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The Parametric Analysis and Numerical Simulation of Pressurized Free Convection Enclosure

Rassol H. Rasheed, Majid H. Majeed , Dr.Ahmed Qasim mohammad

The Technical Engineering College/ The Midland Technical University/ Baghdad- Iraq.

Abstract **-** The heat convection by mean of natural mechanism plays vital role in industrial and domestic applications for heat conservation purposes. The better understanding of natural convection mechanisms promotes high design, operation and development abilities. In present investigation, the free convection in pressurized enclosure within four thermal pipes system (hot and cold pipes) has been investigated experimentally and validated with the numerical simulation. The proposed correlation is obtained then corresponded with experimental results. The effect of aspect ratio, pressure ratio and operation configuration has been taken in consideration. The pressure ratio range of 1.5 to 2, the aspect ratio range of 1.83 to 5.04 and operation configuration of one and two heated pipes are utilized through the experimental work. The results shows that when Ra increases, so does Nu. The Nu values for the two heated pipes arrangement are greater than the one pipe design for various pressure ratios. Inside the enclosure, the two heated pipes generate double the amount of heat, indicating a double heat flow in the thermal system. Within the heat transfer, the double heat transfer area is also shown. When the pressure ratio is equal to 1.75 and two heated pipes are employed, the maximum heat transfer improvement is around 36%. When the aspect ratio is increased, the heat transfer resistance reduces. The heat transfer rate will be successfully transmitted from hot pipe to cold pipe. When As=5, the maximal heat transfer improvement is roughly 51%. Between the Nu and Ra. The numerical simulation has good corresponding with experimental data. The proposed correlation is validated with experimental results.

Index Terms **-** Free convection, Pressure ratio, enclosure, numerical simulation, Correlation

INTRODUCTION

In the realm of technology and infrastructure, heat transport is a critical method. It manifests itself in such a variety of ways (conduction, convective, and irradiation, for example) [1]. Dispersion is the transference of heat through one location to another through the motion of fluid [2]. Fluid temperature distribution is frequently dominated by this method. It happens when the buoyant pressures that come from densities fluctuations owing to changes in the fluid's temp induce the fluid to move [3]. Exchangers intended for viscous fluid in industrial operations and the food industry, compact exchangers for gas mixture, heat transfer for medicinal purposes, and temperature control devices for spaceships [4] are just a few examples of cylindrical heat exchange. Solar thermal collecting, elevated energy nuclear power stations, super furnaces, conditioning of electronic devices [5], and conditioning of moving elements also including jet engine propeller blades and turbojet engines linked to rotating blades [6] are some more instances. Because of its numerous uses in the construction business and in the surroundings. Also there are drawbacks in the research that compare the impact of the body 's internal inside the enclosing to that of an enclosures lacking interior bodies. In addition, a baffle inside the container is proposed as a thermal transfer enhancement strategy.

