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An experimental Investigation for the Effect of the V-cut Baffles in a Grooved Cavity

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ABSTRACT: - V cut baffles are being used inside a cavity in the current study to speed up heat transfer. To conduct testing, rectangular cavity ducts were manufactured and used. For heat flux (4800, 8000 W/m^2), constant heat flux was applied to the cavity's bottom wall. Experiments were conducted on a slew of variables, including Reynolds number, cutting height, and heat flux. Cutting height of 5, 10, and 15 centimeters is maintained, as is the Reynolds number (16000-5000). Using a 15-cm V-cutting baffle at Re=13000 and a heat flux of (4800 W/m^2) increases the Nusselt number by 87.1 percent when compared to the straight baffle while using a 5-cm V-cutting baffle at Re=5000 and a heat flux of (q=4800 W/m^2) in a cavity increases the Nusselt number by (5.4 percent) when compared to the straight baffle. Baffle height of 10cm at Re=5000 and heat flux (q=4800 W/m^2) did not result in any improvement. Another interesting finding is the increase in Nusselt number when using a V-cutting baffle with a heat flux of (q=8000W/m2) and cutting height of 15 cm, and Re=5000, as compared to a straight baffle, which has a heat flux of (q=5000 W/m^2). The average Nusselt number (q=8000W/m^2) can be predicted using empirical correlation.
KEYWORDS: Convection heat transfer, cavity, baffle, cutting baffle.

INTRODUCTION. When it comes to storing cryogenics, heating or ventilating a room [1–3], or protecting a high-temperature system, cavities and enclosures are essential. It is possible to reduce conduction losses by using low emissivity surfaces and cavities in a vacuum [4] for many applications. Adding turbulators to a channel can speed up the flow of heat from one place to another (such as winglets). The shape, angle, and height of the attachment, as well as the distance between them and their location, have all been the subject of numerous studies. The effect of channel ribs on flow and heat transfer rates was studied experimentally by Skullong et al. 2014[5]. An experimental range of between 4000 and 21,000 (Re) was used. These papers show three different P/H ratios (PR = P/H = 0.5, 1, and 2) with an example of BR = b/H = 0.25 as three different R/C heights. Using the ribbed groove at smaller PR results in significantly higher pressure drop and heat transfer enhancements (Nu/Nu0 =4.4–7.69) depending on PR, rib array, and rib spacing, respectively. For the most part, the in-line rib groove has the most influence (Re). Nabil J Yasin et al. 2014[6] conducted an experimental investigation of mixed convection heat transfer to the air inside an enclosure. The top wall oscillates to keep temperatures lower, while the left and right walls are well-insulated to keep temperatures higher. The effect of Richardson number and aspect ratio on the airflow behavior inside the enclosure was studied using this rig. Nusselt numbers (Nuavg) increase with aspect ratios at a constant Richardson number. Sharma et al. 2015[7] investigated numerically the flow structure and heat transfer characteristics in a baffled grooved channel with differentially heated sides. The baffle is positioned vertically from the top wall of the grooved channel geometry to divert outside flow into the square cavity. As the baffle height increased, pumping power and pressure drop increased as well. Sriromreun et al. 2012[8] investigated numerically and experimentally the effect of Z-shape baffle turbulators on increasing heat transfer in a rectangular duct. The isothermal-fluxed chamber's upper wall was covered with zigzag-patterned Z-shaped baffles to aid in heat transfer (4400 - 20,400). The Z-baffle significantly increases friction loss when compared to a smooth channel without a baffle, according to the findings of these experiments. The thermal performance enhancement factor (TEF) of in-phase Z-baffles decreases as Re increases. While maintaining adiabatic conditions on the cavity's other walls, Aya H Yasin et al. (2020)[9] used experimental and numerical methods to investigate the impact of cavity baffles on heat transfer efficiency. To the top wall of a grooved rectangular duct with a cavity, three square baffles are fixed in place as a test rig setup. There is a constant flow of heat into the bottom of the room. The numerical analysis was carried out using ANSYS FLUENT. Researchers examined the impact of baffle placement and number in the (Re) range (4000-16000) and with air at (Pr=0.7) as a working fluid. You can increase (Nu) by 73% if you insert a square baffle into an empty cavity and 60%, 67%, 67% for the baffles placed to the left or center of the cavity respectively. Aun et al. in 2021[10] investigated experimentally and numerically the natural and forced convection heat transfer in an enclosure with a vertical heated block and baffles. The adiabatic walls of the enclosure heat the heating block, which has baffles that extend into the enclosure. All models have heat flux (q) ranging from 240 to 1425 W/m^2, while forced convection heat transfer is 5650 to 15950 W/m^2. In comparison to a plain heating block, partially cut baffles improved performance by 30 percent, according to the findings of the study. experimentation with cutting baffles in cavities has been documented (s). These baffles are used to study heat transfer in a cavity with different heat flux, Reynolds number, and cutting height.

