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Improvement Of Free Convection From Three horizontal Finned Cylinders Fixed Between Two Walls

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ABSTRACT: Improvement of free convection heat transfer from three finned cylinders arranged at a triangle shape fixed between two walls has been investigated in this study. Three mild steel finned cylinders fixed between two walls from Pyrex glass have been used as a test rig. It has been changed the spacing between the cylinders (X/D=1,2,3 & S/D=2,4,6) and the head orientation of a triangle to the top under constant heat flux values (38, 254, 660, 1268) W/m^2 and compare with case of three finned cylinders arranged in vertical array in line fixed between two wall. The experiments are carried for Rayleigh number (Ra) from (15x10^3 to 14 x10^4) and Prandtl number from (0.706-0.714). The results indicated an increase in Nu with increasing Ra for all cylinders. Furthermore,h_x and Nu increased proportionally with the increasing of cylinder spacings for all heat fluxes. Also the experimental results show the case of triangle arrangement is improvement the heat transfer more than case of vertical arrangement. Heat transfer dimensionless correlating equation is also proposed.

Nomeclature: A_x: surface area(m^2), T_∞: surrounding temperature(k), D: the outer diameter of fin (m), K_f: the thermal conductivity for air at film temperature(W/m.k), hx: Local convection heat transfer(W/m^2.k), g: Gravitational acceleration(m/s^2), I: Electric current (Amp), Nu: Nusselt number, Pr: Prandtl number $\boldsymbol{\nu}/\alpha$, Qg: Power supply (W), Ra: Rayleigh number $\frac{\beta.g.(T_s-T_\infty).D^3}{\vartheta_{air}^2}.Pr$, T_s: Surface temperature (K), T_1:temperature of heat exchange surface, T_2 : temperature of surface which heat transmitted to him, V: Electric voltage (v), β: Thermal expansion coefficient (1/K), ϑ: Kinematics viscosity of air (m^2/s), **δ**: is Stefan Boltzmann constant, X: the distance from the head of a triangle to the its base, S: the distance between the cylinders that form the base.

Keywords: *Natural convection heat transfer, horizontal cylinders, separation distance, two walls, correlating equation.*

تحسين انتقال الحرارة الحر من ثلاث اسطوانات أفقية مزعنفة مثبتة بين جدارين

حسن كريم عبد الله، حنين حسن رحمن

الملخص :- تحسين انتقال الحرارة الحر من ثلاثة اسطوانات مزعنفة مرتبة أفقيا على شكل مثلث ومثبتة بين جدارين، قد تم دراسته عملياً. ثلاثة اسطوانات مزعنفة متكونة من الفولاذ الطري [القطر الخارجي (١٢ ملم)، القطر الداخلي (١٠ملم) ، قطر الزعنفة الخارجي (٣٠ملم)] مثبتة بين جدارين من مادة البايركس استخدمت كجهاز اختبار. تم تغيير المسافات بين الاسطوانات ثلاث مرات (X/D=1,2,3 & S/D=2,4,6)، أتجاه رأس المثلث للأعلى .تم في الدراسة اختبار أربعة مستويات من الفيض الحراري (٣٨ ، ٢٥٤ ، ٦٦٠ ، ١٢٦٨) واط/ م^2 وكذلك تم المقارنة مع حالة ثلاثة اسطوانات مزعنفة مرتبة على شكل عمودي ومثبتة بين جدارين. أجريت الدراسة ضمن مدى عدد رايلي (15x10^3 -14 x10^4) وعدد برانتل (٠,٧٠٦ -٠,٧١٤). أظهرت النتائج زيادة عدد نسلت مع زيادة عدد رايلي لجميع الاسطوانات وكذلك زيادة معامل انتقال الحرارة وعدد نسلت مع زيادة المسافات بين الاسطوانات لجميع مستويات الفيض الحراري. كذلك أظهرت النتائج ان حالة ترتيب الاسطوانات على شكل مثلث تحسن انتقال الحرارة بمقدار (١,٣٤) أكثر من ترتيب الاسطوانات بشكل عمودي.

1. Introduction

Natural convection is still a problem in engineering applications. Heat transfer from various geometries has been studied and, because of the low heat transfer coefficients, the technicalities have been advanced to enhance the heat transfer rate. One of problems of this division that has received concern in recent years, it is natural convection heat transfer from a single cylinder or arrays of cylinders. Effects of confining walls on heat transfer rate from a single cylinder or arrays of cylinders have been achieved extensively in recent years [1].

Natural convection heat transfer from a array of cylinders and fins have a great important in engineering application, such as distribution transfer cooling systems, radiators, condensers of refrigerators, oil cooling systems and cooling of electronic devices. Any small increase in the rate of heat transfer decreases the power consumption and this increases the equipment's life [2].

The addition of fins to the cylinder playing important rule on heat transfer process, when there are fins can be use a cylinders with small diameter instead of large diameter thus reducing the size of heat exchanger and enhancement the heat transfer rate[3].

The authors in Ref. [4], performed a numerical study of natural convection heat transfer around a horizontal cylinder set inside triangular enclosure. It was achieved the effects of the aspect ratio(D/H), Rayleigh number, geometry of the inner cylinder, and inclination angle on the heat transfer and flow were studied. The results showed the construction of thermal plumes impinging for the enclosure top corner and the thermal layers in the middle and bottom zones were clearly observed at higher Rayleigh numbers. The flow became multi-cellular at the highest aspect ratio and when the aspect ratio increased, the influence became more significant. While, the cross section geometry was find to had little effects of the overall heat transfer.

The natural convection around a horizontal square heated cylinder set inside an enclosure was numerically investigated in [5]. It had been studied at the range of Rayleigh number [10^3-10^6]. The aspect ratio and the heated cylinder location had been reported. The results showed was the heated cylinder location does not have important role which was certain by local and average Nusselt numbers. Variation in overall heat transfer for several aspect ratios was find of the lower Rayleigh numbers, however it decreased as Rayleigh number was increased. Constant wall temperature heating was more efficient at comparison with the constant wall heat flux process in view of the overall heat transfer.

In the research presented in Ref.)[6], the analysis of a natural convection heat transfer from a vertical cylinder is conducted. A numerical experiments had been performed to measure the average Nusselt numbers for the isothermal vertical cylinders located on an adiabatic surface in a stationary ambient environment at (Pr= 0.7), (10^2< RaL< 10^9), and the height of cylinder to cylinder diameter L/D (0.1 < L/D < 10). The case when the cylinder had an adiabatic top was compared with several other solutions. The case when the cylinder had a heated top, it had experienced less attention. Results showed that the Nu_{Ave} to the heated top were lower than that to the adiabatic top, the correlations equations are presented.