The free convection heat transport of a horizontally arranged warmed square cylinder housed in a vessel was investigated by **De and Dalal, 2006 [7]** using a frontier finite difference approach. At an elevated temp, the internal body This was separated into two sections, each with a distinct temp, and the enclosure's borders were kept at an isotherm extreme cold. They looked at the effect of Rayleigh number and the horizontal location of the interior body's upwards and the backward directions. The findings demonstrate that perhaps the location of a tube has no influence, but if the ratios of widths to altitude alter, it creates a narrow path for the fluid to flow through, and therefore the cylinder's location is functional, and hence Nu grows as Rayleigh numbers are rising**.** **Kim et al. [8]** investigated free convection heat transport between an interior circular tube and a rectangular enclosing air filled using an embedded boundary finite volume technique. The use of a two-dimensional assessment was explored. The inside component was maintained at a high temp, while the enclosure's walls were maintained at an isothermally low temp. The studies explored naturally convective heat transfer coefficient between this and an interior circular tube and a rectangular enclosure air filled using an embedded border finite volume technique. The findings show that raising Rayleigh numbers raises the average Nusselt number whilst boosting heat transfer rate. It was discovered that moving the tube below is advised for improved heat transmission improvement. To use the finite volume approach, **Xu, X., et al [9]** investigated natural convective heat transfer coefficient between such a warmed triangle cylinders as well as its circular cross section enclosing air filled. The inside component is maintained at a high temp, whereas the enclosure's sides were maintained at an isothermally low temp. The research shows that raising Rayleigh numbers raises the average Nusselt number while improving heat transfer performance, although the rise is higher when the percentages of the interior cylinders diameters were reduced. **Yoon et al.** [10] studied using the at a fixed Rayleigh number ($Ra=10^7$), the free circulation owing to the thermal gradient among external square enclosure (cold) and the inside round tube (hot). The effect of the consists of an inner cylinder's placement on flowing fluid and thermal expansion was studied. The findings shows that the amount of the Nusselt number increased when the inner cylinder's short and long term positions changed. **S.H. and A.K** [11] investigated convection heat transfer between an interior circular tube and a rectangular enclosure air filled using an embedded border finite volume technique. A two-dimensional study has been taken into account. The inside core is maintained at a warm temperature, whereas the enclosure's walls were maintained at an isothermally cold conditions. Given the significant impact of convective instability, they regarded the impact of Rayleigh number and vertical component of the internal body motion above and down. They discovered that the overall and local Nusselt number efficiency increases with various upward and straight down places of the inner diameter with rising Rayleigh number. **Costa et al.** [12] investigated numerically combined heat circulation in a rectangular chamber with a spinning cylinder in the center. Because of the spinning cylinder, the impacts of drive and convective heat transfer may be combined. Despite enforcing a thermal behavior on its exterior, the revolving cylindrical was influenced in heat local heating. The diameter, heat resistance, angular speed, and thermal properties of the spinning cylinder were used to evaluate its influence on the ensuing mixed convection example. The isotherms and flow structure, accordingly, depict the temperature area and streamline. The impacts of the rotating shaft on the cavities thermal efficiency were among the findings. The physical thermal characteristics of the cylinder were critical in the whole heat transfer rate. **Lee, et al** [13] o investigate natural convective heat transfer coefficient between an interior circular tube and a square enclosure filled with air. The use of a two-dimensional analysis was considered. The inside body is kept at a high temperature, while the enclosure's walls are kept at an isothermally low temperature. If Rayleigh's number rises to 10^5 or 10^6 , the effect of buoyancy circulation on fluid flow and heat transfer in the instance rises, and the heat rises as a result. When the Rayleigh number is as low as Ra = 10^3 or 10^4 , conduction dominates fluid movement and heat transmission. The convective heat transport in a square cavity with an interior revolving cylinder was explored numerically by **Roslan et al.** [14]. The left and right surfaces were heated and cooled, respectively, while the other walls and rotating cylinder remained adiabatic. Using a finite volume technique, **Hussain et al.** [15] studied numerically a laminar stable mixed convection in a two-dimensional square cavity with a spinning circular cylinder. The left and right side walls, respectively, are heated and chilled. The hollow walls on the lower and higher levels are both insulated. With a Prandtl value of 0.71, the considered cavity was filled with air. For Richardson numbers (0, 1, 5, and 10) and Reynolds numbers (0, 1, 5, and 10) the stream function, isothermal lines, and the average Nusselt number are given (50, 100, 200, and 300). The effects of different positions on a circular cylinder and thermal conductivity ratios on heat transmission were investigated. The findings revealed that when the Richardson and Reynolds numbers rise, so does the average Nusselt number. At a large concentration of nanoparticles with a high conductivity value, slow positive rotation, and a tiny cylindrical size in the cavity center, maximal heat transfer is accomplished. **Park,et al**.[16] investigated the numerical analysis of natural convection generated by a temperature differential between a cold inclined exterior square container and a hot circular cylinder filled with air using the finite volume approach.three– dimensional analysis had been considered. The inside body is kept at room temperature, while the enclosure's walls are kept at isotherm cold. In this example, the effects of the following on fluid flow and heat transmission were investigated. Taking into account the cylinder's radius and the e container's oblique angles It relies on time where the isothermal distribution is simplified. The surface-averaged Nusselt number drops along the top and left walls as the tilted angle rises, but increases along the bottom and right walls, they found. For different dimensionless radii when 10^3 <Ra< 10^5 , the change in the surface-averaged Nusselt number according to the tilted angle was comparable. **Ravnik and Skerget** [17] numerically simulated the flow and heat transport of heated circular/elliptical cylinders in a chilled square chamber. For all nanoparticles with volume fractions of 0.1 and 0.2, the characteristics of nanofluids were consistent across the region. The results show that using nanofluids improves heat transmission in situations where convection is the primary heat transfer mechanism. Furthermore, when comparing the circular and elliptical cylinders, the heat transmission characteristic in the elliptical case is somewhat superior. **Shih et al.[**18] examined the influence of high viscosity fluid on fluid flow and heat fields in an enclosure with an inner adiabatic-rotating circular cylinder of various forms (equilateral triangle, square, and circle). The governing equations are investigated using a computer technique based on finite volumes. The inside circular cylinder was heated and the enclosing walls were chilled. The results indicated that the triangular cavity had the best capacity to disperse internal heat energy over the walls, meanwhile the cylindrical cavity had the less performance. **Sourtiji et al**. [19] used a control volume based finite element approach to investigate natural fluid flow between circular cylinders within a triangular nanofluid enclosure. Brinkman and Maxwell-Garnetts were used to predict nanofluid thermal thermo-physical parameters such as viscosity and thermal conductivity. At low Rayleigh numbers, it was discovered that introducing a void percentage of nanofluid had a significant influence. Furthermore, it has been shown that increasing the inner circular cylinder diameter significantly improves heat transmission. **Mansour et al**.[20] nvestigated steady-state laminar 3D mixed convection in a lid-driven cubical square cavity heated by its fixed bottom wall. It was supposed that the top wall was chilly and going in the appropriate direction. The other walls were considered to be adiabatic. The findings for [0.001 <Ri< 10] were provided, At Re=100, the Reynolds number was assumed to remain constant. They came to the conclusion that increasing the Richardson number increased the average Nusselt number. The mixed convection heat transfer between an inner-heated circular cylinder moving counter-clockwise and a trapezoidal enclosure was explained by **Khan et al**. [21]. The rectangular enclosure's bottom and top walls are maintained adiabatic, while the two inclined walls are kept cold. They compared the impact of a static cylinder vs a moving cylinder in a square cage. The revolving cylinder, as well as the inclination angle linked to sidewall effect, had a substantial impact on heat transmission, according to their findings. **Hatami and Safari**[22] investigated the convective heat transfer of nanofluid within a wavy-wall container computationally. The authors looked at several cylinder places along the model's Cartesian coordinate. It was discovered that the cylinder's center placement aids heat transmission in both wavy sides. **Faroogh and Faraz** [23] investigated natural and numerically mixed convection in a constant temperature square container comprising many pairs of hot and cold tubes using the SIMPLE algorithm based on the finite volume approach. The cylinder's surface is temperature stable, while its walls are filled with Nanofluid and are heat insulated. The research shows that altering the direction of movement of the hot and cold cylinders can change the rate of heat transfer. Furthermore, altering the thermal source/sink design from base - top to top - base dramatically reduces the heat transfer, and the findings revealed that altering the orientation of the cold cylinder from perpendicular to parallel greatly reduced the approximate rating of nails.The objective of the present research is to study numerically as well as experimentally the convection within enclosure considering the existence of circular pipes. Also, we elaborate the study in the numerical direction by adding the empirical correlation development characteristics. Nusselt number was taken as an indicator for the enhanced of heat transfer so we calculate it under various parameters.

