Modeling the Free Convection Heat Transfer in a Partitioned Cavity by the Use of Fuzzy Logic

T. Yousefi, A. Karami, S. Mahmoudinezhad, M. Mahdipour Jalilian, and M. Ahmadi

Abstract—**In this paper fuzzy logic method has been used to model and predict the experimental results of steady free convection heat transfer in a partitioned cavity with adiabatic, horizontal and isothermally vertical walls and an adiabatic partition. Experiments covered Rayleigh number ranging from 1.5×10^5 to 4.5×10^5 and the angle of the partition with respect to horizon from 0° to 90°. Results indicate that, at a constant angle of the adiabatic partition, the average Nusselt number and consequently heat transfer increases with the increase of Rayleigh number and at a constant Rayleigh number, the maximum and minimum heat transfer occurs at the partition angle of 45° and 90°, respectively. Velocity contours from a commercial code, Fluent, has been used to analyze the variation of heat transfer in the cavity. 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 tool for predicting the experiments, due to its low error. The average error of fuzzy predictions with respect to experimental results was found to be 0.37% for this study.**

***Index Terms*—Free convection, partitioned cavity, interferometry, mach-zehnder, fuzzy logic, mamdani inference system.**

I. Introduction

A. Free Convection Heat Transfer in a Partitioned Cavity

The study of natural convection heat transfer is important because of its usage in many engineering applications. It has vast applications on solar energy systems, cooling of electronic circuits, air conditioning, and in many other fields. Natural convection in a partitioned cavity has been widely investigated numerically and experimentally because of its interest and its importance in industrial applications, such as solar collectors, fire research, electronic cooling, aeronautics, fenestration systems and building engineering. Most of the studies in this field are substantially oriented toward the study of natural convection in enclosed square or rectangular cavities. Many researchers have studied the free convection heat transfer in partitioned cavities [1-8]. Also, Yousefi et al. [9] studied the effect of partition angle on free convection heat transfer in a partitioned cavity by laser interferometry method. They found that, maximum and minimum values of heat transfer occurred at the diverter angle of 45° and 90°, respectively. The aim of that paper was to investigate the effect of partition angle on free convection heat transfer in the partitioned cavity experimentally using Mach-Zehnder interferometer.

The aim of the present study is to use fuzzy logic in predicting the effect of partition angle and Rayleigh number on laminar free convection heat transfer from vertical hot wall of an air filled cavity. The experiments are carried out using Mach–Zehnder interferometer. A scheme of the problem can be found in Figure. 1. The partition length L, partition width W, cavity side length H, angle of the partition θ, and boundary conditions associated with this problem are shown in this figure.

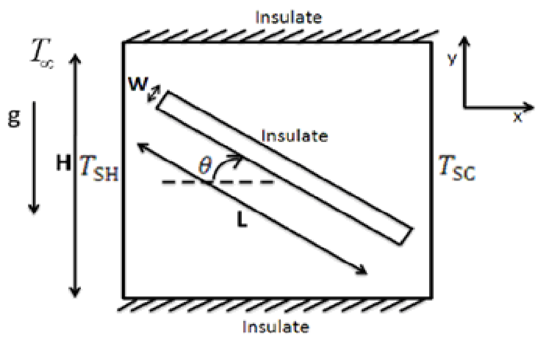

Fig. 1. Model geometry of the partitioned cavity [9]

B. Fuzzy Logic

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 [10]. 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 logic as it can be seen from Figure. 2, consists from 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

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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 [11], Sugeno fuzzy models [12], and Tsukamoto fuzzy models [13]. The difference between these models is related to consequents of their fuzzy rules. Other properties of these models can be found in reference [14]. 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 α, and θ is β, then Nu is γ. Where α, β and γ are arbitrary parameters.