A natural convection heat transfer of vertical array of five horizontal elliptic cylinders confined between two adiabatic walls was investigated experimentally in [7]. The Rayleigh number was in the range $10^3 \leqslant Ra \leqslant 2.5\times10^3$, and wall spacing $1.5 \leqslant t/b \leqslant 9$ and infinity. It was performed the effect of Rayleigh number and wall spacing on the heat transfer of individual cylinder and the array. Experiments were carried out for ratio wall spacing to the major diameter t/b = 1.5, 2, 2.5, 3, 3.5, 4, 5, 6, 7, 8, 9 and infinity. Results showed that, approximately 10% increase in the transfer of heat from the confined array of cylinders had been observed when it compared with the unconfined case at optimum wall spacing.

The author in Ref. [8], has achieved a free convection heat transfer of annular fins on a horizontal cylinder. the purpose of the study was to investigated the effects fin diameter(D) and fin spacing(S). The working fluid was air. The results showed that the convection heat transfer rate from the fin arrays based on fin diameter and fin spacing. For all arrangement the rate of convection heat transfer increased with the fin diameter increased. The rate of convection heat transfer decreased with fin spacing was increased. The correlation was obtained for the optimum fin spacing(S_{opt}) depending on fin diameter and Rayleigh number.

A study performed an experimental study of natural convection heat transfer of a vertical array of three evenly horizontal cylinders, with dissimilar cylinder separation distance as in [9]. Nusselt numbers were carried out at Rayleigh numbers $1.96\times10^7$and $5.35\times10^7$and at separation distances (2D, 3D, 4D, 5D). The results showed that in the three-cylinder array, the Nusselt number of the second cylinder increased compared to the lower cylinder for two Rayleigh numbers carried out and for all separation distances. The Nusselt number of the upper cylinder in array increased compared with the lower/unconfined cylinder, but was comparable with the middle cylinder at the separation distances carried out.

The researchers in Ref.[10], experimentally investigated a laminar natural convection heat transfer of a pair of vertical arrays of horizontal cylinders placed in free air. Experiments were achieved for pairs of tube-arrays including five circular cylinders. For center-to-center horizontal spacing ranging from (2D to 145D) and vertical spacing ranging from (4D to 12D), and the Rayleigh number values based on the cylinder diameter at the range between 2.4 and 11.9. The results showed that any cylinder may display an enhanced or reduced Nusselt numbers depending on the geometry of the array, its position in the array and on the Rayleigh number. Also, the Nusselt number was increased when the Rayleigh number increased.

2. EXPERIMENTAL APPARATUS

The test rig and test procedure which are achieved to discuss the behavior of heat transfer from fined cylinders made of mild steel arranged in triangle shape fixed between two walls under constant heat flux values (38, 254, 660, 1268) W/m^2, which it is the orientation of triangle to the top and the distance between the cylinders change, which it: (X/D=1,2,3)& (S/D=2,4,6) and

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compare with case of three finned cylinders arranged in vertical array in line fixed between two walls which change the distance between the cylinders (X/D=1,2,3). The arrangement of the finned cylinders are shown in figures 1 (a & b).

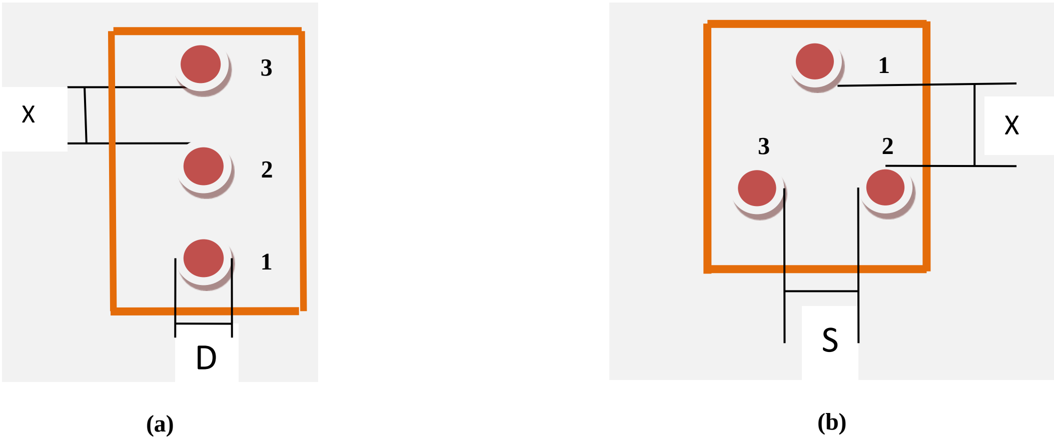


Fig. 1: (a): Three horizontal finned cylinders fixed in vertical array in line between two walls & (b): Three horizontal finned cylinders arranged in the form of a triangle fixed between two walls.

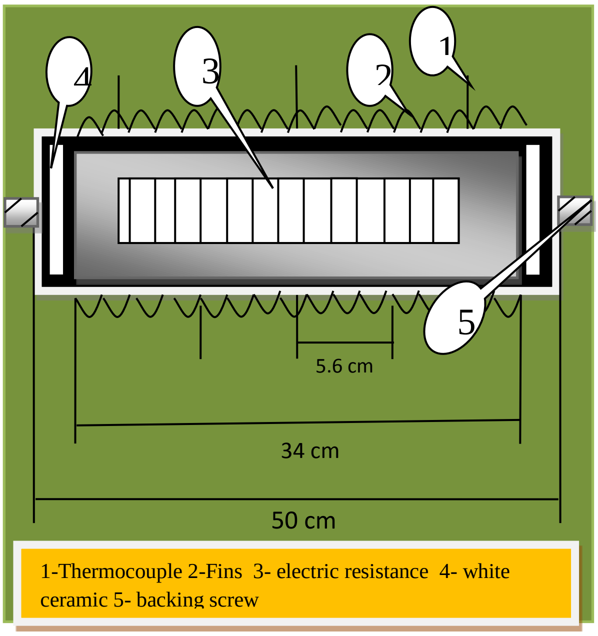


Fig. 2: shows the section of finned cylinder

2.1 The Walls

manufacturing two rectangular walls made from Pyrex glass, the dimensions (700×350×8)mm length , width and thick respectively, which installed on four iron bases from ends to make way for the air to enter as well as open both sides . rectangular plates contain convergent holes on both sides, so that it can install the cylinders horizontally, the holes filled with silicon to prevent air leakage. The amount of distance between a hole and other is (30mm). Figure (3) show the test rig for the triangle shape arrangement.

