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A Review of Heat Transfer Fitted with different RIB geometries in elliptical passage

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Abstract: *This paper presents a test examination for heat move upgrade and liquid stream in elliptic al sections fitted with various rib geomettries. Limit conditions are: bay coo lant air temperature is 300 K and stream Reeynolds number range (11000, 13500 and 16000). The encompassing steady tourist temperatures was (673 K).Results present the impact of utilizing diverse rib geometries in various circular entry perspective r atio on the liquid stream and warmth move charracteristics. The cooling air temperature appropriation at the section centerline, inward divider surface temperature of the channel, normal Nusselt number, contact factor rattio, and warm execution factor are p disdained in this paper. I was indicated that normal Nusselt number expanded with in wrinkling Reynolds number, and the most elevated worth was found for utilizing rib 1 and chann el perspective (2).Increasing coolant wind current vellocity diminishes the coolant air temperatur e at channel centerline, so diminishes the inward divider channel temperature. Utilizing ribs d ecreases the inward divider channel temperature and expands the coolant air temperature at channel centerline. Erosion factor ratiio increment with increment Reynolds numberr and the lower pressure drop (lower contact factor proportion) is found for rib 1 at all aspecct proportion.*
Keywords: *Gas Turbine, Heat Transfer Enhancement, Internal Cooling, Rib Turbulator.*

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Nomenclature

Symbol	Description	Units
A	Surface area	m^2
C_p	Air Heat Capacity	J/kg.K
D_h	Hydraulic Diameter	m
e	Rib Height	m
f	Friction Factor	[-]
g	Acceleration of gravity	m/s^2
H	Height of Channel	m
h	Heat Transfer Coefficient	$W/m^2.K$
k	Thermal Conductivity	W/m.K
L_c	Characteristic Length	m
$\dot{m}$	Mass Flow Rate	kg/s
Nu	Nusselt Number	[-]
μ	Air Dynamic Viscosity	$N\ s/\ m^2$
P	Rib Spacing(Pitch)	m
Q	Rate of Heat Transfer	W
pw	circumference	m
Re	Reynolds Number=ρuD/μ	[-]
T	Temperature	K
u	Flow Velocity	m/s

I. Introduction

Transferring of thermal energy from the outerturbine blade surfaces to the inner regionsvia conduction and then this heat will removed by internal cooling. The passages of internal cooling are modeled as rectangular or square ducts with different aspect ratios[1].

The aim of presenting the ribs at regular spaces is to improve the heat transfer averages. Ribs are manmade protrusions that are sited in a controlled technique along the walls. The rib prompts a separation through flow and hence causes an increase in the friction loss. The improvement of the heat transfer has a drawback in the rising pressure drop, which sometimes be able to several times larger than for the smooth passage[2,3].

The heat transfer and pressure drop are strongly associated to the height of the rib. Though the ribs can be placed at different orientation, almost studies focus on the ribs placed orthogonally (at 90 degrees) to the mainstream flow. The rib size and the space between the two following ribs, the pitch has great importance [4,5].

The performance of heat transfer in the ribbed passage depends on Reynolds number on the cool air, rib shape, the passage aspect ratio. When the coolant passes over the ribs, the flow separates and reattaches.

J.C.Han [6] studied the compounding effect of using different attack angles of rib and channel aspect ratio on heat transfer coefficient distribution in a rectangular channel. Where the ribs fixed on the upper and lower side of the channel, air flowed with $Re=10*10^3$ to $60*10^3$, attack angle of the rib was varying from 30 to 90, and the aspect ratio was raging from 1 to 4. Result found that the effect of varying attack angle was slightly in the channel with aspect ratio (2).Thermal performance was changing from 1.05 to 1.85 depending on the attack angle and channel aspect ratio. Semi-empirical friction heat transfer and heat transfer correlations had been obtained for an account for rib spacing, rib angle, channel aspect ratio, Reynolds number, and rib height. The results could be utilized in the designing channel of the blade of the gas turbine.

M. Amro[7] performed an experimental investigation of the heat transfers in a triangular channel having rounded edge which roughened with ribs as a model that simulates the passage in the blade of gas Turbine. To measure the heat transfer, it was used the method of A transient liquid crystal. Reynolds numbers vary between5 × 10 5 × 10 and. it had been found from results that the ribs of 60^o were better than the ribs of 45^o in heat transfer and with this ribs of 60o were had high friction factors. The enhancements of overall heat transfer depend on the rib and also structure rib angle.

