Chapter (5)

EXPERMENTAL RESULTS AND DISCUSSION

5-1 Introduction

The analysis of the expermental results and discussion are presented in this chapter. The experimental results are done for the convective heat transfer inside an annulus gap formed between two cylinders. Overall heat transfer coefficient and Nusselt number are determined. An experimental analysis of the heat transfer performance has been made for a stationary concentric annulus filled with air under steady state conditions. The experimental results obtained here has been compared with the avilable data in the existing literature. The experiments done on stationary concentric annulus are considered for comparison to indicate the degree of enhancement resulting from rotation and eccentricity. The experimental results are first verified by comparion with the available existing data. The average Nusselt number of the present study for stationary concentric annulus is comparion with the average Nusselt number for available existing data.

Figure (5.1) show the the average loccal temperature alonge length of annulus. From thise figure, it clear that the distrubution of temperature along the length is the same value with deviation 1%. From the above, The heat is transffered in longtuidal direction is very small compared with the heat is transffered in radial and peripheral directions. Then heat transfer in the present study is two dimension coordinate.

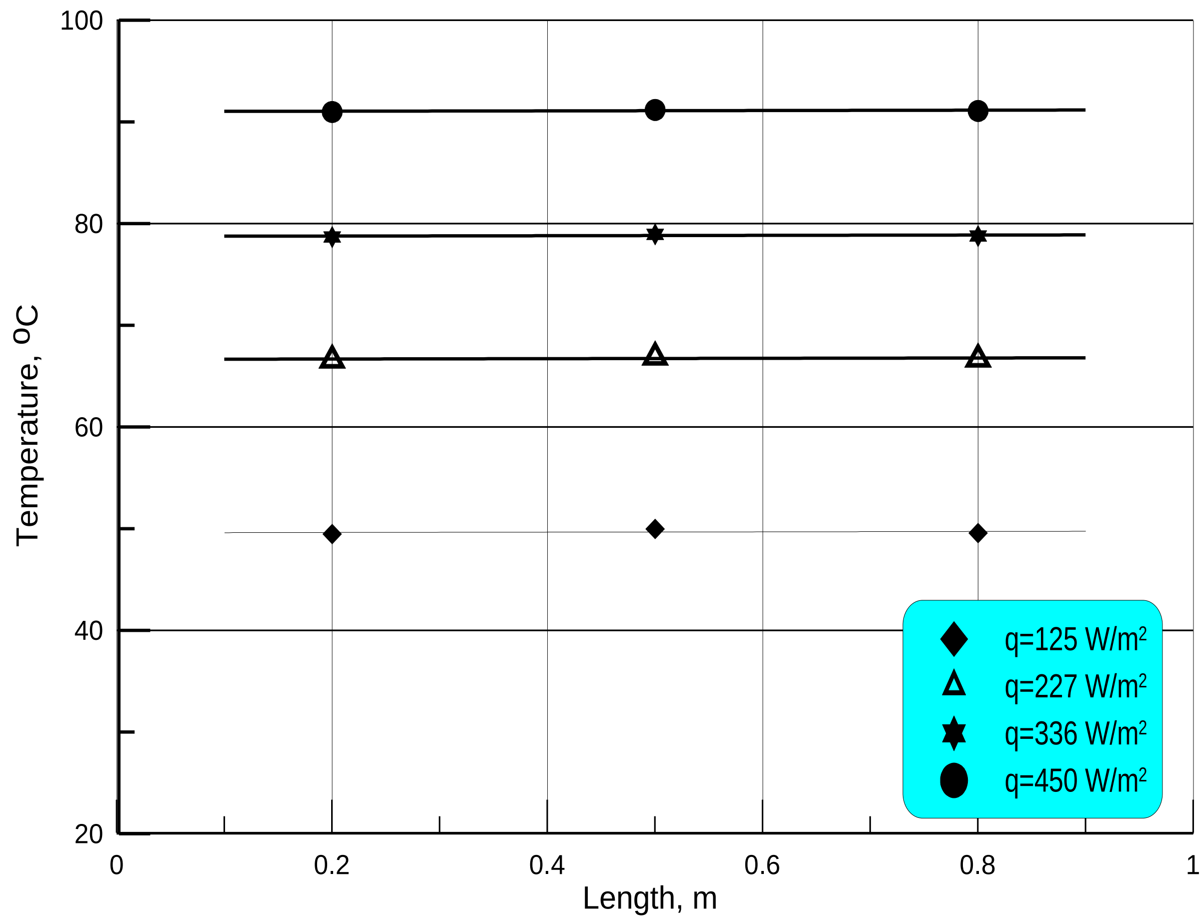


Fig. (5.1) Variation of the temperature with length of inner cylinder.

5-2 Stationary Concentric Annulus

An experimental analysis of the heat transfer performance has been made for a stationary concentric annulus with air as a working fluid under steady state conditions. This set of experimental work has been obtained, in order vertify the predicated results obtained in the preevious chapter. Also the result are compared with the available literature data. The experiments for stationary concentric annulus were carried out to indicate the value of enhancement resulting from rotation and eccentricity. The experimental results are first verified by comparing them with the available existing literature. The average Nusselt number of the present stationary concentric annulus is compared with the data provided by the two different results obtained by, Keyhani [1] and Davies [88], as shown in Figs.(5.2a), to (5.2d). Comparison of the present results for the variation of the average Nusselt number with Rayleigh number for stationary concentric annulus with the published data at radius ratio = 3.1. and Comparison of the present results for the variation of the average Nusselt number with Rayleigh number for stationary concentric annulus with the published data at radius ratio = 3.1., Comparison of the present results for the variation of the average Nusselt number with Rayleigh number for stationary concentric annulus with the published data at radius ratio = 3.1.. It is observed that the present experimental results are in fair agreement with the available published data. The correlation deduced in the present work is compared with the available correlations in published literature which are given equation 5-1.

$$\overline{Nu} = 0.668 \mathrm{Ra}^{0.27} \mathrm{As}^{-0.264} \mathrm{R}^{0.14} \qquad \text{Present experimental (5.1)}$$

The present experimental results fit the correlation with maximum deviation of ± 5.4%, While the correlations obtained by Keyhani [1] and Davies [88] are given by equations (5.2) and (5.3) as:

$$\overline{Nu} = 0.291\, Ra^{0..322} \mathrm{As}^{-0.238} \mathrm{R}^{0.442} \qquad \text{[Keyhani] (5.2)}$$

$$\overline{Nu} = 0.3325\, Ra^{0.3} \mathrm{As}^{-0.25} \mathrm{R}^{0.442} \qquad \text{[Davies] (5.3)}$$

Comparison of the correlation deduced here gives a deviation of +8% deviation i.e. greater than that given by Keyhani [1], while the present correlation shows -11% deviations lower than that obtained by Davis [89].

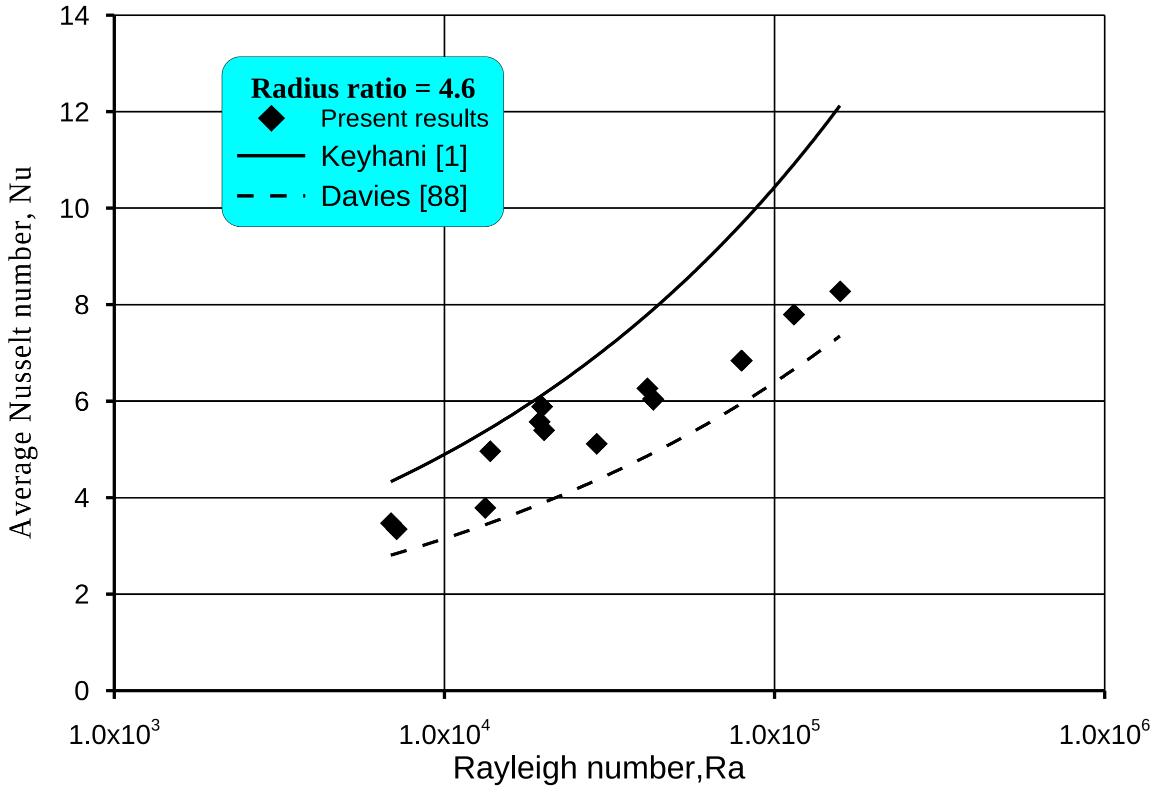


Fig. (5.2a) Comparison of the present results for the variation of the average Nusselt number with Rayleigh number for stationary concentric annulus with the published data at radius ratio = 4.6.

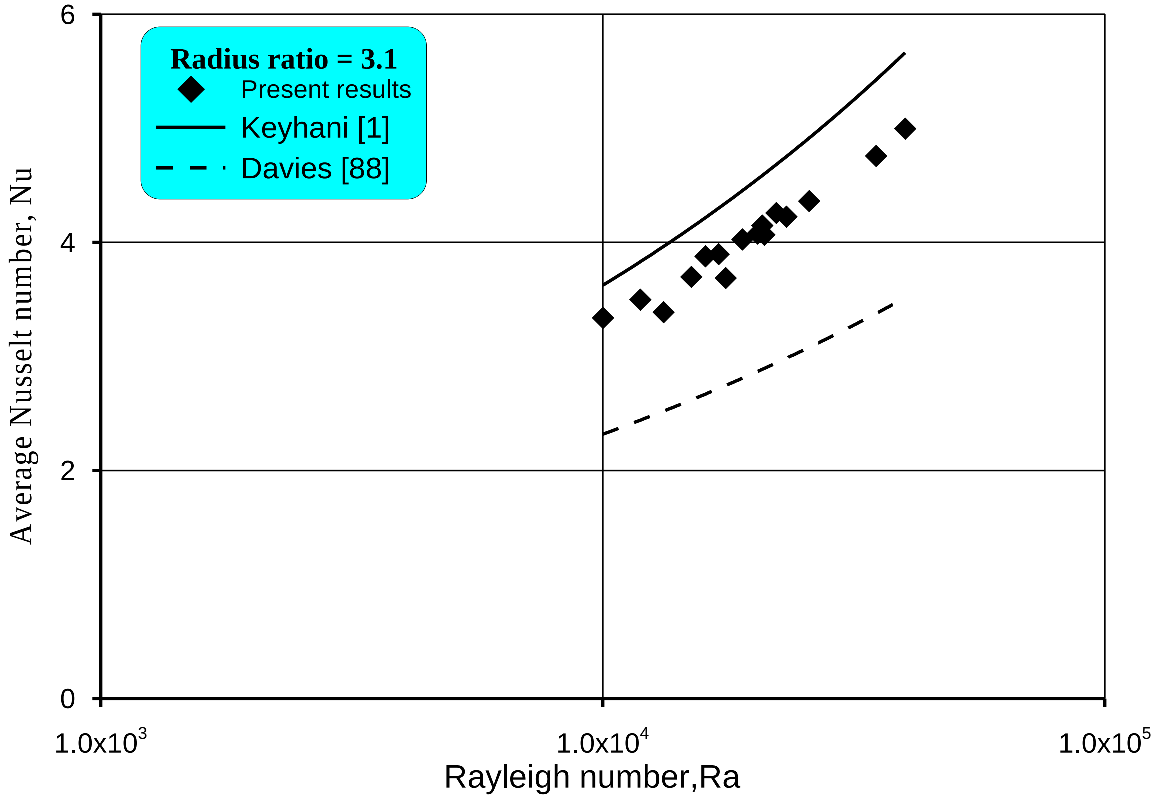


Fig. (5.2b) Comparison of the present results for the variation of the average Nusselt number with Rayleigh number for stationary concentric annulus with the published data at radius ratio = 3.1.