Fig. 3: Test rig for the triangle shape arrangement

2.2 The Heat Exchanger

The heat exchanger consists of three horizontal finned cylinders, the cylinders made from mild steel, total length of cylinder is (500mm) , the length of finned section of the cylinder is (340mm). Fins used spirle type and made from Iron , the inner diameter of cylinder is (10mm), the outer diameter of cylinder is (12mm) , the inner diameter for fins is (12mm) , the outer diameter for them is (30mm) and by (66) fin along (340mm) of the cylinder. The fins used is annular with meanders , fins installed on the cylinder by twist ribbon, its:(length (1760 mm), width (9mm) and thick (0.5 mm) and thus get finned tube for heating the surface of heat exchanger. Proven electrical resistance file type (Ni-Cr) and used (MnO_2) a high thermal conductivity material as electric insulator separates the electric file and the tube. It was connect the ends of electrical resistance by wires for each side and for reduce conduction losses and installed the wires by tube, used white ceramic material, its thick (10mm) and a diameter equal to the cylinder diameter.

2.3 Measurement Devices

The measurement devices are used in this study as Stabilizer to supply (AC) power stable to the heater and measuring devices to getting constant heat flux. Variac control of the electric power supply to the heater, it is supply a constant heat flux to the heater. Digital multimeter measure the voltage supply to the finned cylinders. Digital clamp meter is used to measurement the current passing through the heater. The Digital thermocouple reader is used to read the values of temperatures from thermocouples and Thermal Imager.

3. MATHEMATICAL FORMULATIONS

The total heat that is generated by the heater can be calculated as:

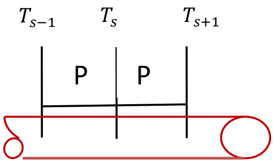
$$Q_{gen} = V * I \tag{3.1}$$

$$Q_{gen} = Q_{conv} + Q_{rad} + Q_{cond} \tag{3.2}$$

Heat loss by radiation is:-

$$Q_{rad} = \epsilon * \delta * F * A\,(T_1^4 - T_2^4) \tag{3.3}$$

Heat loss by conduction is:-



$$Q_{cond} = K.\frac{\pi}{4}(d_o^2 - d_i^2)\left(\frac{T_s - T_{s+1}}{P}\right) + K.\frac{\pi}{4}(d_o^2 - d_i^2)\left(\frac{T_s - T_{s-1}}{P}\right) \tag{3.4}$$

Heat transfer by convection is:-

$$Q_{conv} = Q_g - Q_{rad} - Q_{cond} \tag{3.5}$$

Then to calculate the local heat transfer coefficient:-

$$h_x = \frac{Q_{conv}}{A_x(T_s - T_\infty)} \tag{3.6}$$

The mean heat transfer coefficient calculated from the integrating the local heat transfer coefficient as following:

$$h_{mean} = \frac{1}{L}\int_0^L h_x \,.ds \tag{3.7}$$

The Rayleigh number is defined as the ratio between the buoyancy force and the viscous force:

$$Ra = \frac{\beta.g.(T_s - T_\infty).D^3}{\vartheta_{air}^2}.Pr \tag{3.8}$$

To calculate the local Nusselt number:-

$$Nux = \frac{h_x.D}{K_{air}} \tag{3.9}$$

The mean Nesselt Number can be calculated by :

$$Nu_{mean} = \frac{1}{L}\int_0^L Nu_x \,.ds \tag{3.10}$$

4. RESULTS AND DISCUSIONS

The purpose of the present work is to study the heat transfer from three cylinders arranged in triangle fixed between two walls and compare with case of three finned cylinders in vertical array in line fixed between two walls. The cylinders is heated under constant heat flux (38, 254, 660, 1268) W/m^2 , the head orientation of triangle to the top, it has been change the ratios (X/D) & (S/D) three time and Prandtl number from (0.706-0.714) and Rayleigh number from ($15\times 10^3 - 14 \times 10^4$).

Figure 4 (a,b,c,d) show the surface temperature distribution along three cylinders for triangle arrangement, the temperatures of the lower cylinders are less than the temperatures of above cylinder in all separation distance because the lower cylinders were exposed to the drawn air from the room which equal to the ambient air while the higher cylinder was exposed to the hot air that floats from the lower cylinders consecutively, and as a result, these cylinder will lose heat less than the lower cylinders. The highest value of the temperature reached when the maximum value of heat flux. The temperature values of two cylinders that make up the triangle base almost symmetric (including simple difference). The temperatures are less at the sides of cylinders because of the conduction losses. Figure 5 show the increase in mean temperature when heat flux increased and the decrease in temperature when the cylinders spacings (X/D&S/D) increased because the cylinder will dispelling larger amount of heat when the spacing between them increased.

Figure 6 (a,b) show the distribution of local heat transfer coefficient along the three cylinders, The values of heat transfer coefficient are decreases when was reach at the middle of cylinder because of the height temperature in this region more than the sides.. The values of heat transfer coefficient in the lower cylinders are higher than the above cylinder in all separation distances because of the temperatures of the lower cylinders are less than the temperatures of above cylinder so the heat transfer coefficient will be higher for lower cylinders . Figure 7 show when the (X/D)&(S/D) ratioes increase, the values of mean heat transfer coefficient increase and when the heat flux values are increased, the values of heat transfer coefficient along the cylinders are increased.

Figures 8 (a,b) show the local Nusselt number along the three cylinders, It is clear that the behavior of local Nusselt number (Nux) is look likes the behavior of the local heat transfer coefficient (hx) except the difference in the values. From figure 9 notice the increase in the mean Nusselt number when the separation distances and heat flux are increased.

Figure 10 show that the effect of Rayleigh number on the mean Nusselt number and for all applied heat fluxes. It notes that when the Rayleigh number is increase, the Nusselt number is increased for all the separation distances (X/D)&(S/D) and all the heat flux.

Figures 11 (a,b,c,d) show the temperature distribution along three cylinders for vertical array, the temperatures of the lower cylinders are less than the temperatures of above cylinders in all separation distance because the first cylinder was exposed to the drawn air from the room which equal to the ambient air while the second cylinder was exposed to the hot air that floats from the first cylinder and the third cylinder was exposed to the hot air floats from the first and second cylinders, and as a result, the third cylinder will lose heat less than the first and second cylinders and the second cylinder will loss heat less than first cylinder. The highest value of the temperature reached when the maximum value of heat flux.. Figure 12 show the increase in mean temperature when heat flux increased and the decrease in temperature when the cylinders spacings (X/D) increased.

Figure 13 (a,b) show the distribution of local heat transfer coefficient along the three cylinders in vertical array, The values of heat transfer coefficient are decreases when was reach at the middle of cylinder because of the height temperature in this region more than the sides. The values of heat transfer coefficient in the lower cylinder is higher than the above cylinder in all separation distances because the cold air attached it firstly. Figure 14 show when the (X/D) ratio increase, the values of mean heat transfer coefficient increase and when the heat flux values are increased, the values of heat transfer coefficient along the cylinders are increased.

Figures 15 (a,b) show the the local Nusselt number along the three cylinders in vertical array, It is clear that the behavior of local Nusselt number (Nux) is look likes the behavior of the local heat transfer coefficient (hx) except the difference in the values. From figure 16 notice the increase in the mean Nusselt number when the separation distances and heat flux are increased. and figure 17 show the effect of Rayleigh number on the the mean Nusselt number in vertical array arrangement.