EXPERIMENTAL WORK

The tester is manufactured to meet the requirements of the test system for free-load heat transfer and the effect of pressure on it. Experimental component device mainly in Figure (1) and its parts as: Enclosure, Tubes (4), Variac, Digital Thermometer, Thermocouples, Selector temperature switch, Min-type digital clamp-meter, gauge pressure, One-way valve, Air compressor, Heaters. Most of these components were manufactured in the domestic market and During the operation of the test rig, care has been taken to prevent air leakage between the associated parts. The experimental procedure that had been used in the present work can be summarized as indicate below;

- Supply the heaters with the required amount of power supply.
- Keep the pressure of the enclosure constant
- The inner pipes positions had been changed.
- Waiting 30 minutes to reach the steady state conditions.
- Five thermocouples had been installed on each pipe to find out the temperatures with a distance between each thermocouples 9 cm.
- These measured temperatures had been utilized in order to calculate Rayleigh number and Nusselt number
- Three different pressures and heater power supplied had been considered.
- The number of heaters had been changed also as one heater case and two heater case
- These procedures had been returned many times with each various experiment.

Figure 1: Experimental rig setup of present work.

NUMERICAL ASPECTS

The investigation of CFD modeling and simulation of cylindrical enclosure with in four pipes has been conducted and explained in this chapter. The numerical solution based on 3D modeling is utilized briefly. The solution of momentum and heat transport have been included in the present work by coupling and solving laminar fluid flow and heat transfer by using COMSOL Multiphysics V 5.5. The main applied physics in present work are momentum transport (turbulent k-ε) and heat transfer through fluid and solid. The complex partial differential equations are converted in to algebraic equations based on force balance and heat balance with control system by mean of mesh distribution. The Multiphysics coupling is enabled by interaction between velocity and temperature distribution, the velocity components is used for convection purpose in heat transfer equation while the temperature can manipulate the physical properties which are polynomial expressions. The main boundary conditions for free convection as shown in Figure (2) :

- At the inner pipe: Constant heat flux surface
- At the outer cylinder: Isotherm cold surface temperature
- Wall function for interior and exterior walls
- The main boundary conditions for mixed convection:
- Constant heat flux surface

- Isotherm cold surface temperature
- Wall function for interior and exterior walls
- Inlet flow: from top to bottom
- Outlet pressure: outlet pressure
- Inlet Temperature: the temperature of inlet fluid

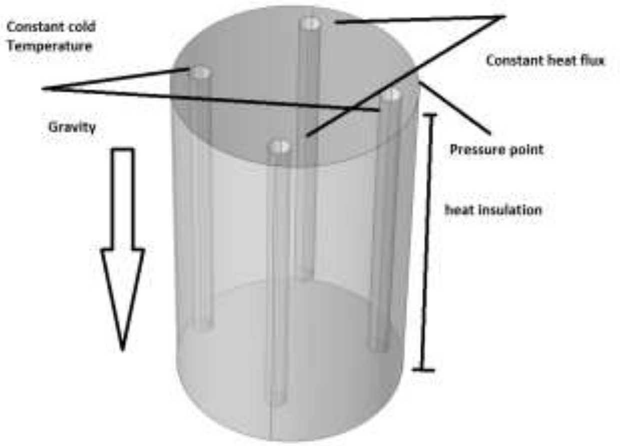

Figure 2: The boundary conditions of present study.