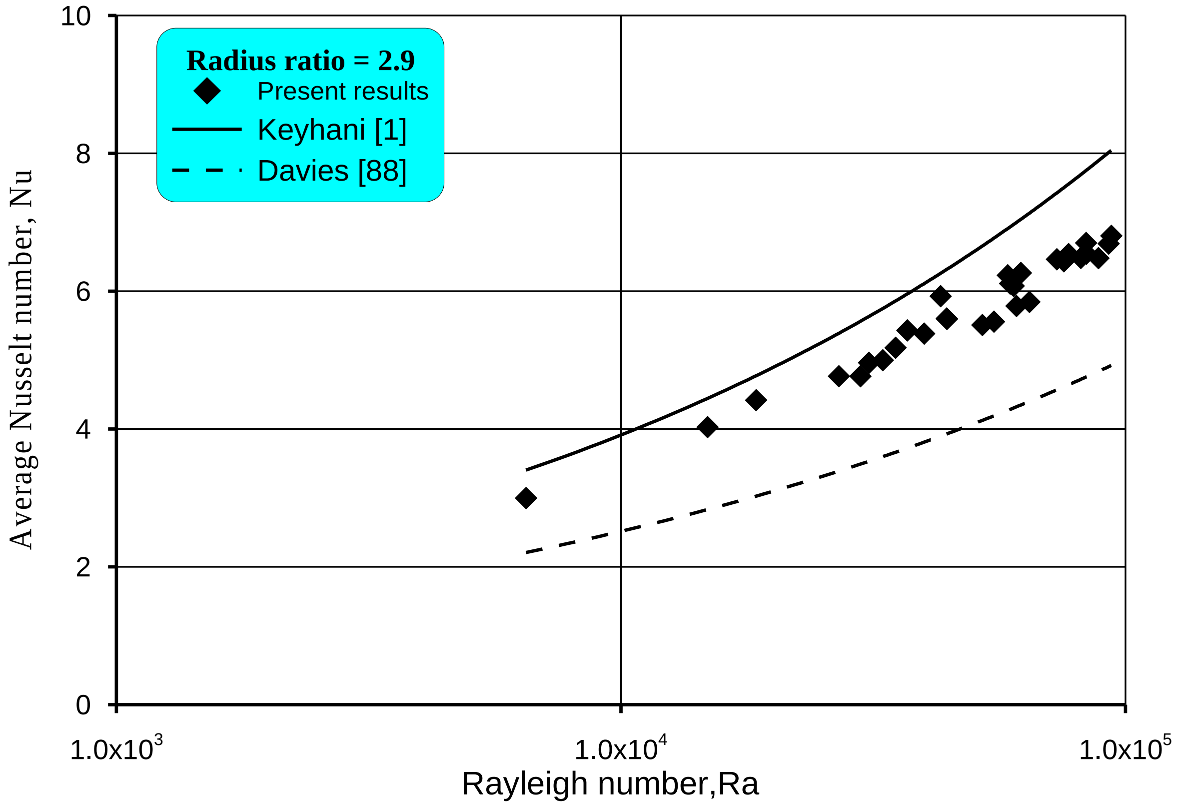


Fig. (5.2c) Comparison of the present results for the variation of the average Nusselt number with Rayleigh number for stationary concentric annulus with the published data at radius ratio = 2.9.

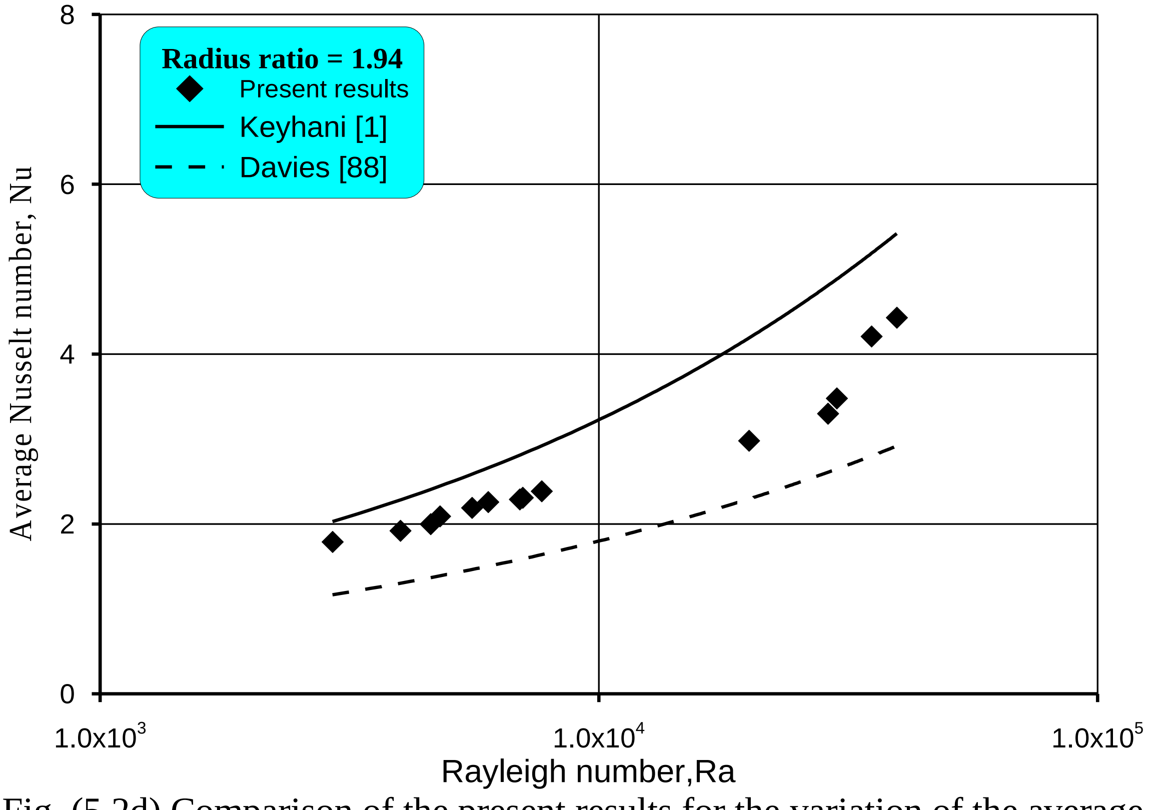


Fig. (5.2d) Comparison of the present results for the variation of the average Nusselt number with Rayleigh number for stationary concentric annulus with the published data at radius ratio = 1.94.

5-3 Rotating Concentric Annulus

In this part the experimental results are obtained for rotating concentric annulus with radii ratio (R) varied from 1.94 to 4.63 and Rayliegh number range from 3×10^3 to 1.6×10^5. Rotation Reynolds number varied from 0 to 850 and heat flux varied from 120 to 1140 W/m^2.

In this experiment, there are two factors related to centrifugal buoyancy force: one is the centrifugal force triggered by rotation and the other one is due to buoyancy effect arises due temperature difference between the inner wall surfaces of the outer cylinder and heated inner cylinder. In this research, the Grashof number (Gr) for buoyancy force effect and rotation Reynolds number, (Re_Ω), for centrifugal force effect are the key factors affecting the inner thermal behavior of the entire rotating annulus.

The influence of the Rotation Reynolds number (Re_Ω) of the concentric annulus on the average Nusselt number for various values of Rayleigh number (Ra) and Radii ratio (R) is shown in Fig.(5.3a) to Fig (5.3d). From this figure it is clear that the average Nusselt number ($\overline{Nu}$) increases with the increases of Rotation Reynolds number (Re_Ω) for same Radii ratio and Rayleigh number. Also, it can be shown that the average Nusselt number ($\overline{\mathrm{Nu}}$) increases with the increase of Rayleigh number for same Radii ratio and Rotation Reynolds number. From the above figures it is obvious that the Rayliegh number is the major parameter affect the average Nusselt number.

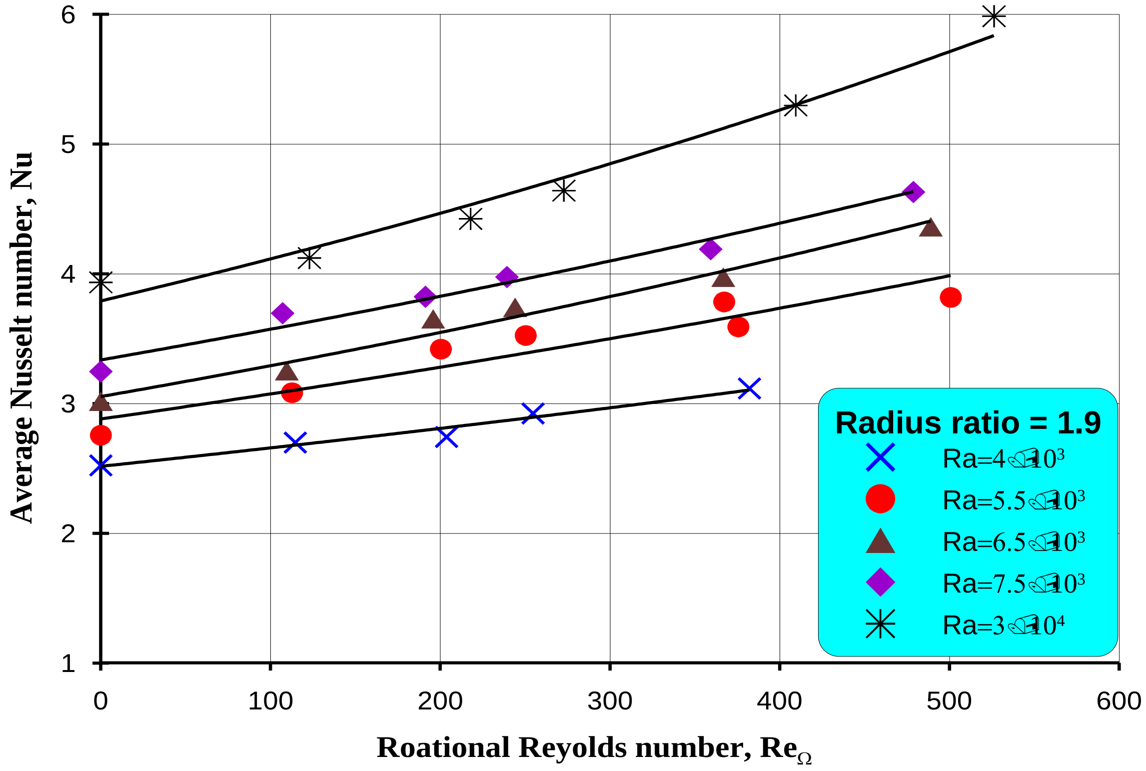


Fig. (5.3a) Variation of the average Nusselt number (Nu) with rotational Reynolds number (Re_{Ω}) for different values of Rayleigh number (Ra) for concentric annulus at Radius ratio (R= 1.9).

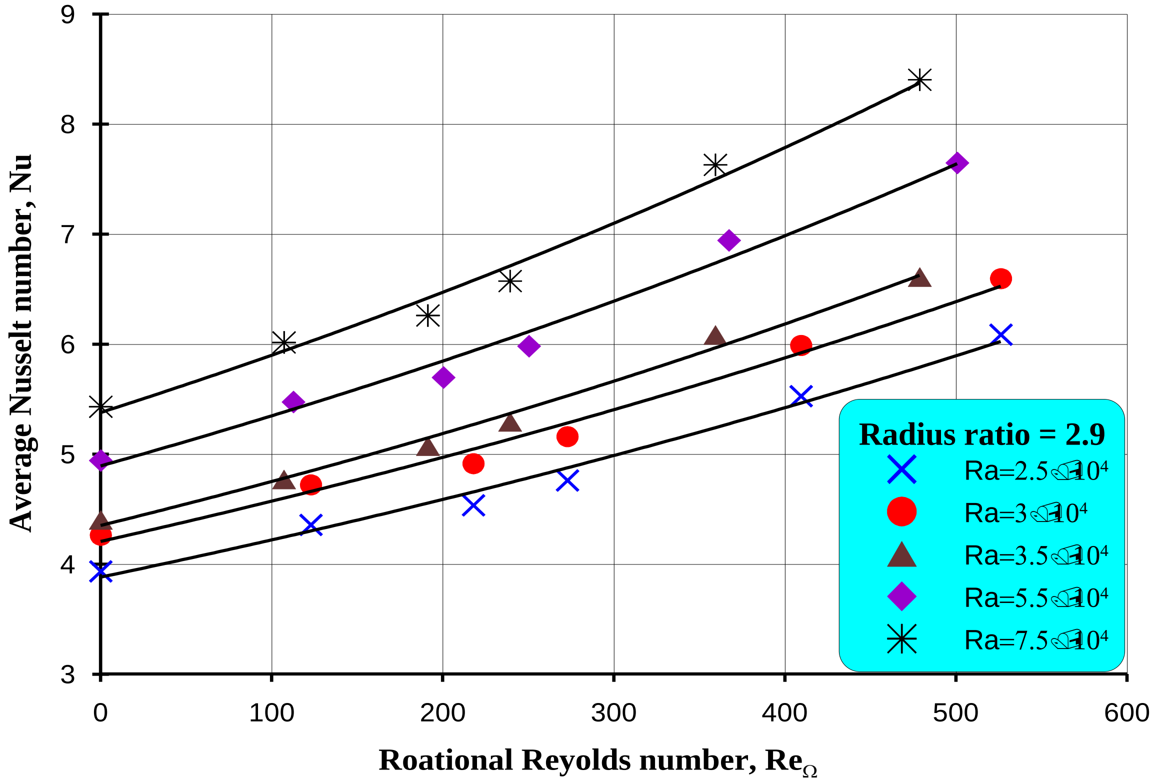


Fig. (5.3b) Variation of the average Nusselt number (Nu) with rotational Reynolds number (Re_{Ω}) for different values of Rayleigh number (Ra) for concentric annulus at Radius ratio (R= 2.9).

