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Experimental Investigation of Heat Transfer with Natural Convection of Non-Newtonian Fluid Inside the Enclosure with Hot Obstacle

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A R T I C L E I N F O

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A B S T R A C T

In this study, heat transfer utilizing non-Newtonian fluids with a power-law model in a rectangular enclosure containing a hot obstacle was verified experimentally. The impact of aspect proportion (AR) on fluid flow characteristics and heat transfer, obstacle shapes, and various amounts of carboxymethylcellulose was explored with distilled water which in turn controls the index of powers-law (n). The findings show that the increases in the Number of Rayleigh, lead to the greater the Number of Nusselt, and the greater the non-Newtonian behavior, increased the heat transfer. There is also a noticeable impact when changing the shape of an obstacle on heat transfer as the cylindrical shape enhances heat transfer greater than the cuboid shape. As for aspect proportion, it also affects heat transfer inversely.

1. Introduction

The phenomenon of natural convection in containers is in place and modern since liquid-filled packaging being integral parts of a diverse range of technical systems. Heat exchangers, electronic device cooling, nuclear reactors, solar collectors, and crystal formation in hardening metals are all examples of natural convective heat transfer in industrial and technical systems, as reported by oztop et al.2012 [1] Natural convection occurs in such cavities as a finding of buoyancy generated by the body's force field combined with differences in the fluid's density.. Many types of fluids have been utilized in Newtonian and non-Newtonian studies. This phenomenon differs in terms of the geometry and orientation of the case. From an engineering point of view, the enclosure phenomenon can be divided into two large categories: hot attachments from the bottom and hot closure from the side Solar collectors, double-wall insulation, and air movement across rooms in a building are under the first group. The performance of horizontally oriented thermal insulation, such as heat transmission via an attic with a flat roof vacuum, falls into the second group, as mentioned Thohura et al.2019 [2]. Heat transfer has been researched by a wide number of researchers in a variety of flow configurations with various boundary conditions, Various researchers utilized numerical models to study natural convection heat transfer (NCHT), as Turan et al.2011[3], conducted a numerical simulation of the stratified convection in a square container of a non-Newtonian energy law model with lateral heating at a constant temp with isolated horizontal walls where he studied the impact of a force law index in the range (0.6–1.4) on heat transfer And momentum. In his findings he found that the mean Nesselt number increases with increasing Number of Rayleigh for both Newtonian fluids and force law fluids, and with the increase in shear thickness (i.e. n > 1), the mean Nesselt number stabilizes in the unit (Nu = 1: 0) where the heat transfer occurs in a form Primary since the thermal conductivity.

Conducted by Lamsaadi et al. 2006 [4] a numerical and analytical simulation of a shallow rectangular container, the long horizontal walls of which were isolated, while the short vertical walls were subjected to a uniform heat flow, filled with non-Newtonian fluids. A model of force's law was proposed by Ostald-de Weil, which examined the impact of the non-Newtonian behavior of fluid on its flow and heat transfer properties. Because the shear thinning behavior (0 < n < 1) enhances fluid circulation and heat transmission through convection, while the shear behavior (n > 1) causes the opposite impact, the energy law index and Number of Rayleigh may be utilized to regulate the magnitudes of heat load in shallow cavities . Non-Newtonian fluids are not affected by changing the A & Pr magnitude when they have large magnitudes.

Studied for Lamsaadi et al., 2005 [5] also layered convection in a shallow, rectangular container filled with a non-Newtonian liquid but was heated from the bottom and cooled from the top by expos-

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ing it to a uniform heat flow this time while its vertical sides were stationary. Fluid flow, temp, and heat transfer patterns were found to be somewhat sensitive to the behavior of non-Newtonian fluids, compared to Newtonian fluids (n = 1). The flux system enhances the convection heat transfer when the index of powers-law is low (shear-thinning fluids, 0 < n < 1) and gives the opposite finding when increased, as in (shear thickening fluid, n > 1).

Kim et al., 2003 [6] studied transient convection (a condition that occurs when a liquid is at rest in the case and then begins to heat) for a non-Newtonian liquid model of the energy law in a closed square container where heating is by raising the sidewall temp and cooling by lowering The temp opposite the wall. Explain the impact of (Ra), (n) and the number pr) on Nu number, and the numerical findings of this study showed that the average Number of Nusselt increases with decreasing energy law index n for a given set of Ra and Pr magnitudes Salehapour et al.2019 [7] The heat transport by natural convection in a rectangular was studied analytically., variousially heated container, which has a sinusoidal wavy side to the walls at constant temps. The container was filled with a non-Newtonian fluid (law of force). The findings showed that as the Number of Rayleigh increased, the required stabilization time would be shorter. When increased corrugation frequency (CF), the flow pattern is at the boundary, but when corrugation amplitude (CA) grows it affects the flow pattern in the core region. CF does not significantly affect the flow pattern, unlike CA. As Ra grows, heat transfer intensifies, and this increases the average Number of Nusselt. Increasing n causes a reduce in heat transfer inside the container as well as an increase in time, resulting in a steady state.

Yigit et al. 2015 [8] numerically analyze the thermal load in Rayleigh-Bénard and the impact of aspect proportion on it, for non-Newtonian liquids represented by the energy law model in a rectangular container with stably heated horizontal walls where the lower wall has the greatest temp. The findings showed that the convection was weak with increasing the aspect proportion of the AR. Only heat transfer since thermal conductivity at AR > 2, the shape of the flux changed dramatically with the change of AR decreasing (increasing) in (Ra, n) magnitudes. Therefore, the Nesselt number does not show a reduce (increase) with increase (n, R), at AR $\leq$ 2, changes in flow pattern occur within the enclosure. Pandey et al.2020 [9] examined the flow and heat transfer properties of a non-Newtonian fluid in a square cavity contain an inner cylinder, as it changed the position of the cylinder along its horizontal and diagonal axis in various places and demonstrated the impact of shear-thinning and thickening fluids' behavior on the heat transfer mechanism. The findings showed an increase in the rate of heat transfer when utilizing pseudo-plastic fluids, as for the use of dilatant fluids in applications that need a reduce in the rate of heat transfer, the temp and velocity fields are also affected by the location of the cylinder inside the container, as well as that the Nesselt number was a decreasing function of the index of powers-law.