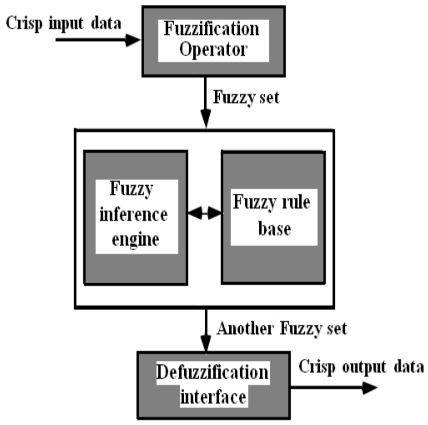


Fig. 2. Schematic view of the performance of a simple fuzzy model

II. Experimental Setup

A. Interferometer

The experimental study was carried out using Mach–Zehnder interferometry (MZI) technique. The interferometer consists of a light source, a micro lens, a pinhole, two doublets, three mirrors and two beam splitters. Figure. 3 show the interferometer setup. Beam splitters BS_1 and BS_2, along with plane mirrors M_1 and M_2 constituted the basic MZI. The laser beam gets expanded after passing through spatial filter and the Doublet1. The expanded beam is split into two equal beams by BS_1. One beam passes through the test section and the other through the undisturbed field. These two beams again recombine at BS_2. The light source which was used is a 10 mW Helium–Neon laser with a 632.8 nm wavelength. All the interferograms were digitized with a ‘‘ARTCAM-320P’’ 1/2″ CCD camera with 3.2 M pixels. To acquire the interferograms the camera was connected to a PC.

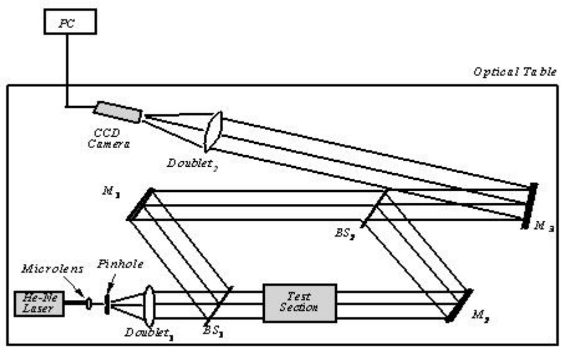


Fig. 3. Plane view of the Mach–Zehnder setup [9]

B. Experiment Test Section

The details of the partition cavity used in the experiments are shown schematically in Figure. 4. The length of each isothermal wall was chosen to be 100 mm which is enough for the induced flow to be two-dimensional. Also wooden end caps with thermal conductivity of 0.05 W/m K [15], were installed on each aluminum plate bases to minimize the end effects. By passing electricity through each heater that placed back of each aluminum plate and considering relatively thick-walled aluminum plate, constant surface temperature was achieved. The local surface temperatures of each heated aluminum plate were recorded via K-type thermocouples, embedded vertically in 3 different locations of the aluminum plate, as shown in Figure. 4. The differences in measured temperature for each aluminum plate surface were about 0.1˚C. Two other K-type thermocouples were used to measure the ambient and the Reference temperatures which are needed for data reduction. All the temperatures were monitored continuously in a PC and a calibrated ‘‘TESTO 177 T4’’ four-channel data logger. The laboratory pressure was recorded during all the experiments. In all the experimental runs the heater voltage and current was recorded. Two windows were used on both side of the cavity to prevent external air to enter to the cavity.

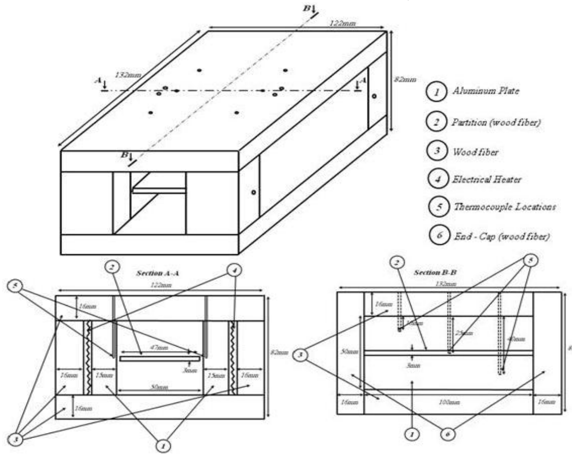


Fig . 4. Details of the partition cavity used in the experiments [9].

