An Experimental Study for Mixed Convection through a Circular Tube Filled with Porous Media and Fixed Horizontally and Inclined

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Abstract

The porous media have a great influence on the heat transfer and storaging it characteristics. In this study an experimental work has been conducted to measure the mixed convection though the filled circular tubes. First, the test apparatus has been manufactured; filled circular tubes with a porous media and fixed horizontally first then tilted with different angles. Secondly, the circular tube is heated with a constant heat flux and, thermocouples have been stickled in proper positions. Then many readings, for temperatures, have been registered for each thermocouple with different speeds of the outlet air (from the circular tube) and the inclination angle of the tube has been changed many times to be 0^o, 30^o,45^o & 60^o. These experiments have been conducted for the range ($108.54 \le Ra \le 907.73$) of Rayleigh number and for the range ($29.31 \le Pe \le 516.94$) of Peclet number. Three tests for the heat flux have been conducted, for each five Peclet number has been used. Finally, the experimental result shows that the surface temperature of pipe has a proportional relation with the tube length for all values of the heat flux and Peclet number. In addition, the heat transfer is achieved by free convection for small Peclet number, by forced convection for large Peclet number and by mixed convection for medium value of Peclet number.

Keywords: Mixed convection, Constant heat flux, Porous media, Inclined Horizontal circular tubes

Nomenclature

A tube surface area (m^2)

C specific heat ($J.kg^{-1}. K^{-1}$)

D tube diameter (m)

d grain diameter (m)

g acceleration due to gravity (m/s^2)

Gr Grashof number

h heat transfer coefficient ($W.m^{-2}.^oC^{-1}$)

I electrical current (ampere)

K permeability (m^2)

k thermal conductivity ($W.m^{-1}.^oC^{-1}$)

L tube length (m)

m mass flow rate ($kg.s^{-1}$)

Nu Nusselt number

Pe Peclet number

Ra Rayleigh number

Re Reynolds number

Ri Richardson number

Q heat input (W)

q heat flux ($W. m^{-2}$)

T temperature (^oC)

u velocity of air ($m. s^{-1}$)

V heater voltage (volt)

Greek symbols

θ tube angle of inclination

ε Porosity

ν kinematic viscosity ($m^2.s^{-1}$)

μ dynamic viscosity ($kg.m^{-1}.s^{-1}$)

ρ density ($kg.m^{-3}$)

ζ percentage of heat loss

Subscripts

av average

b bulk

e effective

f fluid (air)

i inlet

o outlet

s surface

p grain (glass sphere)

z local

1. Introduction

Over the last three decades Heat transfer though porous media has received considerable attention in many other fields searching for alternative energy. The analytical treatment for convective heat transfer through porous look for the first time complicated. Depending on the fluid properties, the temperature will effect the fluid flow in the internal and external flows and will complicate the assumptions of heat transfer particularly laminar flow at low Reynolds number, the effect of the bouncy can't be neglected and free convection convicted by forced convection in heat transfer will cause a new field for study called mixed convection. It is difficult to know it's whole nature(Donald A. Nield and Adrian Bejan, 1999)(Al- Daher M.. 2000).

The combined forced and free convections in an inclined surface and saturated in a porous medium, in the case of stream lines and surface temperature distribution will be in harmonic with distance. The parameter (Gr/Re) is the one who will decide the type of the effective convection, when it's value is very small the forced convection is the dominant, and when it's value very large the free convection is dominant(Ping Cheng, 2003).

Analytical study and investigating the influence of permeability of the combined force and free convection around inclined buried surface in saturated porous media was presented by (chandraseekhara& P.M. S, 1985). The researchers had studied two cases, uniform surface temperature and linearly variable with distance measured from the front edge of the plate with assistance and opposing flows. They found that the non-dimensionless parameter (Gr/Re^2) and (σ^2/Re) will conduct the flow behavior , also they noticed that the permeability change will increase heat transfer for all (σ^2/Re) values.

(W.L etal. 1999) conducted an experiments on a mixed convection heat transfer in a vertical packed channel with a symmetric heating of opposing walls. The experiments were carried out in the range of $2<Pe<2200$ and $700<Ra<1500$. The measured temperature distribution indicates the existence of a secondary convective cell inside the vertical packed channel. A correlation equation for Nusselt number in terms of Peclet and Rayleigh number was obtained from experimental data and plot the relation between them. Three convection regimes were exist: forced convection $Ra/Pe<1$, mixed convection $11<Ra/Pe<105$ and natural convection $105</Pe$.

Mixed convection analysis on a vertical packed plane in two direction using unbalanced heat was studied by (Nawaf,2004). He assumed one side is insulated and the other one is cooled by a constant temperature media. The study was carried out for Pe (0.1- 100), Ra (10, 50, 100), thermal conductivity ratio Kr (0.01- 100) and heat transfer coefficient H (0.01- 100). He found that the net average Nusselt number decreases as H increases at low Peclet number, while for large Peclet number and H values and when Kr increases the average Nusselt number will increases.

(Y.M.F. etal. 2006) Studied laminar mixed convection in the entrance region for horizontal semicircular ducts with the flat wall at the bottom. They used momentum and energy equation which were solved by control volume approach using finite control volume by SIMPLER Algorithm. Results were for the thermal boundary condition of uniform axially heat flux and with uniform wall temperature circumferentially to distribute velocities temperature and local Nusselt number showed that Nu decreases in mixed convection case in the entrance region, and decreases when the entrance length is increased and increased with the natural convection effect before reaching a constant value (fully developed). While Gr and Nu increase with increasing mean coefficient of friction for the wall in fully developed case.

Mixed convection was studied experimentally in a circular inclined channel with different angles and vertical for laminar downward flow by (Hussein, et al. 2007). The used a copper pipe (length 900mm) inner diameter (30mm). The outer surface was heated at constant heat flux, Re range was (400- 1600), Ra ($1.78*10^5$-$3.56*10^6$). They found the tune surface temperature increases a long the tube with downward flow extensively increasing comparing with upward flow. Nu in the downward flow is less in the upward case. A correlation was obtained between Nu, Ra and Re in the till and vertical cases in the from $Nu = Ra/Re$.

2. Experimental Work

Mixed convection heat transfer is one of the most important convection transfer so we conduct an experiment mixed convection in a packed saturated porous media heated with a constant heat flux in the horizontal position and changing the inclination tube angle (30^o, 45^o, 60^o) respectively.

A copper tube is used , its internal and external diameter are (45mm) and (47mm) respectively, the length was (850mm). The active heated length is only (800mm). The channel was packed with glass sphere, their diameter is (5mm) and their thermal conductivity is (0.81W/m.^{o}C). They were fitted between two permeable discs made of galvanized iron. The tube is provided with air by a blower at (2500 rpm) and A.V at (220 v). The voltage was stabilized by a stabilizer. The tube surface temperature was measured by (48) thermocouple (T type) were position a long the test section tube, three thermocouples were position for each locate. The mean read was used, this position represent one from 16. One thermocouple is used to measure the air temperature at the entrance of the tube which was located in the air flow, another one was located after packed to measure the out flow air temperature and it was positioned in the same pervious way. Another thermocouple measures the laboratory ambient temperature.

The test section was heated electrically using coil and an electrical resistance around tube of (28m) in length with a resistance (1Ω/m). To increase the supplied power the test section was thermally insulated with fiber glass of (100mm) in thickness. The two ends of the tube were insulated electrically and thermally using two parts of tephlon made of insulator and thermal resistor lapanate also it was used to reduce the thermal losses in the axial direction. The entrance sector was packed to be insure to get fully developed before the test section. The heater was supplied with an alternative electrical power using converter that supplied with a steady voltage through a voltage regulator (220v). An Ameter was used to measure the current pass through the heater with accuracy (10^{-4}A). Digital Anemometer AM4200 with an accuracy of (0.1 m/s) is used to measure the velocity of entering air to the test section, the maximum velocity that the anemometer can measure is (30m/s). A photo (1) shows the test section, and fig. (2) illustrates the schematic drawing of the test section.