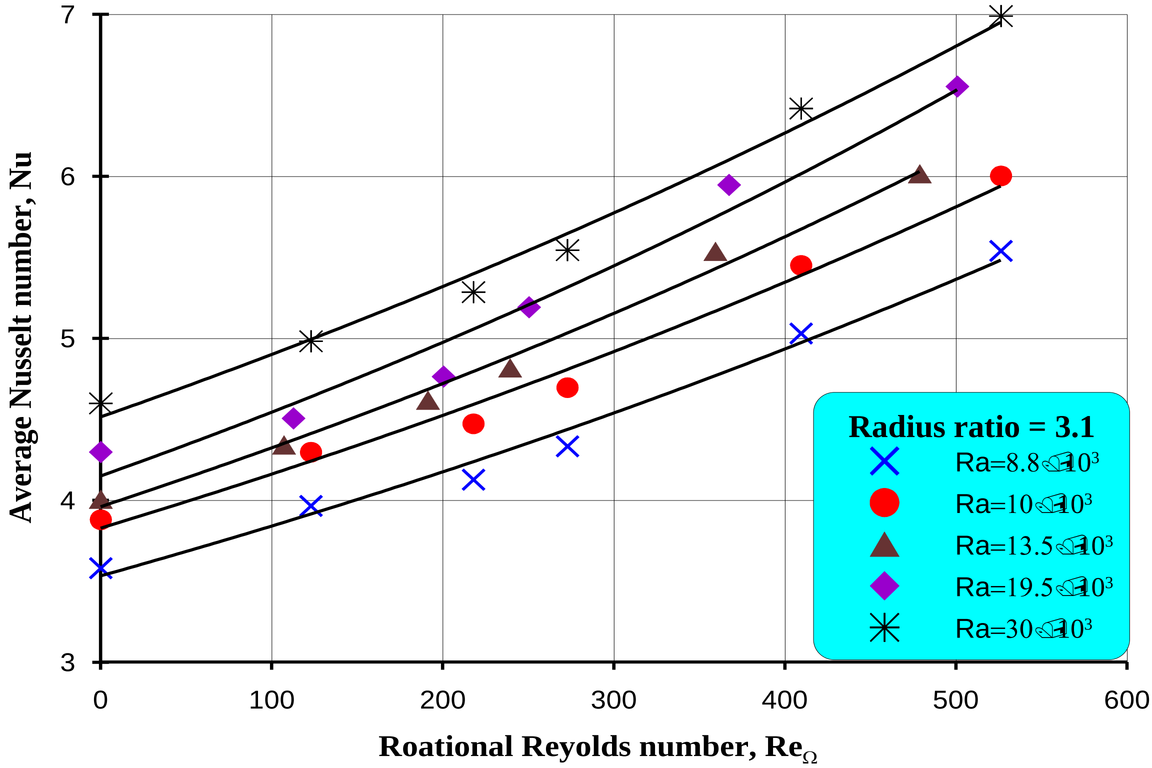


Fig. (5.3c) Variation of the average Nusselt number (Nu) with rotational Reynolds number (Re_Ω) for different values of Rayleigh number (Ra) for concentric annulus at Radius ratio (R= 3.1).

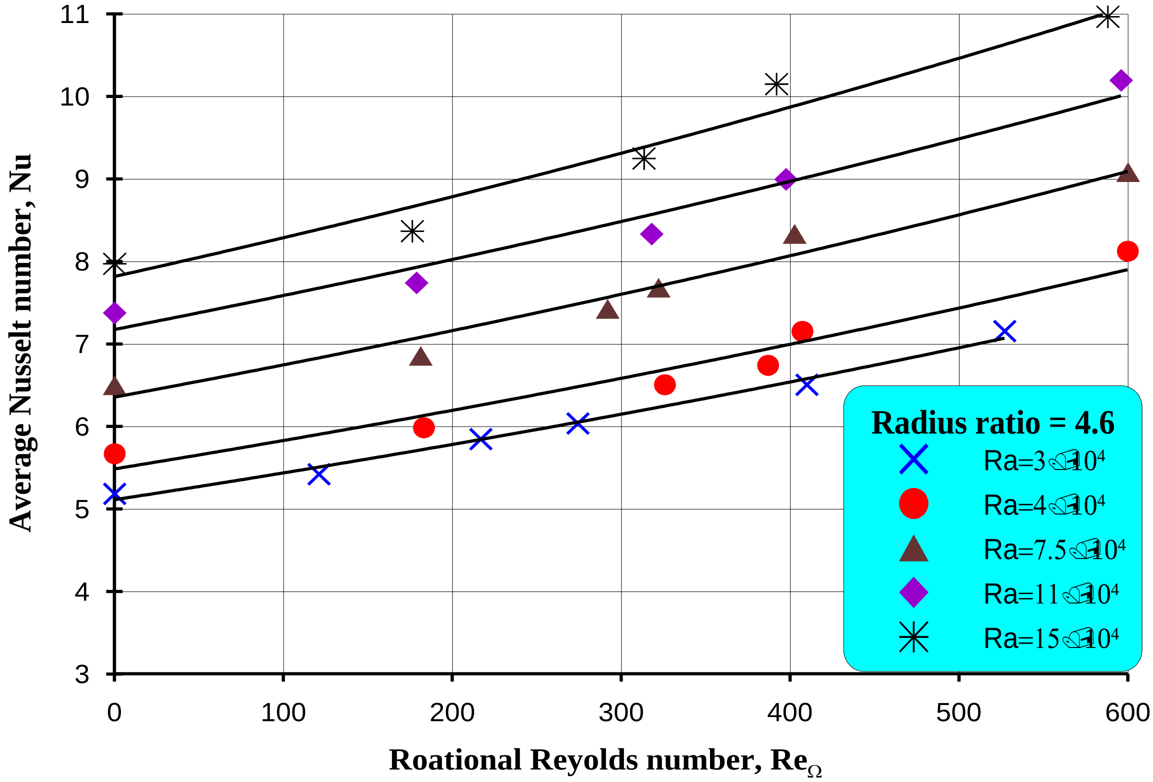


Fig. (5.3d) Variation of the average Nusselt number (Nu) with rotational Reynolds number (Re_Ω) for different values of Rayleigh number (Ra) for concentric annulus at Radius ratio (R= 4.6).

5-3 Eccentric Annulus

Experimental results are obtained for stationary and rotating eccentric annulus with Radii ratio (R) varied from 1.9 to 4.5, Rotation Reynolds number varied from 0 to 820 and Rayliegh number from 3×10^3 to 1.6×10^5. Heat flux varied from 120 to 1140 w/m^2 and eccentricity ratio varied from 0.0 to 1.2.

The influence of the Rotation Reynolds number (Re_Ω) of the eccentric annulus on the average Nusselt number for various values of Rayleigh number and eccentricity ratio at constant Radii ratio of 1.93 is given in Fig (5.4a) to Fig (5.4d). The figure shows that the average Nusselt number ($\overline{Nu}$) increases with the increase of (Re_Ω) for constant eccentricity ratio, Radii ratio and Rayleigh number.

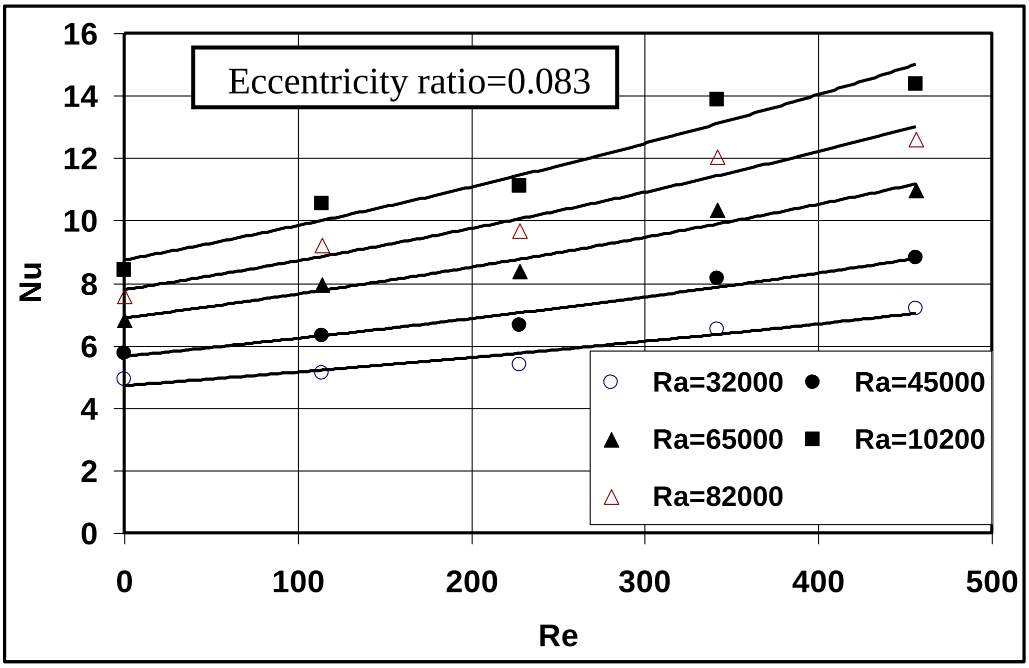


Figure (5.4a) Variation of average Nusselt number (Nu) with Reynolds (Re_Ω) number for different values of Rayleigh number (Ra) at eccentricity (ε= 0.083) for Radius ratio(R=1.933.)

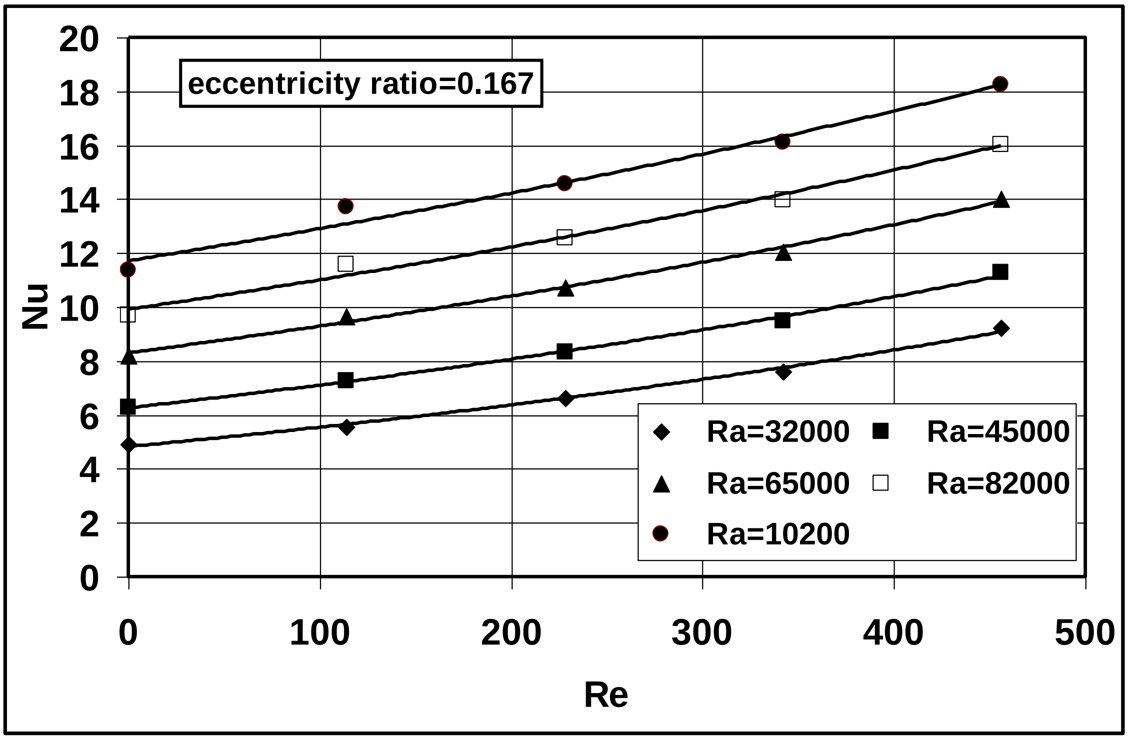


Figure (5.4b) Variation of average Nusselt number (Nu) with Reynolds (Re_{Ω}) number for different values of Rayleigh number (Ra) at eccentricity (ε= 0.167) for Radius ratio(R=1.933.)

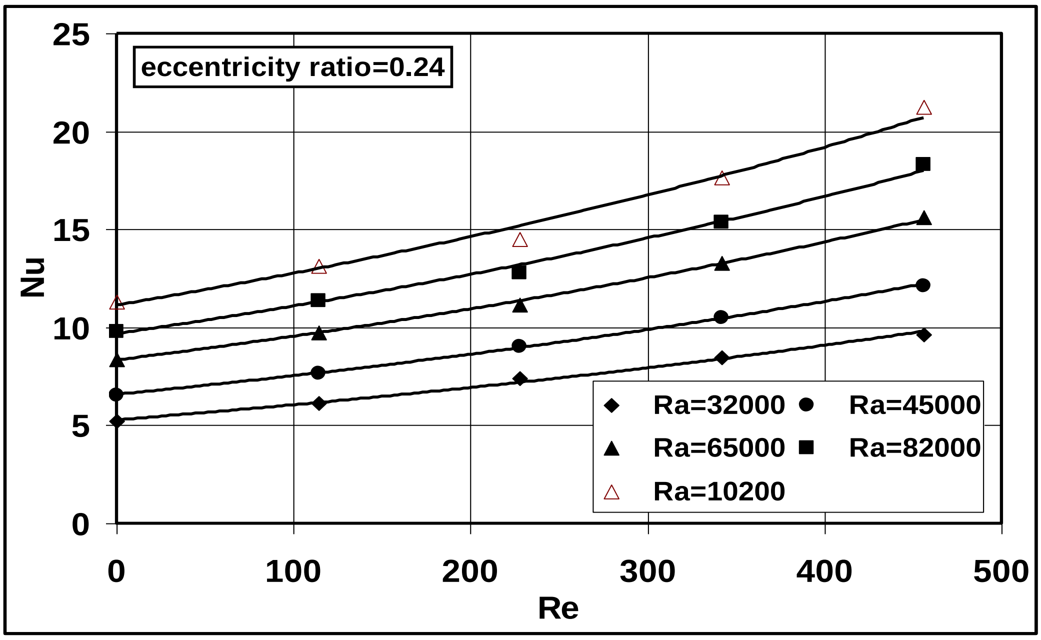


Figure (5.4c) Variation of average Nusselt number (Nu) with Reynolds (Re_{Ω}) number for different values of Rayleigh number (Ra) at eccentricity (ε= 0.24) for Radius ratio(R=1.933.)

