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A STUDY OF NATURAL HEAT TRANSFER FROM HORIZONTAL AND INCLINED CYLINDERS

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Abstract :

Heat transfer by free convection occurs at any temperature differences. This mode of heat transfer was covered with thousands of researches to find the relations that related between the heat transfer coefficient and the parameters affected the heat transfer by natural convection. This paper including the simple study of heat transfer by free convection from cylinders heated at constant heat flux exposited to the ambient air at low Grashof number (>3x10^5). Heated cylinders with a constant heat flux were fixed horizontally and with inclination angles with the horizontal until 45^o. Results showed the relation between Nussult number and (Gr.Pr). Empirical relations between these numbers were obtained to calculate the heat transfer coefficient depending on the range of (Gr.Pr). It was also shown that the heat transfer coefficient was decreased with angle of inclination.

الخلاصة :

يحدث انتقال الحرارة بالحمل الحر عند أي فرق في درجات الحرارة. غطي هذا النوع من انتقال الحرارة بآلاف البحوث لإيجاد العلاقات التي تربط معامل انتقال الحرارة بالعوامل الأخرى التي تؤثر على انتقال الحرارة بواسطة الحمل الحراري الحر. يحتوي هذا البحث دراسة مبسطة لانتقال الحرارة بالحمل الطبيعي من اسطوانات مسخنة بثبوت الفيض الحراري معرضة إلى الهواء وعند عدد كرا شوف واطئ ($Gr > 3\times10^5$) . الاسطوانات سخنت بثبوت الفيض الحراري أفقيا ومائلة بزوايا مع الأفق إلى حد 45˚ . وضحت النتائج العلاقة بين عدد نسلت و حاصل ضرب عدد كرا شوف وبرا ندل (عدد رالي) . وقد تم إيجاد علاقات تجريبية لحساب انتقال الحرارة بالاعتماد على (Gr.Pr). وقد لوحظ بأن معدل انتقال الحرارة يقل مع زيادة زاوية الميل عن الأفق.

LIST OF SYMPOLS:

A	Area (m^2)
C	Constant
Cp	Specific heat (J/kg.K)
D	Diameter of cylinder (m)
Gr	Grashof Number
G	Acceleration due to gravity (m/s^2)
Gr*	Modified Grashof number
H	Heat transfer coefficient (W/m^2.K)
I	Current (A)
K	Thermal conductivity (W/m.K)
Nu	Nussult Number
Pr	Prandtl Number
Q	Heat transfer (W)
Q_h	Heat transfer by convection (W)
Q_r	Heat transfer by radiation (W)
q_w	Heat flux (W/m^2)
T_f	Film Temperature (K)
T_s	Surface temperature (K)
$T\infty$	Fluid temperature (K)
V	Voltage (Volt)
x	Length (m)
β	Thermal expansivity ($^{-1}$K)
ε	Emissivity
σ	Stefan –Boltzmann constant
μ	Absolute viscosity (kg/m.sec)
ν	Kinematics viscosity (m^2/sec)
θ	Angle of inclination
ρ	Density (kg/m^3)
ΔT	Temperature difference (K)

Subscripts and Superscripts

Superscripts

n	Constant
m	Constant

Subscripts

f	At film temperature
x	At local x

INTRODUCTION :

It is very important to study the behavior of the heat transfer due to the temperature difference between the hot surfaces and the fluid in contact with it under the buoyancy force only with out the effect of any external force on the fluid flow. There are many researches that study the heat transfer by free convection. These studies took different cases.

In general the heat transfer by free convection from isothermal surfaces is calculated from the following equation (Holman 1976)

$$Nu = C(Gr.\Pr)^m \tag{1}$$

Where C and m are constants

The values of C and m for heat transfer from a horizontal cylinder with isothermal surface are taken from a figures (MacAdams 1954) for the range (10^{-5}<(Gr.Pr)<10^{4}). These values are 0.53 and ¼ respectively for the range (10^{4}<(Gr.Pr)<10^{9}).

There are some indications from the analytical work of (Bayley 1955),as well as heat flux measurements of (Warner 1968) that the constants become 0.1 and ⅓ respectively.

A more complicated expression of free convection from horizontal surface for use over a wide rang of (GrPr) is given by (Churchill and Chu 1975)

$$Nu^{1/2} = 0.6 + 0.387\left(\frac{Gr\Pr}{\left[1+\left(0.559/\Pr\right)^{9/16}\right]^{15/9}}\right)^{1/6} \tag{2}$$

for 10^{-5}<(GrPr)<10^{12} .

