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Experimental study of influence of porosity on heat transfer rate For hollow horizontal cylinder

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Abstract:
In this paper, a laboratory prototype was designed and built to test the forced convection heat transfer from out surface of hollow cylinder with inner porosity 20% at different heat fluxes. The effect of regarding parameters such as Nusselt, Rayleigh and Reynold numbers on heat transfer and the flow character are observed. The experimental results shows that local Nusselt number of the external cylinder decrease with the reduction of Rayleigh number by 46.7% at maximum level and 21.7% at minimum level when Rayleigh number decrease from $4 * 10^7$ to$1 * 10^7$. While it increase with Reynolds number by 21.8% at maximum level and 40% at minimum when Reynolds number rise from 500 to 2200 (minimum to maximum). Out surface temperature of cylinder was reducing if using porosity.

Keywords: hollow cylinder, porosity, forced convection, heat flux, Reynold number.

Nomenclatı

A_c	Cross sectional area of us	m^2
D_h	Hydraulic diameter	M
E	Voltage	V
g	Gravitational acceleration	m/s^2
h	Heat transfer coefficient	$W/m^2.K$
I	Current	A
k	Thermal conductivity	W/(m K)
l	Length of annulus	M
q″	Imposed heat flux on the outer cylinder	W/m^2
T	Temperature	°C
u	Velocity component	m/s
z	Axial direction	M
Z	Dimensionless axial coordinate	-

<u>Dimensionless Numbers</u>

Gr	Grashof number, $Gr = \frac{Ra}{Pr}$
$\overline{Nu}$	Average Nusselt Number
Nu_Z	Local Nusselt Number, $Nu_Z = \frac{h\,D_h}{k}$
Pr	Prandtl Number, Pr= v/α_m
Ra	Rayleigh Number
Re	Reynolds Number

1. Introduction

Heat transfer happen when temperature difference exists with the surroundings and system or between the system and it is surroundings [1]. The three types of heat transfer are conduction, convection and radiation. Whatever, for any given system, each type of heat transfer can in many stats be examined separately and the results can be put together to give the total heat transfer rate from this system. Whatever, in some stats, heat transfer from a system can include a mixture of two or three of the state of heat transfer which interact with each other [2]. Forced convection from heated horizontal cylinder is an important problem related to many functional applications, such as flow in tubes of HVAC system, in renitent heating of electronic components, loss of heat from process piping, coils of steam heated and electric inundation heater in process vessels…etc. [3][4].

A survey of forced convection from a cylinder is executed. Forced convection from cylinder happened when there is a proportional movement between a hot surface and a fluid discharge over the surface and there is a temperature variance between the surface and the fluid [5]. The convective heat transfer rate relies on the characteristics of the fluid flow. So, convective heat transfer can be sorting according to the nature of the fluid flow and in specified on if the flow is laminar or turbulent. So the force convection is a technique, or type of heat transport, in which the fluid movement is generated by any outer source (like a fan, suction device, pump, etc.) Natural convection happens only by density variance in the fluid occurring cause to gradients temperature [6]. In natural convection, cooler fluid around a heat source receives heat, becomes less dense and increases. This cooler fluid is heated and the procedure continues, shaping convection current [7]. Developing temperature in a concentric annulus and laminar forced convection for fully developed velocity where the temperatures or heat fluxes on the two surfaces has been completely solved by Lundberg et al. [8]. Natural laminar convection has also been widely examined in a horizontal annulus with water and air. Experimental work was concentrated on, Powe et al. [9]

In another study, Kuehnand Goldstein [10] developed a turbulent and laminar model for heat transfer in eccentric circular and concentric annuli.

The fluid flow and heat transfer procedure with the annulus are planned by the mutual influences of inertia, centrifugal forces, and buoyancy. The result impact determines the flow modality and the heat transfer properties within the Grashof number and the Reynolds number. Of special convenience for this case is the ratio of the Grashof number to the square of the Reynolds number, which is described as Richardson number. This ratio pointing to the value of the forced flow and buoyancy influences on the fluid flow and heat transfer through the annulus. Furthermore mixed convection in horizontal concentric cylinders has been the title of a lot researchers, but still lot imagination of fluid flow and heat transfer that need to be studied. The following researches of both numerical and experimental previous work shows that money of the existing research on mutual forced and free convection heat transfer in horizontal annuli are exclusive to the fully developed zone [11–22] and developing zone[23].Thereby the aims of this study is to exanimate the effect of porosity on heat transfer processes and find empirical correlation between Reynolds and overall Nusselt numbers to specification force convection heat transfer for heated cylinder.