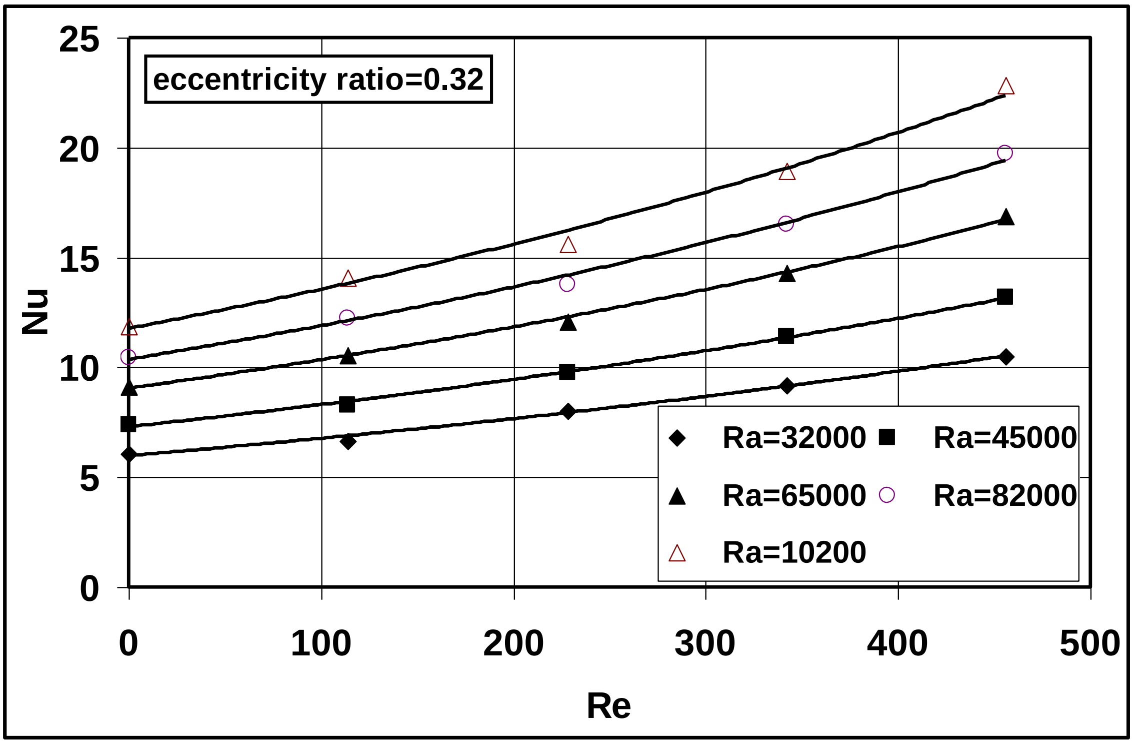


Figure (5.4d) Variation of average Nusselt number (Nu) with Reynolds (Re_Ω) number for different values of Rayleigh number (Ra) at eccentricity (ε= 0.32) for Radius ratio(R=1.933.)

The effect in variation of the Rayleigh number on the average Nusselt number at constant Radii ratio and different values of the Rotation Reynolds number is indicated in Fig.(5.5a) to (5.5d). The figures shows that the average Nusselt number ($\overline{Nu}$) increases with the increase of Rayleigh number at constant Rotation Reynolds number and eccentricity ratio. Rayleigh number provides a measure of the significance of the buoyancy force. For increase Rayleigh number the effect of buoyancy force increase and temperature difference increase. Temperature difference causes the circulation and heat transfer rate.

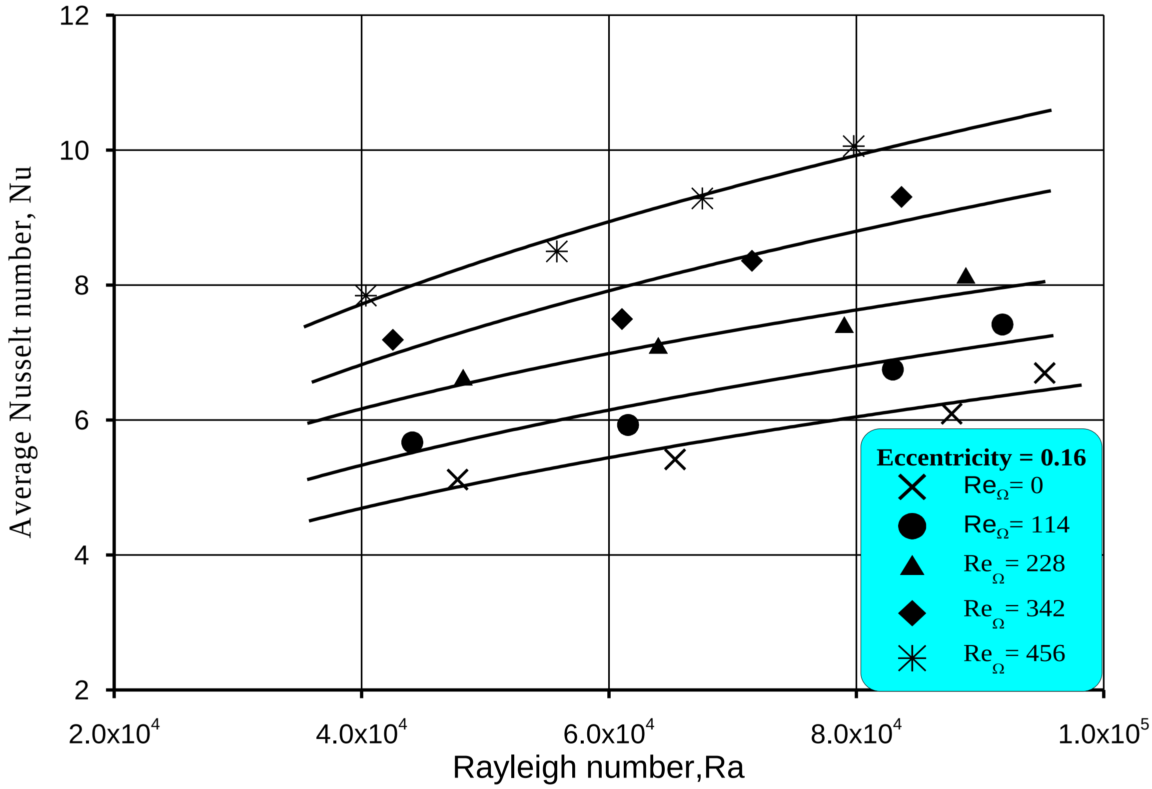


Fig.(5.5a) Variation of average Nusselt number with Rayleigh number for different values of rotational Reynolds number at Radius ratio =2.84 and eccentricity = 0.16.

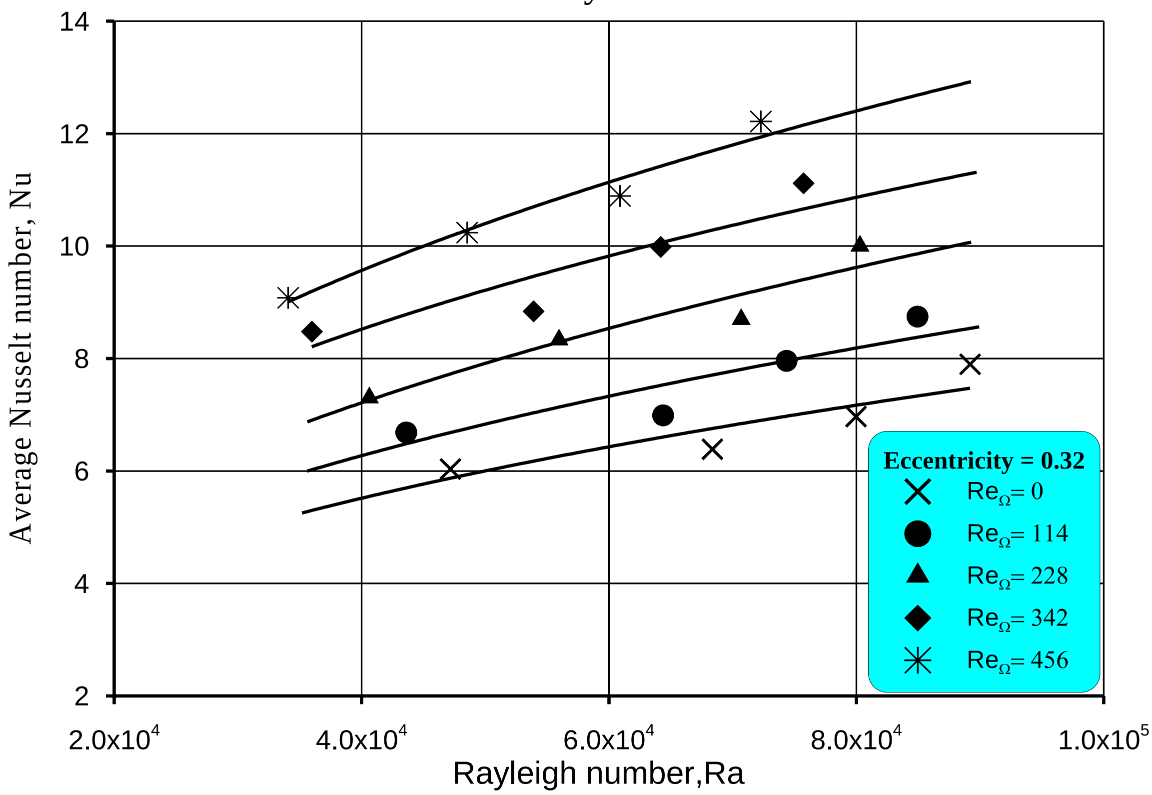


Fig.(5.5b) Variation of average Nusselt number with Rayleigh number for different values of rotational Reynolds number at Radius ratio =2.84 and eccentricity = 0.32.

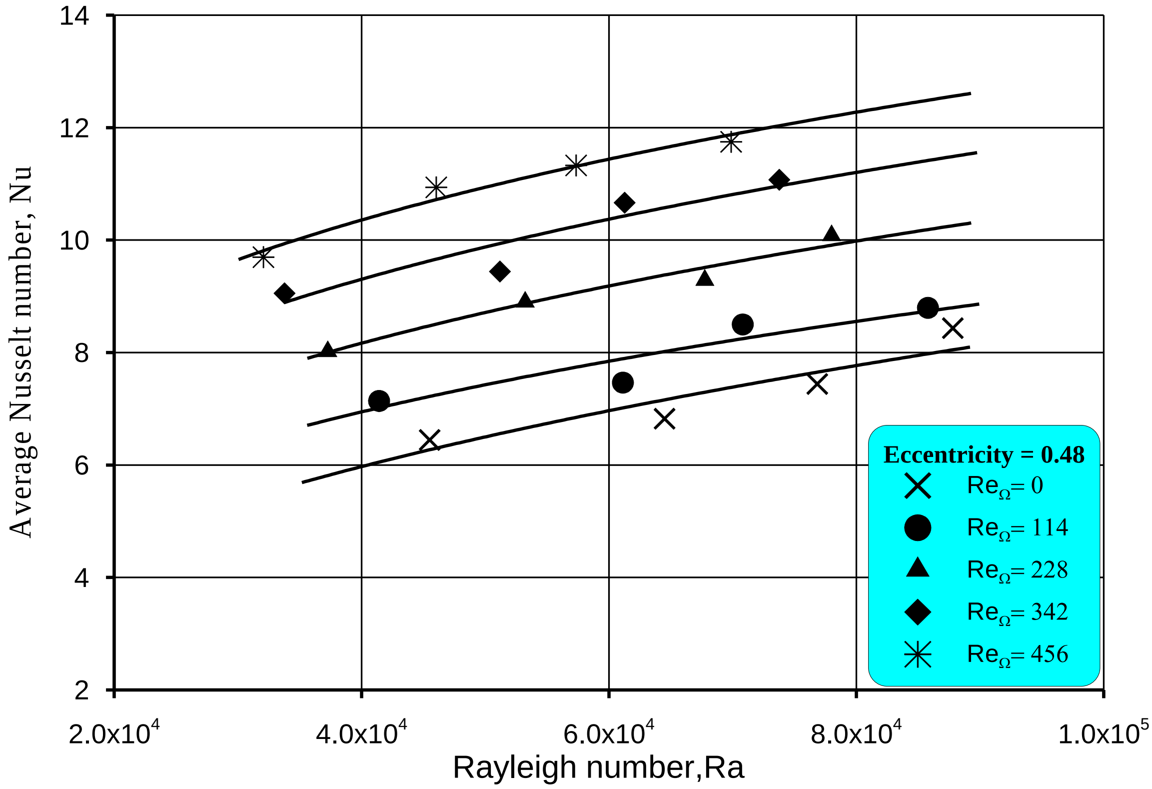


Fig.(5.5c) Variation of average Nusselt number with Rayleigh number for different values of rotational Reynolds number at Radius ratio =2.84 and eccentricity = 0.48.