Ilyas et al. 2017 [10] studied the behavior of heat transfer with natural convection in fluids. It was study in a vertical rectangular container (AR = 4) with heating of one of the walls and cooling of the other. A new greatly stable functional thermal oil based on Nano-alumina fluid was utilized in its study. Various amounts of Nanofluids ranging from 0 to 3% wt percent were tested. The effectiveness of the convection heat transfer mechanism is mostly determined by the cooling medium's characteristics. An enhancement in the cooling performance of Nanofluids was observed. Nanofluids with greater nanoparticle amounts have a greater coefficient of heating transfer than pure thermal oil.

Jiwa et al. 2020 [11] Natural convection of hybrid Nano fluids was explored experimentally in a square cavity the corresponding vertical sidewalls were heated variously, and the rest of the cavity walls were well insulated to reduce heat loss in the surrounding areas. The cavity contained Al2O3 - MWCNT / aqueous Nano fluids with various weights of percent weights for diploid particles (Al2O3- MWCNT). The range of Number of Rayleigh utilized is (1.65 $\times$ 108–3.80 $\times$ 108) and the temp range is between (20–50) °C. His findings showed that there is a direct relationship between the Number of Rayleigh and the average Number of Nusselt. The temp and weight percentage gradients of the diploids in the Nano fluids were observed to increase Nu av, h av and Q av. The use of hybrid Nano fluids enhances thermal properties and flow. The findings also show the benefit of utilizing hybrid Nano fluids over single-particle Nano fluids in heat transfer studies.

Garbadeen et al. 2017 [12] Examination of improving the performance of heat transfer fluids for Nanofluids in the vertical wall cube is a heat exchanger working to achieve variously heating of the vertical walls in the cavity. The study was performed with nanotubes (CNT) consisting of multi-walled carbon nanotubes in an aqueous base. The study was conducted in (pr = 5.83) and the range of volumetric amounts (0–1.0%) and Number of Rayleigh (Ra = 108) utilizing the experimentally determined viscosity and thermal conductivity magnitudes. The findings showed that there is an ideal amount that achieves the maximum enhancement in the heat transfer performance when the Nanofluids possess a thermal conductivity greater than the thermal conductivity of the primary fluid. The maximum enhancement was reached by approximately 45% when a particle size amount of 0.1% at a specific Number of Rayleigh was achieved.

Mahrood et al. 2011 [13] Explore natural convection in a PTFE-lined vertical cylindrical cylinder, which was experimentally heated evenly from the bottom and cooled uniformly from the top. Aluminum oxide (Al2O3) and, titanium oxide (TiO2) nanofluids are two separate forms of non-Newtonian nanofluids in an aqueous solution of carboxymethyl cellulose (CMC) at an amount of 0.5% were utilized. The findings found that the heat transfer with natural convection of non-Newtonian Nanofluids increases when the amount of nanoparticles is low, as the increased amounts have the opposite impact in enhancing the heat transfer of the

Nanofluids. Joshi et al. 2018 [14] Explored experimentally to enhance NCHT inside a closed square container utilizing Nanofluids (MWCNT / water). The vertical side was differentially heated from one side heated with a plate heater while the other side was kept at a constant temp. MWCNT / water was utilized with a volume proportion of 0.1%, 0.3%, and 0.5%. The Nesselt number of MWCNT / water was compared with the Al2O3 / water nanoparticles in volume proportions of 0.1% and 0.3%. The Number of Nusselt magnitudes for MWCNT / aqueous Nanofluid were greater for = 0.1 percent than those for Al2O3 / water and basic fluids, according to the findings. The increase was about 35% and found 40% of the Number of Nusselt magnitude of MWCNT / aqueous Nanofluid of 0.1% by volume when compared with the base fluid and Al2O3 / water Nanofluid, respectively. In comparison to the base fluid and Al2O3 / Water Nanofluids, the Number of Nusselt magnitude at = 0.3 percent MWCNT / aqueous Nanofluids was around 11 percent and 17 percent greater, respectively.

Torki1 and Etesami 2019 [15] studied the NCHT of a Nano-type liquid (SiO2 / water) at various amounts inside a closed rectangular vessel. It has cold and hot vertical walls, the other sides are insulated. The container was tilted at an angle between the hot wall and the horizontal line from 0 to 120. The findings showed that a heat transfer does not change significantly at low Nanofluid amounts. When the volumetric proportion of nanoparticles was>0.005, the coefficient of heating transfer reduced with the amount of the Nano fluid.. The findings also showed that the impact of the angle of inclination on heat transfer at low amounts of Nano fluids is more pronounced and this is evident in the Nesselt Fig.. Whereas, With raising the angle of inclination of the cavity or approaching the heated wall to the vertical condition, the influence of the Nano amount impact on the Nesselt number diminishes. Since the wide application of non-Newtonian fluids in various industries, the current research demonstrates the natural convection of non-Newtonian in a rectangular container that contains an obstacle that is. The obstacle heats it from the bottom and cools it from the top. It should be emphasized that Newtonian fluids were employed as the foundation liquid in all prior studies. For the first time, convective heat transfer was explored utilizing two distinct amounts of non-Newtonian fluids.

2. Materials and procedures

2.1. Preparation of samples

Distilled water without salts was utilized as a basic fluid and a polymer material was added to it to prepare a fluid with non-Newtonian properties utilized in the present work to prepare an amount of 1% and 0.5%. Carboxymethylcellulose was added to the water according to the amount equation mentioned by Hussein et al.2017 [16].

$$[]\div = \frac{\left(\frac{m_p}{\rho_p}\right)}{\left(\frac{m_p}{\rho_p}\right) + \left(\frac{m_{bf}}{\rho bf}\right)} \tag{1}$$

Prepare the working fluid employing a mechanical mixer, and mix well to obtain homogeneous non-Newtonian fluids. Commercial polymer products were utilized in this study, It is outfitted from SINOCMC CO., LTD - China as a powder with cas.NO.9000–11-7,viscosity at 20 0C (250 Cp). The prepared solution is kept at rest at room temp for 24 h before the physical properties measurement or use. Then, the container is gently filled with fluid so that no bubbles form and wait long enough for them to settle before starting work.