3. Calculation Procedures

The temperature of the in flow air to the test section is within (30-40)^{o}C. And the test procedure can be listed as follow.

1-Turn on the air blower in order to supply the test section with the required air. And the air flow is controlled easily using the control valve that shown in photo graph (1).

2-The test section was set to the proper temperature and this was achieved using a variable transformer.

3-After (40- 45) minutes the system would reach the steady state condition. And this technique was adopted by (Al- Daher M. and A. H. Jasim, 2002)(Al-Sammarai A. T. A., 1999).

Many readings for the tube surface and also for the inlet and outlet air and the libratory temperatures have been registered.

The diameter of the filler (glass sphere) was measured and found to be (d=5mm). And the porosity of this filler was found practically and found to be (0.3661), were sphere order in the tube is consider to have random arrangement and when this was compared with the value that calculated by using the following equation(Al-Daher M.. A, 2000):-

$$\varepsilon = 0.32 + \left(0.45 * \left(\frac{d_p}{D}\right)\right) \quad \text{.....(1)}$$

And this equal to (0.37), and the deference between the two values (measured and calculated) is found to be negligible. Therefore the permeability was calculated using the following equation(B. Buonomo, G. Foglia, O. Manca& S. Nardini, 2008):-

$$K = \frac{\varepsilon^3 dp^2}{175(1-\varepsilon)^2} \quad \text{.....(2)}$$

There are many variables have been calculate some of them is locally indirectly measured such as Nusselt number and heat transfer coefficient and the other in between variables have been calculated e.g. Peclet number (Pe), Rayeigh number (Ra) and Richardson number (Ri). Then the local heat transfer coefficient was calculated using the following equation(Hussein A. Mohammed and Yasin K. Salman, 2007):-

$$h_z = \frac{q}{(T_s - T_b)_z} \quad \text{.....(3)}$$

Where (q) is the heat flux for a unit of area and this is calculated from the following equation:-

$$q = \frac{Q}{A_s} \quad \text{..... (4)}$$

Where

$$A_s = \pi.D.L \quad \text{.....(5)}$$

And the bulk temperature for the air was calculated using the following equation(J. P. Holman, 1977):-

$$T_b = \left(\frac{T_i + T_o}{2}\right) + 273.18 \quad \text{..... (6)}$$

The characteristic of the flowing air were calculated through the test section which were variable depending on in the bulk temperature of the flowing air and this were calculated using the following empirical equation(John H. Lienhord IV and John H. Lienhord V, 2003):-

$$\rho_f = 1.21003 + 7.4715 * 10^{-3} Tb - 3.8919 * 10^{-5} * Tb^2 + 4.54786 * 10^{-8} Tb^3 \quad \text{.....(7)}$$

$$\mu_f = 1.577 * 10^{-4} - 1.285 * 10^{-6} Tb + 3.836 * 10^{-9} Tb^2 - 3.662 * 10^{-12} Tb^3 \quad \text{.....(8)}$$

$$k_f = 0.155 - 1.236 * 10^{-3} Tb + 3.760 * 10^{-6} Tb^2 - 3.588 * 10^{-9} Tb^3 \quad \text{.....(9)}$$

$$Pr_f = 2.692 - 1.691 * 10^{-2} Tb - 4.799 * 10^{-6} Tb^2 - 3.588 * 10^{-9} Tb^3 \quad \text{.....(10)}$$

$$C_{pf} = 825.885 + 1.627 Tb - 4.974 * 10^{-3} Tb^2 + 5.205 * 10^{-6} Tb^3 \quad \text{..... (11)}$$

Where the quantity of the added heat transfer (Q) from the air was calculated as follow:-

$$Q = m\, C_{pf} (T_o - T_i) \quad \text{..... (12)}$$

And the generated heat (Pwr_{in}) in the heater was found as flow:-

$$Pwr_{in} = I * V \quad \text{.....(13)}$$

The percentage of the heat transfer heat loss could calculated as flow:-

$$\xi = \left(1 - \frac{Q}{Pwr_{in}}\right) \times 100 \quad \text{.....(14)}$$

And the local Nusselt number was calculated using the following equation:-

$$Nu_z = \frac{h_z D}{k_e} \quad \text{……………………………(15)}$$

Where k_e is the effective coefficient of thermal conductivity for the porous media which could be calculated as follow(B. Buonomo, G. Foglia, O. Manca& S. Nardini, 2008)(C. Y. Choi and F. A. Kulacki, 1992):-

$$k_e = \varepsilon k_f + (1-\varepsilon)k_p \quad \text{…………………..……(16)}$$

Where k_f and k_p is the thermal conductivity of the air and porous media respectively. The thermal conductivity of the air was calculated using equation (9). Reynolds number (Re) was calculated as follow(Al- Daher M.. A. 2000):-

$$Re = \frac{\rho_f u dp}{\mu_f (1-\varepsilon)} \quad \text{…………………….…(17)}$$

And Peclet number (Pe) was calculated as follow:-

$$Pe = Re\, Pr_f \quad \text{……………….……...(18)}$$

And Prandtl number (Pr_f) was calculated depending on the change of the bulk temperature of the air using equation (10).Grashof number (Gr) was calculated as follow(Donald A. Nield and Adrian Bejan, 1999)(B. Buonomo, G. Foglia, O. Manca& S. Nardini, 2008)(C. Y. Choi and F. A. Kulacki, 1992):-

$$Gr = \frac{g\beta K q D^2}{\varepsilon k_e \nu^2} \quad \text{……………………(19)}$$

Where $\beta = \frac{1}{T_b}$

Rayleigh number (Ra) was calculated using the following equation:-

$$Ra = Gr\, Pr_f \quad \text{… ......(20)}$$

Where Richardson number (Ri) was calculated using the following equation:-

$$Ri = Gr/Re^2 \quad \text{……………..…………(21)}$$

And the average value of Nusselt number was calculated as follow:-

$$Nu_{av} = \frac{\int_Z^L Nu_z dz}{L - Z} \quad \text{……………….……...(22)}$$

Five testes had been cared out for the following rang ($29.31 \le Pe \le 516.94$) of Peclet number. And for each value of this number the supplied heat was changed. And this was for three quantities of the heat flux and also the flow was (198.94, 862.10 and 1750.66)W/m^2. And this was depending on the supplied electricity voltage that used for heating the test section the previous test had been repeated ones for each of the following tube position (horizontal and inclined with deferent angles)(30^o, 45^o, 60^o).

The relationship between the change of tube surface temperature and the tube length, for each test position were plotted. Also the relation between average Nusselt number and Peclet number, for a fixed value of a Rayleigh number were plotted. And a relation between average Nusselt number and Rayleigh number for fixed value of a Peclet number were plotted.

4. Result and Discussion

Sixty tests had been carried out for each of the following variables.

1) The angle (θ) of the tube have been change to have different values. These values were (0, 30^o, 45^o, 60^o).

2) Peclet numbers have been varied within the range (29.36 – 516.94) and this was done five times.

3) Rayleigh numbers have been varied within the range (108.54- 907.73) and this was done three times.

The relationship between of the tube surface temperature and its length for the horizontal position for deferent values of heat flux were presented on fig. (3). This figure shows that the tube surface temperature increases proportional with tube length. And this with a linear manner. Except few points at the two ends of the tube. And this exception is increased for high values of Rayleigh number. And this is believed is due to that boundary layer starts from zero at one end of the tube and its thickness is increased to reach its peak some were between the two ends. The decrease in the tube surface temperature at the out flow end is justified by the heat loss at that region. The same behavior would continue for the figs. (4,5 and 6)which are for the angles (30^o, 45^o and 60^o). And it can be notes that the tube surface temperature increases with the increase of the angle of the tube inclination and this is due to the decrease of the thickness of the boundary layer, in addition to absorbed heat by the flowing air.