Figure 18 show the ratio between mean Nusselt Number in both cases: the vertical array and the triangle shape arrangement for all applied heat flux. It can notice the value of (Nu mean for triangle /Nu mean for vertical) was more than one, so that refers to enhancement of heat transfer in the triangle arrangement case compare with the vertical array case and reach to higher value about (1.34) at X/D=1& S/D=2.

5. Correlations

Emprrical equation have been found for the separation distances (X/D &S/D) and Rayliegh number for tiangle shape arrangement with error of +6.8% and -6.8%. .

$$\mathbf{Nu} = \mathbf{1} * (\mathbf{X/D})^{\mathbf{0.102}} * (\mathbf{S/D})^{\mathbf{0.053}}\,\mathbf{Ra}^{\mathbf{0.316}}$$

Where: X/D=1,2,3 & S/D=2,4,6

6. CONCLUSIONS

- The patterns of temperatures distribution is similar in all cylinders for all separated distance with difference values of heat flux.
- The patterns of heat transfer coefficient distribution is similar in all cylinders for all separated distance with difference values of heat flux.
- The increase of separated distance between the cylinders lead to increase of heat transfer.
- When the heat flux is increase, the heat transfer coefficient and Nusselt number are increased.

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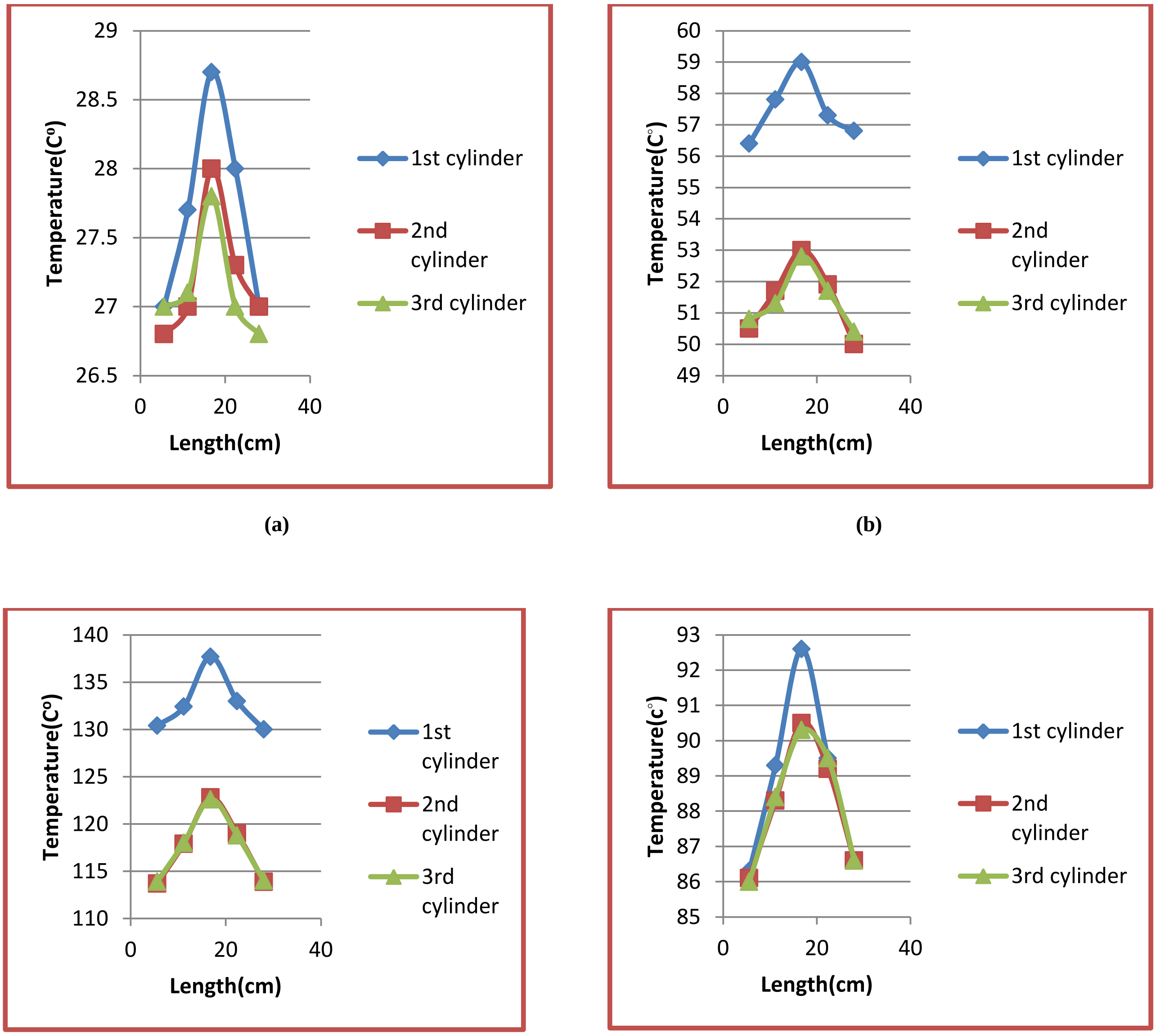
- The Nusselt number increase with the Rayliegh number.
- The triangle arrangement case was improvement the heat transfer more than the vertical array arrangement.

7. RECOMMANDATIONS

1- Use circular walls or triangular instead of rectangular walls to note the effect of walls shape on heat transfer process.
2- Use vortex generation shapes fixed on the fins to heat transfer.
3- Testing other medium of heat transfer instead of air.
4- Testing more values of X/D & S/D.



(a) **(b)**

(c) **(e)**

(a) $q^{\approx} = 38\ W/m^2$ **(b)** $q^{\approx} = 254\ W/m^2$ **(c)** $q^{\approx} = 660\ W/m^2$ **(d)** $q^{\approx} = 1268\ W/m^2$

Fig. 4 (a,b,c,d) : the temperature distribution along three cylinders arranged in a triangle shape at X/D=1&S/D=2 1st cylinder= The head of triangle , 2nd,3rd cylinder= The base of triangle