Experiments have been conducted (Fujii and Imura 1972) for heat transfer in water at various angles of inclination, θ as the angle the plate makes with the vertical, positive angles indicating that the heater surface faces upward. There are many empirical relations for heat transfer from inclined plate written in (Holman 1976)

Experiments have been reported by (Vliet 1969),(Vliet, and Lin 1969), and (Vliet 1969) for free convection from vertical and inclined surfaces to water under constant-heat-flux condition. In such experiments, the results are repeated in terms of a modified Grashof number, Gr^* ,$(Gr^* = (GrNu)_x = \frac{g\beta q_w x^4}{k\nu^2})$ where q_w is the wall heat flux. The local heat-transfer coefficients were correlated by the following relation for the laminar range.

$$Nu_x = 0.6\left(Gr_x^* \Pr\right)_f^{1/5} \tag{3}$$

for the range of $(10^5 < Gr^* < 10^{11})$ and q_w=const. And the properties used are at film temperature.

This paper is to study the heat transfer by free convection from horizontal and inclined cylinders with angles θ, the angles between the cylinder and the horizontal.

For inclined cylinders the data indicated that laminar heat transfer under constant heat flux conditions may be calculated with the following relation(Al-Arabi 1980).

$$Nu_L = \left[0.60 - 0.488(\sin\theta)^{1.03}\right]\left(Gr_L \Pr\right)^{\frac{1}{4}+\frac{1}{12}(\sin\theta)^{1.75}} \tag{4}$$

EXPERIMENTAL RIG AND MEASUREMENT

The experimental rig consist of the following parts as shown in Fig. 1:-

1- The steel structure that used to carry the cylinder and has a movable arm to change the angle of the inclination angle of the cylinder. The moving angle from 0^o to 45^o. It is also able to carry a cylinders with different diameters.

2- The cylinders of copper with different diameters and a length of 30cm are prepared to be the testing cylinders. A electrical coil covered with ceramic rings is used to pass through the cylinder and filled with a sand to give distributed heat flux. The ends of the cylinders were covered with Teflon and a wood covers to prevent the heat transfer in the direction parallel to the cylinder length.

3- A current meter and voltage veriac were connected to the coil to control the electrical power that supplied to the coil.
4- Thermocouple nodes of copper constantan at different places on the cylinder surface were fixed to measure the temperature difference between the surface and the ambient.
The testing method was done in the following procedure:-
1- After fixing the cylinder on the steel structure, the checking of the electrical circuit that is working safely, and the thermocouple nodes read zero.
2- The circuit is turn-on at a certain voltage and current.
3- When the cylinder reach a steady state, the thermocouple reads where recorded.
4- This experiment where repeated with different voltage values by changing the veriac reading.
5- After completing a set of experiments the angle of the inclination of the cylinder was changing, and the testing was repeated.
The heat flow through the tube can be measured as following:

$$Q = IV \tag{5}$$

where I= the current flow through the cylinder,
V= the voltage around the cylinder,
Q= heat transfer (W)
This value of heat transfer occurs in two modes of heat transfer radiation and convection.

$$Q = Q_r + Q_h \tag{6}$$

where Q_r = heat transfer by radiation (W), and
Q_h = heat transfer by convection (W)
The heat transfer by radiation can be calculated by the radiation heat transfer equation as follows

$$Q_r = A\varepsilon\sigma\left(T_s^4 - T_\infty^4\right) \tag{7}$$

Where A=cylinder surface area
ε = the emissivity $\cong 0.9$ factor depends on the surface type and structure
σ = the Stefan-Boltizmann constant= $8\times10^{-8} W/(m^2.K^4)$
T_s= surface temperature (K)
T_∞= ambient temperature (K)
The heat transfer by convection were calculated from the eq.(7). The heat transfer coefficient by free convection can be calculated from the following equation

$$Q_h = hA(T_s - T_\infty) \tag{8}$$

where h= heat transfer coefficient (W/m^2K)

FREE CONVECTION RELATION

The heat transfer coefficient in general is function many parameters that included in heat convection which make the buoyancy force that exert due to the change in the density of the fluid because of the difference in the temperature. These lead to make the following relation:

$$h = f(D, \rho, \mu, Cp, K, \beta, \Delta T, g, ..., \theta) \tag{9}$$

where D= cylinder diameter
ρ= density
μ= viscosity
Cp=specific heat of the fluid
K=thermal conductivity of the fluid
β= thermal expansivity
ΔT= temperature difference =(T_s-T_∞)
g= acceleration due to gravity
θ= inclination angle
the thermal expansivity (β) was calculated from the following equation

$$\beta = \frac{1}{T_f} \tag{10}$$

and the film temperature (T_f) is known as the mean temperature between the surface temperature and the fluid temperature:

$$T_f = \frac{T_s + T_\infty}{2} \tag{11}$$

All properties were measured at the film temperature.