The hot air settle in the upper space of the porous media and the cold air settle in the bottom space of the porous media. The heights difference in the tube surface temperature is ($\Delta T=4.82^oC$). This was registered for the first heat flux and this was for the position between ($\theta=0$) and ($\theta=60^o$). And the heights difference for the second heat flux was (($\Delta T=12.51^oC$). And the heights difference for the third heat flux was ($\Delta T=29.66$).

Figs. (7, 8, 9 and 10) show the relationship between the surface temperature and the tube length for different values of Peclet number. The little difference between Peclet number values is related to the thermal properties which can be calculated for each value of bulk temperature. And thus was clarified in previously (experimental work), in the equations (7, 8, 9, 10 and 11). And for this relationship for the horizontal position and the other angled positions. It can be noticed that the tube surface temperature increased with the increase of the tube length for the different values of the heat flux. The maximum increase was for the maximum value of heat flux. And also the maximum difference for the tube surface temperature was registered for each tube position and they were found to be:

$$\theta = 0\,,\ \ \Delta T = 52.93^o C$$

$$\theta = 30^o\,,\ \ \Delta T = 70.19^o C$$

$$\theta = 45^o\,,\ \ \Delta T = 77.77^o C$$

$$\theta = 60^o\,,\ \ \Delta T = 79.19^o C$$

Fig. (11) shows the distribution of the tube surface temperature with its length for all the tube inclination angles and for (Pe=166) and heat flux ($q=862.10W/m^2$). It is clear from this figure that the tube surface temperature increases with the increase of the tube length. And this increase has a large steps for a higher inclination angle of the tube. The highest temperature for the tube surface register was ($T=67.84\ ^oC$).

The same previous temperature distribution and the same tube position and for (Pe=30) and heat flux ($q=1750.66W/m^2$) are presented in fig. (12). The highest temperature that registered for the tube surface was ($T=124.8\ ^oC$) and this, for the tube position ($\theta=60^o$).

The distribution of the local Nusselt number with the tube length, for different tube positions and for the first heat flux ($q=198.94W/m^2$) were presented on figs. (13, 14, 15 and 16). It can be noticed that at some readings that the local Nusselt number is decreased its thermal fully developed. And the region though to be related to phenomenon of flow and this is due to the existence of the glass sphere. Also could be notice be that the increases of Peclet number cause an increases in local Nusselt number, and this is because of the boundary layer is thin. So the effect of the natural convection increases at low flow speed. And the heights value of Nusselt number was the horizontal position of the tube and it decreases when the inclination angle of the tube increases to reach its maximum value (Nu=7.13) at ($\theta=60^o$).

The relationship between local Nusselt number with tube length for all tube positions are presented on figs. (17, 18, 19 and 20) at the heat flux ($q=1750.66W/m^2$). It is clear that local Nusselt number behaves in the same manor as in the previous case. And all its values are closed to each other. And the reason is because convergence of the local coefficients of the heat transfer, and this is a result from convergence of the difference in the temperature values.

The average value of Nusselt number had been calculated by choosing the convergence values of temperature in the mid section of the tube where the air flow was considered thermally fully developed. That because the simple difference between the temperature values near to the tube end.

The increase of Rayleigh number cause considerable increase in the average value of Nusselt number as shown in figs.21, 22 and 23. And this was for all the tube positions, except inclination with (60^o) angle. And this was down for different values of Peclet number which have been tested. This is because that the effect of natural convection which has a (parabolic relation) which is the common shape for all heat transfer conditions of this sort.

The highest Nusselt number is corresponding to the highest Peclet number. And this is for all tube inclination angles. And the average values of Nusselt number corresponding to the small Rayleigh number are convergence and the difference between the increased at higher values of Rayleigh number.

The relationship between Nusselt number and the average Peclet number for different Rayleigh number for all the tube positions as shown in figs.24, 25, 26 and 27). From all these curves, it is clear that the average Nusselt number increases with the increase of Peclet number and this for all conditions. And the largest Nusselt number is corresponding to the high values of Rayleigh number. Also from these figures it is possible to locate, the heat transfer region (by natural convection) and this is dived into three regions, the first is the left end of the curve. It can be seen that the values of Nusselt number is settle and this continue to a certain point right to the first point in the curve.

So this region is the natural convection zone which hasn't any effect for Peclet number and there is no effect for Reynolds number. And Rayleigh number only play the master role in this mater. The second region to the right of the first one is the mixed convection zone in this region it could be seen that the change of the Nusselt number gives a change in the Peclet and Rayleigh numbers gather. And the third region which is the right portion of the curve, end it could be seen that a large change in Nusselt number values give slight change in the values of Rayleigh number, i., e. this region is a forced convection zone.

Figs. (27, 28, 29 and 30) give a clear picture to the effect of Peclet number for different values of Rayleigh number. It could be seen that the average Nusselt number is increased with the increase of Rayleigh number and this is for all the tube positions. And the increase of the Nusselt number has a large step corresponding to a large Rayleigh number specially at the horizontal tube position.

5. Conclusion

From this study the following conclusion be deduced:-

1) The study surface temperature increases with increases of the heat flux and this increase with larger steps at higher of the tube inclination angle. This is because the Phenomenon of separating the cold air to be settle in the bottom and the hot air to be settle in the supreme.

2) The tube surface temperature for small Peclet number is higher than that for large values of Peclet number. And this is true for all values of heat flux.

3) The values of locally Nusselt number have its highest values for the case of horizontal position of the tube. And this is large value of Rayleigh number.

4) Local Nusselt number increases with the increases of Peclet number all the tube position.

5) This for steady we found that there are three regions of convection this is depending of the change of Nusselt number and this depends of Peclet number. And this is for the tested value of Rayleigh number which is shown in table 1, for all the tested tube position.

6) An empirical relation between the average value of Nusselt number with average Peclet number and average value of Rayleigh number. And this for all tube position. This empirical formal:-

$$\frac{Nu_{av}}{Pe_{av}^{a}} = \left[c_1 + c_2 \left(\frac{Ra_{av}}{Pe_{av}^{b}} \right) \right]^{c3} \qquad \text{.......................(23)}$$

All the constant of the previous formal are shown in table2.

Reconditions

1) Studying the effect of the changing the cross sections of the tested tube (elliptical, square, triangle, etc..) section.

2) Studying the effect of the changing the testing tube diameter.

3) Studying the effect of the change the grain diameter.

4) Studying the effect of the using grains with different diameter.

5) Studying the effect of the change flowing fluid phase, e. g. using vapor.

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Table 1. Result of Testing Tube Position

Natural convection	Mixed convection	Forced convection
Horizontal (0^o)		
Pe<168.23	168.23<Pe<510.84	Pe>510.84
Inclined (30^o)		
Pe<171.99	171.99<Pe<342.16	Pe>342.16
Inclined (45^o)		
Pe<274.3	274.3<Pe<513.2	Pe>513.2
Inclined (60^o)		
33.92<Pe<272.6	272.6<Pe<340.87	Pe>340.87

Table 2. constant of the previous formal

	a	b	c_1	c_2	c_3
$\theta=0^o$	0.85	1.15	1.102	0.566	0.629
$\theta=30^o$	0.85	1.18	0.972	0.669	0.610
$\theta=45^o$	0.84	1.18	0.738	0.541	0.641
$\theta=60^o$	0.80	1.13	0.668	0.389	0.687