1. Heat flux varies from (4800 to 8000 W/m^2)
2- There is a wide range in the Reynolds number (5000-16000).
3-The variation baffle cutting height is (5, 10, and 15cm).

1- EXPERIMENTAL SETUP. Figs. (1) and (2) show the schematic diagram of the test rig's components, which include baffles, ducts, a heater, a fan, and various measuring tools and devices. Using aluminum, the duct has a cross-sectional area of 25x25 cm, a thickness of 0.4 cm, and a length of (200 cm). To create the cavity, we used an aluminum sheet that measured 25cm by 25cm and was 5mm thick. A heater was used to warm the bottom of the cavity wall.

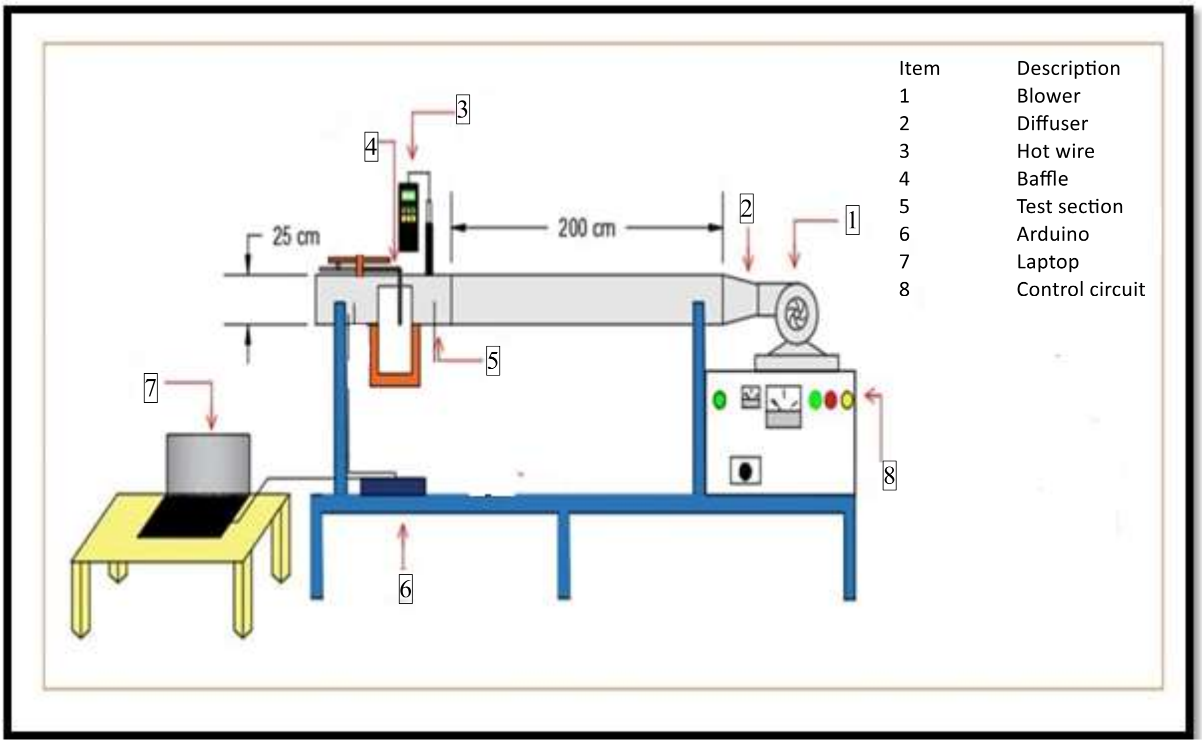


Figure (1) Experimental test rig setup.