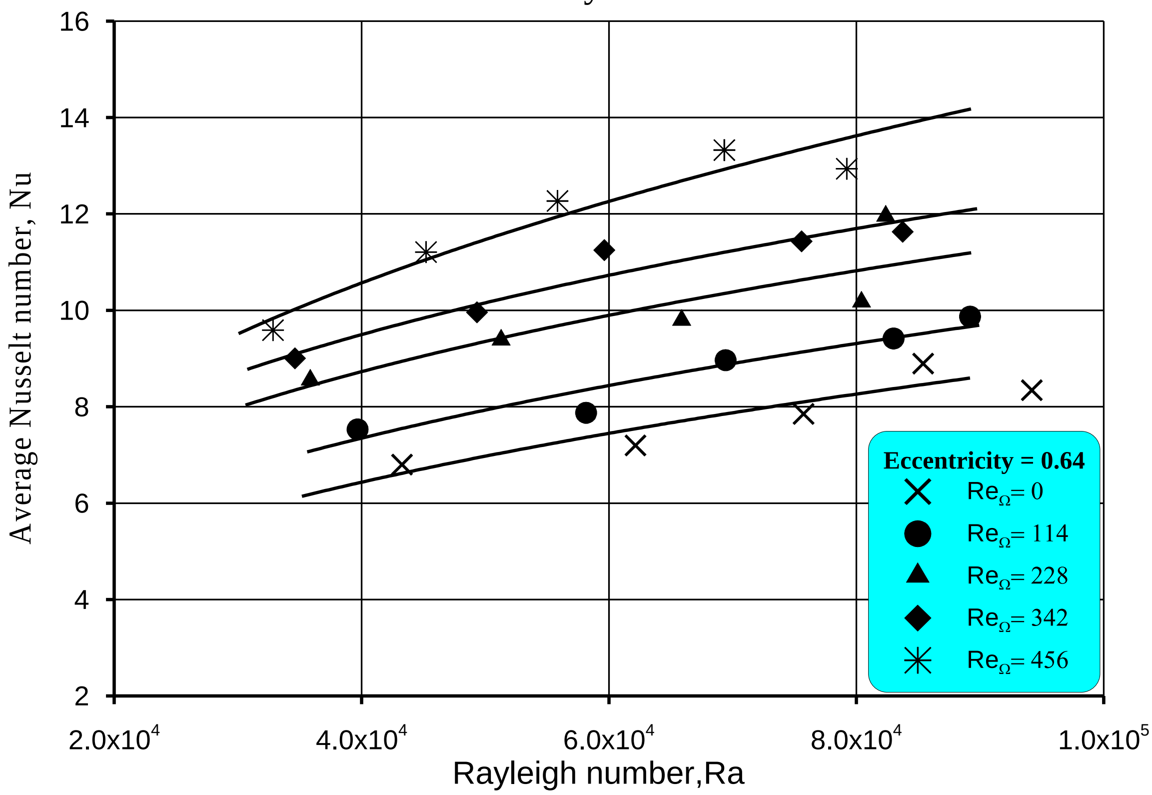


Fig.(5.5d) Variation of average Nusselt number with Rayleigh number for different values of rotational Reynolds number at Radius ratio =2.84 and eccentricity = 0.64.

Figures (5.6a) to (5.6d) show the influence of the eccentric ratio of the rotating eccentric annulus on the average Nusselt number for various values of rotational Reynolds number at radius ratio of 4.5. The eccentricity causes the reduction in the cross-section (direction eccentric direction). The reduction causes the increase in the circulation of the air inside annulus and increase the heat transfer rate. The figures demonstrates that the average Nusselt number ($\overline{Nu}$) increases linearly with the increase of eccentricity ratio for the same Rotation Reynolds's number and Rayleigh number.

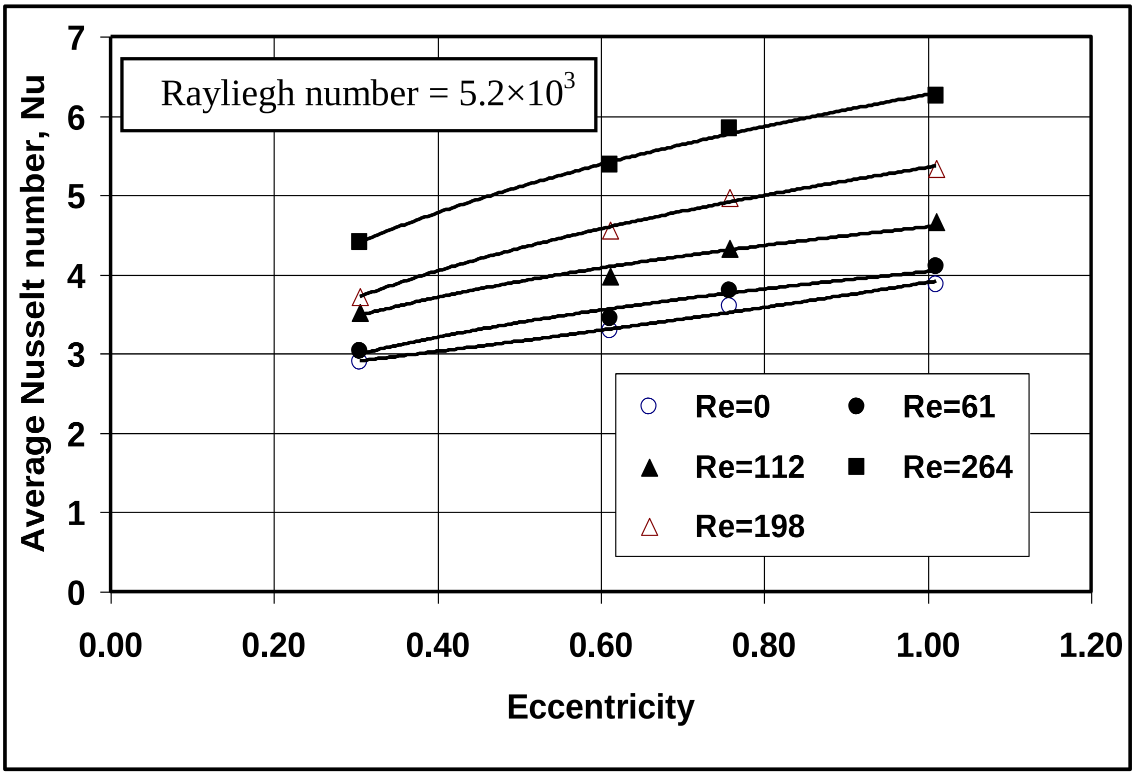


Fig.(5-6a) Variation of average Nusselt number with eccentricity for different values of Reynolds number at Radius ratio = 4.477 and Rayleigh number =5.2×10^3.

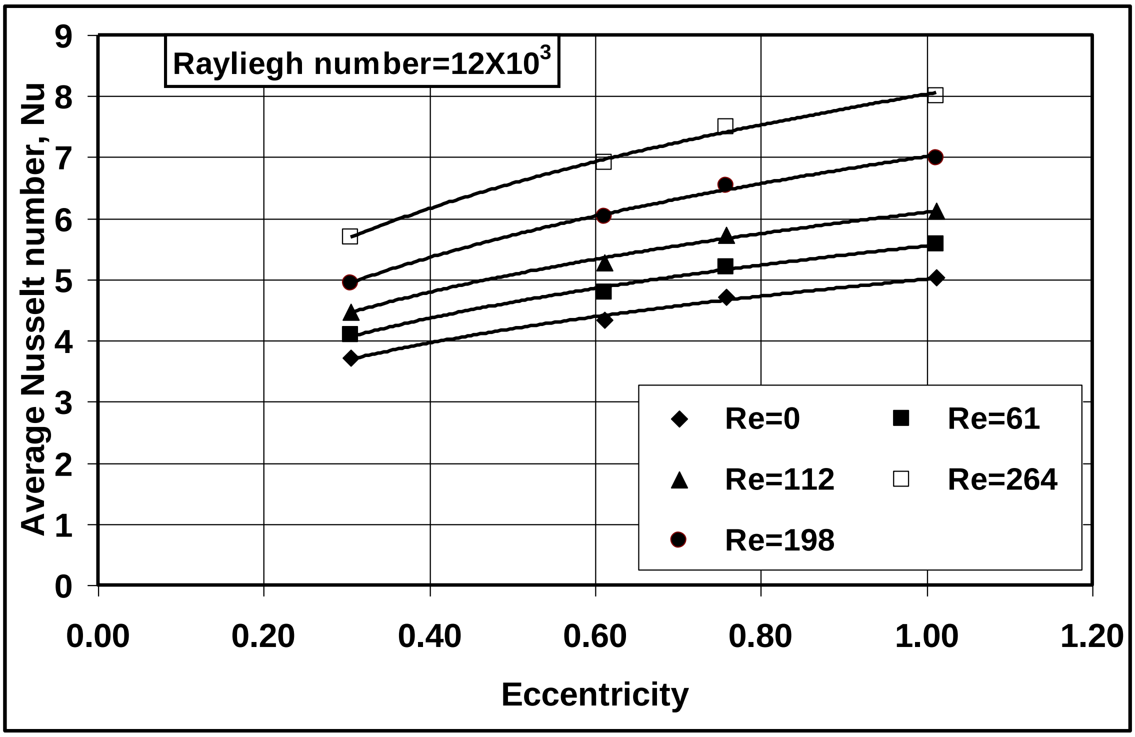


Fig.(5-6b) Variation of average Nusselt number with eccentricity for different values of Reynolds number at Radius ratio = 4.477 and Rayleigh number $=12\times10^{3}$.

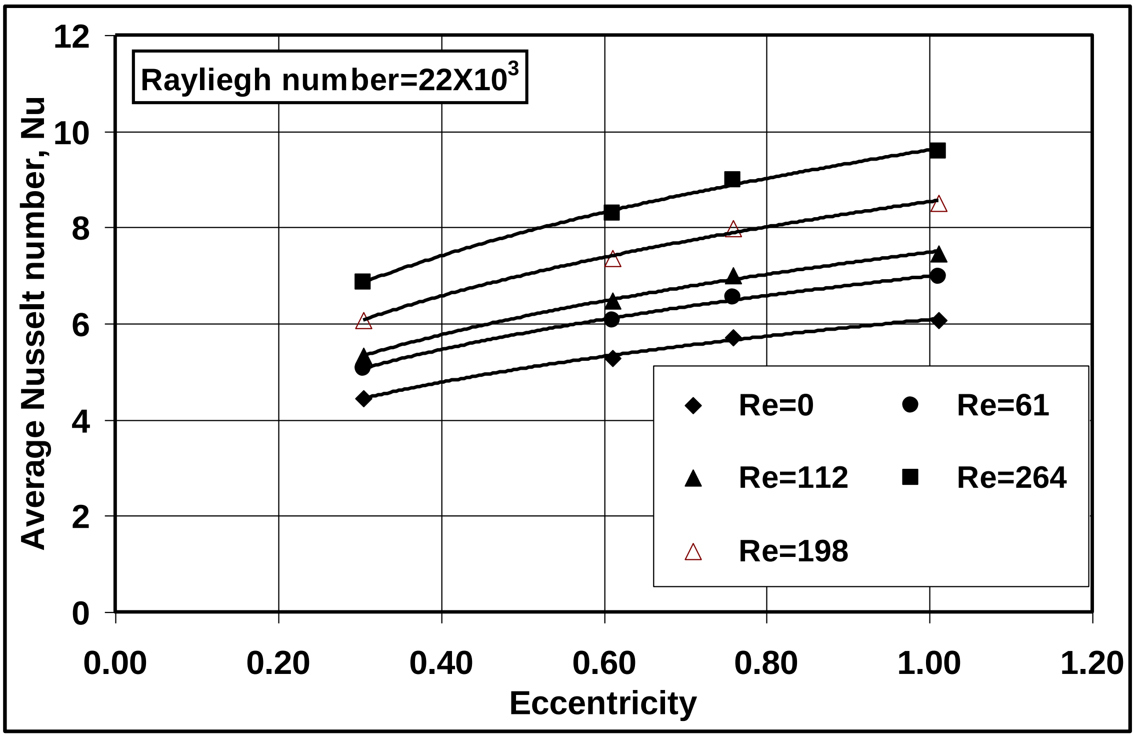


Fig.(5-6c) Variation of average Nusselt number with eccentricity for different values of Reynolds number at Radius ratio = 4.477 and Rayleigh number $=22\times10^{3}$.

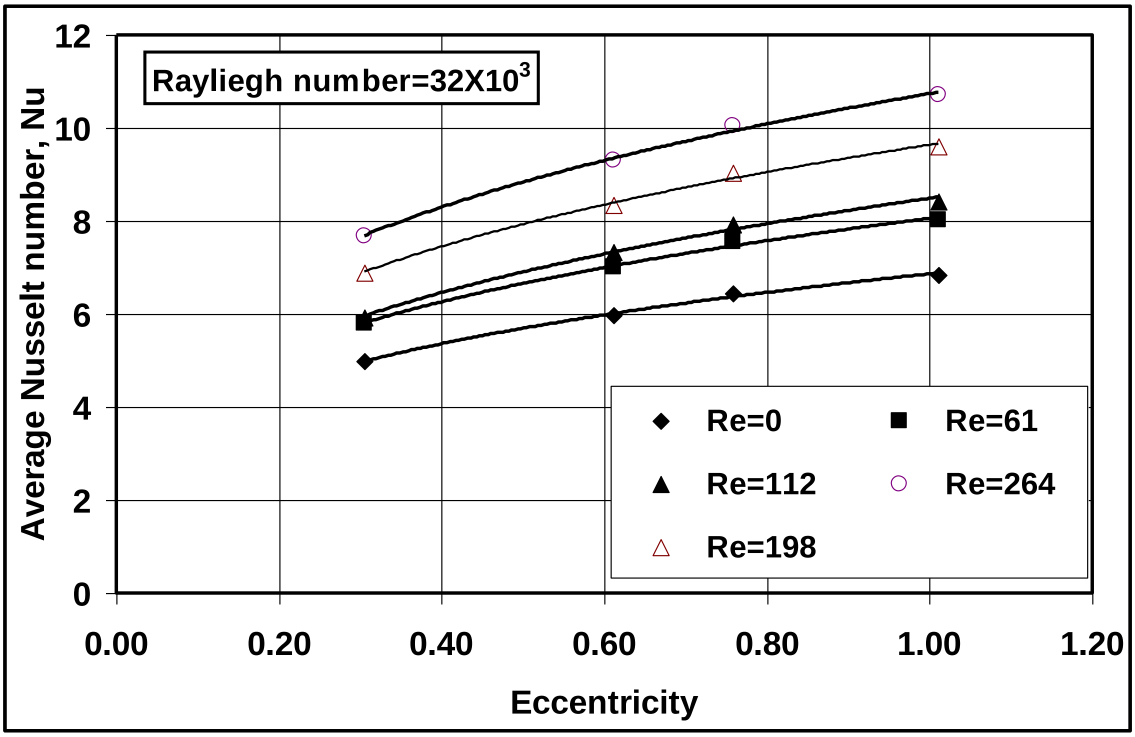


Fig.(5-6d) Variation of average Nusselt number with eccentricity for different values of Reynolds number at Radius ratio = 4.477 and Rayleigh number $=32\times10^3$.

