. Rayleigh number ($Ra$) in four levels ranging from $3.5 \times 10^3$ to $1.4 \times 10^4$, vertical position of the cylinder in five levels from 0 to 5 cylinder diameter as input variables, and average Nusselt number of the confined cylinder ($Nu_{conf}$) as output variable were chosen. After data reduction, the values of average Nusselt number for

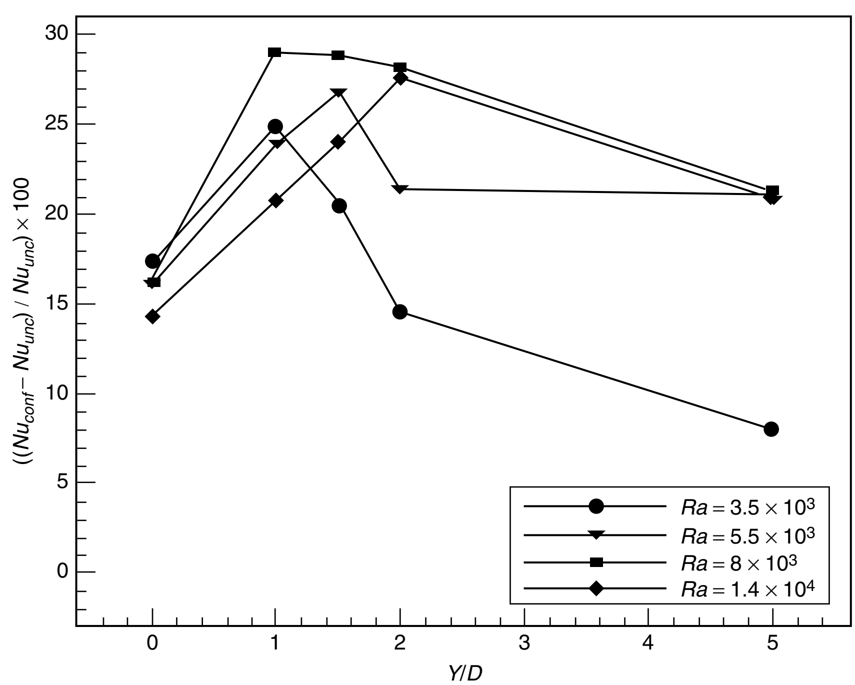


Figure 6 Percent increase of the average Nusselt number of the confined cylinder with respect to its infinite medium case.

twenty different tests were determined. The fuzzy inference system, Mamdani, used in this study is shown in figure 7. Symmetric triangular membership functions [16] for input and output variables were defined. Figures 8 and 9 show membership functions for inputs, i.e.

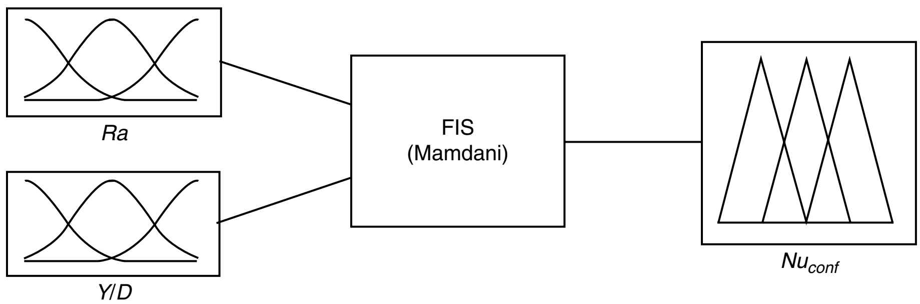


Figure 7 Mamdani system used.