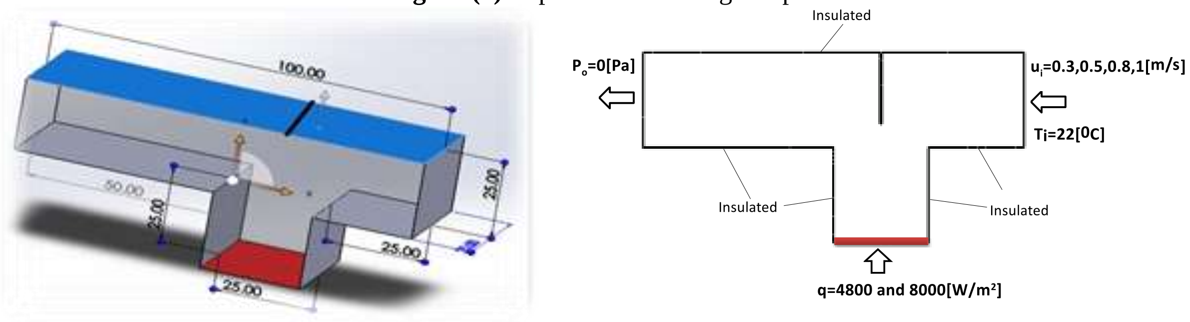


Figure (2) Dimensions and condition of test section (all dimensions in cm).

The baffles are a square plate made from aluminum having a dimension of (25x18.75) cm and (4 mm) thickness which inserted vertically downward inside the cavity from the top wall as shown in Figure (3).

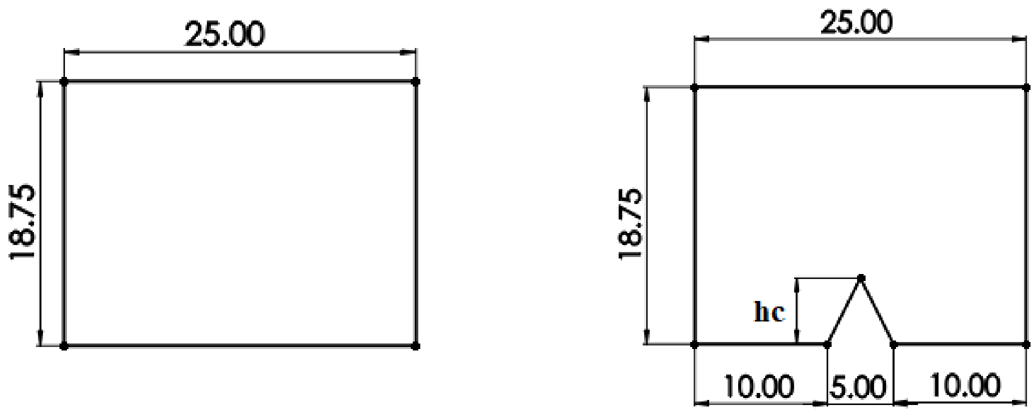


Figure (3) Type of baffles inserted inside the cavity.

In this work, Seventeen K-type thermocouples have been used to measure the temperature distribution inside the test section also to measure the inlet, outlet air, and heater surface temperature. Each thermocouple alone was connected to the Arduino data logger system as shown in Figure (4).

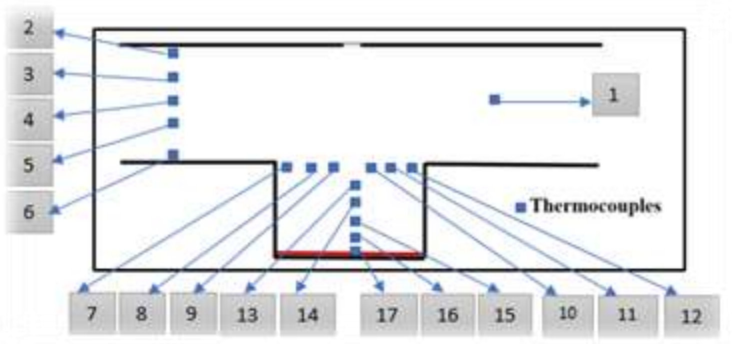
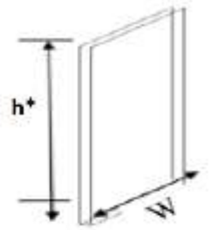


Figure (4) Thermocouples distribution inside thecavity.

A hot-wire anemometer was used to gauge the average air velocity at the inlet section (TES 1341). Experiment results would not be affected by environmental factors such as direct sunlight, vibrations, and temperature fluctuations if the assembled rig was kept at a safe distance from these factors. All of the experiment's measuring devices were calibrated using the same general standard schemes. Measurement precision can be estimated using the [11] method. The calculated value of Nu's uncertainty was (4.8%). Preliminary checks included making sure there were no leaks of conditioned air, turning on and off the heater, and adjusting the fan speed to achieve the desired airflow rate. Previous steps were repeated using ui=0.3,0.5,0.8, and 1 m/s as inlet velocities, respectively. When applying 4800 and 8000W/m^2 heat flux to the bottom wall, various cutting baffle heights (hc=5,10, and15 cm) were employed. The flow is taken into account to be turbulent, incompressible, and to have little viscous dissipation. The fluid's thermophysical properties can be assessed using bulk temperature (T_b). The baffle was cut to a height of hc=5,10, and 15 cm in this study using a square geometrical straight and V-cutting model. The baffles are 25 * 18.75 cm in size and have a thickness of (4mm). A total of nine cases were examined in this experimental investigation; the case details are listed in table (1).