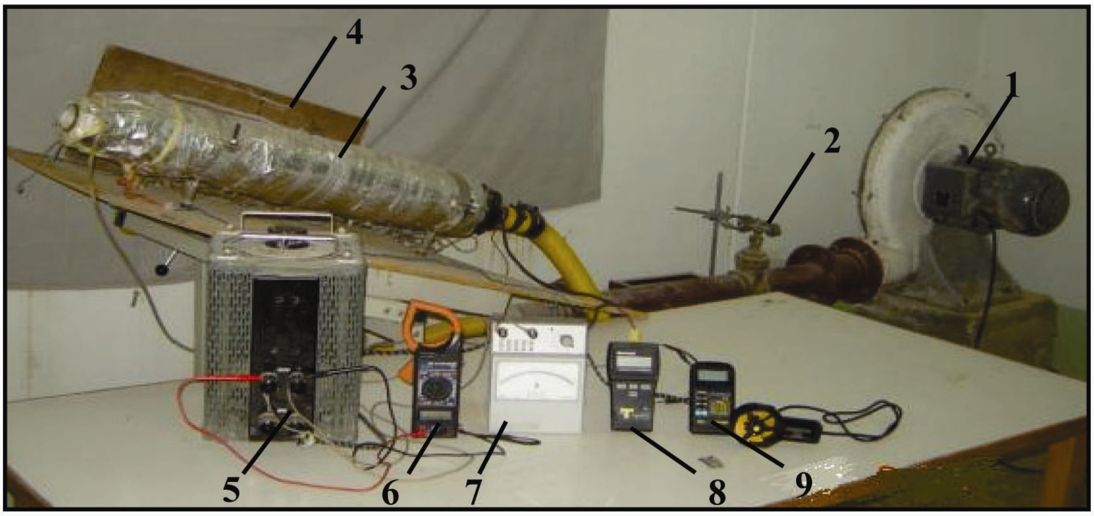

Figure 1. A photo graph showing the test parties
1- Blower, 2- Valve, 3- Test Section, 4- Meter panel, 5- Voltage regular, 6- Voltmeter, 7- Ameter, 8- Thermometer, 9- Flow meter.

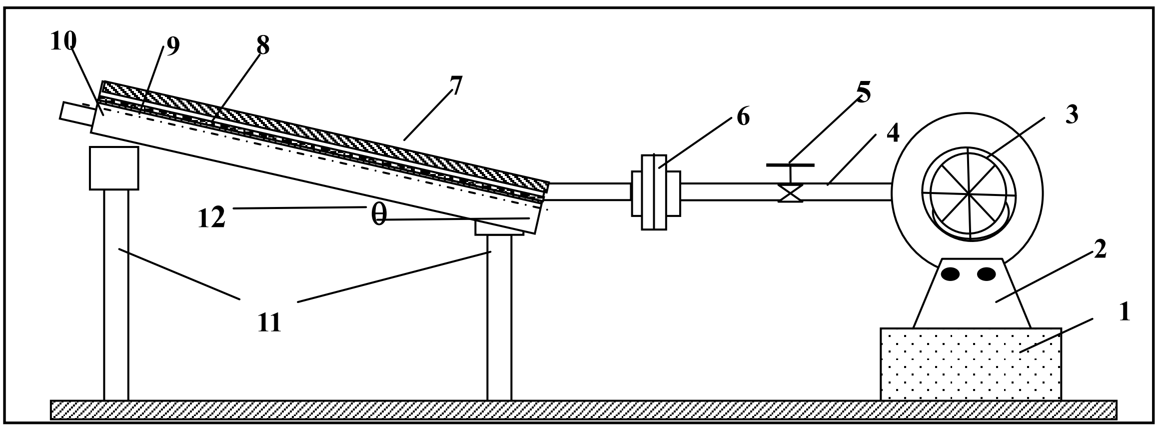

Figure 2. Schematic drawing for the test rig including the test section
1- Concrete base , 2- Blower base, 3- Blower, 4- connecting tube, 5- Air valve, 6- Flange, 7- Fibber glass,

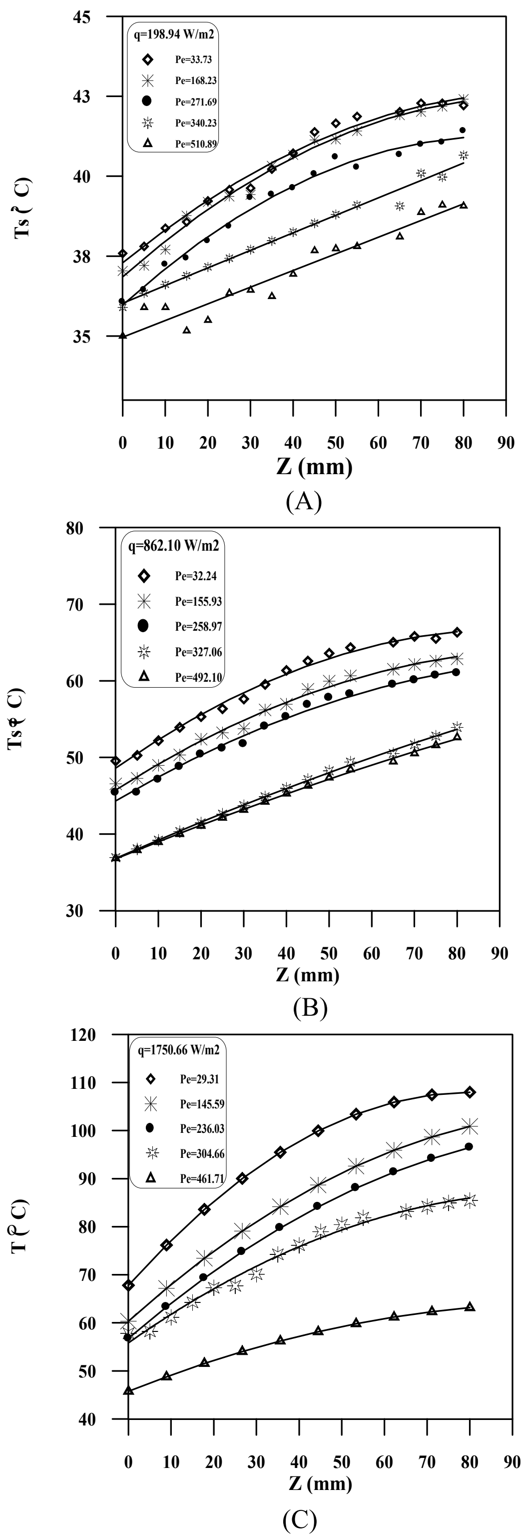

Figure 3. The relation between the tube surface temperature and its length for many values of heat flux at many values of Peclet number at the horizontal position of the tube

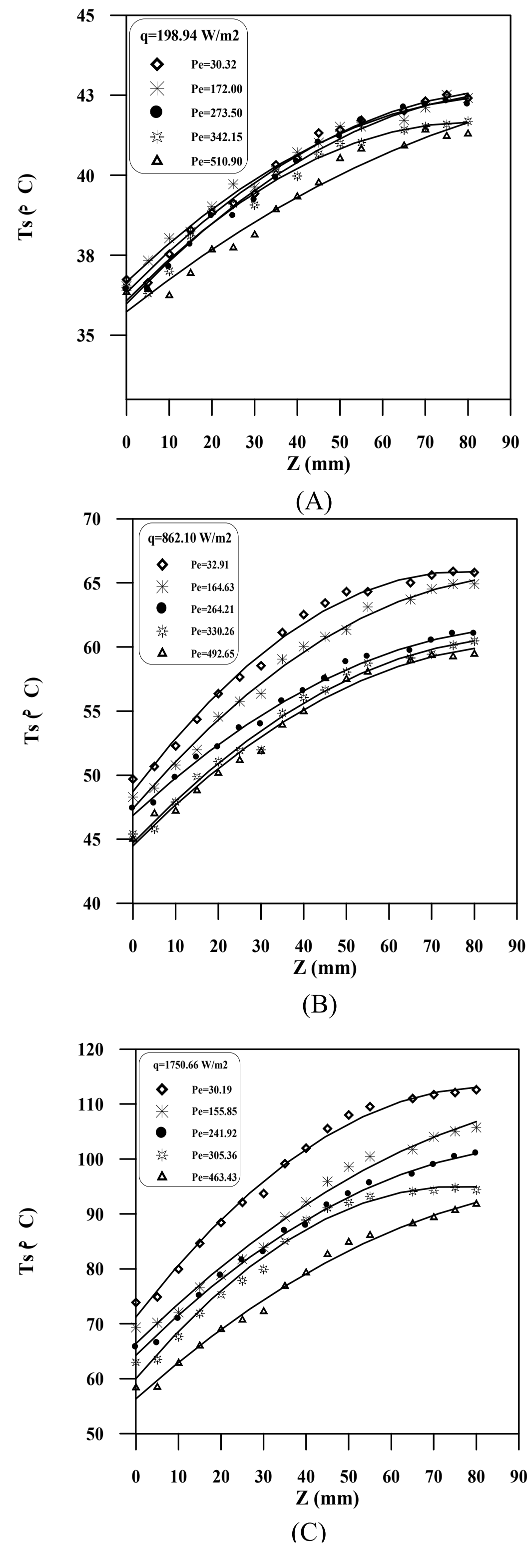

Figure 4. The relation between the tube surface temperature and its length for many values of heat flux at many values of Peclet number at the inclined angle (30^o)