2.2. Experimental setup

The heat transfer apparatus illustrated in Fig. 1 was utilized for all experiments. (1) A test section, (2) a heating system, (3) a cooling system, a power supply, and a measurement system comprised the experimental setup. The test section is a rectangular enclosure whose dimensions are length (L = 040 cm), width2 (W = 030 cm), and height3 (H = 030 cm), and it is made of a double sheet of galvanized steel) 0.15 cm) thick, and the space between them is filled with foam to ensure insulation. The lower wall is made of PTFE (polytetrafluoroethylene), the PTFE plate acts as an insulating material. The obstacle is heated by an electric heater component heating system. To achieve a constant wall temp, the heater was placed inside the diaphragm where it was hollowed out and fixed to the lower wall of the enclosure. The enclosure's upper wall is a portion of the galvanized steel cooling chamber, which can be moved along the enclosure utilizing a screw jack to change the enclosure's aspect proportion. This facilitates a various examination possibility aspect proportion AR, to see the impact of this factor on the heat transfer with the natural convection of the non-Newtonian fluid experiment and was performed at two aspect proportions 0.5 and 0.75. To keep the upper wall temp at the correct level, cold water from a constant temp bath was pumped through the top chamber. Fig. 2 shows the test portion in greater detail. The entire experimental setup was largely isolated by the use of insulating foam material to reduce potential heat loss.

K-type thermocouples were utilized to determine surface temps. It was installed on each panel (top and bottom panels and sidewalls) and also utilized a section of thermocouples to determine the temp of the fluid inside the enclosue. Two more thermocouples were utilized to determine the cold water input and exit temps, as shown in Fig. 3. The accuracy of all thermocouples was 0.1° C. Thermocouples devices were connected to a digital computer through data acquisition in the system.

When steady-state conditions are reached, and the required heating plate temp is determined, the heat flux is determined by the thermometer. To avoid the development of air bubbles, the enclosure (test section) is filled with the prepared working fluids with great care and attention. On the heated surface, tests were carried out for various heat fluxes. It is possible to shift the temp between cold and hot surfaces by altering the flow of heat on the hot surface. To explore the impact of non-Newtonian fluid amount to explore heat transfer, in the range, the temp differential between cold and hot plates was adjusted 5 0C to 25 0C for change the Number of Rayleigh. The heat transfer was examined by natural convection of the non-Newtonian fluid with various amounts of 0.5% and 1%, in addition to water, which is considered a Newtonian fluid.

3. Data analysis

The (DC) power source was utilized to power the electric heater (model HY3020). Input current (I) and voltage (V) to the electric heater have been determined by two millimeters. Since full insulation, the heat flux of an electric heater (q) was computed [13]:

$$q = (IV) \tag{2}$$

Newton's law was cooled to produce the coefficient of heating transfer:

$$h = \frac{q}{A(Th - Tf)} \tag{3}$$

$$Th = \frac{T1 + T2 + T3 + T4 + T5}{5} \tag{4}$$

$$Tf = \frac{T1 + T2 + T3 + T4 + T5 + T6 + T7 + T8 + T9 + T10 + T11}{11} \tag{5}$$

The Number of Nusselt is calculated as follows:

$$Nu = \frac{h.L}{k} \tag{6}$$

The distance between the cold and hot plates is denoted by the L. The Number of Rayleigh of a non-Newtonian fluid (Ra) and the Prandtl number are calculated utilizing the temp difference, and the non-Newtonian fluid's physical characteristics have been determined experimentally:

$$\mathrm{Pr} = \frac{k(\alpha)^{(n-2)} l^{(2-2n)}}{\rho} \tag{7}$$

$$Gr = \frac{g\beta(Th - Tc) l^{(4n-1)}}{\alpha^{(2n-2)} \left(\frac{k}{\rho}\right)^2} \tag{8}$$

$$Ra = \mathrm{Pr} \times Gr \tag{9}$$

Where:

n: index of powers-law.

α : thermal diffusivity which is determined as : $\frac{k}{\rho.cp}$, m2/s.

g: gravitational acceleration, m/s^2.

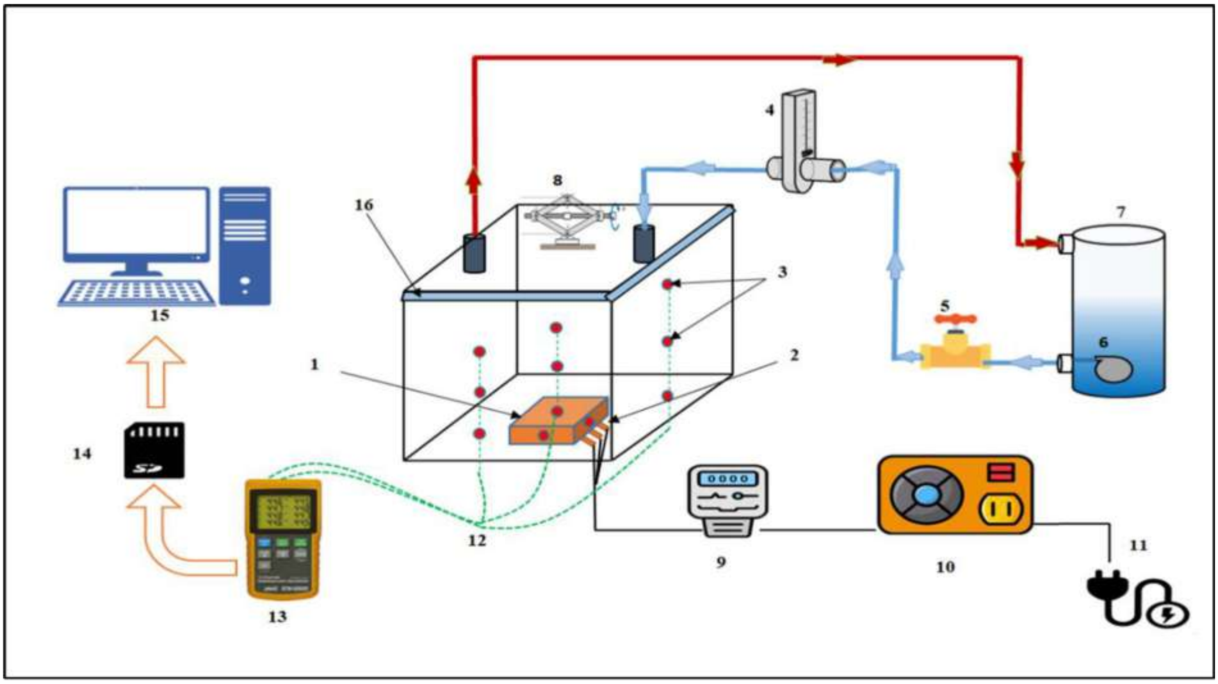
β: coefficient of volume expansion, β = 1/ Tf.