DATA COLLECTION AND CALCULATIONS

The average heat transfer coefficient (for free convection) is obtained from the following expression:

$$Q = h A_s (T_h - T_a) \tag{1}$$

Where:

$$T_h = \frac{T1 + T2 + T3 + T4 + T5}{5}$$

$$A = \pi D L$$

T1, T2, T3, T4 and T5 are the heated pipe wall temperature of different height.

The average Nusselt number (Nuave) (for free convection) can be determined by:

$$Nu = \frac{h L}{K} \tag{2}$$

The resultant Grashof Number is calculated from:

$$Gr = \frac{g * \beta * (Th - Ta) * L^3}{(v)^2} \tag{3}$$

$$Tf = \frac{Th + Ta}{2}$$

$$\beta = \frac{1}{273 + \text{Tf}}$$

$$Ra = Gr\, Pr \tag{4}$$

The Results and Discussion

The effect of pressure ratio

Nu vs. Ra for various pressure ratios for hot pipe are shown in Fig. 3. The overall pattern shows that when Ra increases, so does Nu. The lower Nu develops with a larger pressure ratio, and the minimum Nu values are displayed with a pressure ratio of 2. The pressure exerts a pressure force on the fluid system, causing heat transfer circulation resistance. The pressure force is seen as a supplement to the gravity force. Fig. 4 shows Nu vs. Ra for various pressure ratio for cold pipe. The same to hot pipe behavior is presented, the increasing of pressure decreases the Nu significantly more than the hot pipe. The presence of higher pressure reduces the hot and cold fluid particles circulation inside the enclosure. Nu vs. Ra for various pressure ratios for cold pipe are shown in Fig. 4. The behavior is similar to that of a heated pipe; however, increasing pressure reduces the Nu much more than the hot pipe. The circulation of hot and cold fluid particles inside the enclosure is slowed by increasing pressure.

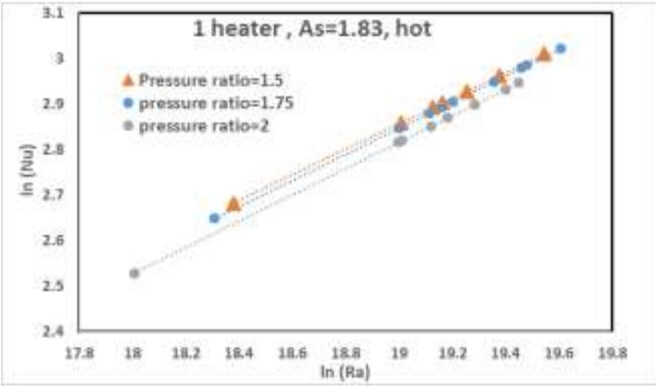

Fig. 3: Nu vs. Ra for various pressure ratios in hot pipe.

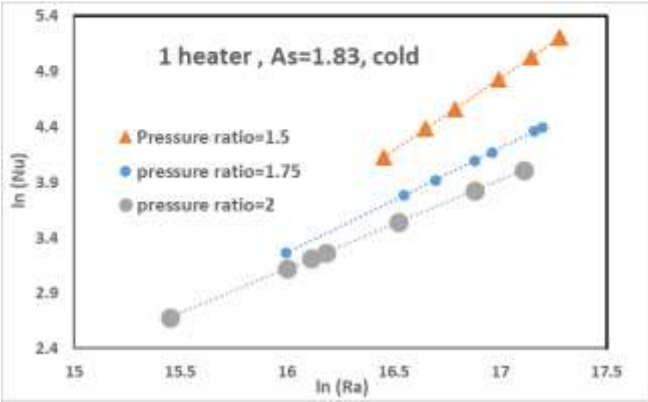

Fig. 4: Nu vs. Ra for various pressure ratios in cold pipe.

The effect of operation configuration

In Figs. 5-7, Nu vs. Ra for various operation configuration and pressure ratios for hot pipe. The Nu values for the two heated pipes arrangement are greater than the one pipe design for various pressure ratios. Inside the enclosure, the two heated pipes generate double the amount of heat, indicating a double heat flow in the thermal system. Within the heat transfer, the double heat transfer area is also shown. When the pressure ratio is equal to 1.75 and two heated pipes are employed, the maximum heat transfer improvement is around 36%.

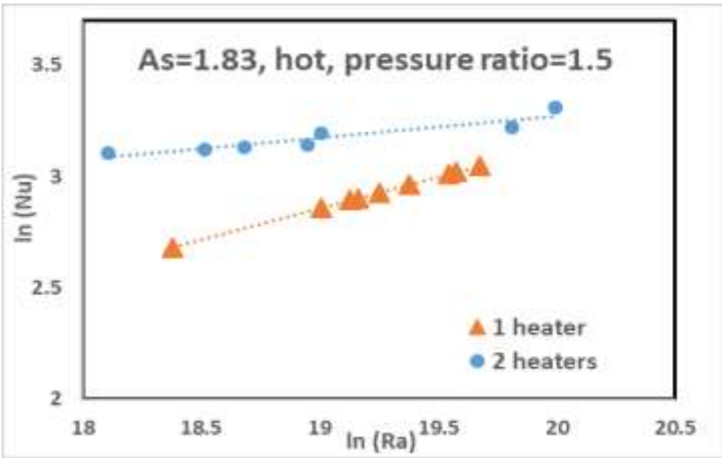

Fig. 5: Nu vs. Ra for various operation configuration at pressure ratio= 1.5 in hot pipe.