2. Experimental study

The test prototype was manually manufacturing. The materials used to structure the test device were silicon sealant, copper cylinder, contract plastic pipes, holder rings, electric wires and blower as shown in figure. 1.

Fig. 1. Schematic diagram of device.

The tested cylinder made from copper with a uniform thickness of almost 3 mm. The test cylinder has an external diameter of 160 mm and a total length 500 mm. the cylinder was drilled at nine equal axial dimensions making small holes. The distance is 50 mm between each hole. Thin thermocouple wires, 1.5 mm external diameter with fiber glass coating, of type K (copper constant) with welded ends were embedded into the cylinder surface from the inner surface and adjusted to keep its end at the external surface of the cylinder wall. A heater has tubular shape which has the same length of cylinder was incorporated in the copper cylinder to work as a heat source.

The porous media as shown in figure. 2. was steady inside the annulus. It's made from polypropylene fibers as a block annulus with 79.5 mm internal diameter, 160 mm external diameter and 500 mm length.

Fig. 2. Porous media.

It consists of a nickel chrome wire of 1.2 mm in diameter and a resistance of (1.8 ohm/m), which was insulated electrically by heat treated fiber glass covered and taped around the external cylinder. The heater was submitted by AC-current from the voltage organizer, to organize supplied current according to the desired heat flux. The heater covered with three layers of 5 mm asbestos stripe to guarantee a good heater fixing and to submit an initial insulation to the test section. The test section was insulated externally with three layers of 50mm thickness of glass wool, which was surrounding by means of plastic tapes. The tubular heaters and the external cylinders have the same length of 500 mm. Out of this length, only 400 mm acts as an effective heated length. The horizontal cylinder (length 500 mm and diameter 3 in) is made from copper because of its high thermal conductivity. Figure. 3. Shows the laboratory prototype used device.

Fig. 3. Laboratory device.

The experiment is repeated with varying the different parameters to study the influence on temperature on out surface and Rayleigh number. The parameters are:

1. Heat flux at outer cylinder (400, 1000, 2000 and 2800 W/m^2).
2. Airflow rate (35, 40, 45, 50and 55m^3/h).

3. Results and discussion:

3.1. Experimental Results

3.1.1. Temperature changes

In general, the variation of surface temperature along the annulus may be effected by many parameters such as Ra number and Re number.

The temperature changes in longitudinal direction for external cylinder are drawn for runs have been selected in figures. 4 – 5. Figure. 4. Explained the change of the surface temperature along external cylinder for different Rayleigh number and for three various values of other parameters. This figure shows that the external surface temperature rises with the dimensionless axial direction (Z). The rate of surface temperature increase is straightly proportional to the Rayleigh number. At lower rate of Rayleigh number, it can be obvious that the surface temperature along the annulus is approximately constant. The temperature rises with rising Rayleigh number as a result of increase in heat flux on the outer surface. The temperature increasing more with dimensionless axial distance (Z) and it reaches to maximum value at the external of the annulus. This increase in temperature with axial distance raises more with rise in Rayleigh number. This could be pointing to increase the thermal boundary layer improve when heat flux rises.

Figure (5) shows the effect of Reynolds number change on the external cylinder surface temperature at fixed heat flux. It is clear that the increasing of Reynolds number decreases the surface temperature when heat flux kept constant. The rise in air flow leads to raise the convicted heat by air and therefore the surface temperature decreases and also reduce with axial distance. It is important to know that as flow rate of air inside annulus decreases the external cylinder surface temperature since the forced convection is the main factor in the heat transfer process.

3.1.2. Local Nusselt Number

The change of (Nuz) for external cylinder with axial distance shows in figures. 6 - 7. As seen from these figures, the local Nusselt number in all cases decreases with the increasing in the dimension less distance (Z), in the same time the heat transfer coefficient depends on the different in surface temperature and bulk temperature. This behavior is expected as the highest temperature difference between the hot surface and the inlet cold air happens at the entrance of test section particularly at higher Rayleigh number. Therefore, the biggest heat transfer amount happens in the entering of the annulus. When the air moves inside the annulus, the local air temperature raises so efficiently increasing the local wall temperature and decreasing the Nuz number at all path of flow. It is clear from this figure that at higher Ra number, the results of the Nuz number were larger than the results of lower Ra number. This may be attributed to the secondary flow effect which increases when the heat flux rises; this leads to bigger heat transfer coefficient. Nuz number reduces with axial distance from entrance section. This decrease is larger at high Ra number cause to the faster rising of the thermal boundary layer thickness. This layer leads to decrease in heat transfer coefficient and heat transfer procedure between hot surface of external cylinder and air. Local Nusselt number reduces by 46.7% when Rayleigh number reduces from 4 x 10^7 to 1 x 10^7at maximum level. While it reduced by 21.7% at minimum level.