SachinBaraskar et al.[8] presented an experiment research of friction factor properties and heat transfer of fixing ribs on one wall of the rectangular channel, the aspect ratio of channel equal to 8, the ribs were with and without gap, ribs spacing to height (p/e) =10,heat transfer and friction properties of this ribbed channel have been compared to the smooth channel with similar condition. The influence of rib has been studied for a range of Reynolds numbers from 5 × 10 to 14 × 10 . The best enhancement in friction factor and the Nusselt number was perceived to be 2.85 and 2.57 times of that of the smooth channel, respectively.

UmeshPotdar et al. [9] presented an experimental work in the stationary square channel with V-shaped and 45°inclined arc of circle rib turbulators to find the thermal and hydraulic performance. Channel aspect ratio of (W/H=1) was considered in the analysis. Square ribs (w/e = 1) were considered as the baseline configuration. The heat transfer performance for the channel was calculated with range of Reynolds numbers from 45x10 to 75x10 . The results obtained for the channel with different ribs configuration proved that the increase in rib width increases the thermal performance of the channels.

Shailesh et al.[10] performed an experimental investigation for ribs which have no gaps and ribs having gaps with (p/e) =10, (e/Dh) =0.06 and two attacking angles (60^o and 90^o), Re= $5x10^3$ to $40x10^3$. The thermal heat transfer performance of continues and discontinuous ribs with (d/w) =0.2 and g/e=1 was investigated under the same conditions, the results of friction factor ratio and heat transfer were obtained from the ribbed channel were compared with the channel without ribs. From the results it was found that the performance of inclined ribs is best than the transverse ribs with and without gaps. The best case of thermo hydraulic performance was found to be the case of inclined ribs with gaps at Re=5000 and it was about (2.03).

channel aspect ratio from 1 to 4.The researcher used three channel having the same hydraulic diameter (=40mm) but different in channel aspect ratio (AR=1,2, and 4) . The Reynold number range from 10000 to 20000 In a rib-roughened channel with angled ribs, the results show that intersecting rib raised the thermal efficiency for every case, despite the channel aspect ratios and Reynolds numbers and the effect of the intersecting rib was strongest for AR = 2.0.

Srivastavaet al. [12] performed an experimental study for the influence of attack angle on the forced convection heat transfer and friction factor of the ribbed channel. The square channel (AR=1) was ribbed on its bottom and the top wall with the square-shaped rib as V-rib and having a gap on its length. The attack rib angle (α) was increased from 300 to 750, the ratio of width (W) to the height of the channel (W/H) was 1, relative roughness pitch (p/e) was 10. The flow rate of air corresponded of Reynolds number (Re) was ranged from 5× 10 to 40× 10 . The pressure drop and heat transfers of different configurations was manifested in the form of friction factor and Nusselt number. The result showed that the changed the attack angle has an effect on friction factor and Nusselt number. The highest enhancement of friction factor (f) and Nusselt number (Nu) were 8.1 and 4.7 times that of the smooth channel, respectively. As the results, the highest performance of 2.6 times that of smooth channel, was given for broken V-shaped ribs with attack angle flow as 60

Sebastian Ruck [13] performed an experimental investigation for heat transfer measurements to examine the thermal-hydraulics in the square, round-edged channel of space to height of (p/e = 10), the air flow Reynolds numbers ranged from 50000 to 250000. Three variously shaped ribs were investigated: transverse ribs, transverse ribs with square cross sections and, upstream directed 60° V-shaped ribs with round-edged rib front and rear surfaces. The thermal performance, Friction factors, roughness functions, and ratios of Nusselt number, were manifested.

Arkan Al Taie et al. [14, 15, 16, 17, 18] presented an experimental and numerical investigation of heat transfer characteristics and thermal performance in 50 cm stainless steel tube long, inside diameter of (30 mm) and outside diameter of (60 mm) with uniform surrounding hot air temperature of 1000, 1200 and 1400 K using ANSYS Fluent 14.5. Results indicate that using internal ribs increase the heat transfer rate and having the highest performance factors for the case of turbulent flow.