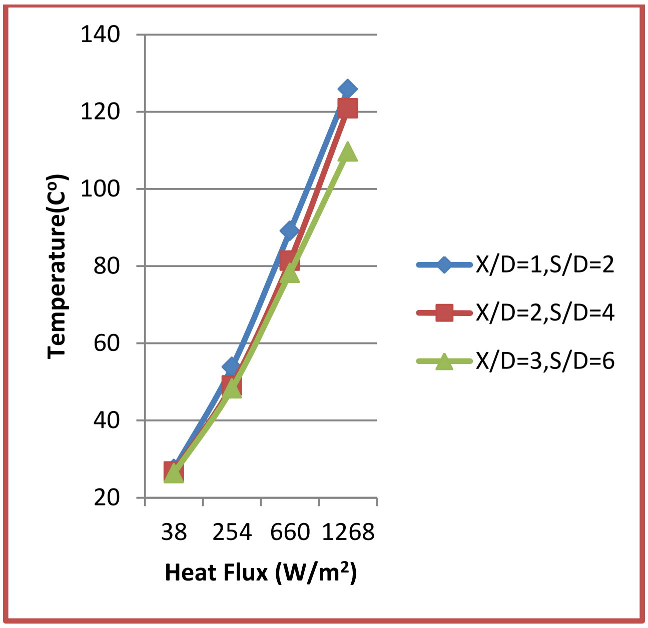
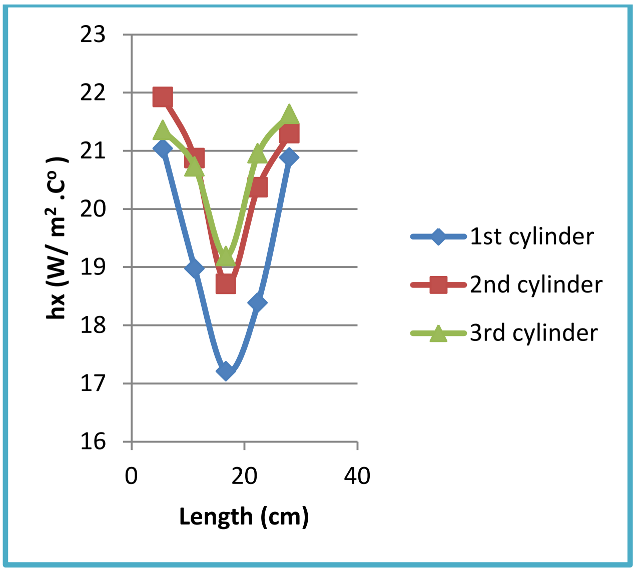
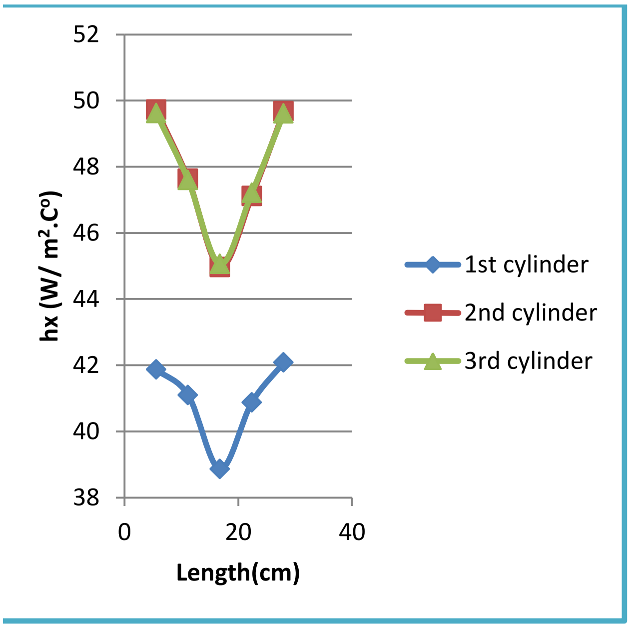


Fig. 5: the effect of heat flux on the mean temperature of the triangle arrangement for different space distance.





(a) **(b)**

(a) $\mathbf{q^{\approx} = 38\ W/m^2}$ **(b)** $\mathbf{q^{\approx} = 1268\ W/m^2}$

Fig. 6 (a,b): the local heat transfer distribution along a three cylinders arranged in a triangle shape at X/D=1&S/D=2

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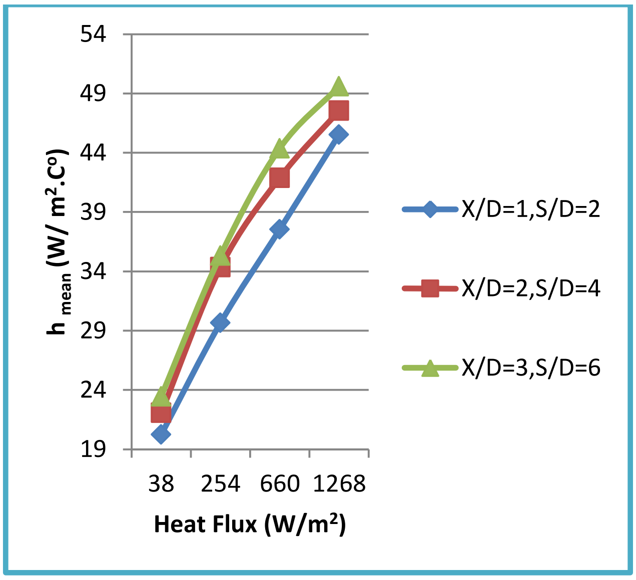
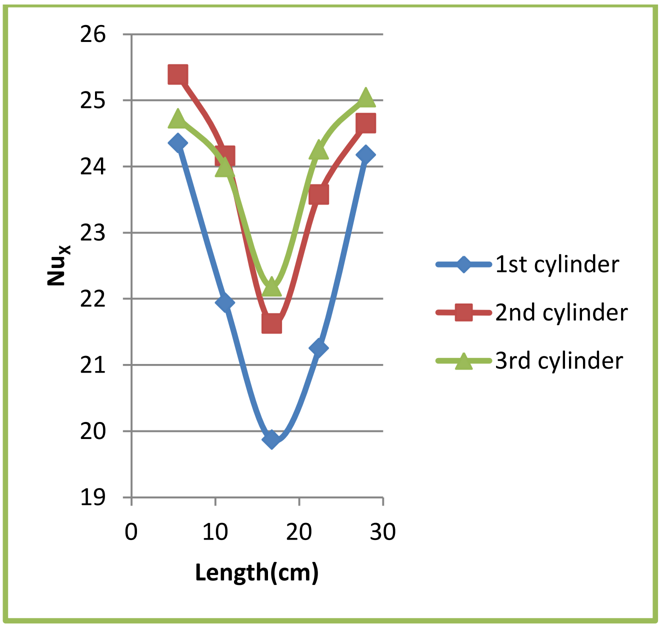
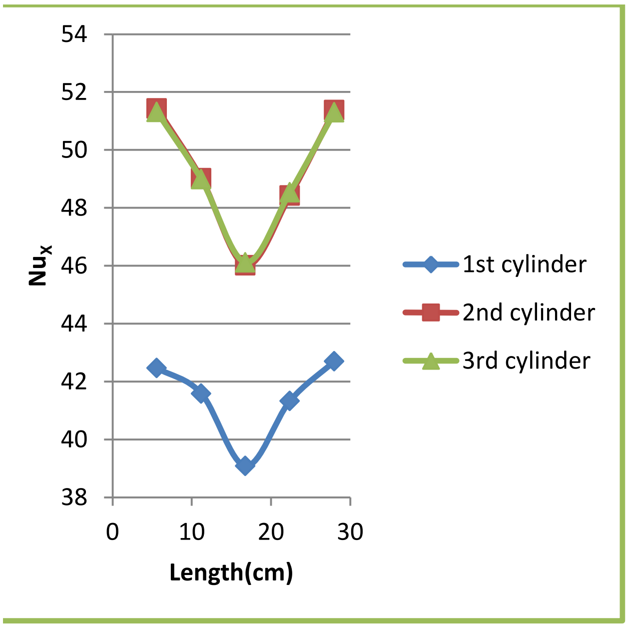


Fig. 7: the effect of heat flux on the mean heat transfer coefficient of the triangle arrangement for different space distance.