Table (1) Cases under experimental investigation.

Model		h* (cm)	W (cm)	hc (cm)	q (W/m^2)	u_i m/s	b (cm)
Straight baffle		18.75	25	0	4800 8000	0.3 0.5 0.8 1	0.4
V-cut baffle		18.75	25	5 10 15	4800 8000	0.3 0.5 0.8 1	0.4

3- RESULTS & DISCUSSION

3-1 The effect of heat flux and Reynolds number.

This experimental study makes use of a cavity with a straight Baffle to compare and investigate the impact of using a cutting baffle on the flow behavior and heat transfer properties of the fluid. It has already been mentioned that a ratio (h*=0.75H) was used to fix the baffle to the top wall of the cavity (18.75 cm). Heat fluxes of (q= 4800, 8000W/m^2) are shown in Figure (5) for a straight baffled cavity with different values of (Re). The temperature inside the heater decreased as (Re) increased, and the highest temperature was found at the front of the heater. In this way, the incoming air pushes hot air into the cavity, and there is a decrease in the interconnection between air molecules as a result of this. Because of this, hot and cold inlets are mixed and carried away.

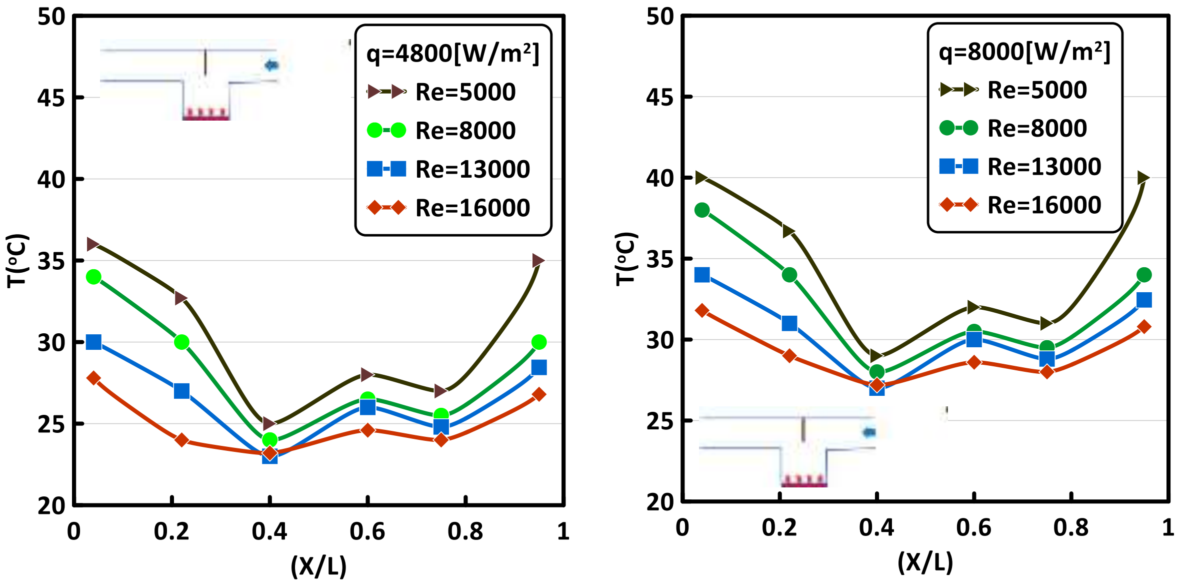


Figure (5) Distribution of temperature along (X/L) of different (Re) and (q) (straight baffle)

In Figure (6) cutting baffle height (hc) has been studied about heat transfer characteristics at various values of hc (Re). When hc=5, 10, 15 cm and q=4800 and 8000 W/m^2 are applied to the V-cutting baffle, the effect on (Re) and on (Nu) is depicted. Increasing the (hc) causes the (Nu) to rise, which is typically due to the effect of a V-cut, which disrupts the flow inside the duct.