The variation of the Nusselt number with the eccentricity ratio for different values of the Rotation Reynolds number and Radii ratio of the annulus Ra=3200, is given in Figs.(5.7a) to (5.7d). The increase of the eccentricity ratio increases the Nusselt number.

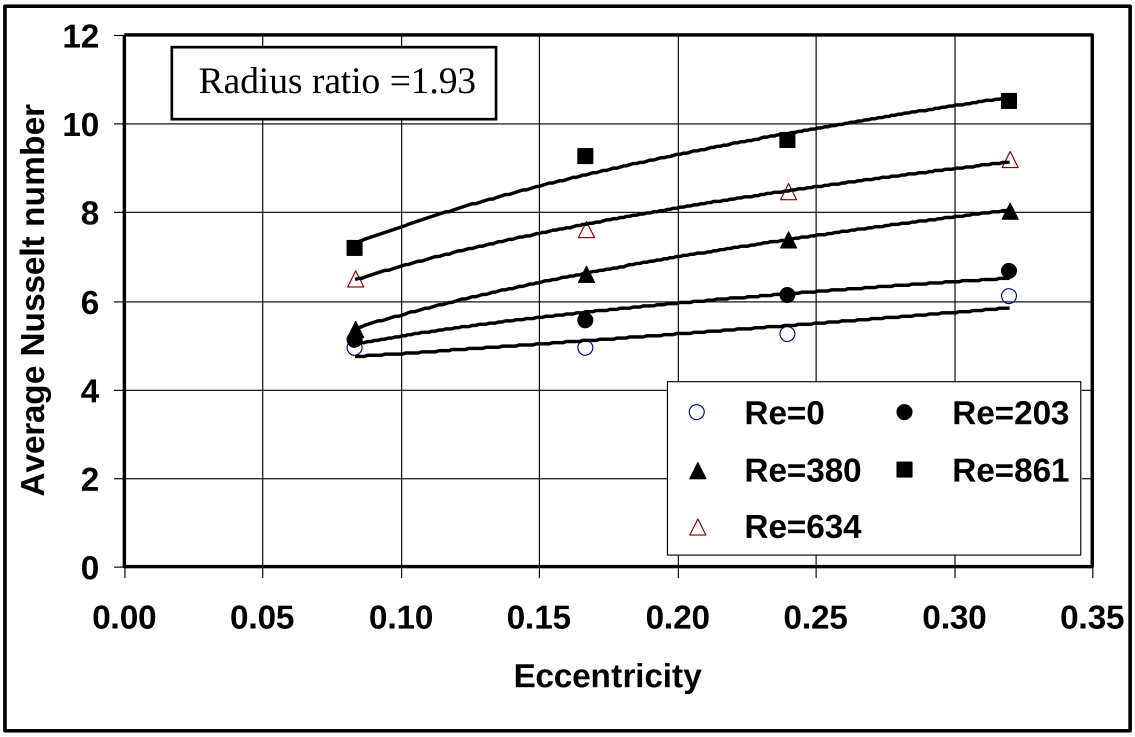


Fig. (5. 7a) Variation of average Nusselt number with eccentricity for different values of rotational Reynolds number at Radius ratio= 1.9 and Rayleigh number =32×10^3.

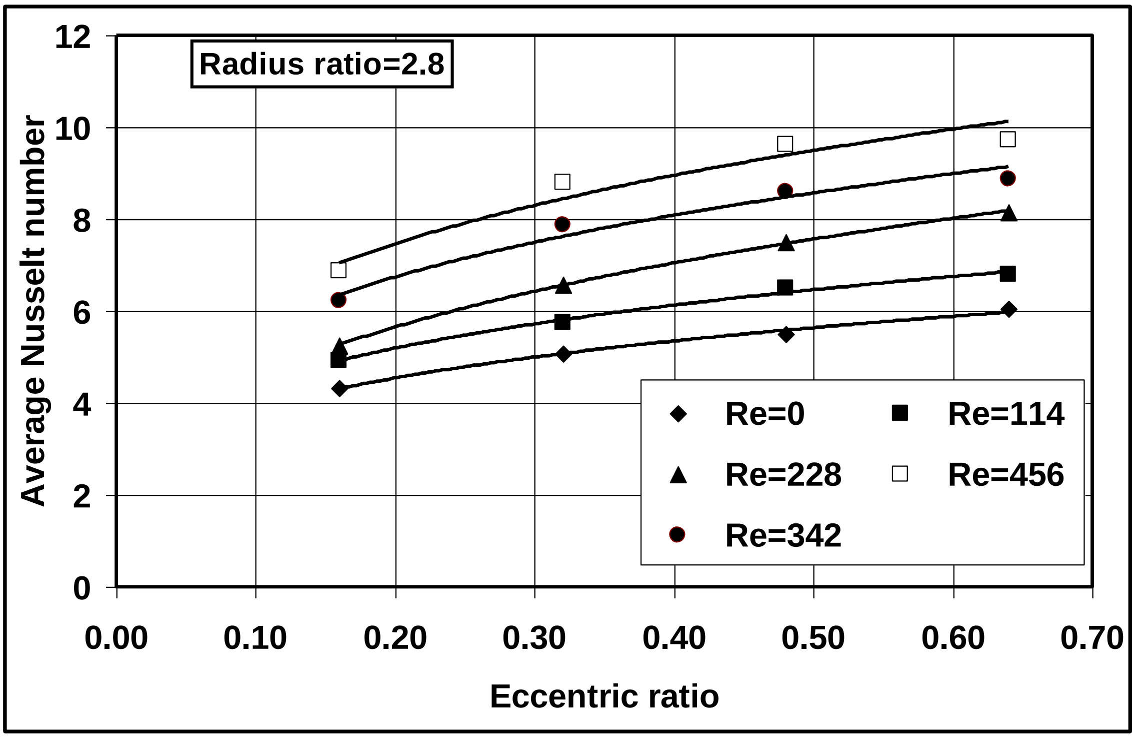


Fig. (5. 7b) Variation of average Nusselt number with eccentricity for different values of rotational Reynolds number at Radius ratio= 2.9 and Rayleigh number =32×10^3.

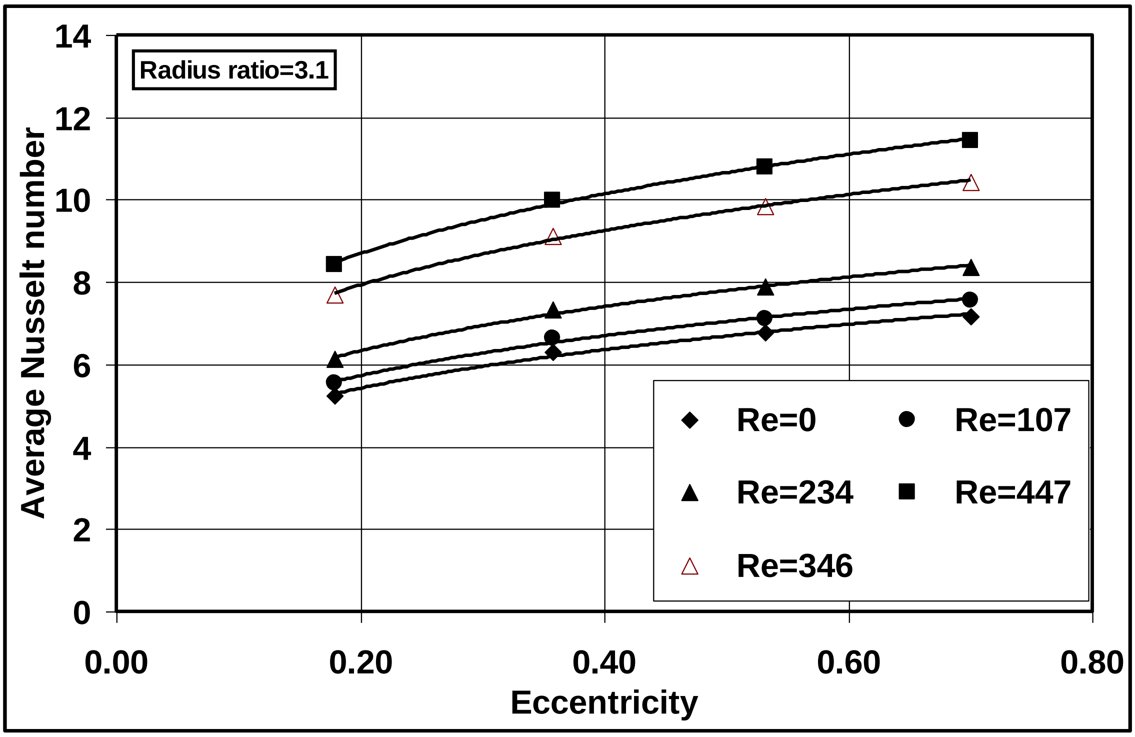


Fig. (5. 7c) Variation of average Nusselt number with eccentricity for different values of rotational Reynolds number at Radius ratio= 3.1 and Rayleigh number Ra=32×10^3.

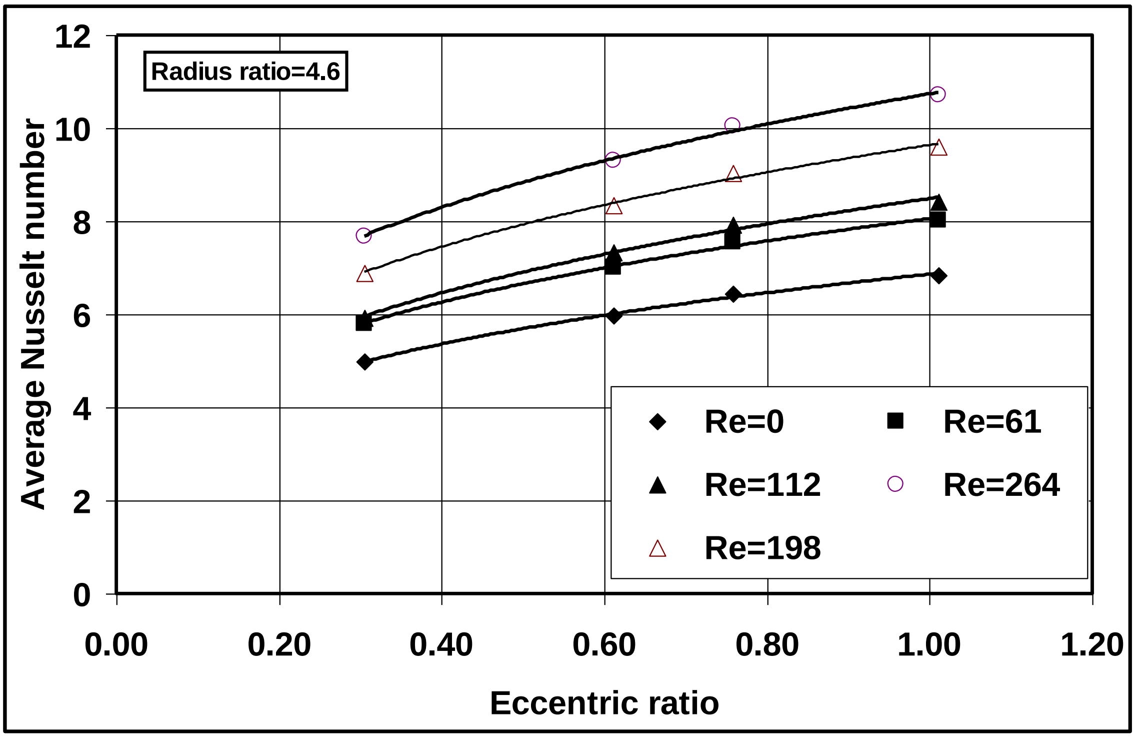


Fig. (5. 7d) Variation of average Nusselt number with eccentricity for different values of rotational Reynolds number at Radius ratio= 4.6 and Rayleigh number Ra=32×10^3.

The influence of angle of eccentricity on the average Nusselt number at various Rayliegh number at constant Radius ratio of 2.83 and same value of eccentricity ratio is shown in Fig.(5.8). The variation is almost sinusoidal curve with maximum value at angle 60 ^{o}, and minimum value at angles of 0.0 ^{o} and -30 ^{o}. it is obvious that the value of Nusselt number increases with increasing Rayleigh number.