The dimensionless analysis were used to find a relation that connects among these variables for horizontal cylinders as the following:-

$$Nu = f(Gr.\Pr) \tag{12}$$

where Nu= Nussult number

Gr= Grashof number, and

Pr= Prandtl number

And this function can be represented as

$$Nu = C(Gr.\Pr)^m \tag{13}$$

and for inclined tube or cylinder this relation can be represented as written as follows:

$$Nu = C(Gr.\Pr)^m.\cos^n\theta \tag{14}$$

where θ is the angle between the cylinder and the horizontal axis.

RESULTS AND DISCUSSION

The results that obtained from the experimental study can be explained in to indicate the effects of each dimensionless number on the (Nu) as in the following points

(a) Horizontal Cylinders

1. The effect of Grashof Number.

It is shown from the Fig.2, the relation between the Grashof Number and Nussult number. The (Gr) changed from 1×10^4 to 3×10^5 while (Nu) changed from 9 to 21. The empirical relation between these two parameters can be written as:

$$Nu = 50.28(Gr)^{-0.1112} \tag{15}$$

for $(1\times10^4 < Gr < 3\times10^5)$

Fig. 3, shows the logarithm relation between (Gr) and (Nu) because it gives good fitting between Nu and Gr as shown.

2. The effect of Raleigh Number.

Raleigh number is defined as the product of (Gr.Pr). Its effect on the value of (Nu) is shown in Fig. 4. The empirical relation between (Gr.Pr) and (Nu) is obtained as follows:

$$Nu = 48.337(Gr.\Pr)^{-0.1111} \tag{16}$$

for $(8\times10^3 < (Gr.\Pr) < 2\times10^5)$

Also the Logarithm relation between (Gr.Pr) and (Nu) is shown in Fig. 5.

(b) Inclined Cylinder

1. The Effect of Raleigh Number.

The effect of the Raleigh Number on the (Nu) for inclined cylinders is shown in the Fig. 6. and Fig. 7, for the same range of (Gr.Pr) written before. The relation that obtained is as follows:

$$Nu = 40.825(Gr.\Pr)^{-0.0967} \tag{17}$$

2. The Effect of The inclination angle

The effect of the inclination angle (θ) on the value of the (Nu) is shown in Fig. 8, and Fig. 9. The relation that obtained empirically is as follows:

$$Nu = 8.07(Gr.\Pr)^{-0.0484}(\cos\theta)^{0.0613} \tag{18}$$

this relation give the empirical relation between (Nu) and (Gr.Pr) and (cosθ), for the following limits

$(9\times10^{3}<(Gr.\mathrm{Pr})<2\times10^{5})$ *and* $(0<\theta<45)$

By making a comparison between equation (18) and equation (4) by solving them together for some data in same condition, they show that there is a small deviation between them as shown in Table-1-

Table-1- Comparison Between The new empirical equation with that of Al-Arabi et.al 1980

Observation number	Diameter D(m)	Length L(m)	Angle θ (°)	Equation (18)	Equation (4)	Absolute Error%
				Heat transfer coefficient (h) $W/m^{2o}C$		
1	0.025	0.3	30	5.4	4.8	11.1
2	0.03	0.3	30	4.64	4.8	3.45
3	0.035	0.4	30	4.64	4.6	0.719

CONCLUSION :

It is concluded that heat transfer coefficient by free convection at constant heat flux increases as shown from Fig.(2) to Fig.(7) with increase of (Gr.Pr) that is due to the increase in temperature difference. It is also found that the heat transfer coefficient for constant heat flux increases with the decreases of the inclination angle, as shown in Fig. 8,and Fig. 9. An empirical relation for heat transfer from horizontal and inclined cylinders at constant heat flux is also derived to calculate the heat transfer coefficient for a range of ($9x10^3$ <(Gr.Pr)< $2x10^5$). From the comparison between the new investigated equation and the equation investigated by Al-Arabi 1980, the error becomes not reasonable. But the new empirical equation is very simple in its form and depending on the diameter of the cylinder instead of the length.