(a) $q^{\approx} = 38\ W/m^2$



(b) $q^{\approx} = 38\ W/m^2$

Fig. 8 (a,b): the local Nusselt number distribution along a three cylinders arranged in a triangle shape at X/D=1&S/D=2

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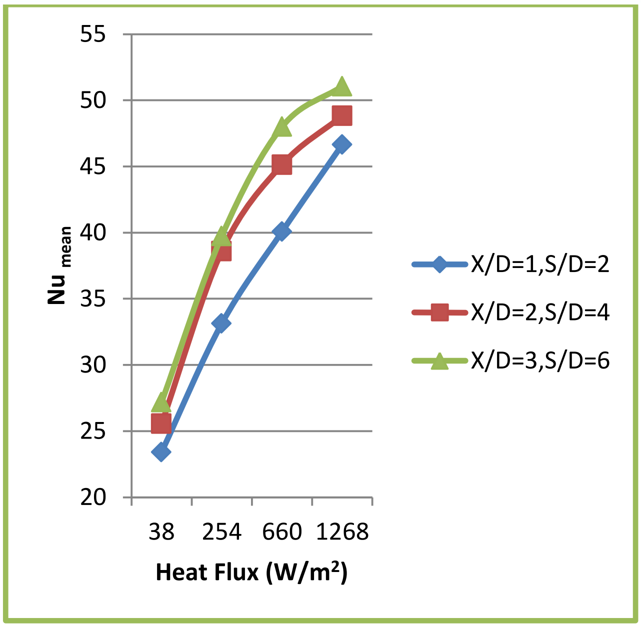

Fig. 9: the effect of heat flux on the mean Nusselt number of the triangle arrangement for different space distance.

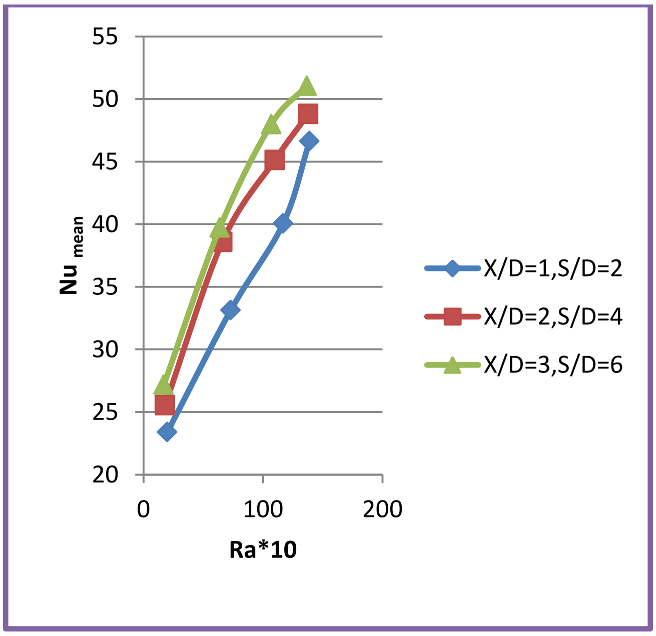

Fig. 10: Variation of mean Nusselt number with Rayleigh number of triangle arrangement for different space distance.

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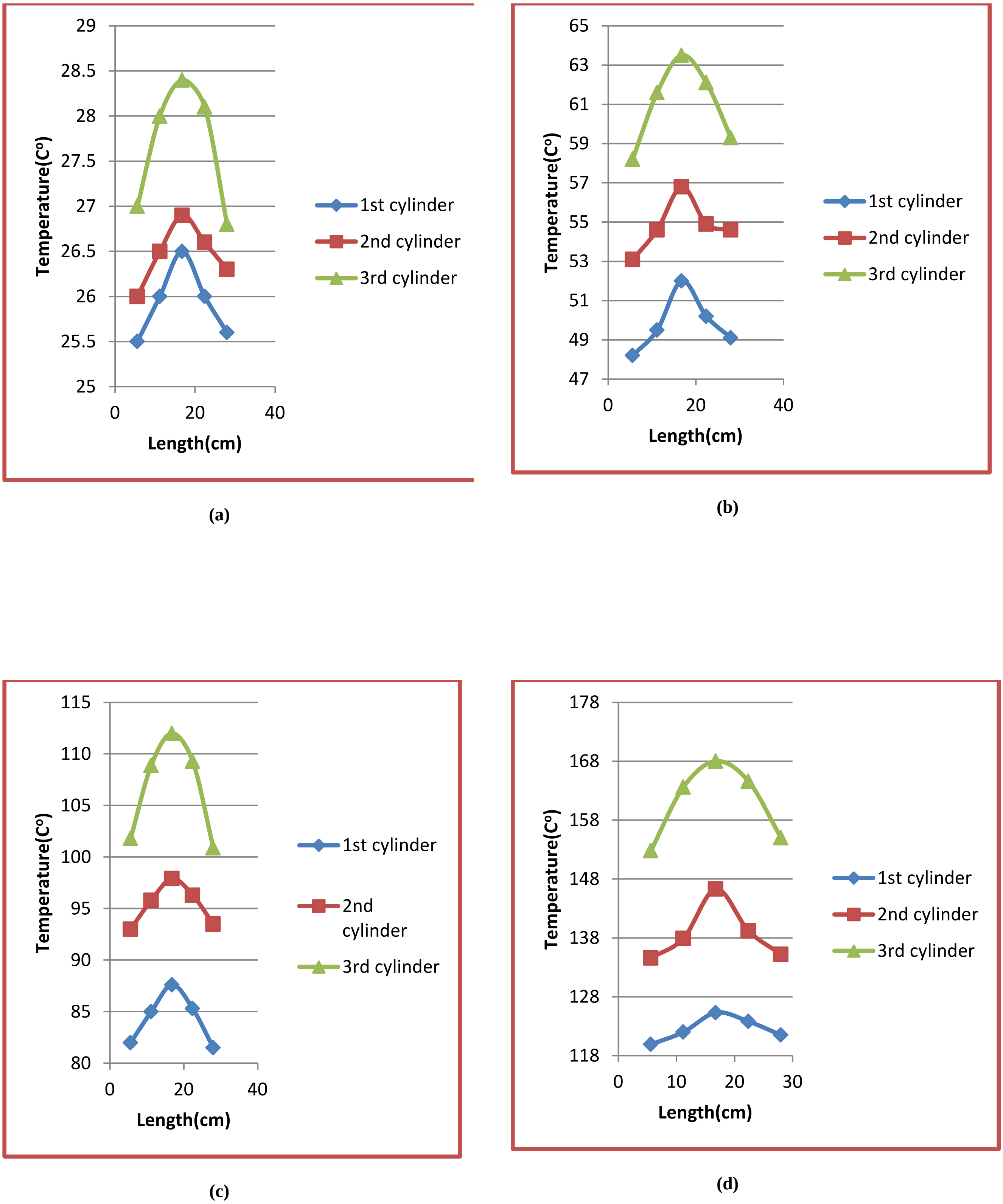