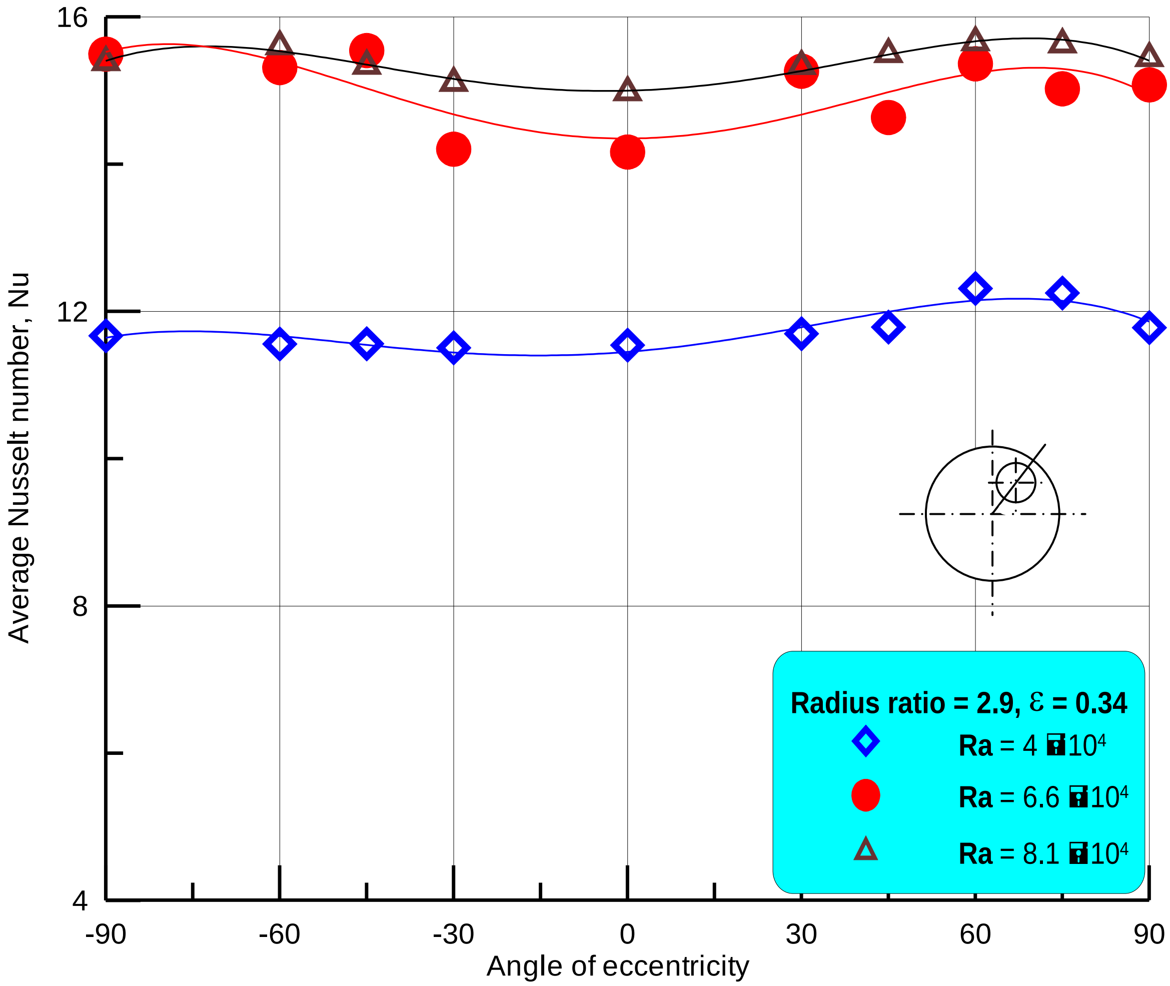


Fig.(5.8) Variation of the average Nusselt number (Nu) with angle of eccentricity (θ) at constant Rayleigh number (Ra=32000) and Radius ratio (R=2.8).

The effect of rotation and angle of eccentricity on the average Nusselt number at constant Radius ratio of 2.8 and constant eccentric ratio is shown in Fig.(5.9). It is noticed that average Nusselt number increases with the increase in the Rotation Reynolds number for all angles. Similar behaviour is noticed with maximum value occurring at angle ofl 67^o and minimum value at angle of 0.0^o.

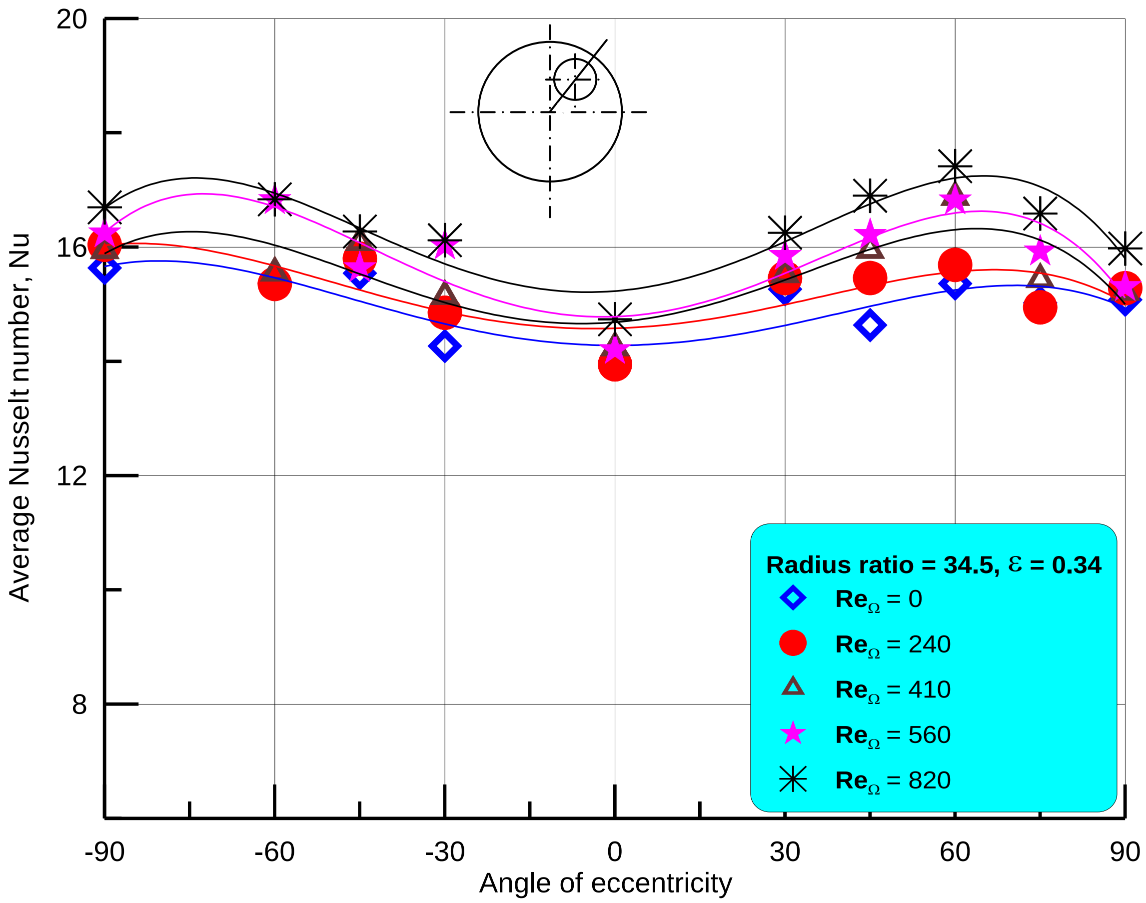


Fig.(5.9) Variation of average Nusselt number (Nu) with angle of eccentricity(θ) at constant Rayleigh number (Ra=32000) and Radius ratio (R=2.8) for different values of rational Reynolds number (Re_Ω).

An empirical correlation is deduced here to fit the present experimental results which correlate the average Nusselt number, Rayleigh number, rotational Reynolds number, Aspect ratio, Radius ratio and eccentricity using the **S**tatistical **P**ackage for **S**ocial **S**cience (SPSS) program. This equation is given by:

$$\overline{Nu} = 0.714 Ra^{0.27} As^{-0.264} \; R^{0.14} (1 + 0.002 \, Re_{\Omega}^{0.98}) (1 + 0.1623\varepsilon) \quad (5\text{-}4)$$

The experimental measurements fit the deduced equation (5-4) with ± 9 % maximum deviation, as shown in Fig. (5-10).

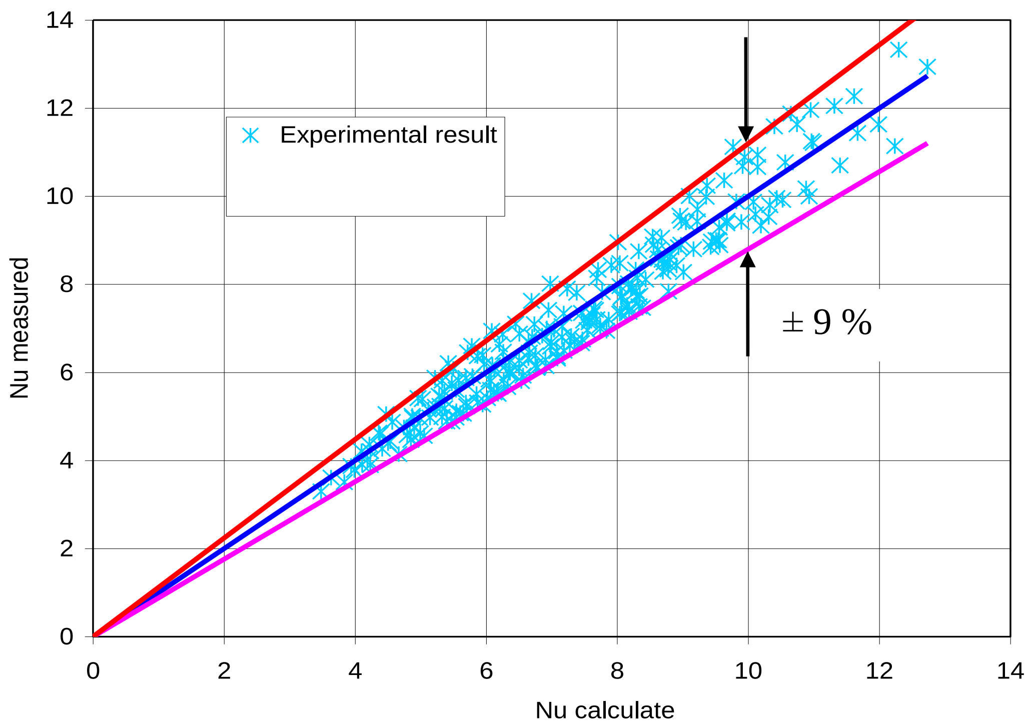


Fig. (5- 10) Variation of the measured average Nusselt number with calculated average Nusselt number.

5-5 Comparison between Present Numerical and Experimental Results

Figures (5.11a) to (5.11d) show comparison between the present experimental and numerical results for air as a working medium. One may observe that the experimental results and numerical result data show same trend. A good agreement between the two results is observed. The deviation may occur due to the assumption of two-dimensional analysis is in solving the numerical model where is these results one over predicted.

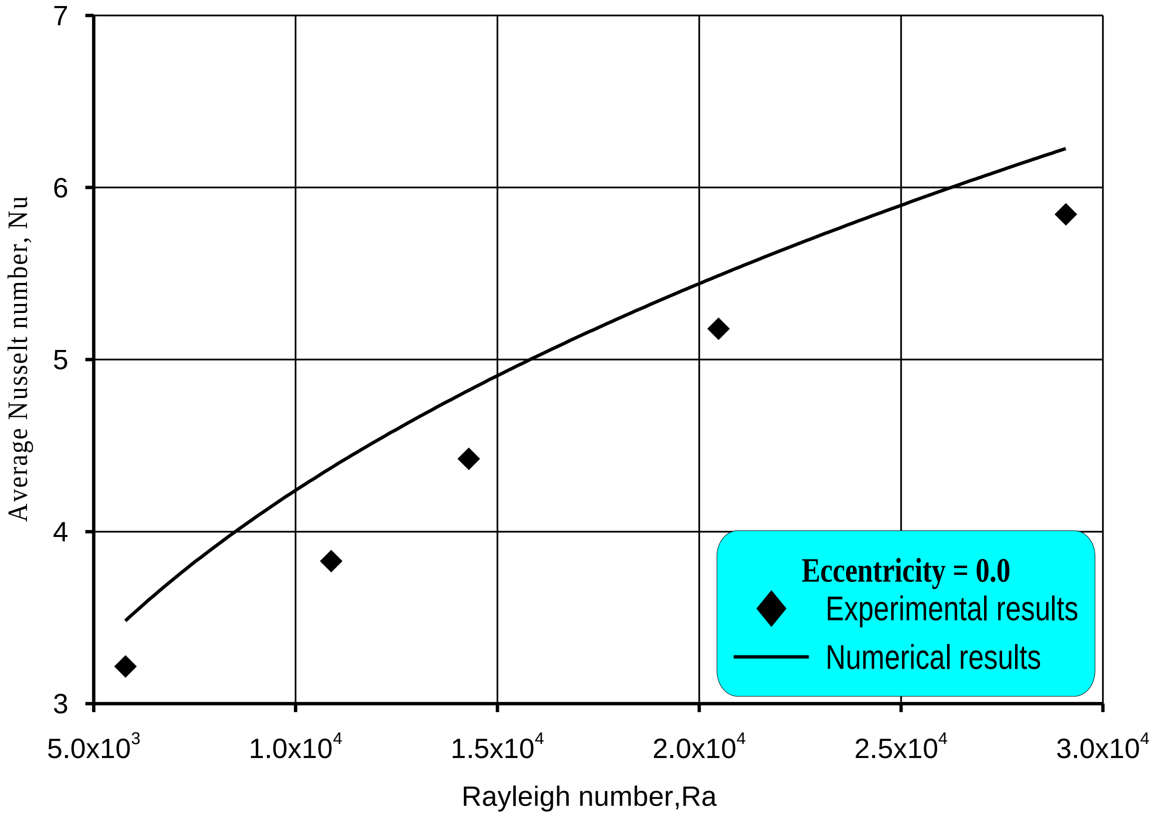


Fig. (5.11d) Comparison of the of the present numerical and experimental average Nusselt number versus Rayleigh number at eccentricity =0.0