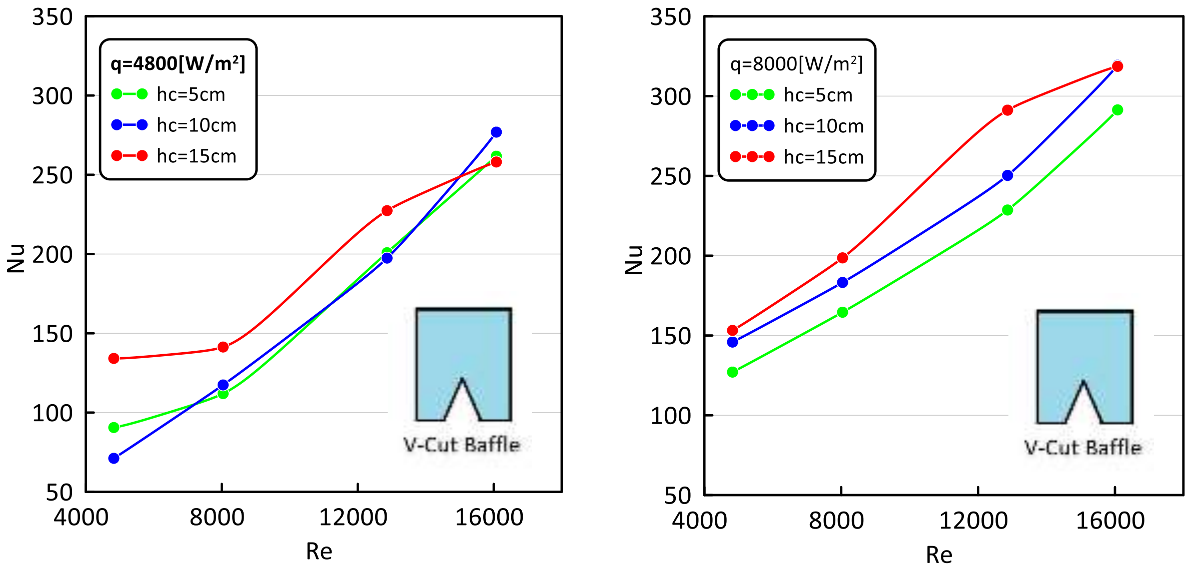


Figure (6) (Nu) versus (Re) for Cavity with the V-cutting baffle at (q=4800, 8000W/m^2).

Figure (7) represents the comparison of (Nu) versus (Re) for Cavity (without baffle, with straight baffle, and the V-cutting baffle) at q=4800, 8000W/m^2 for different values of (hc). It was observed the increases in (Nu) with cutting baffle as compared without and straight baffle.

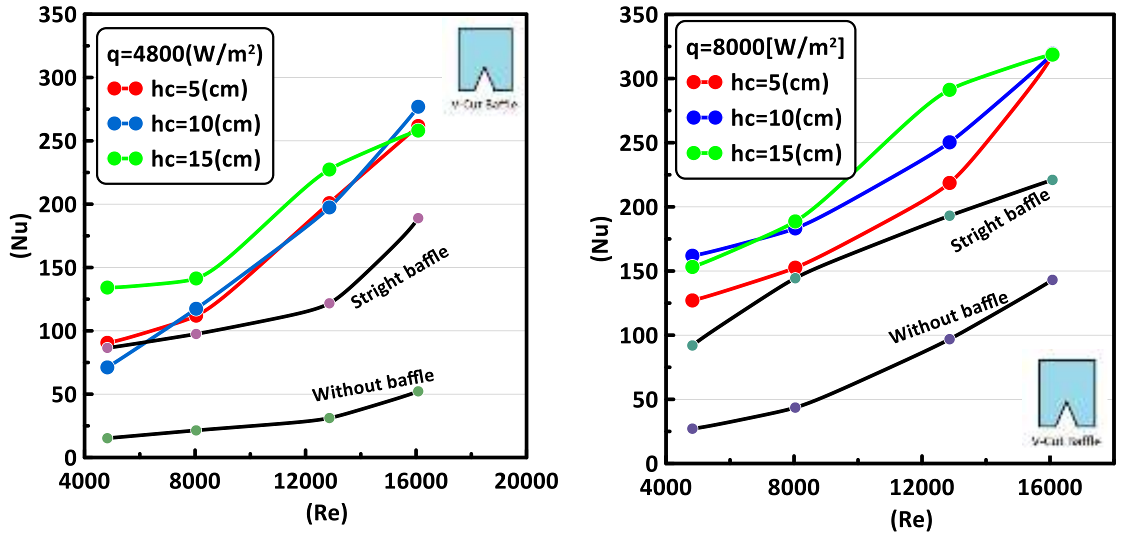


Figure (7) comparison of (Nu) versus (Re) for Cavity without baffle, with straight and the V-cutting baffle at (q=4800, 8000W/m^2).