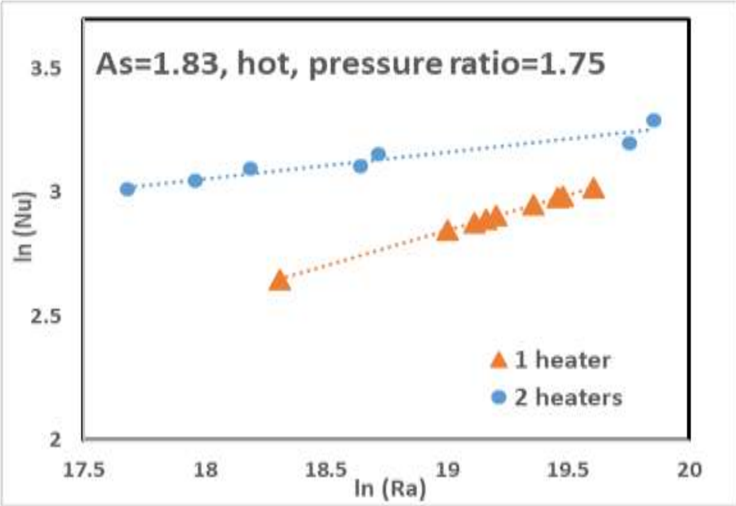

Fig. 6: Nu vs. Ra for various operation configuration at pressure ratio= 1.75 in hot pipe.

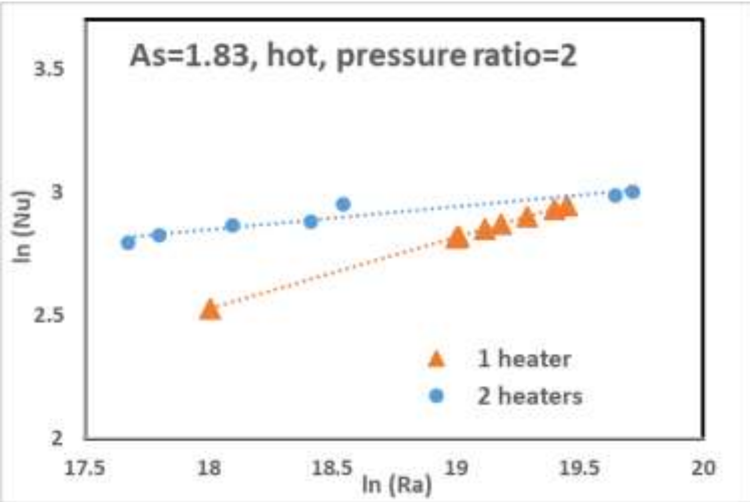

Fig. 7: Nu vs. Ra for various operation configuration at pressure ratio= 2 in hot pipe.

In Fig. 8-10, Nu vs. Ra for various operation configuration and pressure ratios for cold pipe. Because of the low pressure, the one heated pipe arrangement exceeds the two heated pipe configurations by 35%. In two heated pipe configurations, greater pressures result in higher heat transfer improvement of 109 percent for 1.75 pressure ratio and 150 percent for pressure ratio=2. Because the volume of hot fluid is more than the volume of cold fluid at low pressure force, the pressure circulation of cold particles in two pipes configuration is greater than in one pipe arrangement. High-pressure ratios add to gravity's force, overcoming volume forces and resulting in lesser fluid displacement between hot and cold pipe sections. Due to the obvious increased viscous force existing in the current system, the heat transfer amount will be significant at high pressures.

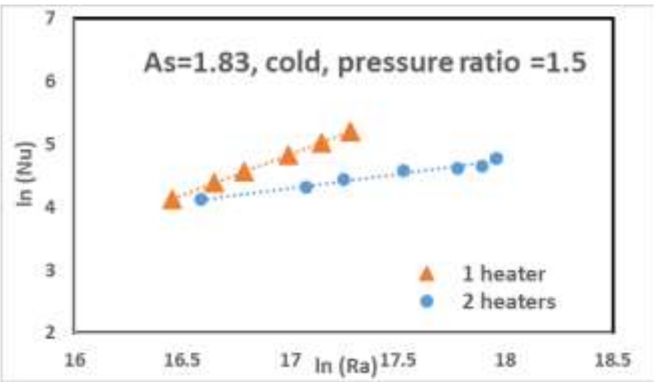

Fig. 8: Nu vs. Ra for various operation configuration at pressure ratio = 1.5 in cold pipe.