(a) $q^{\approx} = 38\ W/m^2$ (b) $q^{\approx} = 254\ W/m^2$ (c) $q^{\approx} = 660\ W/m^2$ (d) $q^{\approx} = 1268\ W/m^2$

Fig. 11 (a,b,c,d) : the temperature distribution along three cylinders arranged in vertical array at X/D=1

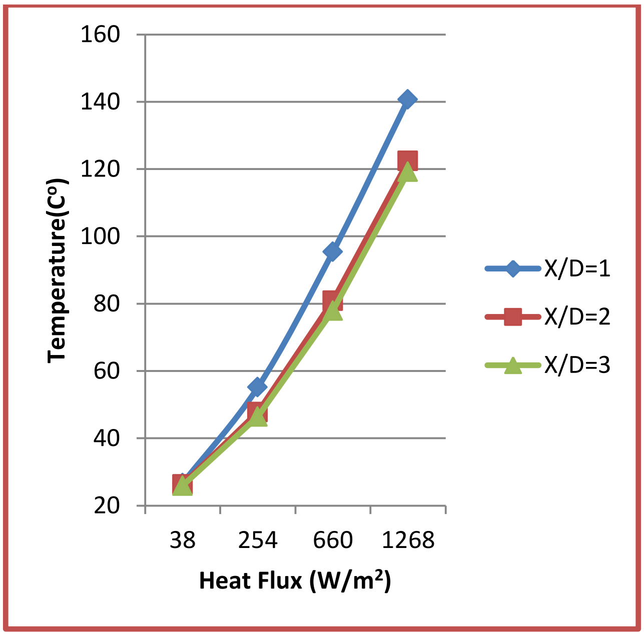
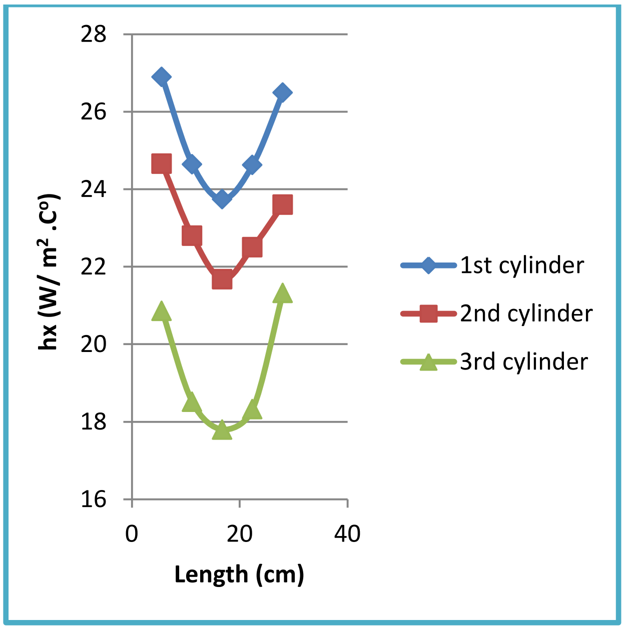
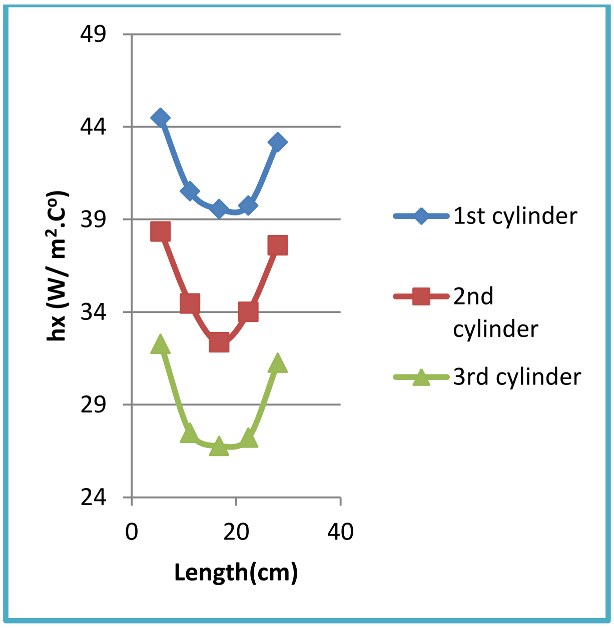


Fig. 12: the effect of heat flux on the mean temperature of the vertical array for different space distance.



(a)



(b)

(a) $q^{\approx} = 38\ W/m^2$ **(b)** $q^{\approx} = 1268\ W/m^2$

Fig. 13 (a,b): the local heat transfer distribution along a three cylinders arranged in vertical array at X/D=1

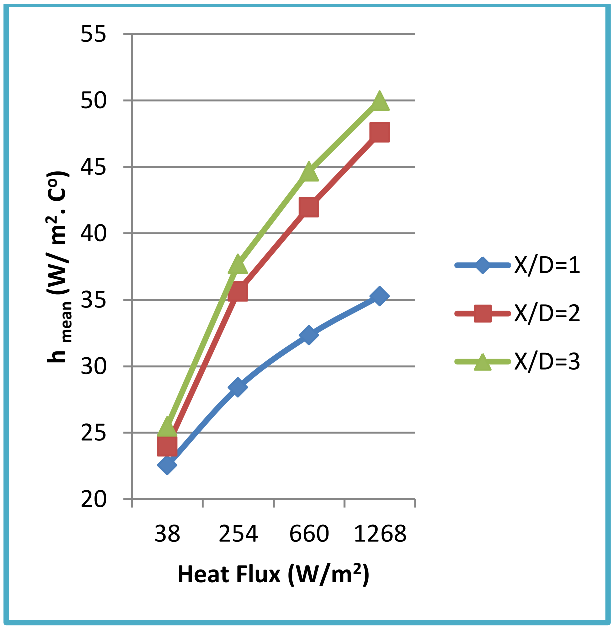
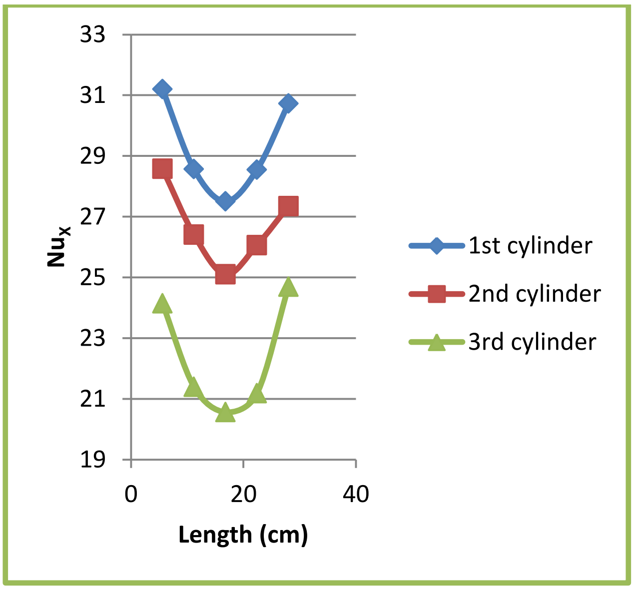