3.2 Effect of Richardson number

The Grashof number is used to describe natural convection, while the Reynolds number governs forced convection. It is important to study the mixed convection in the presence of turbulent flow because it is a transitional heat transfer between natural and forced convection. Natural convection driven by bouncy motion and forced motion is compared using the Richardson number (Ri), which is defined as the ratio of the two (i.e. Ri= Gr/Re2). There are no natural convection effects if (Ri<< 1) and no force convection effects if (Ri>> 1) [12]. This is shown in Figure 3 for the straight baffled cavity with two different values of (q) (8). Increases in (Nu) with increasing (Re) show that the combined effect of free and forced convection, acting in the same direction, may occur at the applied range of (Re), which leads to an increase in the value of (Re) (Nu). While the Grashof number represents natural convection, the Reynolds number governs forced convection. The presence of turbulent flow in a mixed convection zone is required to study the transitional heat transfer between natural and forced convection. Mixed convection states are classified by their Richardson number (Ri), which is defined as the ratio of natural convection to the forced convection (i.e., Ri=Gr/Re2). When (Ri<<1), the effects of natural convection are negligible, while at (Ri >>1), the effects of forced convection are negligible [12]. (Nu), (Ri), (Re) versus (q) for a straight baffled cavity is depicted in figure (8). Free and forced convection may combine to produce a higher (Nu) at a certain range of the (Re) due to vortices generated inside the cavity.

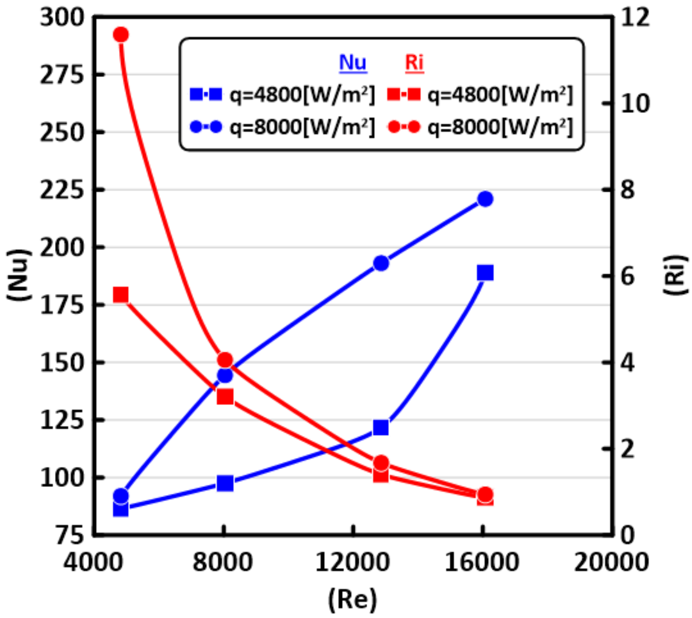


Figure (8) (Nu) and (Ri) versus (Re) for Cavity with the straight baffle.

The effect of variation in the (Nu) with the (Ri) for Cavity with the V-cutting baffle is shown in Figure (9), The Figure shows that (Nu) increases with decreasing of (Ri) for the three cutting height shapes, it is the maximum value of (Nu) was when Ri <1. The reasons are attributed to the buoyancy and circulation along the duct passage.