Th: temp of the heated surface, ^{o} C.

Tc: is the temp of a cold surface, ^{o} C.

l : 1the characteristic length, m.

ρ : density 0of fluid, kg1/m13.



1	Obstacle	5	Valve	9	Power analyzer (Wattmeter)	13	Temperature recorder
2	Electrical heater	6	pump	10	Power supply	14	Memory card
3	Temperature measuring points	7	Constant temperature bath	11	Electrical source	15	Personal computer
4	Liquid flow meter	8	jack	12	Thermocouple's wire	16	Cooling chamber

Fig. 1. schematic diagram of experimental work.

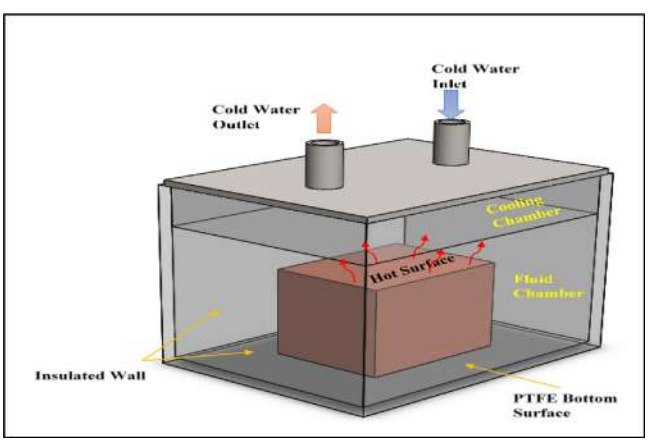


Fig. 2. schematic diagram of the test section.

Cp : specific0 heat , J/1kg .k .

4. Uncertainty

The thermocouple utilized to determine the temps of the top and bottom plates and fluid inside the enclosure has a 0.1 °C. The coefficient heat transfer uncertainty for non-Newtonian fluids was calculated to be<5.3% in all situations. Equation (10) is utilized for calculating uncertainty by Hu et al., [17]

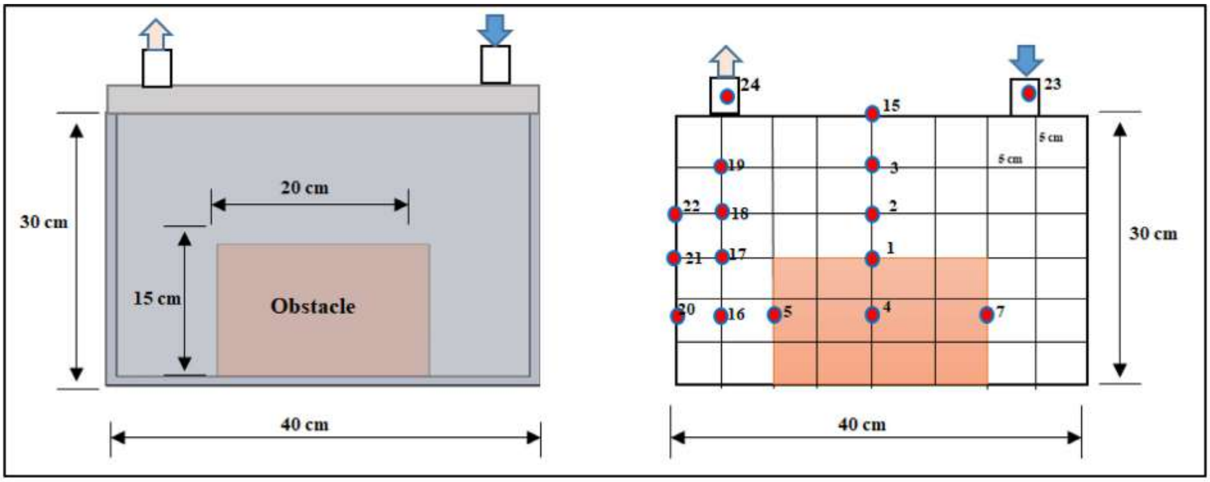
$$UR=\left[\left(\left(\frac{\partial R}{\partial x1}\right)*U1\right)2+\left(\left(\frac{\partial R}{\partial x2}\right)*U2\right)2+....+\left(\left(\frac{\partial R}{\partial xn}\right)*Un\right)2\right]0.5 \quad (10)$$