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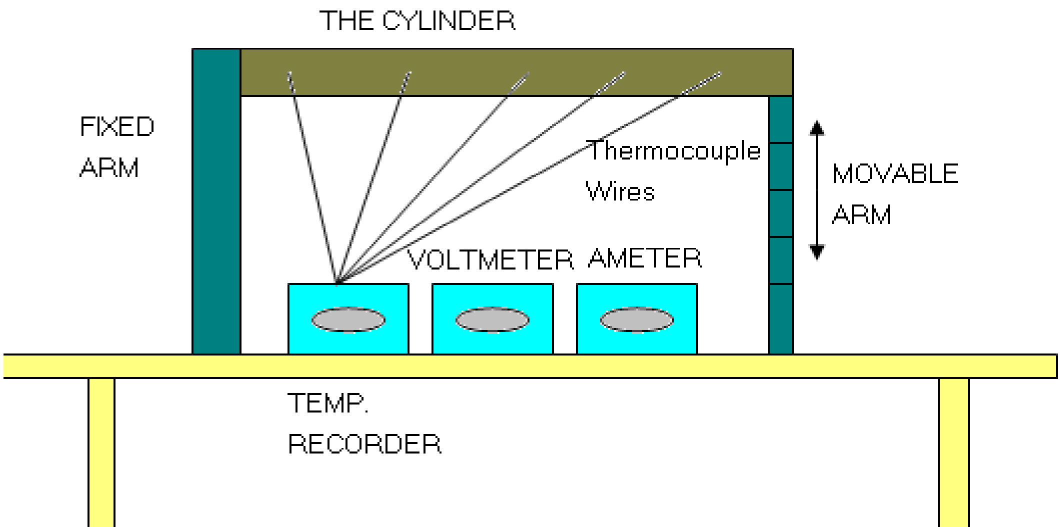