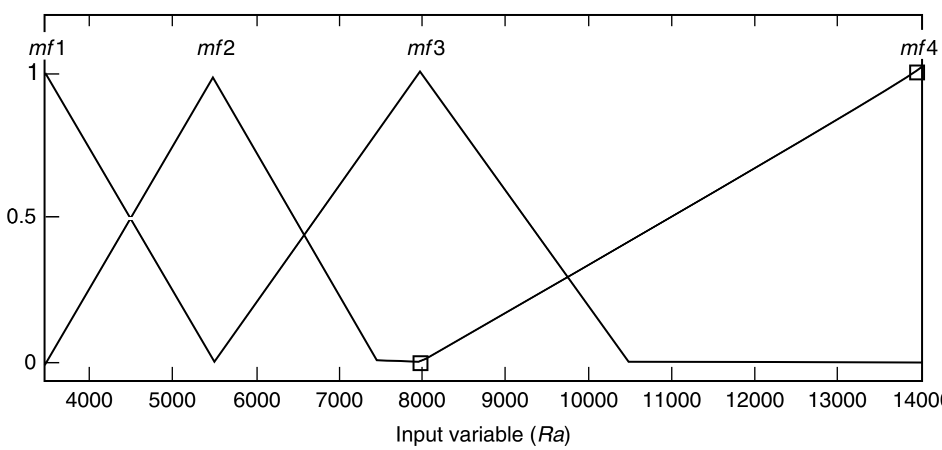


Figure 8 Membership functions of the Rayleigh number.

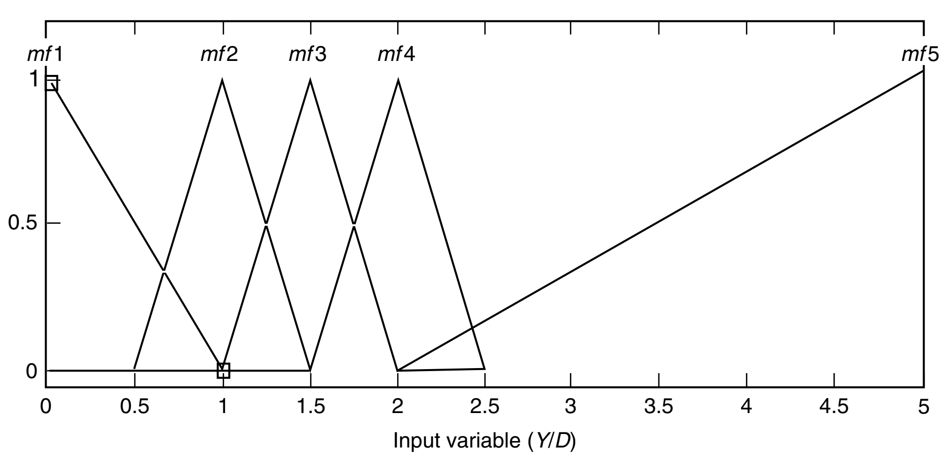


Figure 9 Membership functions of the vertical position of the cylinder to its diameter.

Rayleigh number and vertical position of the cylinder. Membership functions of average Nusselt number are shown in figure10. Some parts of twenty rules which were chosen for the fuzzy model are shown in table 1. The values of the Nusselt number and errors of the fuzzy model prediction with respect to experimental results are shown in table 2. As it can be seen

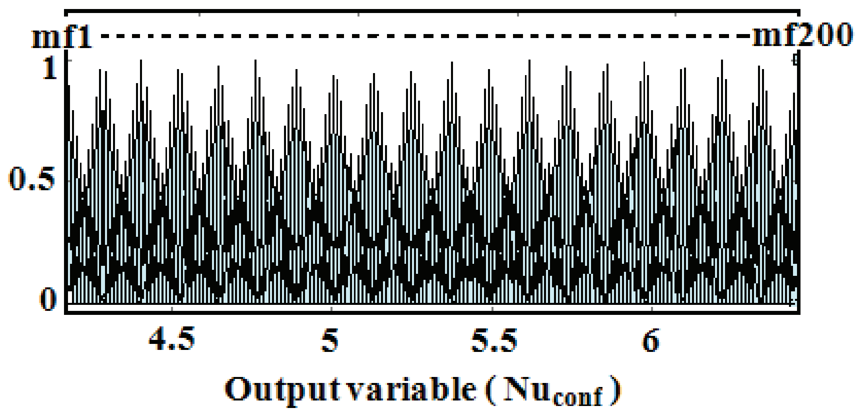


Figure 10 Membership functions of the average Nusselt number.