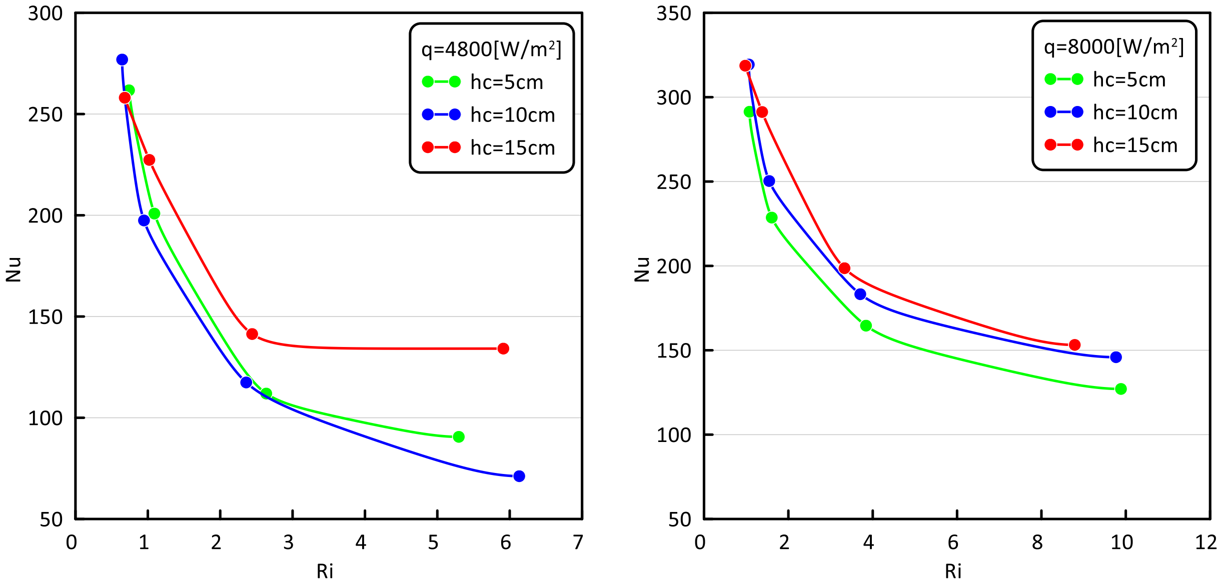


Figure (9) Variation of (Nu) against (Ri) for Cavity with V-cutting baffle

3-3 The heat transfer enhancement (η)

The heat transfer ratio (Nu_{CUT}/Nu_B) is defined as the ratio of the (Nu) with cutting baffle to that with the straight baffle[13]. Figures (10) show the variation of (Nu_{CUT}/Nu_B) of the V-cutting baffle with different (Re) at (q=4800 and 8000 W/m^2). Different (hc) which helps to quantify the enhancement and determine the best height of the cutting. As observed from the figure, there is a relative appreciable heat transfer enhancement with the use of the V-cutting baffle, and the enhancement parameter in some situations increased with increasing of the (hc) of the baffle, while a decrease in other situations. Inspection of the figure shows that the best enhancement obtained for baffle with hc=15 cm at Re=13000 for (q=4800W/m^2) is 87.1% as compared with straight baffle with the same condition. While minimum heat transfer enhancement (5.4%) when hc= 5cm at Re=8000 at q=4800W/m^2. There is no enhancement with hc=10cm at Re=5000 with (q=4800W/m^2). At (q=8000W/m^2), their enhancement was obtained with all values of (hc) and the maximum value of (Nu) at hc=10cm and (Re=5000) is (72%), while minimum value was recorded of (10.3%) at hc=5cm and Re=8000.

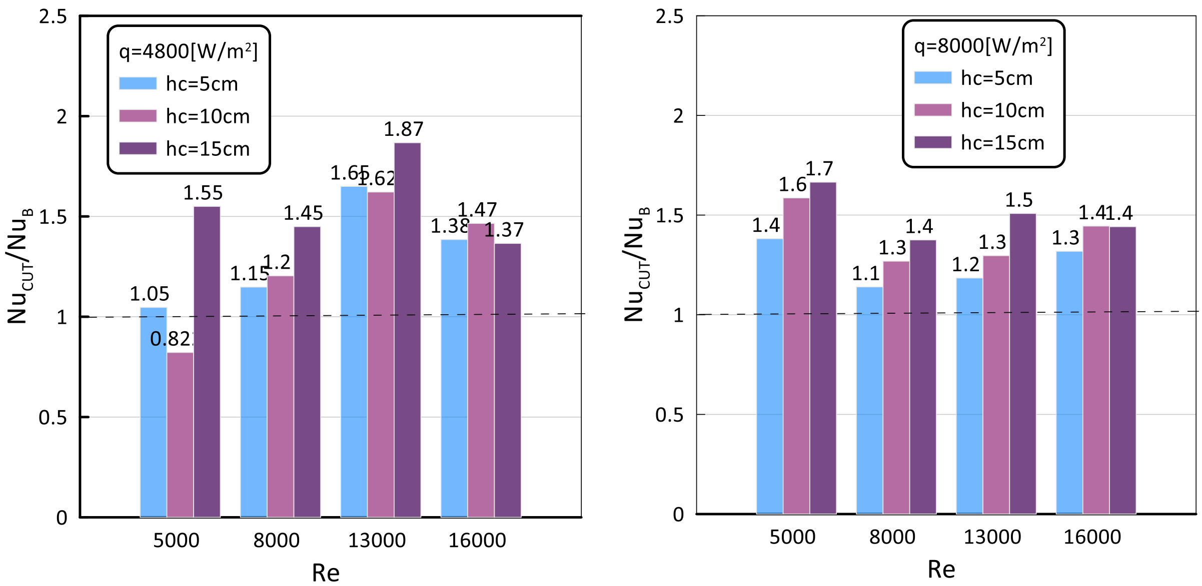


Figure (10) Variation of (Nu_{CUT}/Nu_B) against (Re) for Cavity with V-cutting baffle.