5. Results and discussion

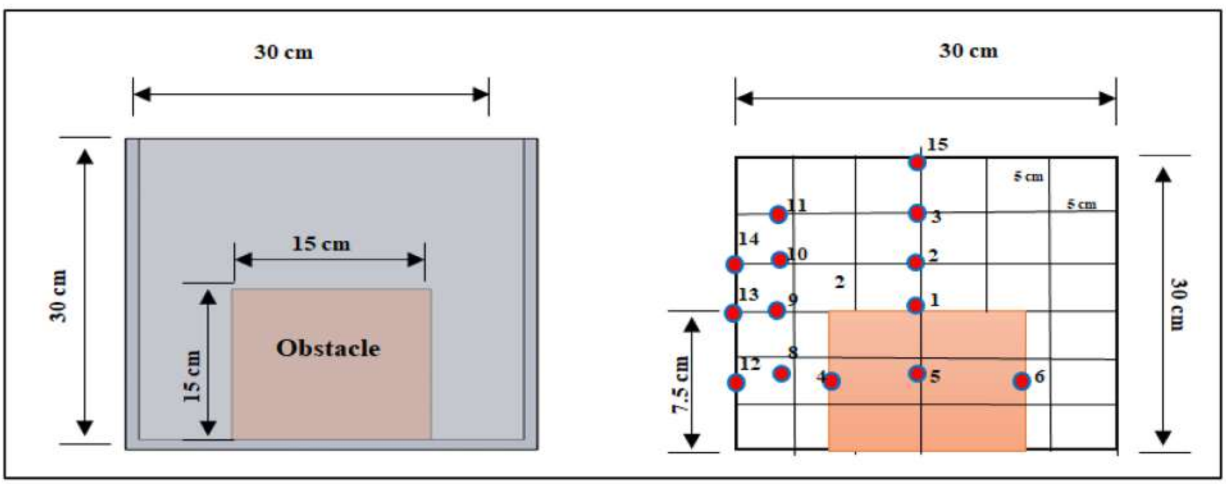
The natural heat flow within the fluid layer is controlled by the aspect proportion AR, the index of powers-law n, and the Number of Rayleigh Ra. The index of powers-law magnitudes in this investigation differed depending on the carboxymethylcellulose content, as we take it in two amounts with water as the main fluid (water), so that n = (0.59, 0.72, and 1) for an amount of 1 %, 0.5 %, and water respectively, where the approved fluid in the practical part is of type shear thinning (n < 1), an addition to water that is considered a fluid with Newtonian properties (n = 1).

The Number of Rayleigh does not vary when the shape of the obstacle changes, as it is constant for both types. Ilyas et al.,[10] indicated that three variables influence the Number of Rayleigh: (a) a change in the working fluid's thermophysical characteristics, (b) the difference in temp between hot and cool walls, and (c) a determine of the enclosure's aspect proportion.

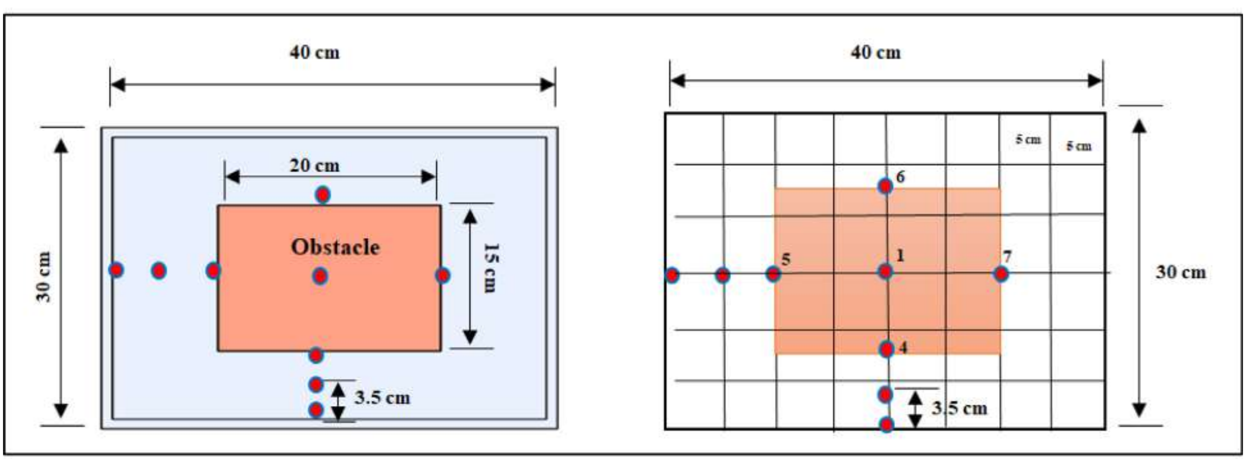
Figs. 4 and 5 demonstrate the difference of the temp difference with the Number of Rayleigh for the three types of fluids utilized in



a- Front view



b- Right view



c- Top view

Fig. 3. thermocouples location inside the enclosure.

the experiment. Fig. 4 shows it when it is Ar = 0.5 and Fig. 5 clarifies it when it is AR = 0.75, and in the two figures, it behaves the same behavior, which is increasing the Number of Rayleigh by increasing the hot temp because it will increase the thermal gradient, thus the increase of Rayleigh because the various temps are directly related to the Number of Rayleigh according to its mathematical relationship and on the physical side, as the temp rises, the physical characteristics linked with the temp rise as well

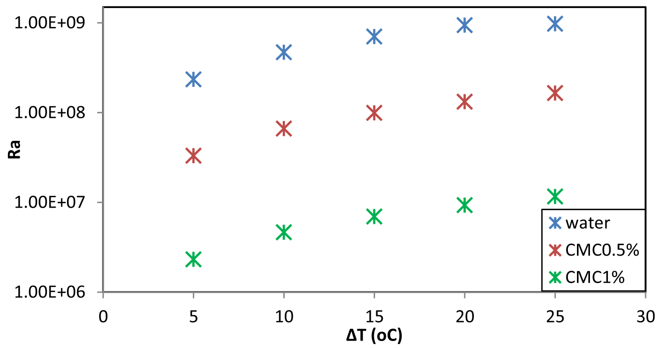


Fig. 4. difference of the Number of Rayleigh with various temps at AR = 0.5.

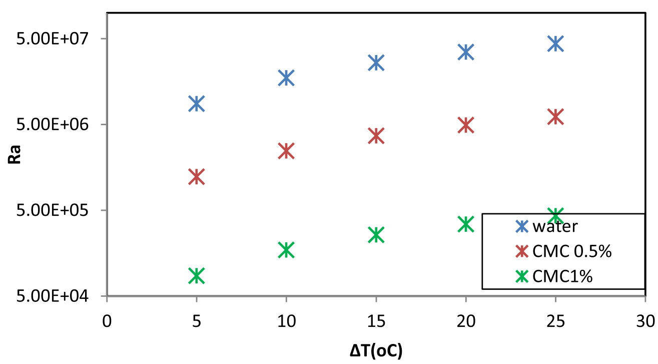


Fig. 5. difference of the Number of Rayleigh with various temps at AR = 0.75.

such as viscosity and thermal conductivity which depends it has a Number of Rayleigh as mentioned by Pishkar et al., [18]. Convection is reduced by an increase in the index of powers-law for all Number of Rayleighs, resulting in an increase in the heat source temp.. It is noted that in Fig. 4 the largest Number of Rayleigh was 9.76 $\times$ 108 when AR = 0.5, but in Fig. 5 the magnitude was 4.36 $\times$ 107with the same properties, the reason is that the increase of Ra increases with the increase in the enclosure size. The increase in volume enhances the velocity of the fluid as well as since Rayleigh's number depending on the distance between the cold and hot surface of the enclosure.