Fig. 1. The Scematic Diagram of Experimental Rig

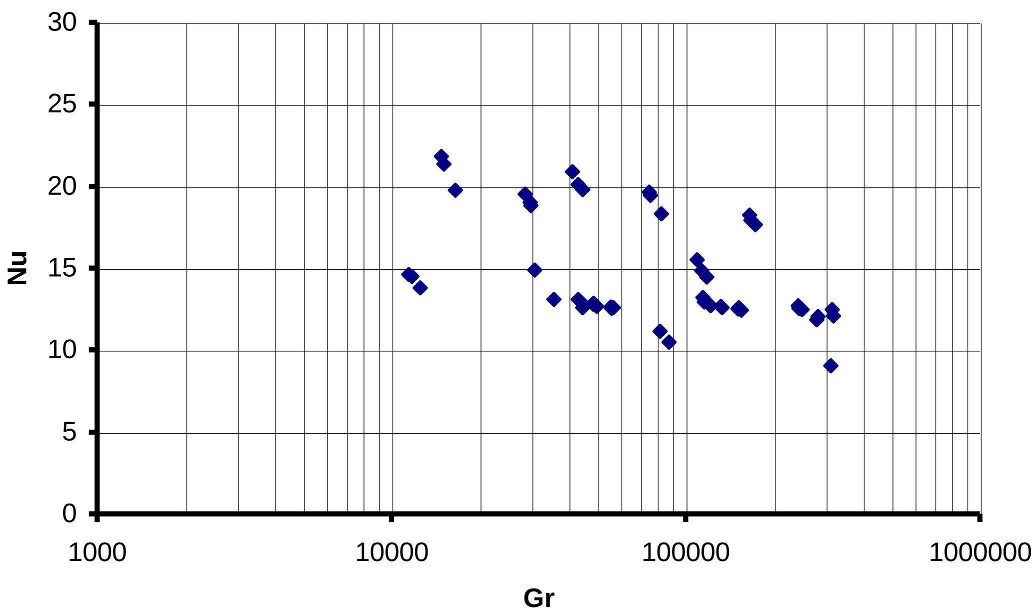

Fig. 2 The Relation Between (Gr) Number And (Nu) For Horizontal Cylinders

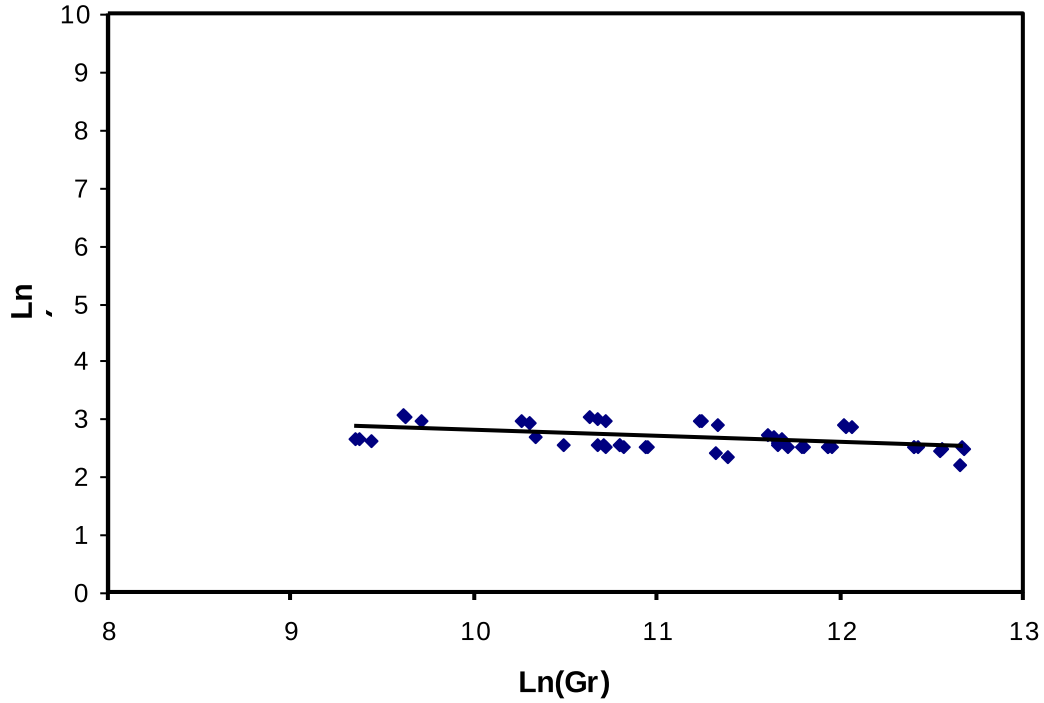

Fig. 3 The Logarithm Relation Between (Gr) Number And (Nu) Number For Horizontal Cylinder