4-Experimental method verification

To verify the present work, the results of average (Nu) are compared with Ref.[14].With the extremely same condition, the comparison is shown in Figure (11) which represents the variation of the Nusselt number with the (Re). The figure shows that both have the same trend them although some deviation was observed, which may be due to some effect of experimental and measuring producer. The minimum and maximum deviation between the present experimental work and Ref. [14] (3.2%) (23.5%) respectively.

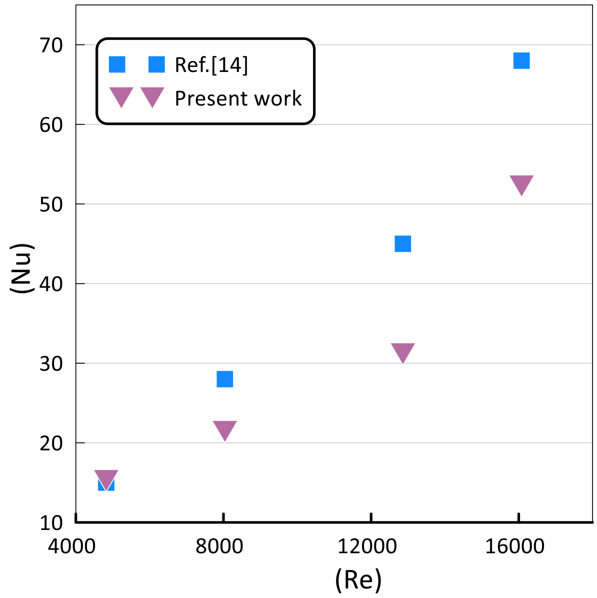


Figure (11) shows the variation of (Nu)versus (Re)for the present work with Ref.[14] for cavity without baffle experimentally.

5- Heat transfer empirical correlations

The (Nu) of the present work results for a cavity with V-shape model cutting can be correlated using conventional of non-dimensional approach that considers the parameters (Re), (hc/h*), and (Pr) as follows:

$$Nu = CRe^{n} \left[\frac{hc}{h*}\right]^{m} Pr^{0.33}$$

Where (C, n, m) are constant determined by experimental results[10]. The experimental results were gathered, and the last square mathematical technique was implemented to obtain the following empirical correlation for this model with minimum and a maximum deviation of (0.06%.) and (7.021%)respectively.

$$Nu = 0.842Re^{0.629} \left[\frac{hc}{h*}\right]^{0.162} Pr^{0.33}$$

The equation above can be applied for the conditions 5000<Re<16000, 5<hc<15 (cm) and q=8000W/m^2.

6. Conclusions

The following conclusion can be derived from the present work:

1-The V-cutting baffle in a cavity leads to enhancing the heat transfer process within it, where the temperature of the air inside the cavity is decreasing when the Reynolds number increases.

2-The (Nu) increases with decreasing of (Ri) for (hc=5, 10, 15 cm).

3-The V-cutting baffle with hc=15cmand Re=13000 for q=4800W/m^2 provides a better enhancement in Nusselt number by approximately (87.1 %) compared with that of the straight baffle whereas the (Nu) improves by approximately (5.4%) for hc=5cm and Re=5000.

4- there is no enhancement with hc=10cm at Re=5000 and q=4800W/m^2.

5-The V-cutting baffle with heat flow q=8000W/m^2, hc=15 cm, Re=5000 lead to increase the heat transfer enhancement by (72%) compared with that of the straight baffle, while (10.2%) was obtained for using the V-cutting baffle with hc=5cm and Re=8000.

6- Empirical correlation for v-cut baffle is introduced and the minimum and maximum deviation between the experimental and correlated (Nu) values are (0.06%) and (5.27%) respectively.

Nomenclature

1	Re	Reynolds number	[-]	10	P_o	Outlet pressure	Pa
2	Ri	Richardson number	[-]	11	b	Baffle thickness	m
3	Pr	Prandtl Number	[-]	12	X/L	Horizontal dimensionless length	[-]
4	h*	Baffle height	m	13	Nu_{cut}	Nusselt number of V-cutting baffle	[-]
5	W	Baffle width	m	14	Nu_b	Nusselt number of straight baffle	[-]
6	q	Heat flux	W/m^2	15	Nu_{cut}/Nu_b	Nusselt number ratio	[-]
7	Nu	Nusselt number	[-]	16	Ti	Inlet temperature	^oC
8	T_b	Bulk Temperature	^oC				
9	u_i	velocity inlet	m/s				

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