III. Uncertainly Analysis

Uncertainty analysis has been carried out using the method proposed in [9, 16, 17]. The standard uncertainties in the gas constant, the thermal conductivity values, the fringe shift and the Helium-Neon laser wave length have been neglected. The uncertainties of the parameters ambient temperature, wall temperatures and ambient pressure can be estimated from the measuring devices precision and the uncertainty of the cavity sides measuring devices. The uncertainty of the difference of horizontal distances of fringes from the surface is other important parameter. Using these uncertainties, the uncertainty in the measurement of local Nusselt numbers has been evaluated to be 3.2 ±0.9%.

IV. Results Analysis and Discussion

The aim of this study is to consider the effect of two main factors, Rayleigh number based on cavity side wall length, H, and partition angle, θ ,on heat transfer in the partitioned cavity, via the use of fuzzy logic. In order to perform fuzzy logic, input and output variables with their levels must be determined. Rayleigh number in five levels ranging from 1.5×10^5 to 4.5×10^5, partition angle from 0° to 90°, as input variables and average Nusselt number as output variable were chosen. After data reduction, the values of average Nusselt number for thirty five different tests were determined. The fuzzy inference system, Mamdani, used in this study is shown in Figure. 5. Symmetric triangular membership functions [18] for input and output variables were defined. Figures 6 and 7, show membership functions for inputs, i.e. Rayleigh number (Ra) and partition angle (θ). Membership functions of average Nusselt number (Nu) are brought in Figure. 8. Some parts of thirty five rules, which were chosen for the fuzzy model, are shown in Table 1. The values of average Nusselt number and errors of the fuzzy model with respect to experimental results are also shown in Table 2. As it can be seen from this table and Figure.9, the average error is 0.37%. Therefore the experimental results are in good agreement with predicted one by fuzzy model, which shows that, the fuzzy logic is a reliable method to predict the average Nusselt number. According to Figure 10, which is obtained from fuzzy analysis, an increasing trend for the average Nusselt number and consequently heat transfer, with respect to Rayleigh number can be observed. Another concept which can be understood from this figure, is that, the maximum heat transfer occurs at θ=45° and the minimum average Nusselt number occurs at θ=90˚. This can be described by preventing of air flow through the cavity at θ=90˚ and strong flow with high speed near the wall at θ=45˚. In addition, as it can be seen from the velocity contours of Figure11, at θ=0˚, partition divide the cavity into two equal parts that each part have a rotational and strong flow that causes the average Nusselt number in θ=0˚ be greater than the average Nusselt number in θ=15˚. With increasing the angle of the partition from θ=0˚ to θ=15˚, some of air flow passes through the distance between the partition and heated wall. With increasing the angle of the partition from θ=15˚ to θ=45˚, this gap is increased and air can pass through this gap easier. With increasing the angle of the partition from θ=45˚ to θ=90˚, the distance between the partition and adiabatic walls is decreased and the circulating flow of air is reduced strongly because of insulating of heated wall from cold wall.

TABLE I. PARTS OF RULES INVOLVED IN FUZZY MODEL

No	Rules	No	Rules
1	If (Ra is mf1) and (θ is mf1) then (Nu is mf 46)	7	If (Ra is mf3) and (θ is mf5) then (Nu is mf74)
2	If (Ra is mf1) and (θ is mf4) then (Nu is mf 63)	8	If (Ra is mf4) and (θ is mf1) then (Nu is mf78)
3	If (Ra is mf1) and (θ is mf7) then (Nu is mf1)	9	If (Ra is mf4) and (θ is mf4) then (Nu is mf92)
4	If (Ra is mf2) and (θ is mf3) then (Nu is mf64)	10	If (Ra is mf4) and (θ is mf7) then (Nu is mf31)
5	If (Ra is mf2) and (θ is mf6) then (Nu is mf32)	11	If (Ra is mf5) and (θ is mf3) then (Nu is mf99)
6	If (Ra is mf3) and (θ is mf2) then (Nu is mf58)	12	If (Ra is mf5) and (θ is mf6) then (Nu is mf66)