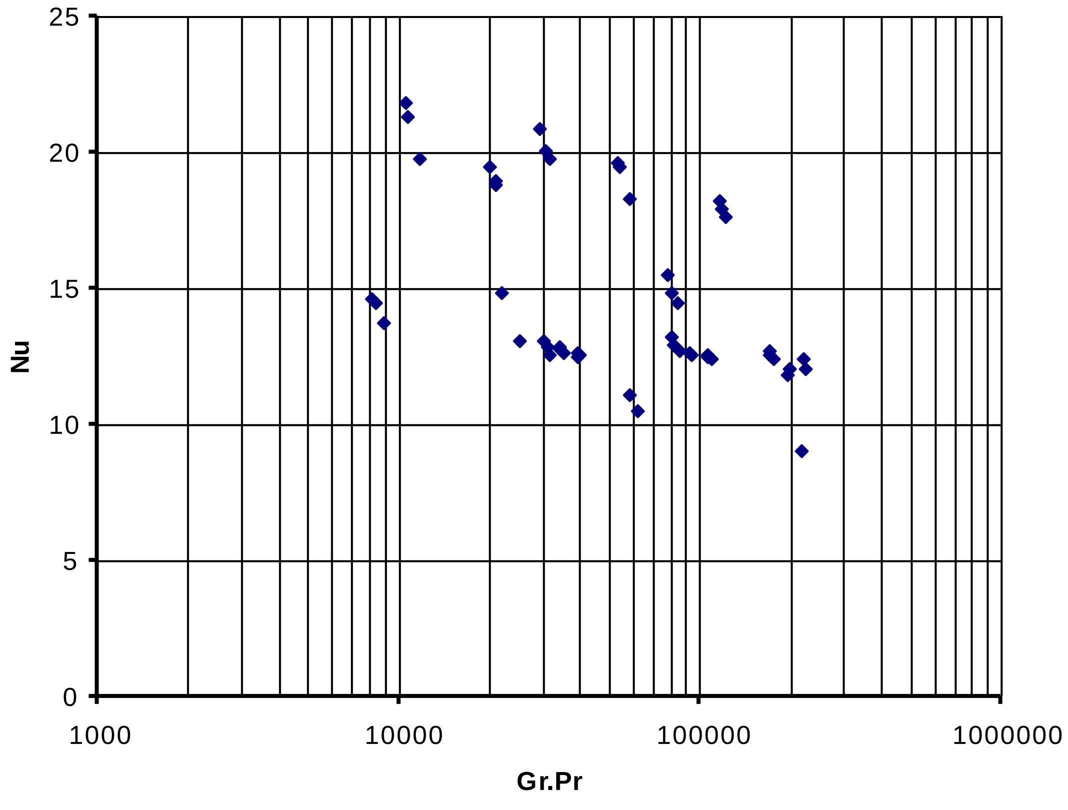

Fig. 4 The Relation Between (Gr.Pr) Number And (Nu) Number For Horizontal Cylinders

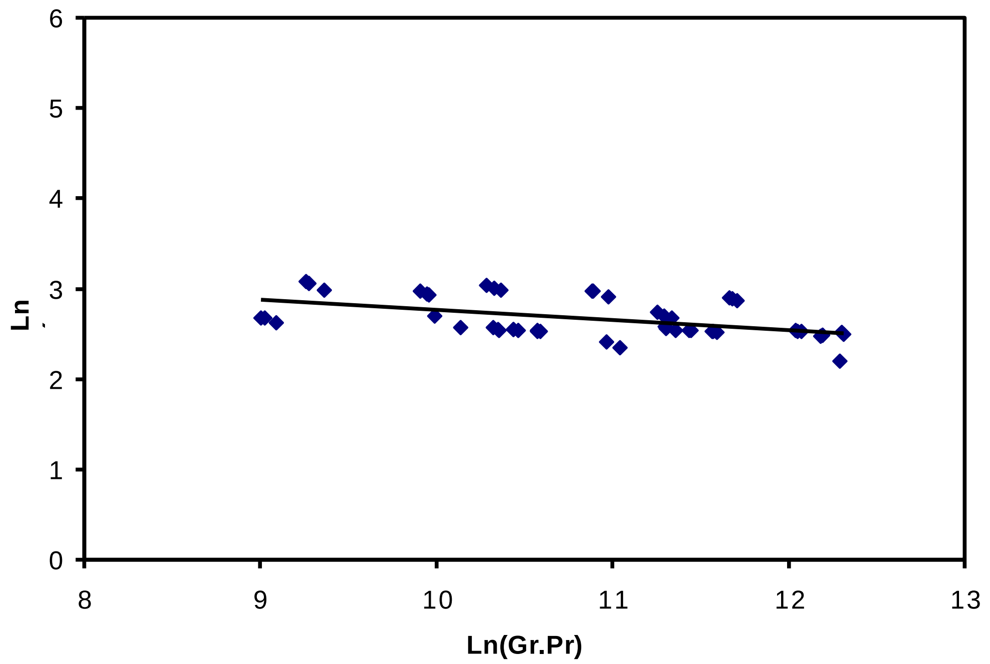

Fig. 5 The Logarithm Relation Between (Gr.Pr) Number And (Nu) Number For Horizontal Cylinders