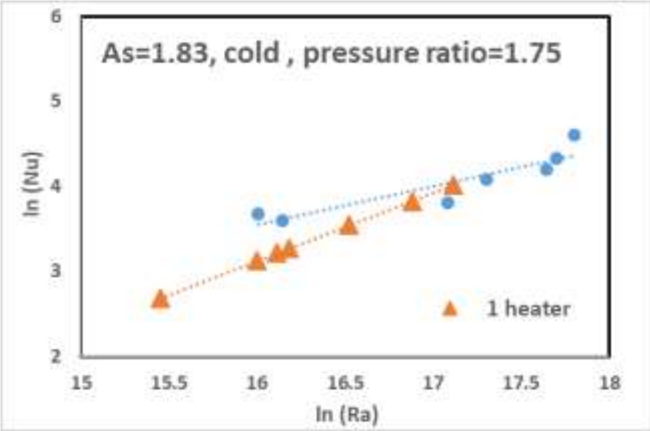

Fig. 9: Nu vs. Ra for various operation configuration at pressure ratio = 1.75 in cold pipe.

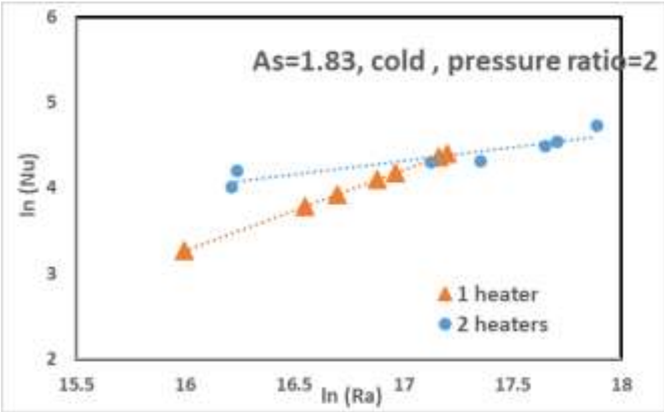

Fig. 10: Nu vs. Ra for various operation configuration at pressure ratio = 2 in cold pipe.

The effect of Aspect ratio

Fig. 11 and 12 show Nu vs. Ra for various aspect ratio and operation configuration when pressure ratio=1.5 for hot pipe region. In one pipe operation, increasing the aspect ratio (decreasing the distance between pipes) considerably raises the Nu number. When the aspect ratio is increased, the heat transfer resistance reduces. The heat transfer rate will be successfully transmitted from hot pipe to cold pipe. When As=5, the maximal heat transfer improvement is roughly 51%. Between the Nu and Ra, the two pipes setup displays a semi trend. . The Nu values of the lowest and highest aspect ratios are greater than those of the mid-aspect ratio (2.7). The heat transfer by natural convection is most successful between As=1.83 and 5, while the heat transfer by fluid conduction is most effective between As=1.83 and 5. The fluid circulation is influenced by the pipe location. In As=2.7, an extra heat transfer resistance is created.

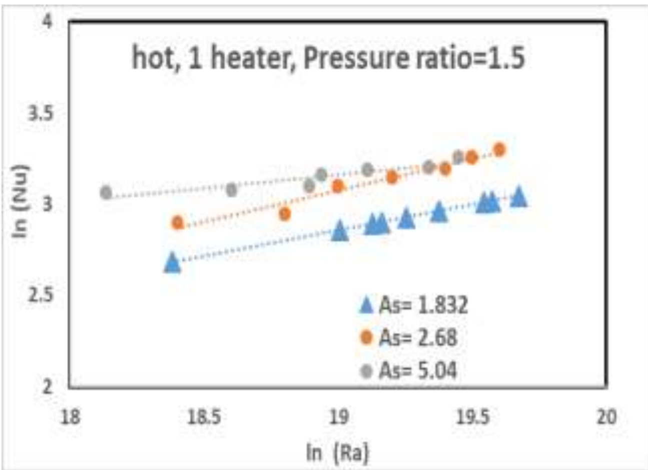

Fig. 11: Nu vs. Ra for various aspect ratio at pressure ratio= 1.5 in hot pipe, one heated pipe.

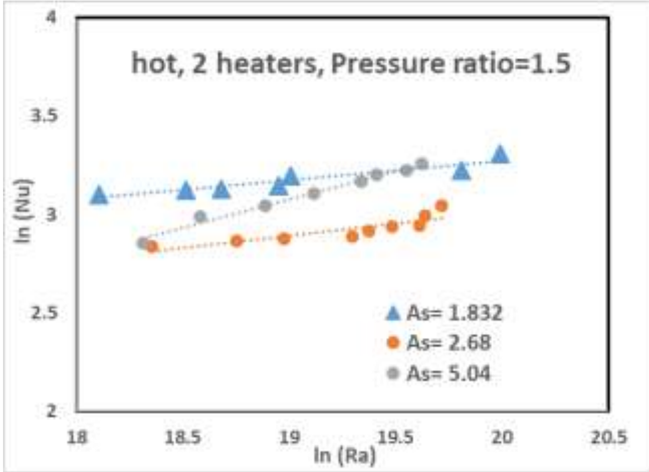

Fig. 12: Nu vs. Ra for various aspect ratio at pressure ratio=1.5 in hot pipe, two heated pipes.