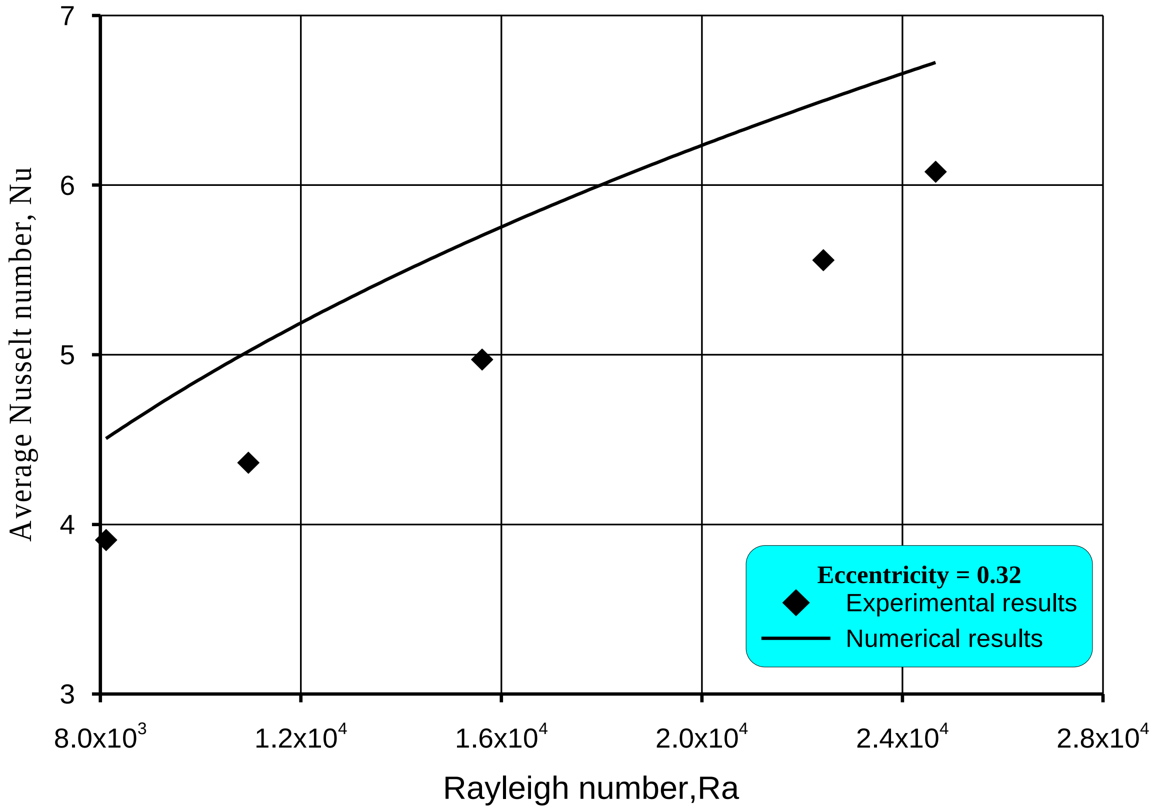


Fig. (5.11b) Comparison of the of the present numerical and experimental average Nusselt number versus Rayleigh number at eccentricity = 0.32

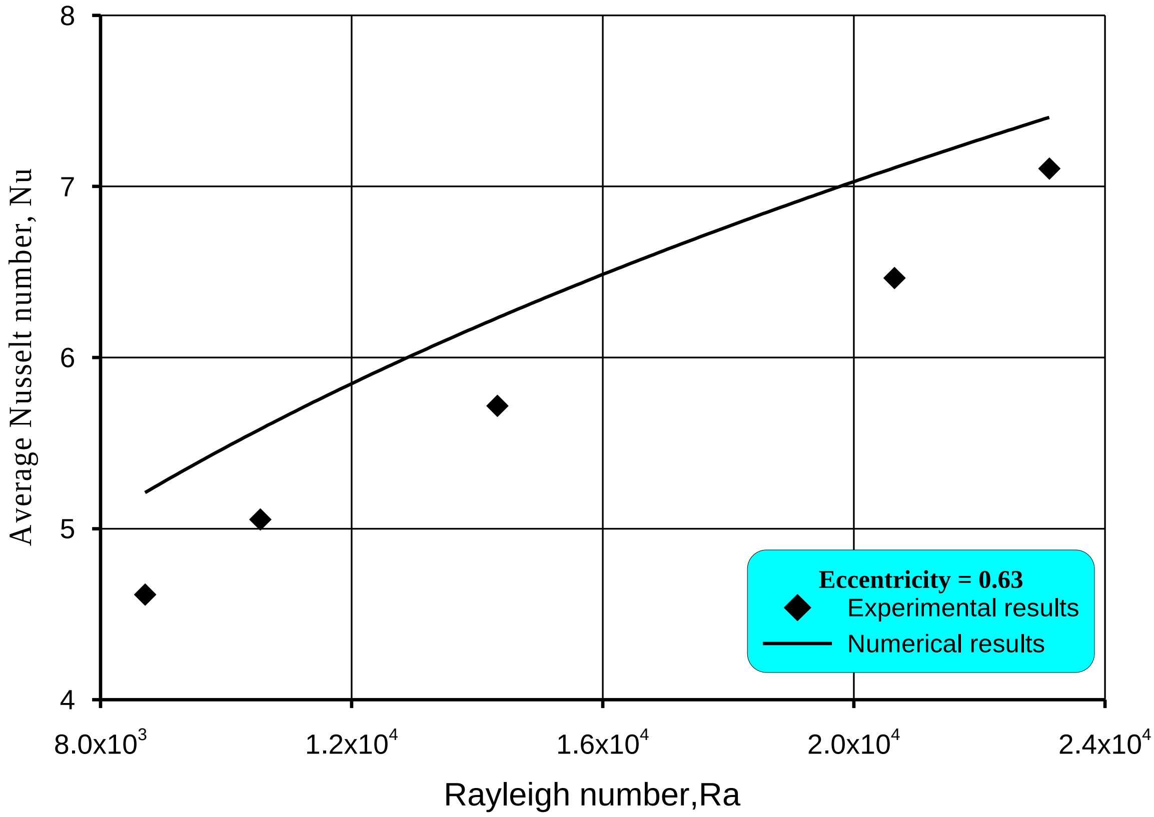


Fig. (5.11c) Comparison of the of the present numerical and experimental average Nusselt number versus Rayleigh number at eccentricity = 0.63

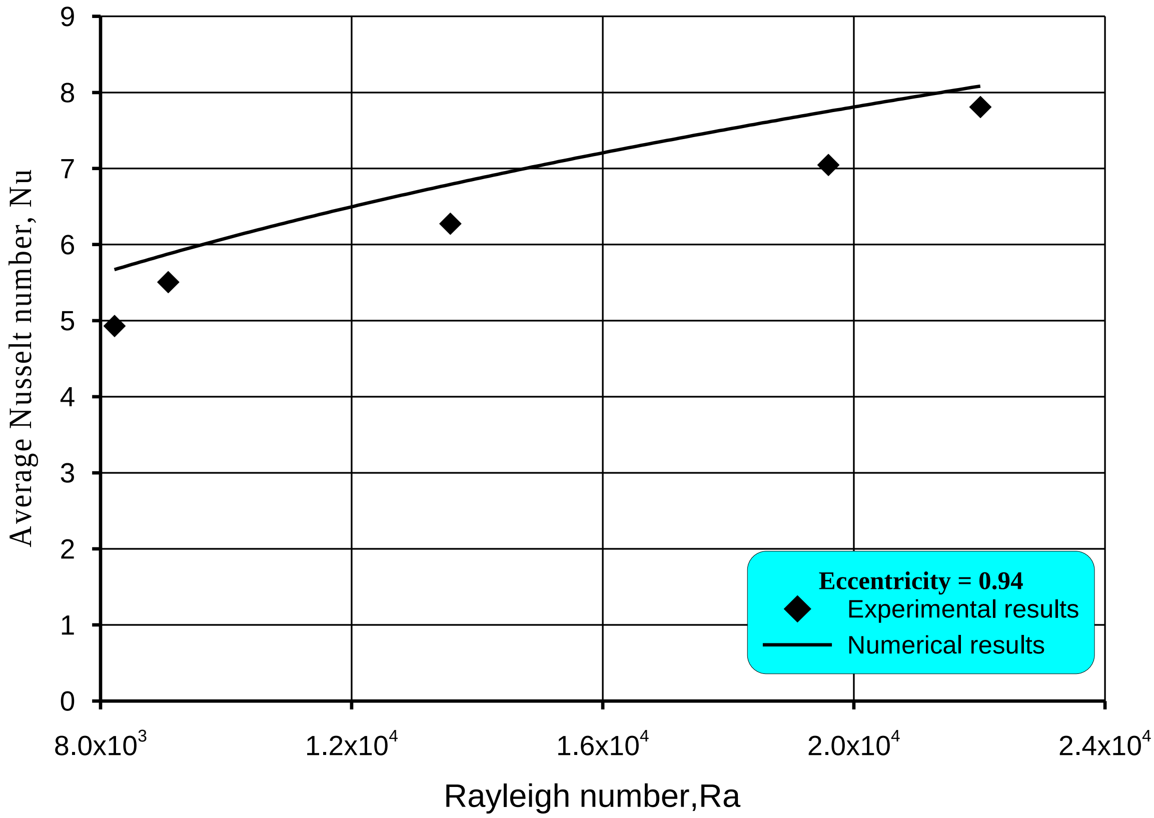
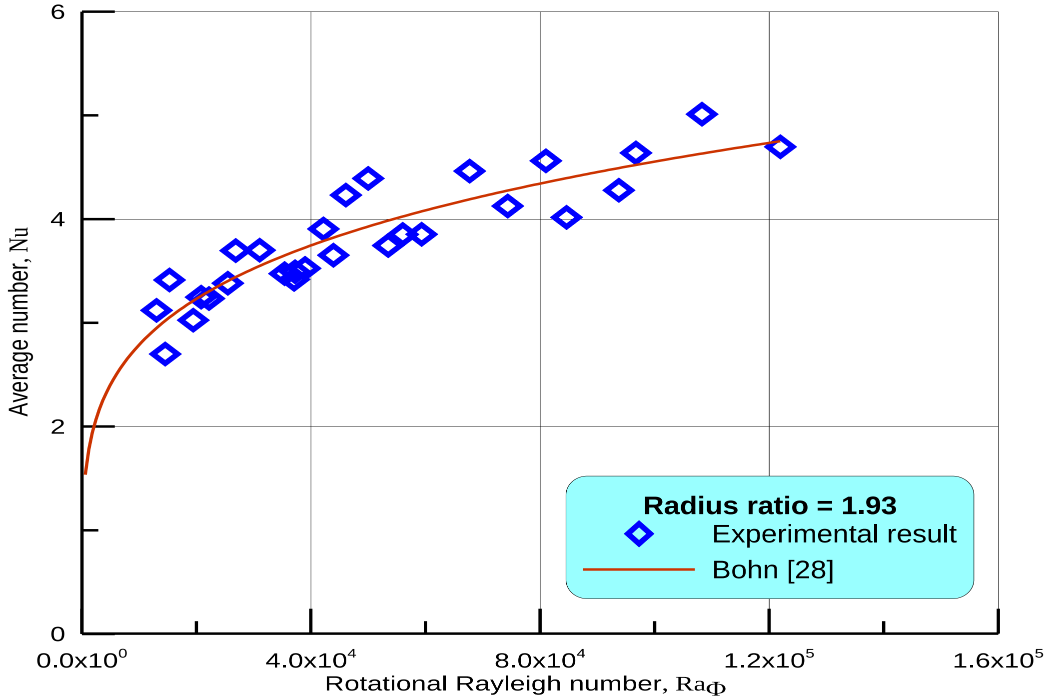


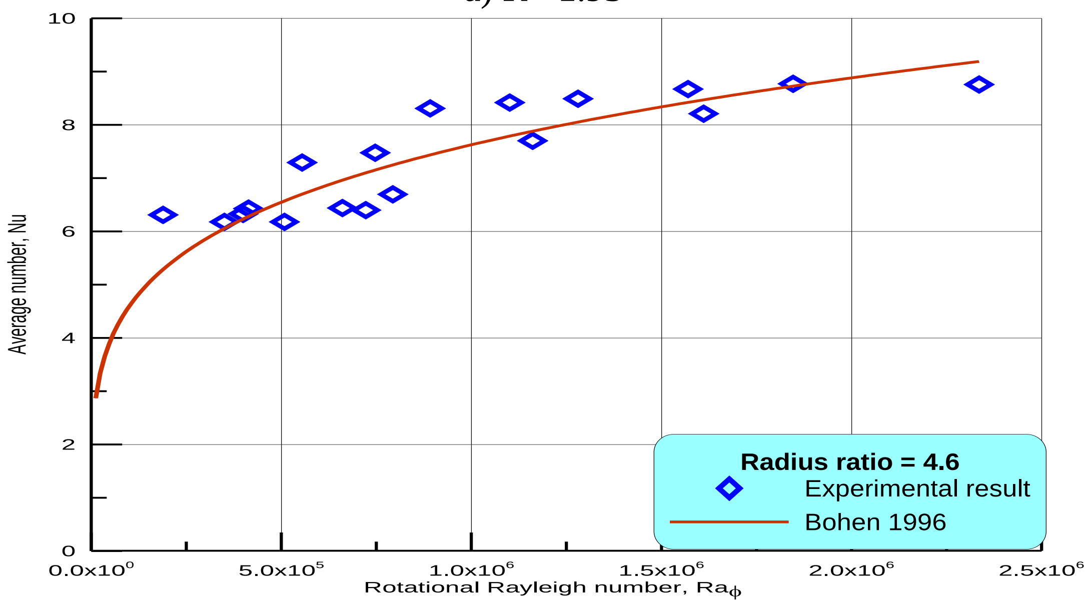
Fig. (5.11d) Comparison of the of the present numerical and experimental average Nusselt number versus Rayleigh number at eccentricity = 0.94

5-6 Comparison between Present Results and Published data

Figure (5-12) shows comparison between the present experimental results with those obtained by Bohn [41] using air as a working medium. From this figure it can be observed that the present experimental results compare favorably with the data given by Bohn [41].



a) R= 1.93



b) R = 4.6

Fig. (5-11) Comparison of the present average Nusselt number versus Rotational Rayleigh number with that given by Bohen [41]