TABLE II. COMPARISON OF AVERAGE NUSSLE NUMBER FROM FUZZY RESULTS AND EXPRIMENTS

No	Experimental Nusselt	Predicted Nusselt	Error%= (Experimental -Predicted)/ Predicted	No	Experimental Nusselt	Predicted Nusselt	Error%= (Experimental -Predicted)/ Predicted
1	8.4536	8.39	0.75	19	11.9466	11.9	0.39
2	7.2632	7.27	0.09	20	8.30500	8.27	0.42
3	9.5079	9.53	0.23	21	4.93870	4.88	1.18
4	10.5254	10.50	0.24	22	12.4030	12.4	0.02
5	8.6875	8.65	0.43	23	11.5620	11.5	0.53
6	5.1557	5.14	0.30	24	13.8095	13.8	0.06
7	2.7528	2.75	0.10	25	14.1643	14.2	0.25
8	9.6306	9.65	0.20	26	13.4135	13.4	0.10
9	8.1588	8.15	0.10	27	10.1717	10.2	0.28
10	10.6133	10.7	0.81	28	6.47900	6.52	0.63
11	11.8893	11.9	0.08	29	13.1377	13.2	0.47
12	10.1799	10.2	0.19	30	12.3310	12.3	1.06
13	6.6513	6.64	0.17	31	15.0155	15.0	0.10
14	3.5564	3.50	1.58	32	15.1779	15.2	0.14
15	11.3169	11.3	0.15	33	14.2620	14.3	0.26
16	9.8656	9.90	0.35	34	10.8721	10.9	0.25
17	12.308	12.3	0.06	35	7.25300	7.27	0.23
18	13.1339	13.2	0.50				

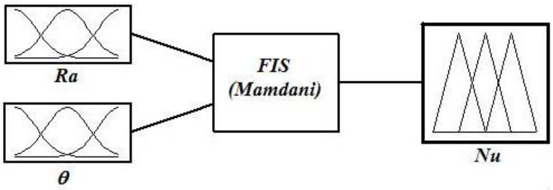


Fig. 5. Mamdani system used

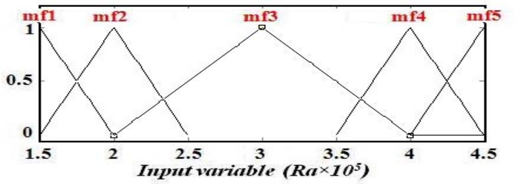


Fig. 6. Membership functions of Rayleigh number

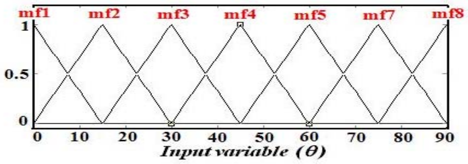


Fig. 7. Membership functions of the partition angle

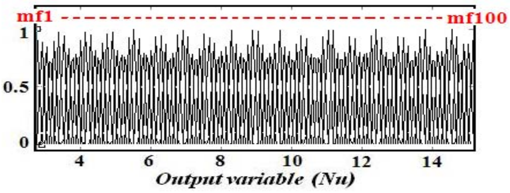


Fig. 8. Membership functions of Nusselt number

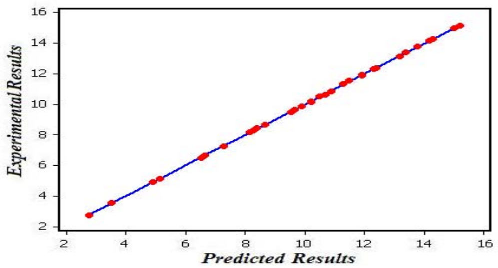


Fig. 9. Comparison of experimental average Nusselt numbers versus predicted Nusselt numbers