Fig. 6,7,8, and 9 show the difference of the Number of Rayleigh of the base fluids with Number of Nusselt for various initial conditions, where the Number of Nusselt represents the heat transfer by convection to the heat transfer by the conduction. Number of Nusselt increases with an increase in Number of Rayleigh for both shear-thinning (n < 1) and Newtonian (n = 1) regardless of the initial and boundary condition and this is consistent with the finding of [6] and [19]. Increasing the Number of Rayleigh leads to an increase in the buoyancy forces, it becomes increasingly dominant over viscous resistance, which in turn increases the temp difference and thus increases the flow, which increases the heat transfer from the source of heat to cold walls. The magnitude of the Number of Rayleigh is excess since enhanced convection that carries heat energy with increased momentum. The relationship between the Nusselt and Number of Rayleighs is irregular since the difference in the magnitude of the aspect proportion and the shape of the obstacle. The greatest magnitudes of the Number of Nusselt are at CMC 1%, AR = 0.5, and cylindrical obstacle where the magnitude of Number of Nusselt reached 77.92, while the lowest magnitude for water was 34.47 at a temp difference of ΔT =25 °C Fig. 7. Fig. 8. Fig. 9.

Fig. 10,11,12, and 13 illustrate the impact of the non-Newtonian behavior represented by the index of powers-law with Number of Nusselt. It has been discovered that when the index of powers-law rises, the Number of Nusselt reduces for both shapes obstacle clearly in Figs. 10 and 11 at aspect proportion (0.5). It was exposed that AR = 0.75 for both shape obstacles there is an increase and reduce with the excess magnitude of the index of powers-law. This happened as a finding behavior of non-Newtonian fluids, as well as the narrow distance between the cold and hot walls, which was apparent in Figs. 12 and 13. The maximum magnitude of Number of Nusselt (77.92) at AR = 0.5, index power law (n = 0.59), Ra = 9.76$\times$108, and cylindrical obstacle shape, while at cuboid obstacle it was (43.4) at the same condition. Yigit et al., [20] indicated that increasing the magnitude of the index of powers-law leads to a reduction in the magnitude of the Number of Nusselt. Reduce of an index of powers-law as a finding of the increase of the amount of non-Newtonian fluid for shear-thinning fluids (n < 1), and increases in the viscosity, which guide to slower movement of the fluid and the shear pressures in the fluid become weaker and consequently the velocity reduces. This findings in an accumulation of heat in the enclosure and an increase in the temp of the working fluid. This explains why CMC 1% has the greatest magnitude in all the indicated Figs for both obstacle shapes.

Figs. 14, 15, 16, 17, 18 and 19 shows impact of the shape of obstacle on Number of Nusselt for each shape of obstacle with two magnitudes of aspect proportion (0.5 and 0.75) for water, CMC0.5%, and CMC1%. For both types of working fluids utilized in the experiments, as well as both obstacle forms and aspect proportions, it was discovered that a greater Number of Rayleigh leads to a maximum Number of Nusselt. It was found that the magni-

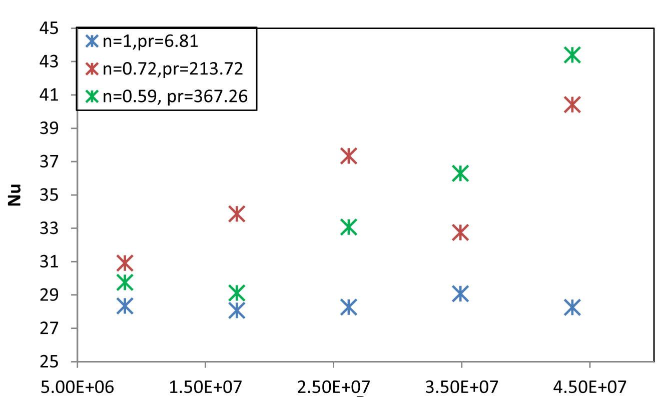


Fig. 6. difference of Number of Rayleigh with Number of Nusselt for a cuboid obstacle at AR = 0.5.

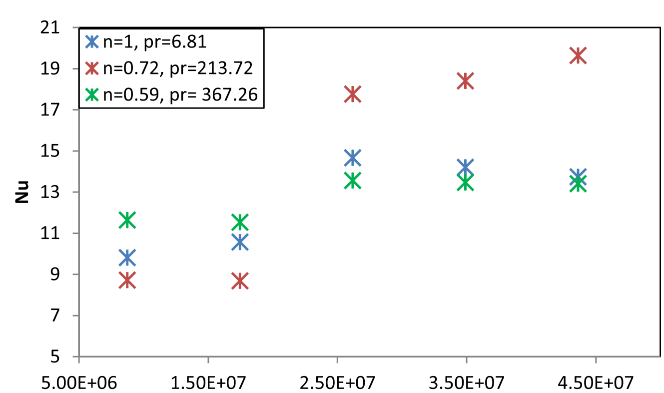


Fig. 7. difference of Number of Rayleigh with Number of Nusselt for a cuboid obstacle at AR = 0.75.

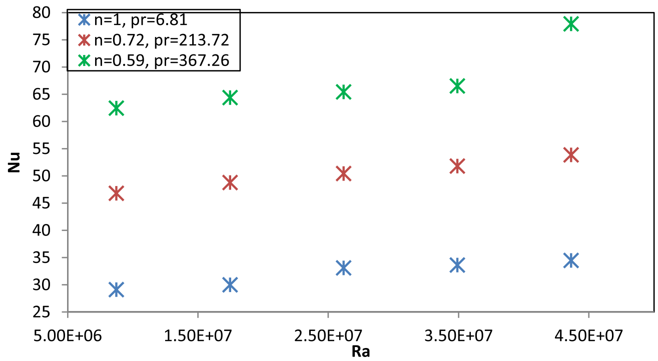


Fig. 8. difference of Number of Rayleigh with Number of Nusselt for a cylindrical obstacle at AR = 0.5.