Table 1 Parts of rules involved in fuzzy model.

| No | Rules | No | Rules |
|---|---|---|---|
| 1 | If (*Ra* is *mf*1) and (*Y*/*D* is *mf*1) then ($Nu_{conf}$ is *mf* 33) | 5 | If (*Ra* is *mf*3) and (*Y*/*D* is *mf*1) then ($Nu_{conf}$ is *mf* 98) |
| 2 | If (*Ra* is *mf*1) and (*Y*/*D* is *mf*4) then ($Nu_{conf}$ is *mf* 23) | 6 | If (*Ra* is *mf*3) and (*Y*/*D* is *mf*3) then ($Nu_{conf}$ is *mf* 149) |
| 3 | If (*Ra* is *mf* 2) and (Y/D is *mf*1) then ($Nu_{conf}$ is mf66) | 7 | If (*Ra* is *mf*4) and (*Y*/*D* is *mf* 1) then ($Nu_{conf}$ is *mf* 142) |
| 4 | If (Ra is *mf* 2) and (*Y*/*D* is *mf*3) then ($Nu_{conf}$ is *mf* 105) | 8 | If (*Ra* is *mf*4) and (*Y*/*D* is *mf* 5) then ($Nu_{conf}$ is *mf* 171) |

Table 2 Comparison of average heat flux from fuzzy results and experiments.

| No | Experimental results | Fuzzy logic predictions | Error% = (predicted – experimental)/ experimental × 100 | No | Experimental results | Fuzzy logic predictions | Error% = (predicted – experimental)/ experimental × 100 |
|---|---|---|---|---|---|---|---|
| 1 | 4.530 | 4.53 | 0.00 | 11 | 5.287 | 5.29 | 0.06 |
| 2 | 4.818 | 4.81 | 0.16 | 12 | 5.872 | 5.86 | 0.20 |
| 3 | 4.651 | 4.65 | 0.02 | 13 | 5.863 | 5.86 | 0.05 |
| 4 | 4.424 | 4.42 | 0.09 | 14 | 5.833 | 5.84 | 0.12 |
| 5 | 4.166 | 4.17 | 0.09 | 15 | 5.515 | 5.52 | 0.09 |
| 6 | 4.909 | 4.92 | 0.22 | 16 | 5.787 | 5.79 | 0.05 |
| 7 | 5.242 | 5.24 | 0.04 | 17 | 6.106 | 6.11 | 0.06 |
| 8 | 5.363 | 5.36 | 0.06 | 18 | 6.272 | 6.27 | 0.03 |
| 9 | 5.133 | 5.13 | 0.06 | 19 | 6.454 | 6.45 | 0.07 |
| 10 | 5.121 | 5.13 | 0.17 | 20 | 6.121 | 6.11 | 0.18 |

from this table and figure 11, the average and maximum errors are 0.1% and 0.2% respectively. Therefore the experimental results are in good agreement with the predicted one by fuzzy model, which shows that, fuzzy logic is a reliable method to predict the Nusselt number. According to figure 12, which is obtained from fuzzy logic analysis, it can be observed that the average Nusselt number of the cylinder increases with the increase of the Rayleigh number at each vertical position. At each Rayleigh number, there exists an

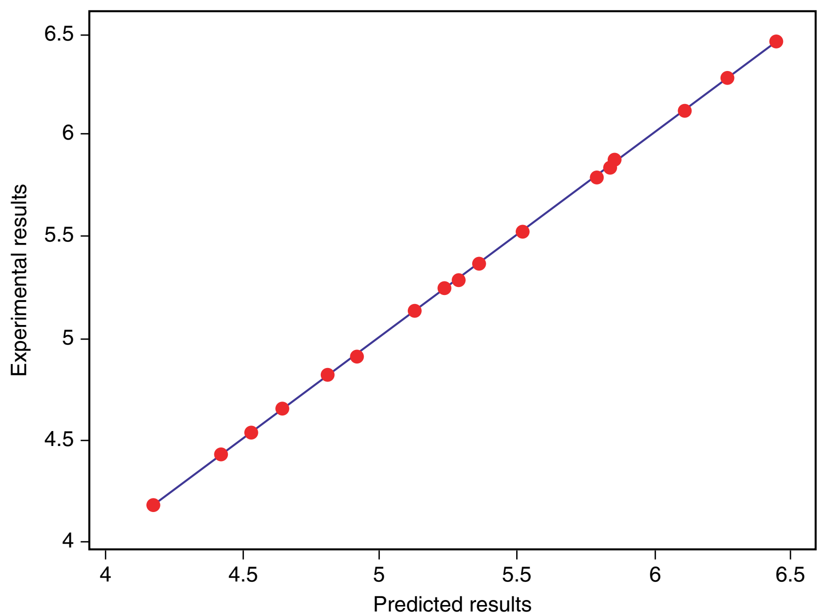


Figure 11 Comparison of experimental Nusselt number versus predicted Nusselt number.