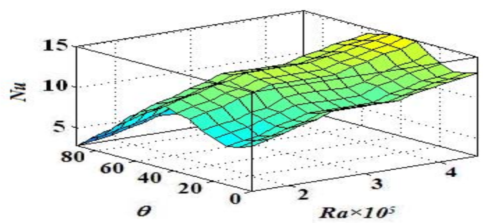
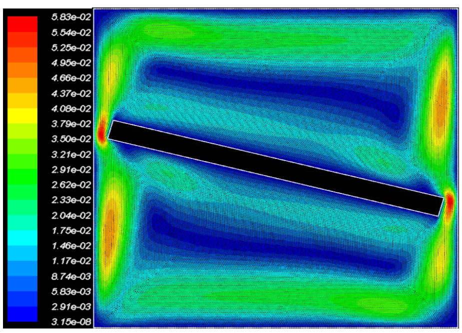
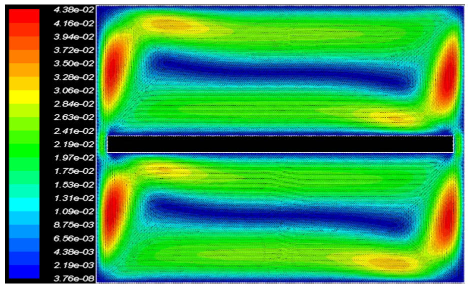


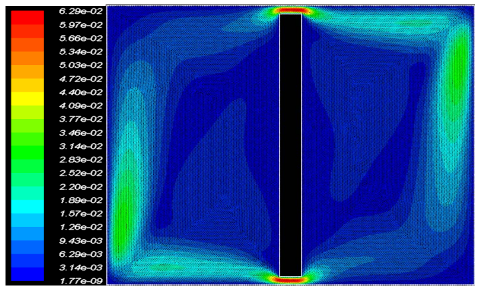
Fig. 10. Effect of Rayleigh number and partition angle on average Nusselt number



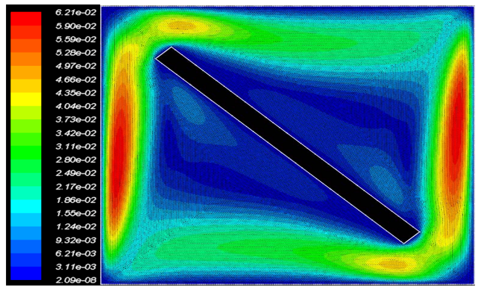
(a)



(b)



(c)



(d)

Fig. 11. Velocity contours at Ra= 300000 for (a) θ=0° (b) θ=15° (c) θ=45° (d) θ=90°

V. Conclusions

The prediction of experimental results of free convection heat transfer in a partitioned cavity with adiabatic horizontal and isothermally vertical walls with adiabatic partition was studied, by the use of fuzzy logic. This method was used to gain relationship between two main parameters namely Rayleigh number, partition angle and an output variable, average Nusselt number. Experiments have been carried out using a Mach-Zehnder interferometer. The effect of different partition angles and Rayleigh numbers on free convection heat transfer in the partitioned cavity was studied. Following results were obtained:

1. Average Nusselt number will increase with the increase of Rayleigh number.
2. The maximum and minimum heat transfer occurs at the partition angle of 45° and 15° respectively.
3. 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.

Nomenclature

g	Gravitational acceleration (m/s^2)
H	Cavity side length (m)
k	Thermal conductivity of air (W/m K)
L	Partition length (m)
mf	Membership function

Nu Average Nusselt number
P Pressure (pa)
R Gas constant (J/kg K)
Ra Rayleigh number based on the cavity side length
T Temperature (K)
W Partition width (m)
x Direction normal to hot surface

Greek symbols
ε Fringe shift
λ Laser wave length (m)
θ Angel of the partition (degree)

Subscripts
f Film condition
ref Reference condition
∞ Ambient condition

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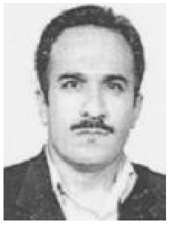

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