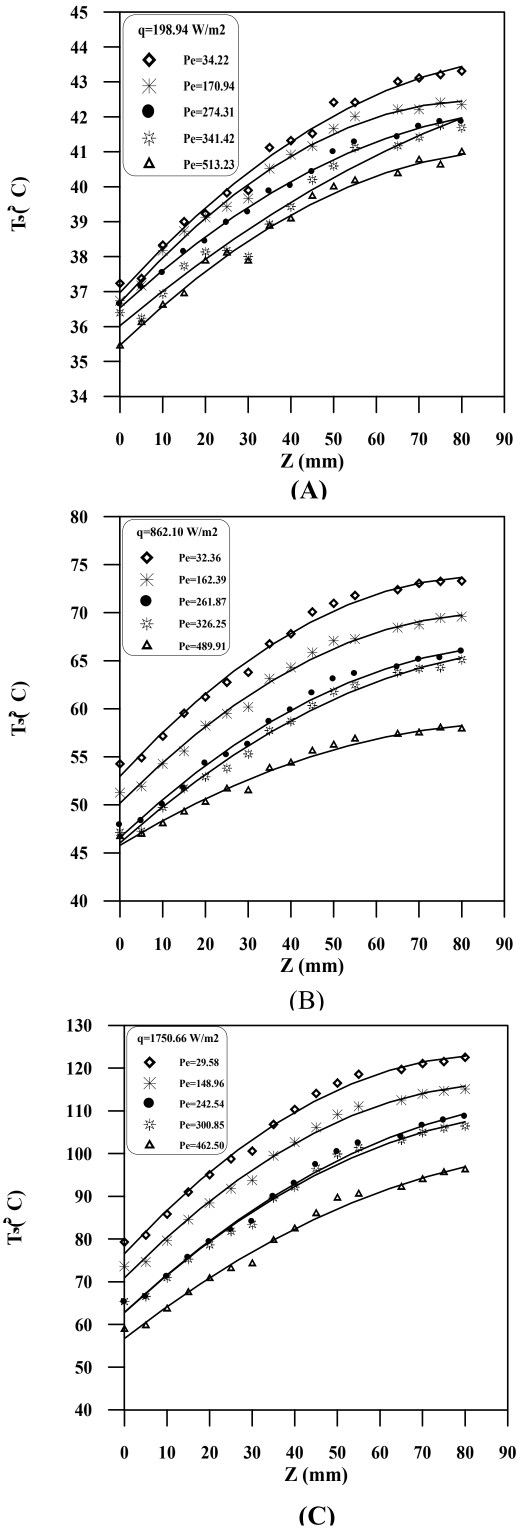

Figure 5. The relation between the tube surface temperature and its length for many values of heat flux at many values of Peclet number at the inclined angle (45^o)

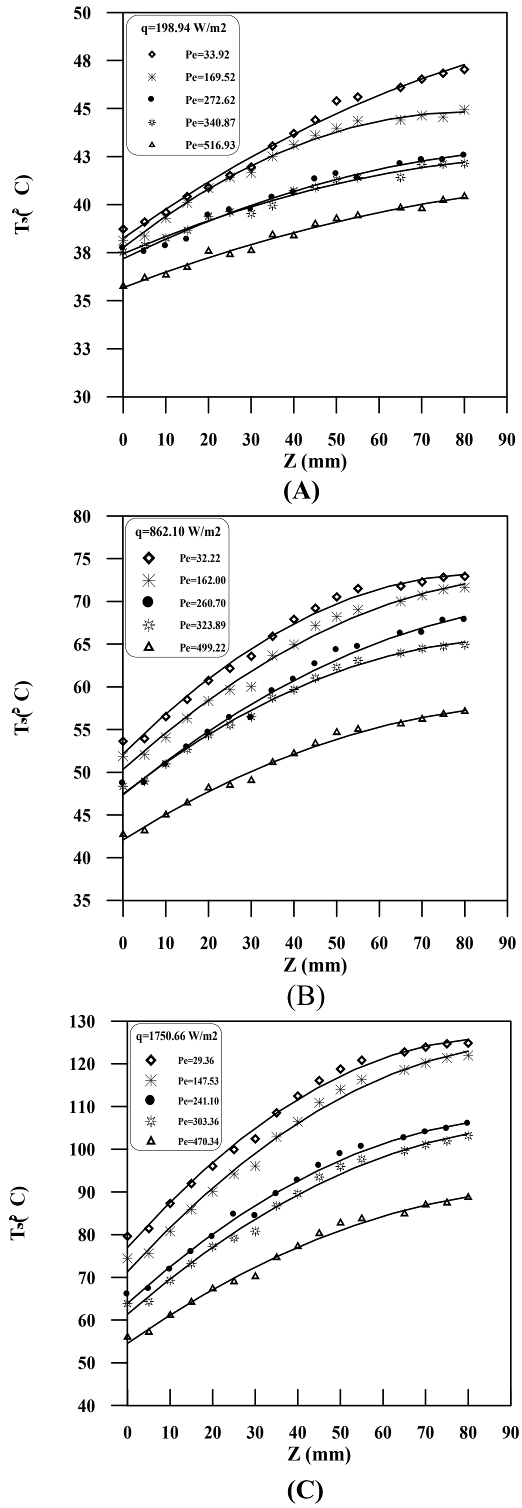

Figure 6. The relation between the tube surface temperature and its length for many values of heat flux at many values of Peclet number at the inclined angle (60^o)

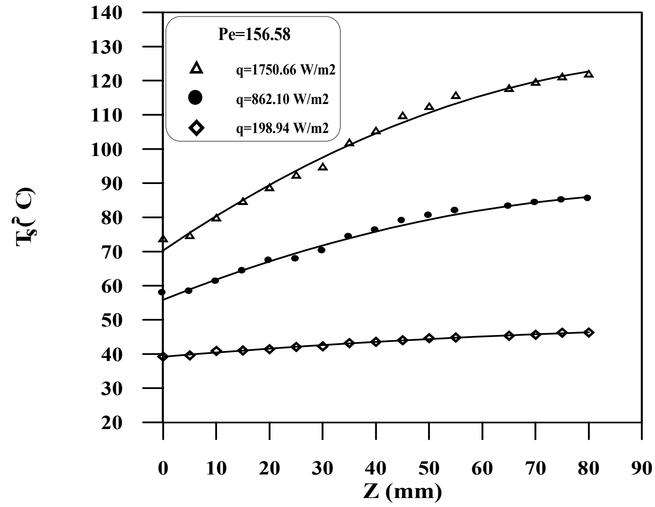

Figure 7. The relation between the tube surface temperature and its length for many values of heat flux for Pe=156.58 and horizontal position of the tube