The effects of Rayleigh number on local Nusselt number differences with dimensionless axial distance are shown in figure (7). Momentum of air is raised with rising Reynolds number, which yields to rise in heat transfer rate. Reynolds number rise local Nusselt number at Z = 3.50 by 48.15% when it rise from 500 to 2200 at maximum level while it rise Nusselt number 40% at minimum level.

3.1.3. Average Nusselt Number

The relevance between average Nusselt number ($\overline{Nu}$) and Rayleigh number are shown in figure. 7. The figure shows an rising in average Nusselt number as Reynolds number rise because of the rising in heat transfer rate between air and hot wall. It is also seen that the effect of Reynolds number on the heat transfer rate is more dominant at high Rayleigh number. The average Nusselt number rise 40% when Reynolds number rise from 500 to 2200 at minimum level and 21.8% at maximum level.

3.2. Correlations of Average Nusselt Number

The magnitudes of the average Nusselt number ($\overline{Nu}$) for the experimental and numerical work with Ra and Re for the range of Re from minimum to maximum, and Ra from

1×10^7 to 4×10^7 and by using Data fit program have been correlated. The correlation equations are studied for each state of porous media. All the points as shown represented by linearization of the following equations:

$$\overline{Nu} = 0.0721\, Ra^{0.136} Re^{0.581} \qquad (1)$$

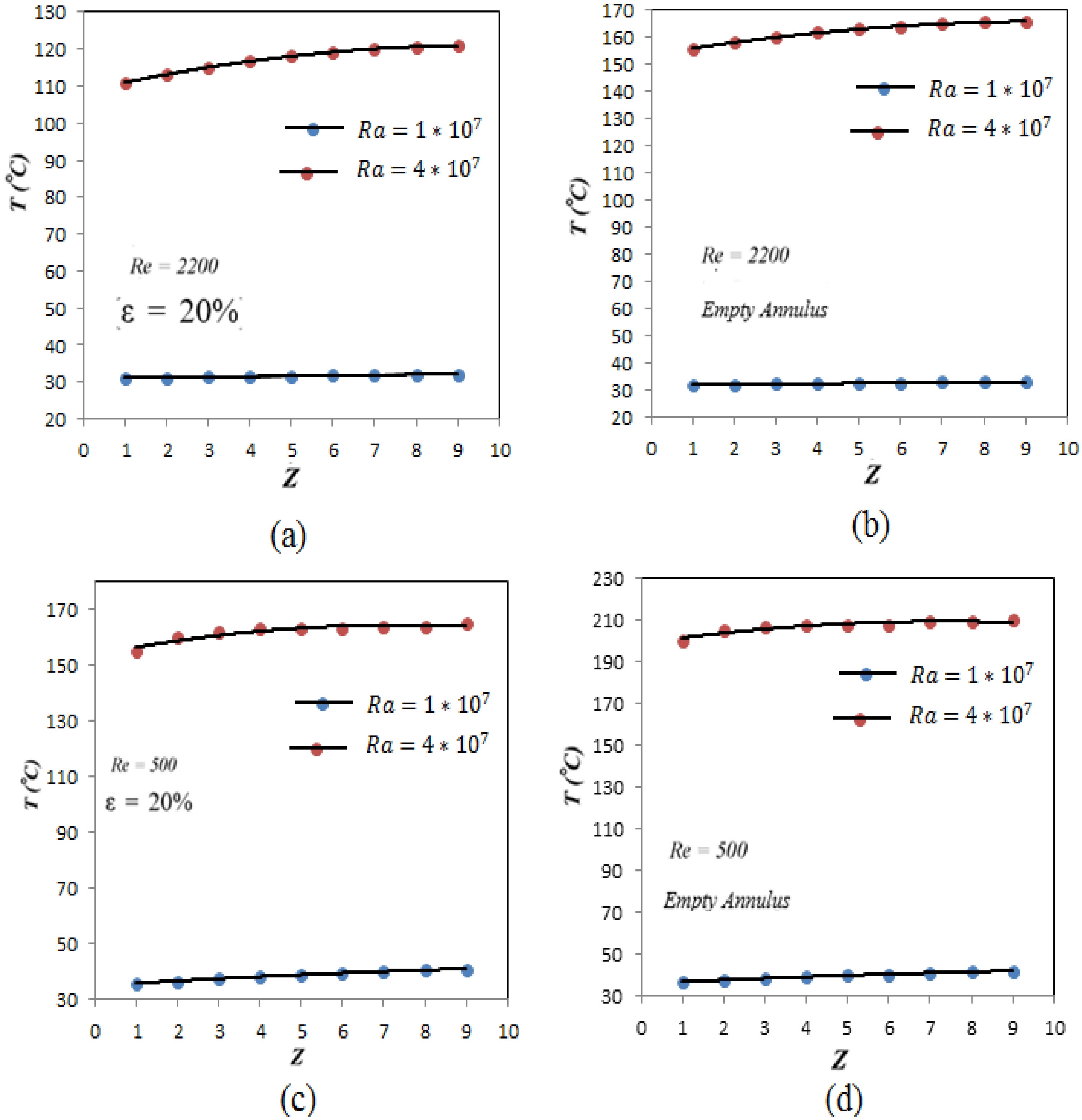

Fig. 4. Effect of Rayleigh Number on the Longitudinal Variation of the Experimental Surface Temperature of the Outer Cylinder