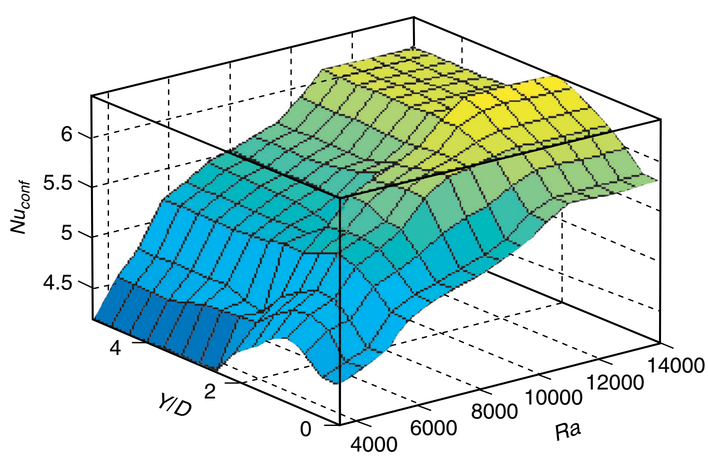


Figure 12 Effect of Rayleigh number and the vertical position of cylinder on average Nusselt number.

optimum vertical position, where the heat transfer from the cylinder is maximum. It can be deduced that the fluid has been guided better to pass over the cylinder at the optimum *Y/D* ratio. Also figure 12 indicates that the decrease of the cylinder vertical position or *Y/D* ratio from its optimum value for each Rayleigh number causes a sharp decrease in the Nusselt number. This can be due to the shorter distances between the bottom of the walls and cylinder and weakness of the chimney effect. The chimney effect become maximum at the optimum *Y/D* ratio, and after this point the chimney effect become weaker because of the interference of boundary layer over the tube and confined walls. It can be seen that the values of the optimum *Y/D* ratio are not the same for each Rayleigh number and indicated an increasing behavior from the value of 1 to 2 for the $Ra = 3.5 \times 10^3$ to $Ra = 1.4 \times 10^4$, respectively. This shift in optimum *Y/D* ratio from low to high Rayleigh numbers is due to the thinning of the boundary layer on the cylinder. Therefore maximum Nusselt number has occurred at longer distances from the bottom of the walls.

## 4. CONCLUSIONS

The prediction of experimental results of free convection heat transfer from the horizontal cylinder confined between two adiabatic walls was investigated by the use of fuzzy logic. This method was used to gain relationship between two input parameters namely Rayleigh number, the vertical position of the cylinder and an output variable, average Nusselt number. Experiments have been carried out using a Mach-Zehnder interferometer. The effects of Rayleigh number and the vertical position of the cylinder on free convection heat transfer from the confined cylinder between two walls were studied. It was observed that, at each Rayleigh number there exists an optimum vertical position for the cylinder in which the Nusselt number is maximum. Another main result of this study is that fuzzy logic is a reliable method for the prediction of results due to its high accuracy and can be used to model the experiments precisely.

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## NOMENCLATURE

| | |
|---|---|
| $D$ | diameter of circular cylinder ($m$) |
| $g$ | gravitational acceleration ($m/s^2$) |
| $H$ | height of adiabatic walls ($m$) |
| $mf$ | membership function |
| $Nu_{conf}$ | average Nusselt number of the cylinder confined (confined cylinder) between two adiabatic walls |
| $Nu_{unc}$ | average Nusselt number of the cylinder in an (unconfined cylinder) infinite medium |
| $Ra$ | Rayleigh number based on the cylinder diameter $g\beta(T_w - T_\infty)D^3/\alpha\nu$ |
| $T$ | temperature ($K$) |
| $W$ | wall spacing ($mm$) |
| $Y$ | vertical distance from bottom of the walls and center of the cylinder |

### Greek Symbols

| | |
|---|---|
| $\alpha$ | thermal diffusivity ($m/s^2$) |
| $\beta$ | volumetric expansion coefficient ($1/K$) |
| $\nu$ | kinematic viscosity ($m/s^2$) |

### Subscripts

| | |
|---|---|
| $\infty$ | ambient condition |
| w | at the cylinder surface |