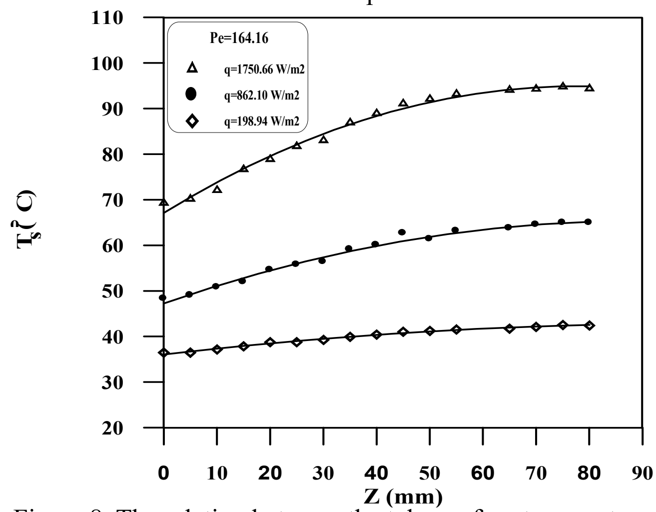

Figure 8. The relation between the tube surface temperature and its length for many values of heat flux for Pe=164.16 and inclination angle (30^{o})

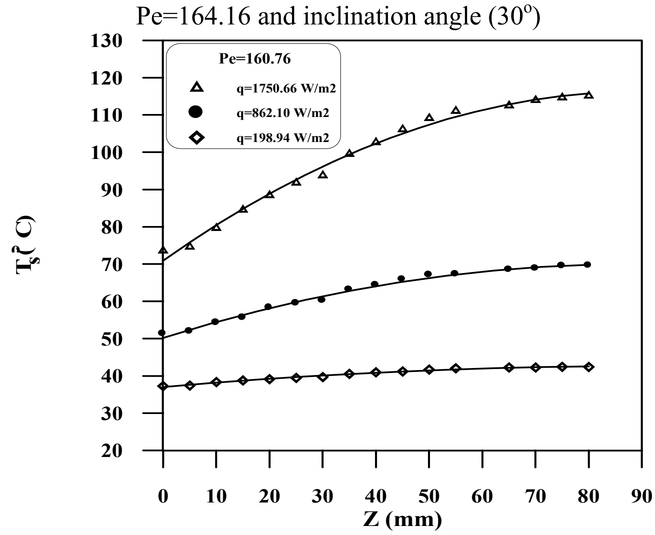

Figure 9. The relation between the tube surface temperature and its length for many values of heat flux for Pe=160.76 and inclination angle (45^{o})

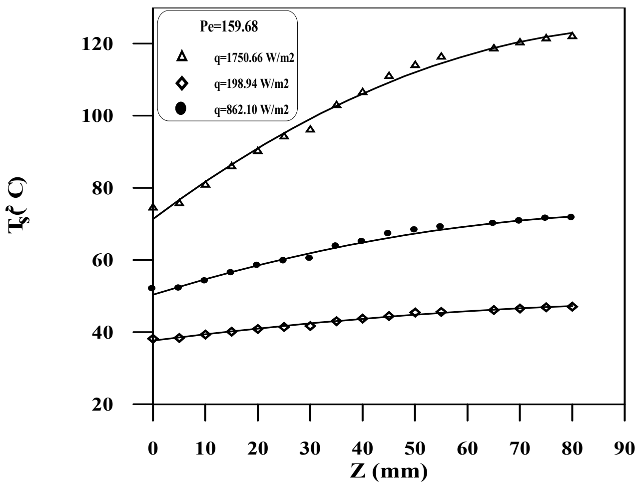

Figure 10. The relation between the tube surface temperature and its length for many values of heat flux for Pe=159.68 and inclination angle (60^{o})

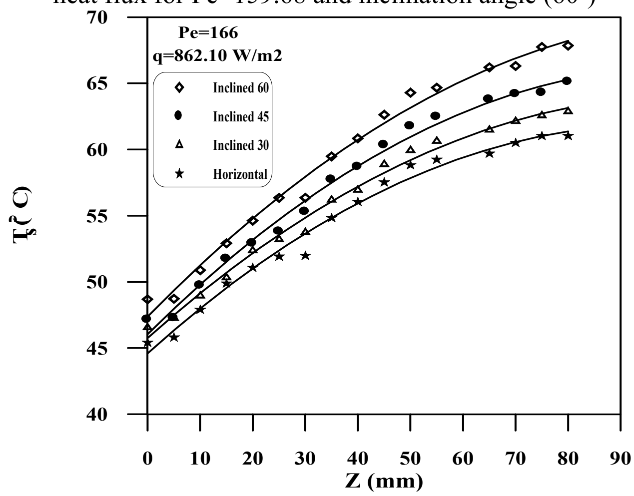

Figure 11. The relation between the tube surface temperature and its length for all the tube position and for the minimum value of heat flux

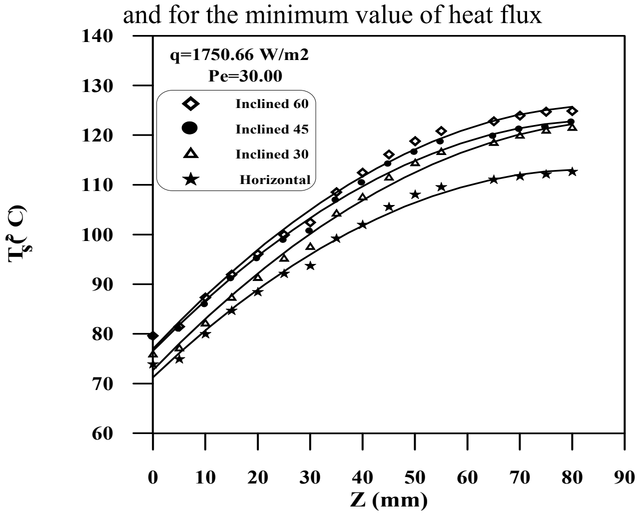

Figure 12. The relation between the tube surface temperature and its length for all the tube position and for the maximum value of heat flux

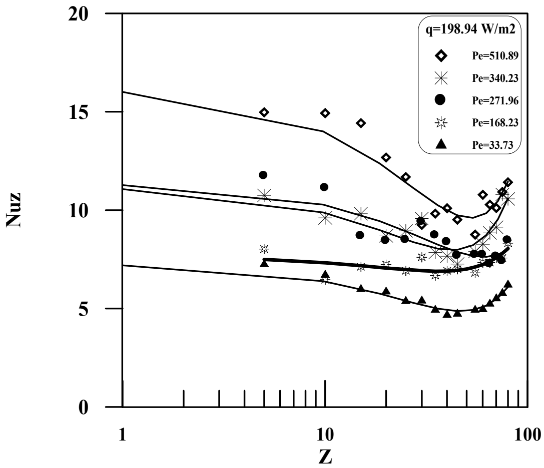

Figure 13. The relation between local Nusselt number and the tube length for many values of Peclet number and horizontal position of the tube at minimum heat flux

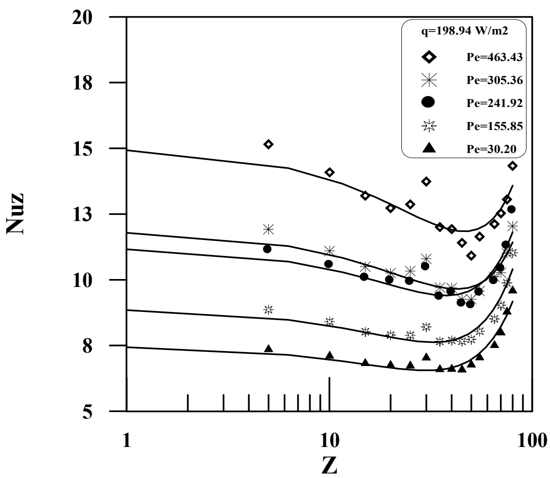

Figure 14. The relation between local Nusselt number and the tube length for many values of Peclet number and inclination angle (30°) at minimum heat flux