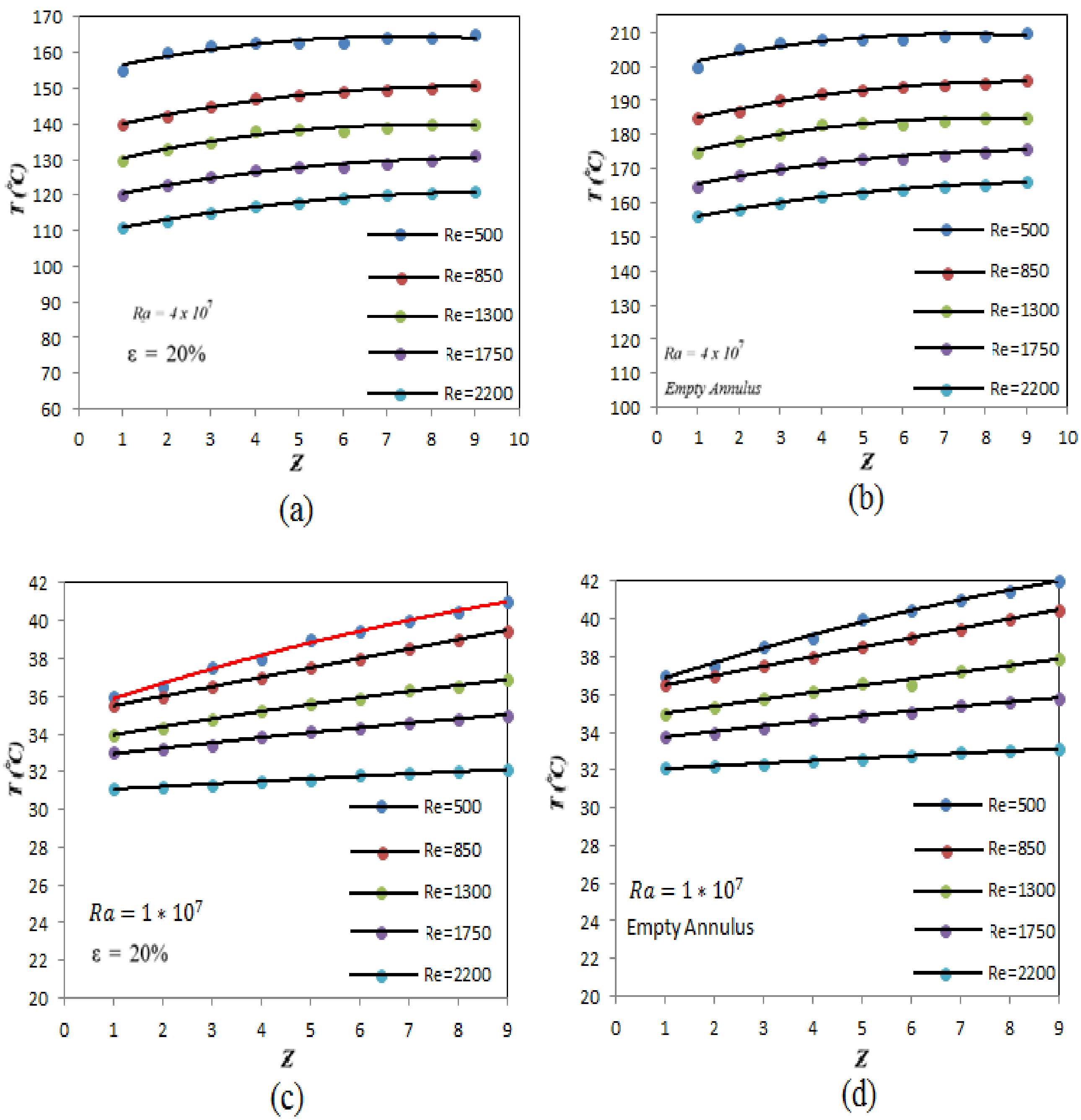

Fig. 5. Effect of Reynolds Number on the Longitudinal Variation of the Experimental Surface Temperature of the Outer Cylinder