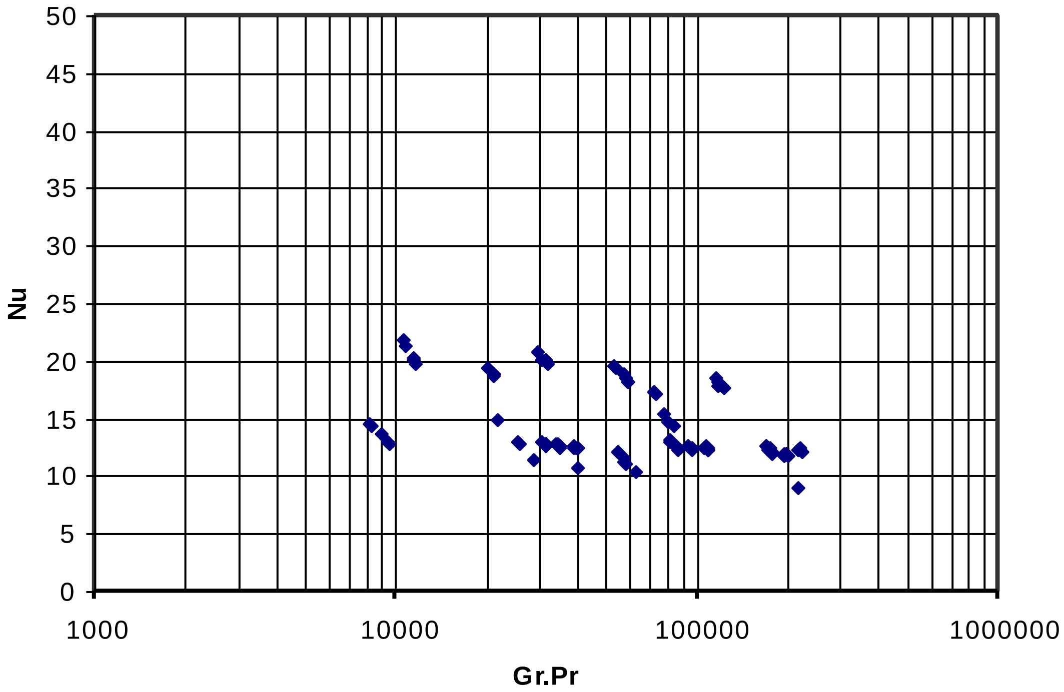

Fig. 6 The Relation Between (Gr.Pr) Number And (Nu) Number For Inclined Cylinders

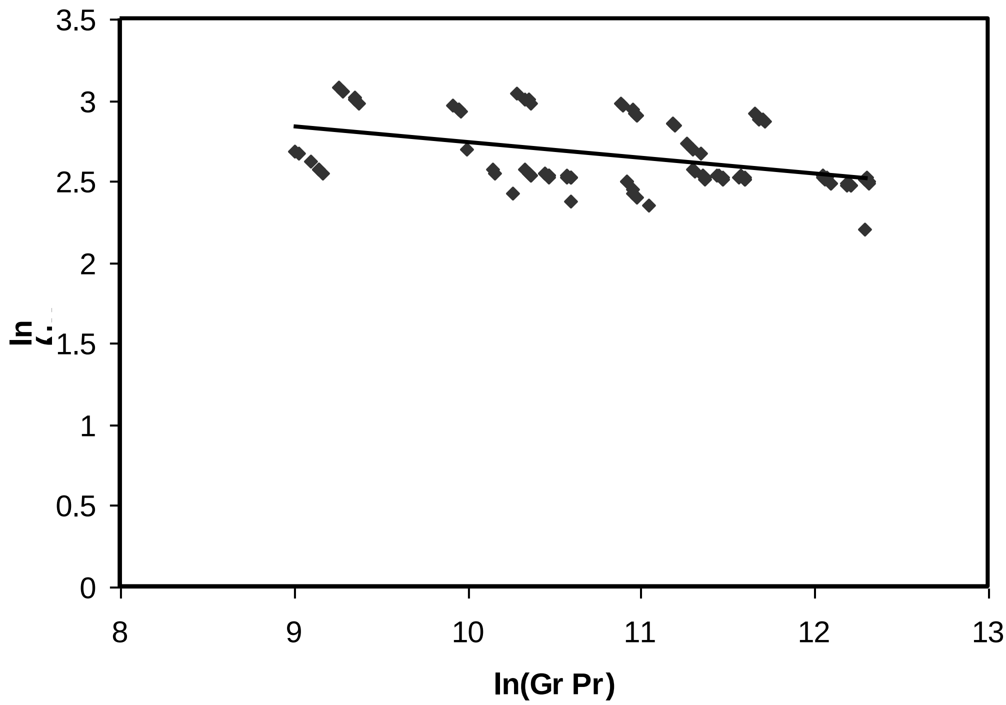

Fig. 7 The Logarithm Relation Between (GrPr) Number And The (Nu) Number For Inclined Cylinders