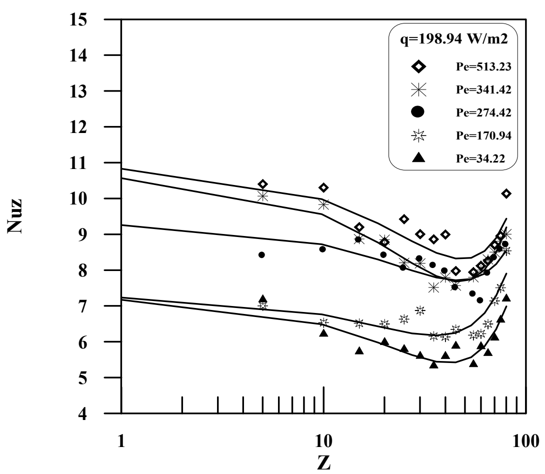

Figure 15. The relation between local Nusselt number and the tube length for many values of Peclet number and inclination angle (45°) at minimum heat flux

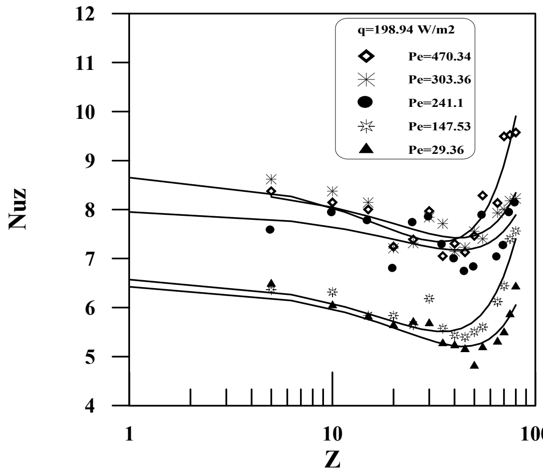

Figure 16. The relation between local Nusselt number and the tube length for many values of Peclet number and inclination angle (60°) at minimum heat flux

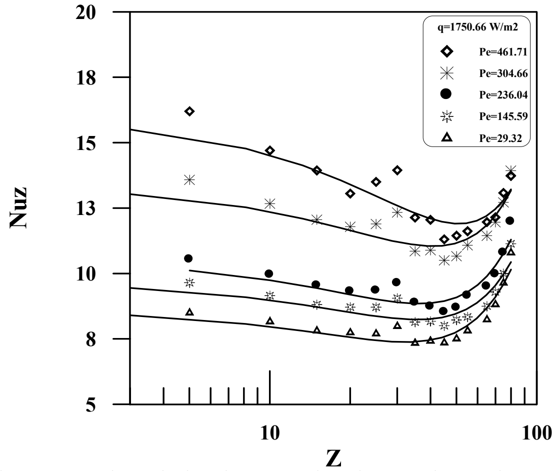

Figure 17. The relation between local Nusselt number and the tube length for many values of Peclet number and horizontal position of the tube at maximum heat flux

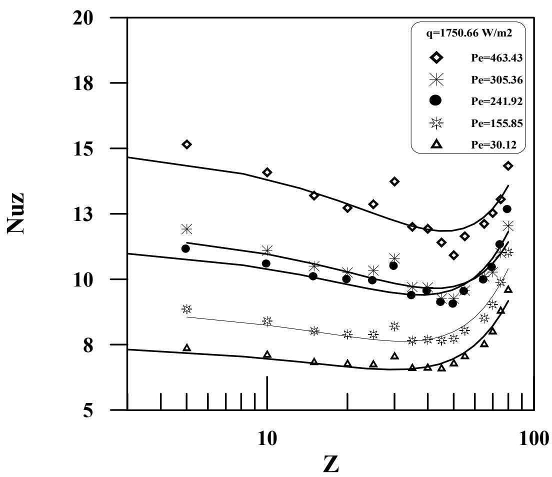

Figure 18. The relation between local Nusselt number and the tube length for many values of Peclet number and inclination angle (30°) at maximum heat flux

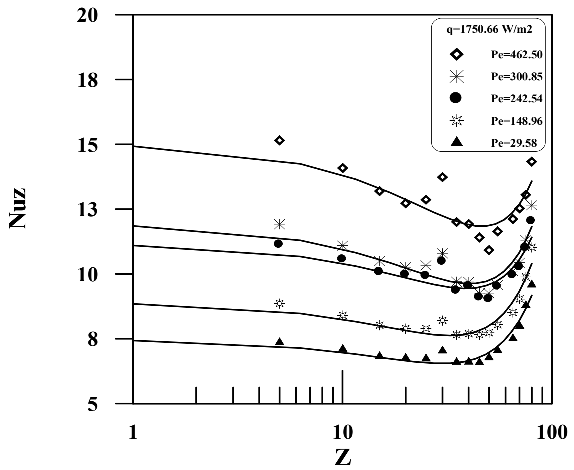

Figure 19. The relation between local Nusselt number and the tube length for many values of Peclet number and inclination angle (45^o) at maximum heat flux

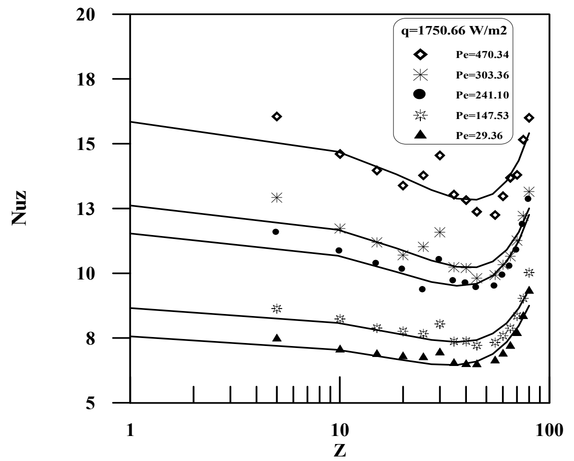

Figure 20. The relation between local Nusselt number and the tube length for many values of Peclet number and inclination angle (60^o) at maximum heat flux

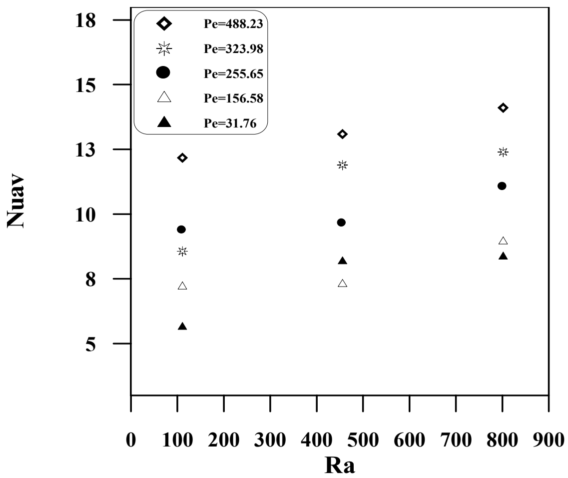

Figure 21. The relation between average value of Nusselt number and Rayleigh number with changing the value of Peclet number for the horizontal position of tube

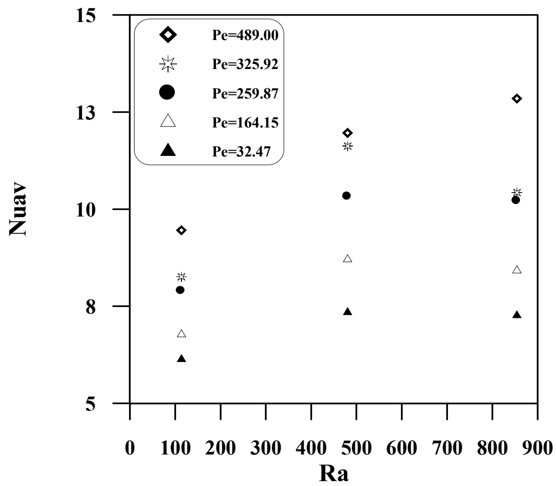

Figure 22. The relation between average value of Nusselt number and Rayleigh number with changing the value of Peclet number for the inclination angle (30^o)