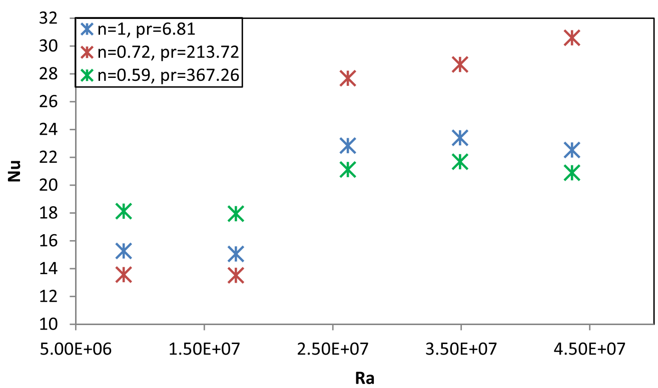


Fig. 9. difference of Number of Rayleigh with Number of Nusselt for a cylindrical obstacle at AR = 0.75.

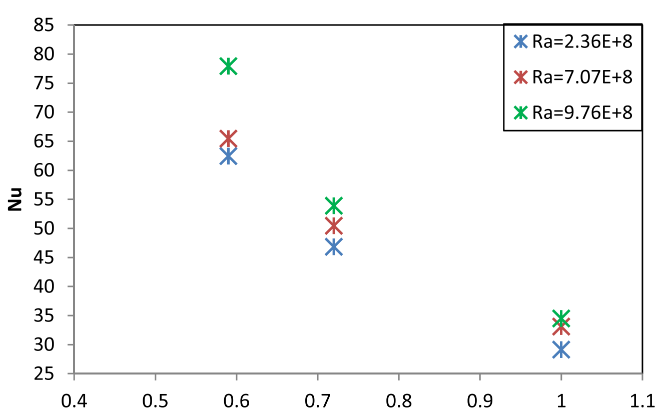


Fig. 10. Number of Nusselt difference with the index of powers-law for the enclosure with a cylindrical and AR = 0.5.

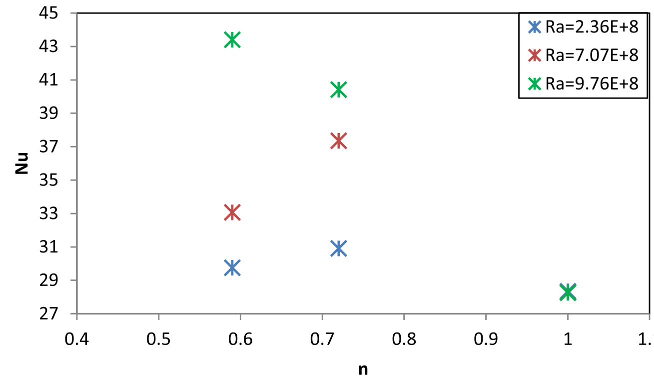


Fig. 11. Number of Nusselt difference with the index of powers-law for the enclosure with a cuboid and AR = 0.5.

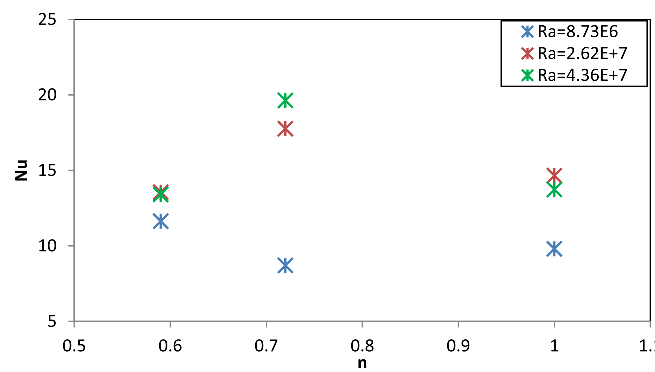


Fig. 12. Number of Nusselt difference with the index of powers-law for the enclosure with a cuboid and AR = 0.75.

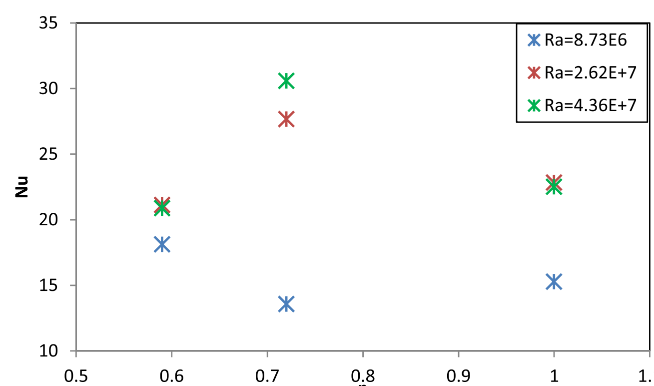


Fig. 13. Number of Nusselt difference with the index of powers-law for the enclosure with a cylindrical and AR = 0.75.

tudes of the Number of Nusselt in the case of utilizing the cylindrical obstacle were greater than the magnitudes of the Number of Nusselt in the cuboid obstacle under the same condition. The reason for this behavior is that the bouncy force increases with increasing temp in addition to the surface area and which has relatively very large curvatures of the cylindrical obstacle was greater than a cuboid obstacle.

The percentages of increase in heat transfer when utilizing the cylindrical obstacle shape of water, CMC0.5%, and CMC 1% were 14%, 25%, and 49% respectively at aspect proportion (0.5) andΔT = 25 oC.