Fig. 13 and 14 show Nu vs. Ra for various aspect ratio and operation configuration when pressure ratio=1.5 for cold pipe region. Different behavior is noticed in the hot zone. When the aspect ratio is increased, the Nu lowers, and at As=5, the Nu reduces in one heated pipe. As As increases, the amount of displaced cold and hot fluids decreases; however, as As=5, the volume of displaced fluid increases due to lower thermal resistance and more heat dispersion via the fluid between the pipes. The heat transfer performance decreases when the volume of hot fluid particles mixed with cold fluids increases, since the amount of cold fluids mixed with the hot fluid is greater than the amount of cold fluids mixed with the hot fluid.

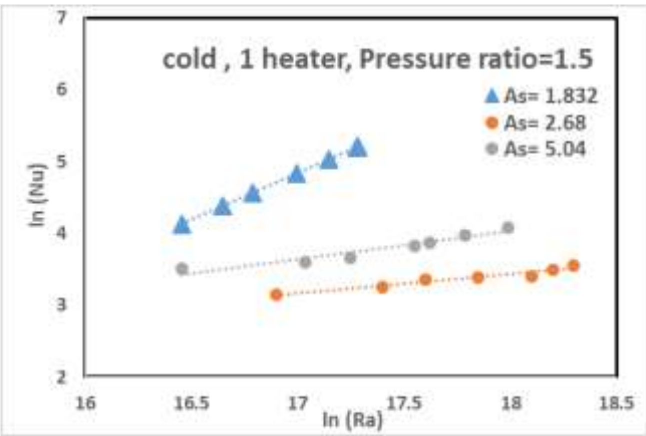

Fig. 13: Nu vs. Ra for various aspect ratio at pressure ratio= 1.5 in cold pipe, one heated pipe.

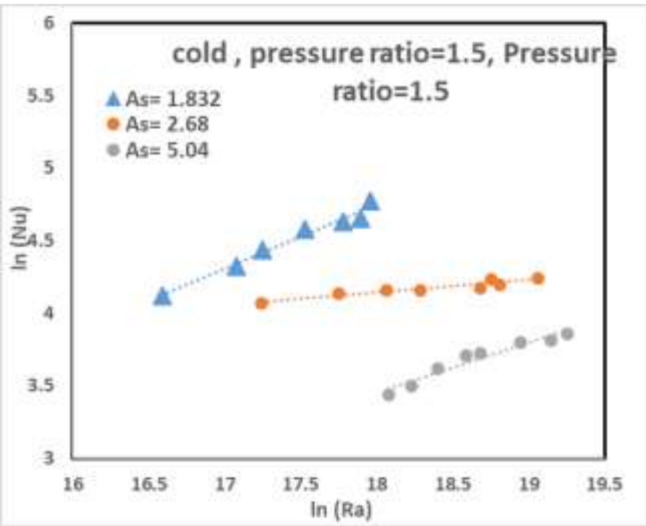

Fig. 14: Nu vs. Ra for various aspect ratio at pressure ratio=1.5 in cold pipe, two heated pipes.

The validation with numerical results

Fig. 15-27 show the Nu vs. Ra for various pressure ratios with the same plot for numerical results. The two heated pipes and aspect ratio of 1.83 are used in hot pipe region. The numerical investigation shows the great validation with experimental work for the whole Ra and Pressure ratio. The maximum error % is observed at pressure ratio of 1.5 by value of 16 %. The error % is observed at pressure ratio equals to 0.5 % at pressure ratio=1.75.

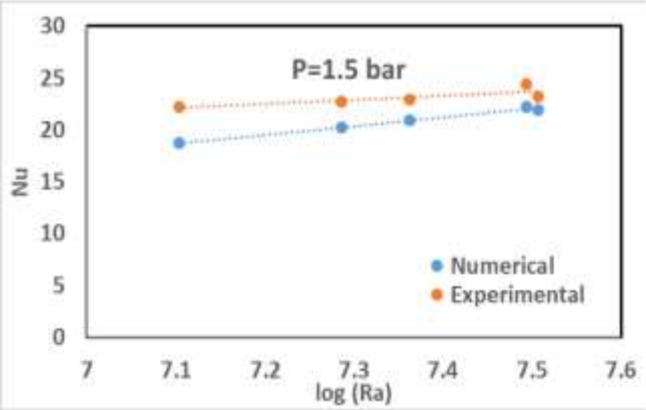

Fig. 15: The validation of Nu vs. log Ra with numerical results at pressure ratio=1.5 in hot pipe, two heated pipes.

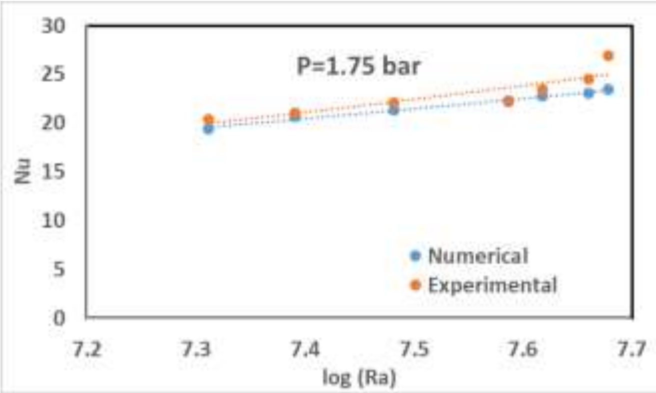

Fig. 16: The validation of Nu vs. log Ra with numerical results at pressure ratio= 1.75 in hot pipe, two heated pipes.