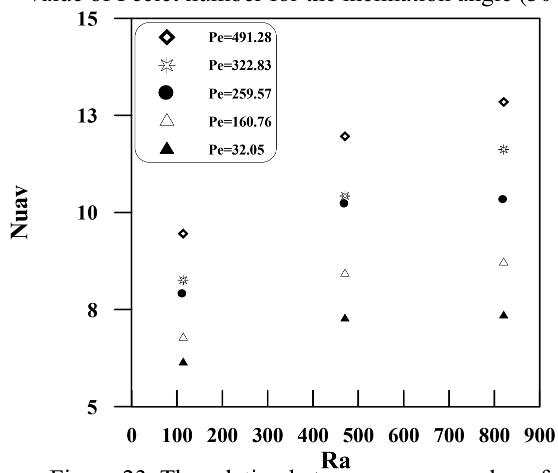

Figure 23. The relation between average value of Nusselt number and Rayleigh number with changing the value of Peclet number for the inclination angle (45^o)

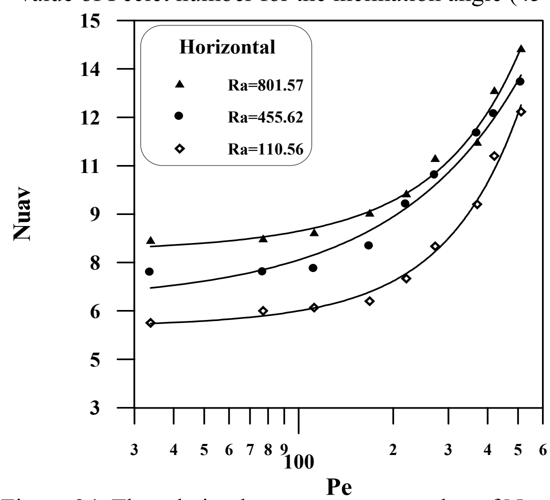

Figure 24. The relation between average value of Nusselt number and Peclet number for the horizontal position and for different values of Rayleigh number

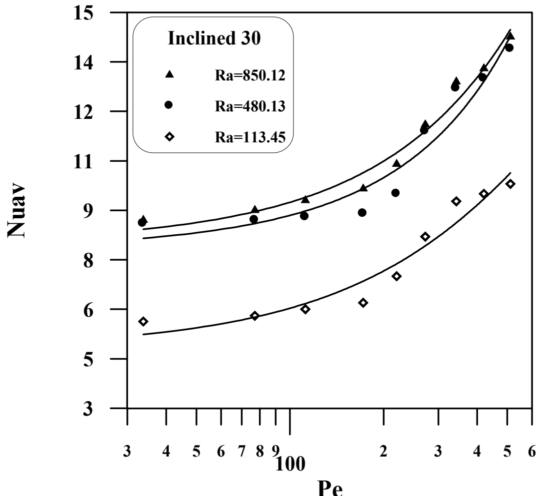

Figure 25. The relation between average value of Nusselt number and Peclet number for inclination angle (30°), and for different values of Rayleigh number

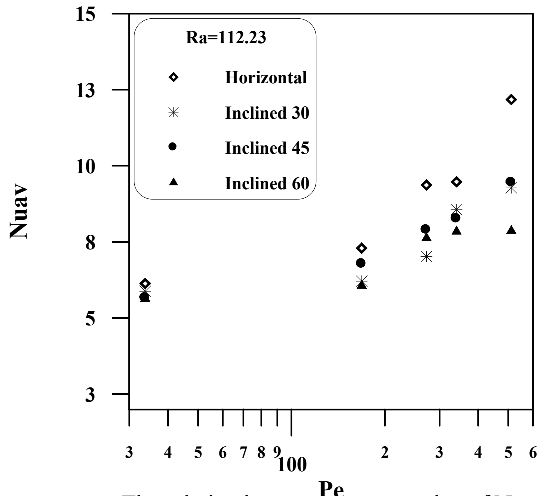

Figure 28. The relation between average value of Nusselt number with Peclet number for Rayleigh number (Ra=112.23) for all tube position

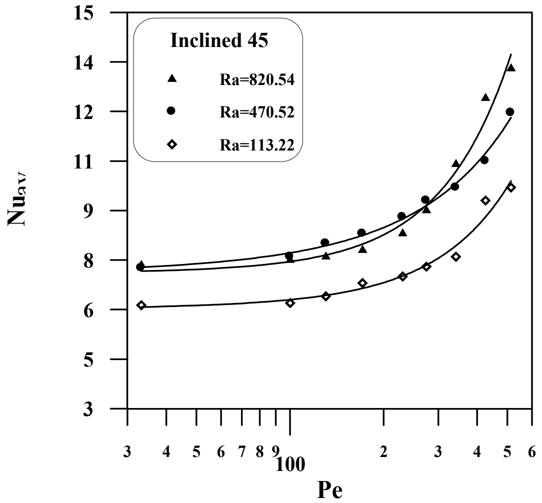

Figure 26. The relation between average value of Nusselt number and Peclet number for inclination angle (45°), and for different values of Rayleigh number

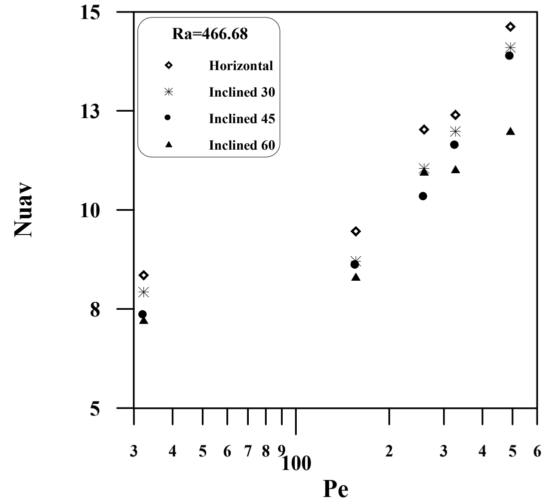

Figure 29. The relation between average value of Nusselt number with Peclet number for Rayleigh number (Ra=466.68) for all tube position

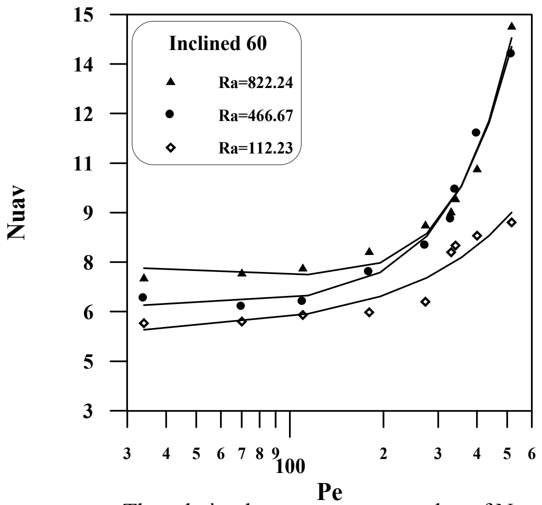

Figure 27. The relation between average value of Nusselt number and Peclet number for inclination angle (60°), and for different values of Rayleigh number

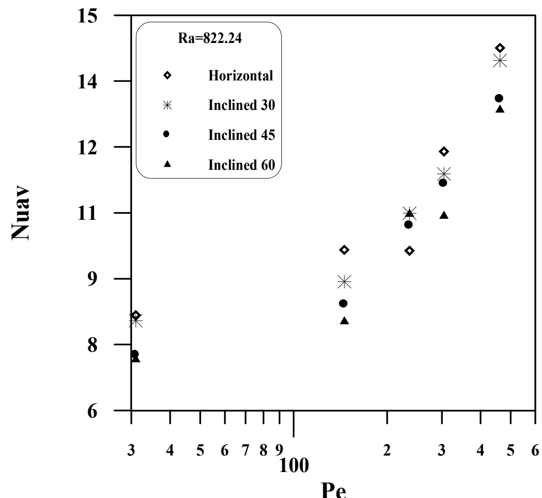

Figure 30. The relation between average value of Nusselt number with Peclet number for Rayleigh number (Ra=822.24) for all tube position