While when changing the aspect proportion at (0.75), the percentage increase in the heat transfer change is estimated at (35 %,35.6%, 38.8 %) in favor of the cylindrical obstacle shape for working fluids water, CMC0.5%, CMC1% respectively under the same conditions. It was noted that when the aspect proportion of the enclosure is reduced, It causes a rise in heat transfer or a rise in the Number of Nusselt. as mentioned by Yigit et al.,2015 [8].This is since as AR increases, this means that the volume increases and vice versa, which adversely affects the movement of fluid den-

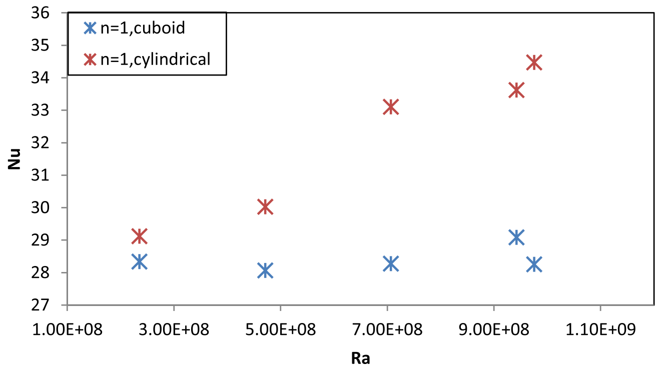


Fig. 14. impact of the shape of obstacle on Number of Nusselt for water and AR = 0.5.

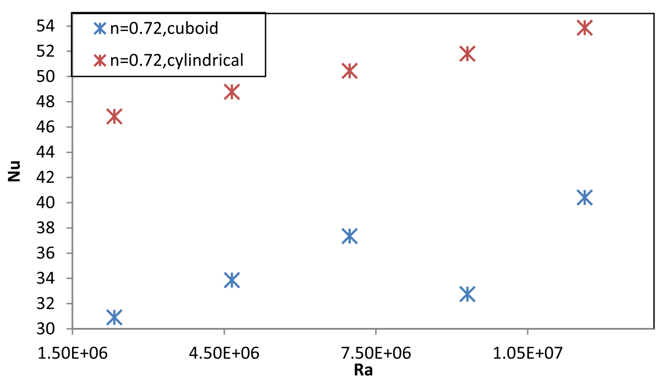


Fig. 15. impact of the shape of obstacle on Number of Nusselt for CMC 0.5% and AR = 0.5.

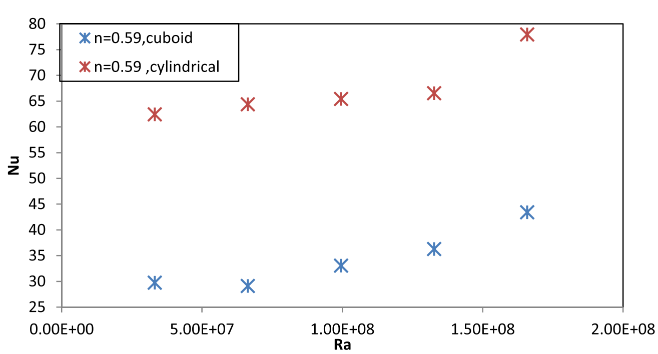


Fig. 16. impact of the shape of obstacle on Number of Nusselt for CMC 1% and AR = 0.5.

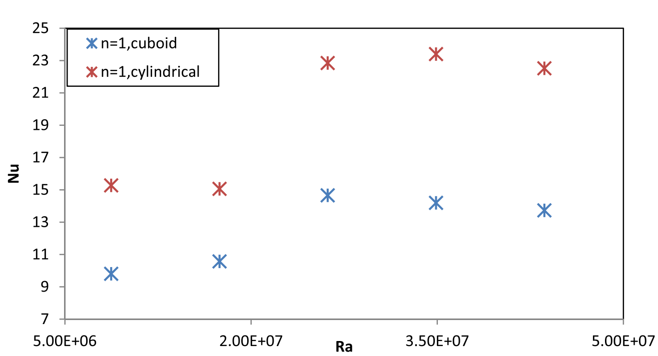


Fig. 17. impact of the shape of obstacle on Number of Nusselt for water and AR = 0.75.

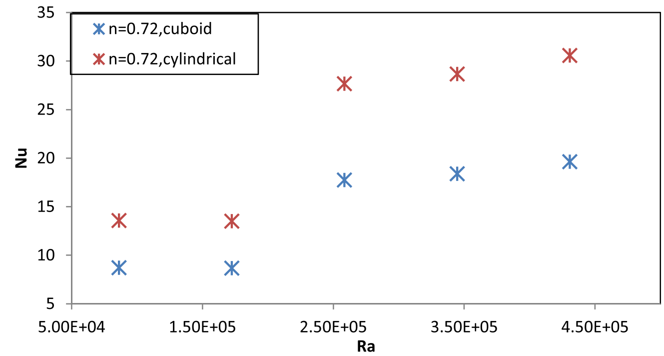


Fig. 18. impact of the shape of obstacle on Number of Nusselt for CMC 0.5% and AR = 0.75.

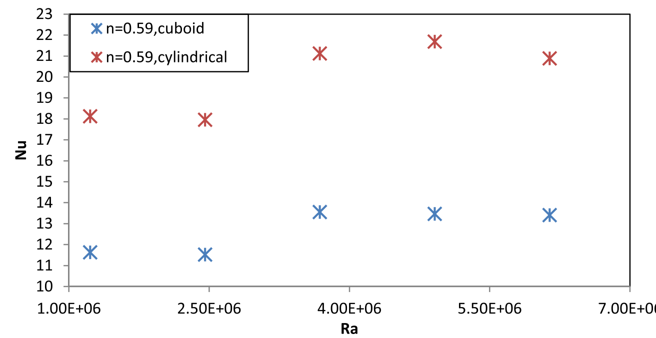


Fig. 19. impact of the shape of obstacle Number of Nusselt for CMC 1% and AR = 0.75.

sity, and thus leads to a reduce in velocity rates leading to a reduce in heat transfer.

6. Conclusions

The impacts of changing the aspect proportion, altering the form of the barrier, and varying the amount of Non-Newtonian liquids in a rectangular enclosure for NCHT were explored experimentally. The findings revealed that:

- The Number of Rayleigh increases with the temp of the system, which in turn leads to an increase in the Number of Nusselt since the increase in the impact of the buoyant forces.
- the obstacle shape, has a significant impact on heat transfer, as it was found that the cylindrical shape enhances heat transfer more than the rectangular shape.
- Impact of aspect proportion on heat transfer in natural convection is the opposite impact, as the greater the AR leads to a reduce in the Number of Nusselt.
- As for the impact of non-Newtonian behavior, it is a reverse impact, as an increase in the index of powers-law leads to a reduce in heat transfer, i.e. a reduce in the Number of Nusselt.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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