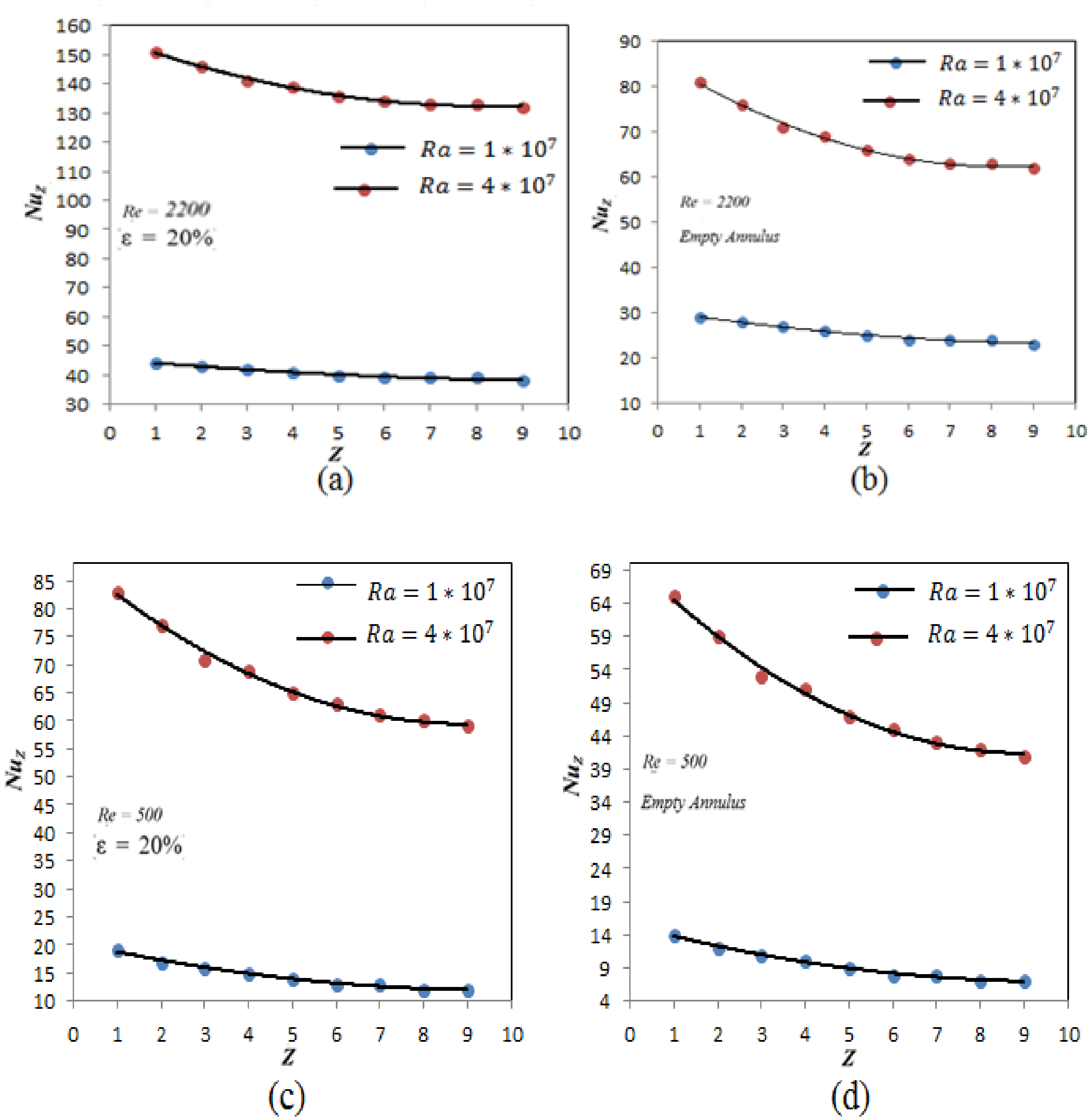

Fig. 6. Effect of Rayleigh Number on the Longitudinal Variation of the Experimental Local Nusselt Number of the Outer Cylinder

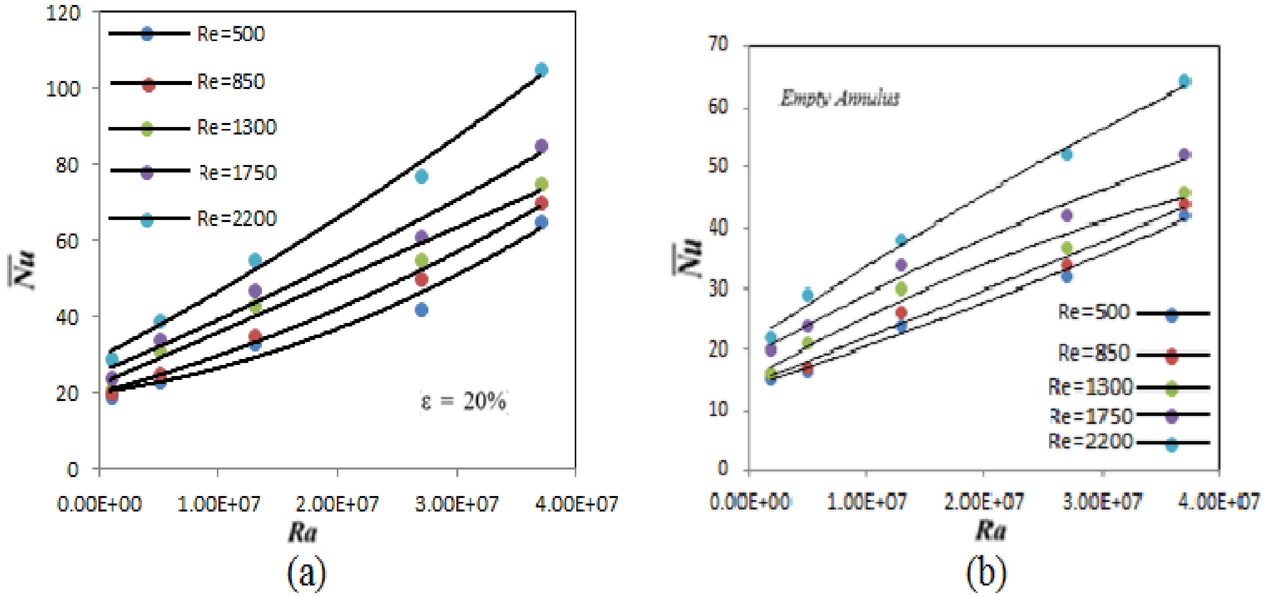

Fig. 7. Effect of Reynolds Number on the Longitudinal Variation of the Experimental Local Nusselt Number of the Outer Cylinder

4. Conclusions:

For the experimental values, the following results can be made:

1. The experimental surface temperature of external cylinder rise with longitudinal direction while the local Nusselt number of the external cylinder reducing.
2. The local Nusselt number of the external cylinder reducing with the reduce of Rayleigh number by 46.7% at maximum level and 21.7% at minimum level when Rayleigh number reduce from 4×10^7 to 1×10^7. While it rising with Reynolds number by 21.8% at maximum level and 40% at minimum level when Reynolds number rising from 500 to 2200.
3. The average Nusselt number reduced by 53% when Rayleigh number reducing from 4×10^7 to 1×10^7 at minimum level and 59% at maximum level.
4. The average Nusselt number rising by 38.6% when Reynolds number rise from 500 to 2200 at minimum level and 27.8% at maximum level.
5. Reynolds number and porosity influence obviously on heat transfer rate due they influence on the flow resistance.
6. Surface temperature of external cylinder reduce with using porous media and the local and average Nusslet number rising with porous media comparison with empty cases.

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