Fig. 14: the effect of heat flux on mean the heat transfer coefficient of vertical array for different space distance.



(a) $q^{\approx} = 38\ W/m^2$

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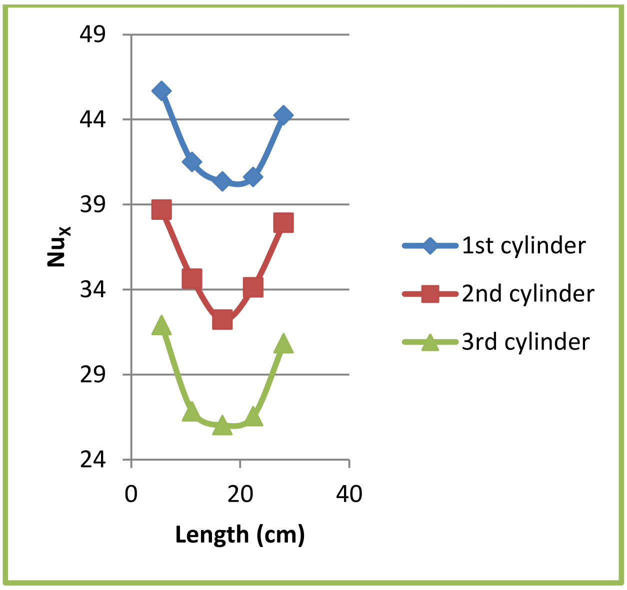

(b) $q^{\approx} = 1268\ W/m^2$

Fig. 15 (a,b): the local Nusselt number distribution along a three cylinders arranged in vertical array at X/D=1

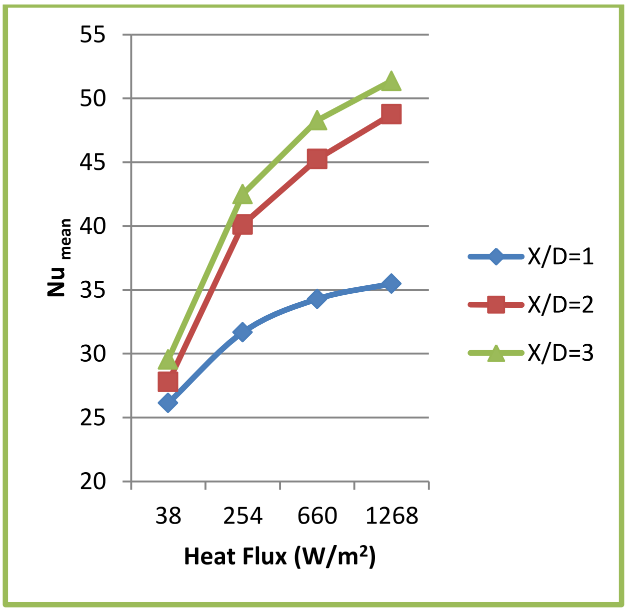

Fig. 16: the effect of heat flux on the mean Nusselt number of vertical array for different space distance.

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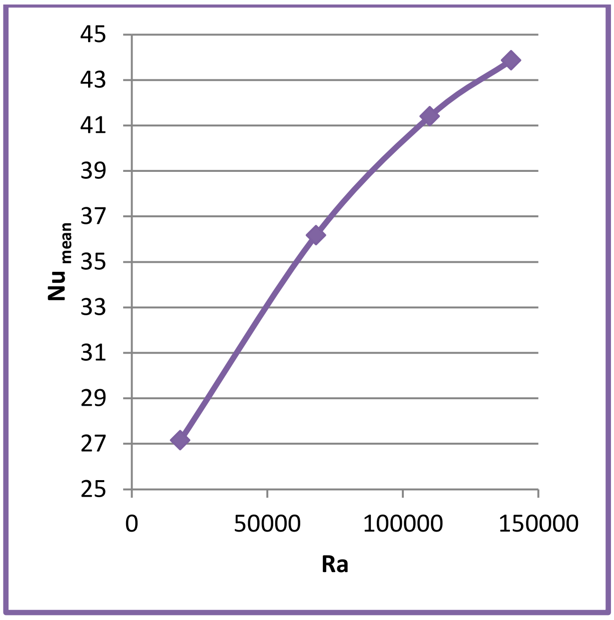

Fig. 17: Variation of mean Nusselt number with Rayleigh number for vertical array

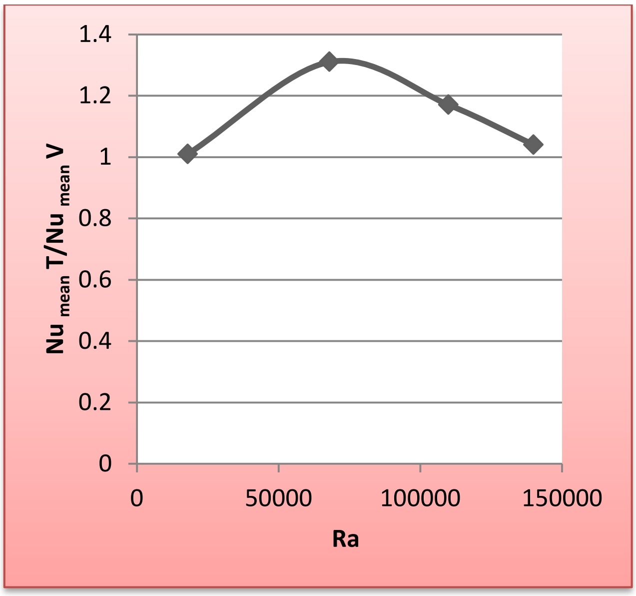

Fig. 18: The ratio between mean Nusselt number of triangle to that of vertical array at X/D =1 &S/D=2

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