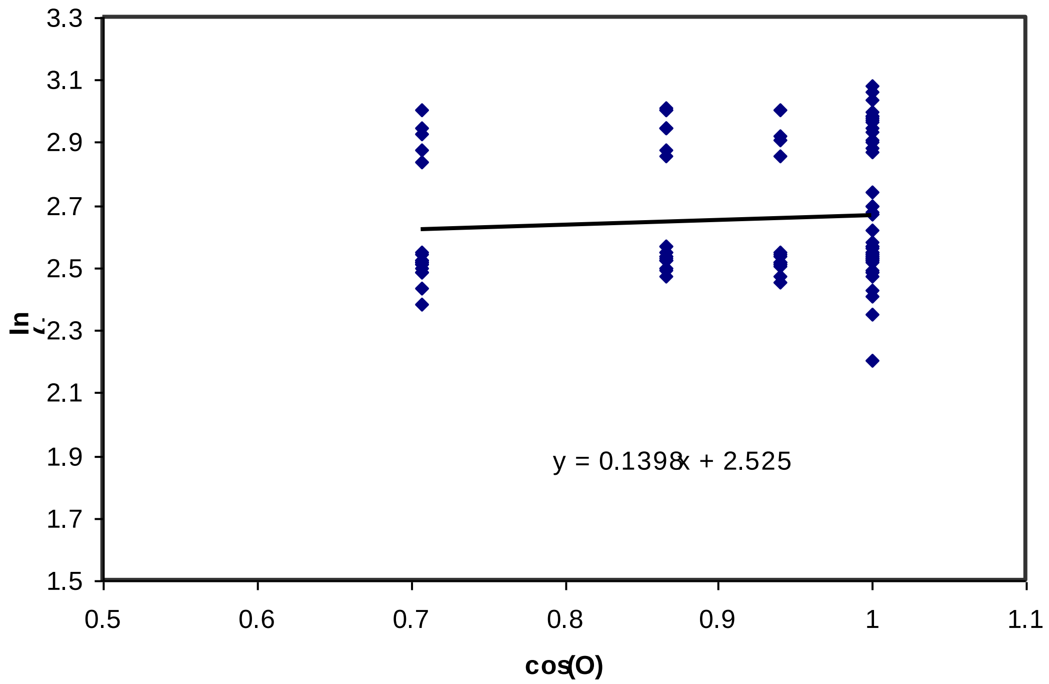

Fig. 8 The Relation Between The Inclination Angle (θ) and (Nu) For inclined Cylinders

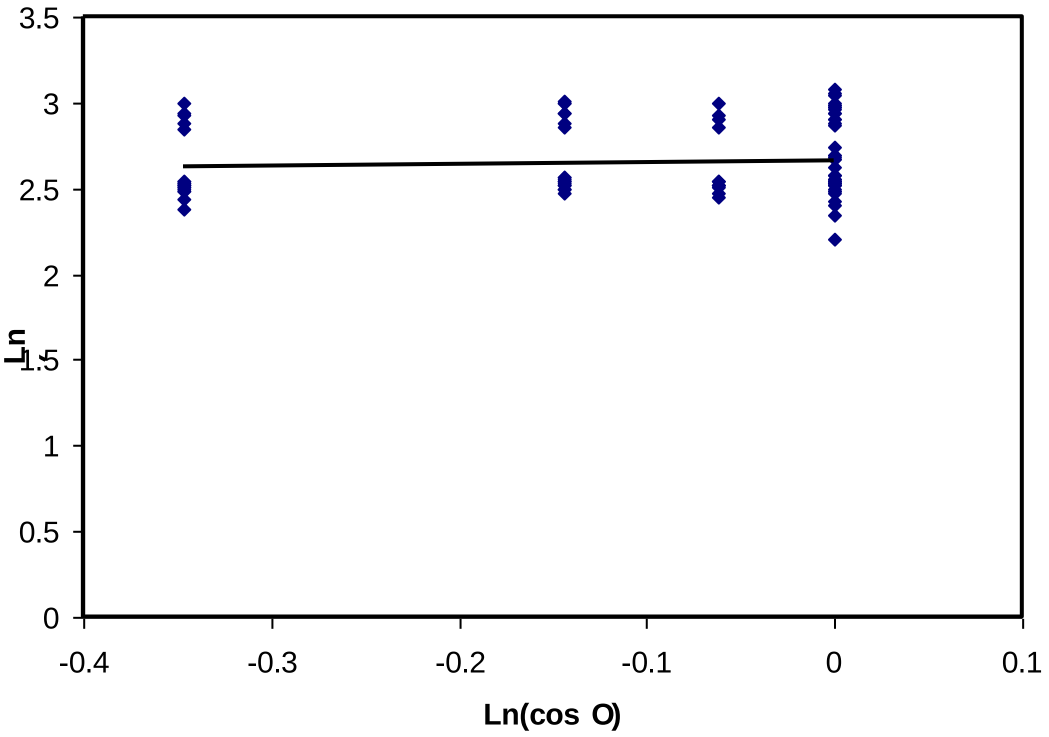

Fig. 9 The Relation Between The Logarithm Of cosθ and (Nu) Number for Inclined cylinders