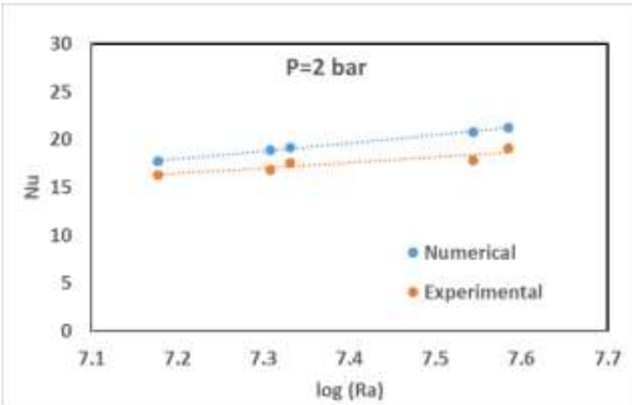

Fig. 17: The validation of Nu vs. log Ra with numerical results at pressure ratio=2 in hot pipe, two heated pipes.

The validation with obtained correlation

The experimental data develops a correlation including Nu as dependent variable then the pressure ratio, aspect ratio and Ra as independent variables for one and two heated pipes in hot pipe region. The maximum error % is around 17. 6 % with one heated pipe and 28 % with two heated pipes as shown in fig. 18 and 19. The obtained correlations are expressed as following by using Multiple regression:

For one heated pipe

$$Nu = 0.23\ Ra^{0.231} P^{-0.258}\ As^{0.195} \quad (5)$$

For two heated pipes

$$Nu = 15.452\ Ra^{0.0444} P^{-0.754}\ As^{0.164} \quad (6)$$

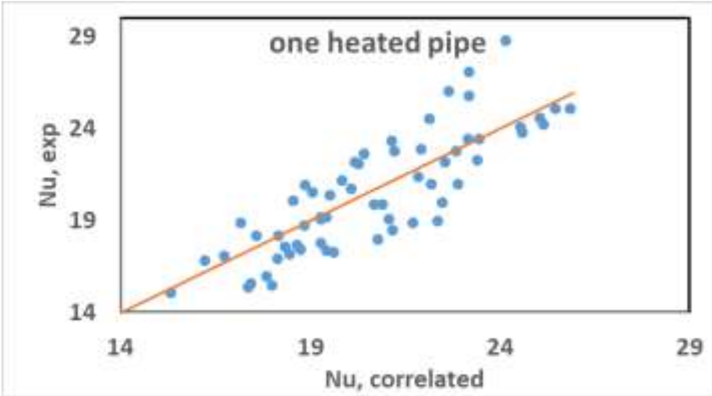

Fig. 18: The validation with the experimental obtained correlation for one heated pipe.

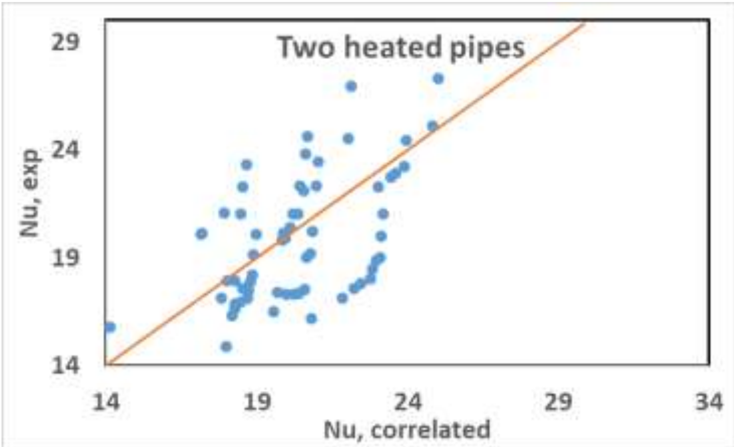

Fig. 19: The validation with the experimental obtained correlation for two heated pipes.

Conclusions

The experimental investigation of pressurized enclosure for various parameters are successfully analyzed. The results demonstrated that when Ra rises, so does Nu. For various pressure ratios, the Nu values for the two heated pipes arrangement are greater than the one pipe design. The two heated pipes inside the container create twice as much heat, showing a twofold heat flow inside the thermal system. Double heat transfer area is also represented within the heat transfer. The highest heat transfer improvement is roughly 36% when the pressure ratio is equal to 1.75 and two heated pipes are used. The heat transmission resistance decreases when the aspect ratio is raised. The heat transmission rate between the hot and cold pipes will be successful. The maximum heat transfer increase is around 51% when As=5. It's a battle between the Nu and the Ra. The numerical simulation closely matches the experimental results. Experimental evidence backs up the hypothesized link.

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