Heeyoon Chung [11] has performed an experimental investigation of the influence of channel aspect ratio and an intersecting rib on performance in rectangular channels with two angled ribs and 1027

Mohammed W. Al-Jibory et al. [19, 20] designed and built an experimental system to simulate gas turbine blades conditions. Boundary conditions include: temperature of inlet coolant air is 300K with air flow Reynolds numbers (Re=7901) .The surrounding constant hot air temperatures was (673 K). It was presented the effect of ribbing rectangular channel passages with circular ribs on coolant air flow and heat transfer characteristics. It can be seen that the channel with all used ribs was the better case which leads to increase the coolant air temperature and decrease the inner wall temperature.

In this paper, the effect of using different rib geometries in elliptical cross section passages with internal flow and uniform wall surface temperature will be experimentally investigated.

EXPERIMENTAL PART

Experimental Devices and Test Rig

Figure (1) displays the essential segments of the test rig. The experimental rig was built in the laboratory of fluid mechanics/college of Engineering /kerbala University as shown in figure (2), this rig consists of:

- Test sections (four elliptical channels).
- Cooling air supply system.
- Heating system.
- Ribs.
- Measuring tools.

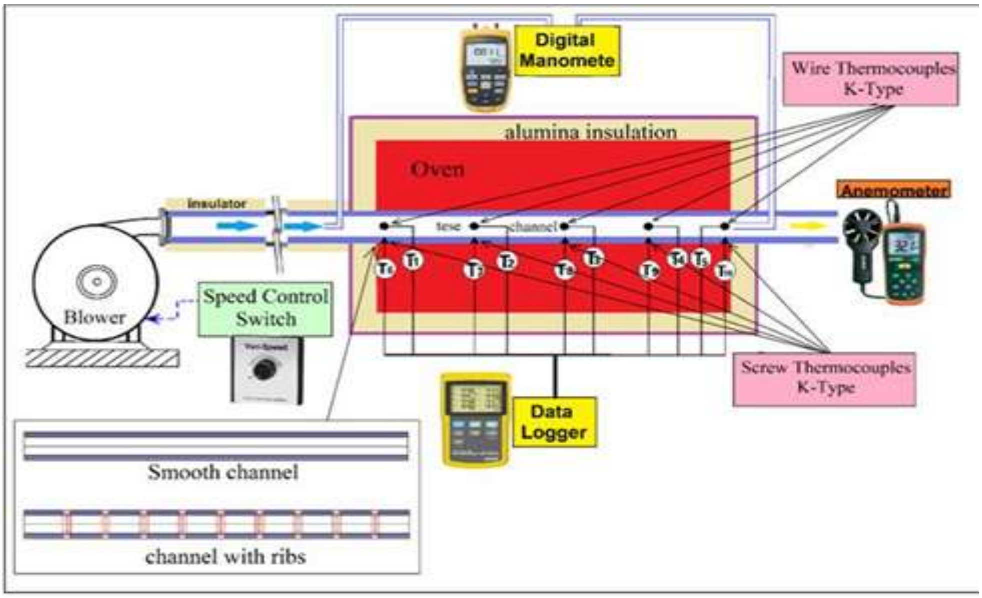

Figure (**1**)Schematic diagram of the experimental setup

Figure (2): Photographic views of experimental rig

Test section

The test section consists of a stainless steel box. The box was internally insulated with alumina and the box with a dimensions of (700x500x500 mm), including the heaters of (4.4 kW) power to produce a constant hot air temperature of (673K). It surrounds the stainless steel elliptical channel with a length of 500 mm and inner hydraulic diameter of 37 mm as shown in figure (3), coolant air passed through the channel, and ribs are fitted into the channel test section at the same pitch (spacing) of 50 mm. The physical proprieties of channel and ribs material are listed in table (1).

Table (1): Physical properties of channel material

Metal	Thermal Conductivity (K) W/m.K	Specific heat (C_p) $W/m^2.K$	Density (ρ) Kg/m^3
standstill steel (ASM4120)	37.7	444	7822

Figure (3): Elliptical channel

Cooling air supply system

The device that produces the channel with a cooling air consists of the followingparts:

1. Centrifugal blower
2. Converging nozzle
3. Entrance channel
4. Flange
5. Insulation cover

1. Centrifugal blower

A centrifugal blower was used in the experimental rig to supply the coolant air. It was driven by A.C. Motor of 220 volt 325 W at 3000-4000 RPM. The airspeed is controlled by an electric switch to control the blower, and the airflow velocity (flow rate) can be measured in the test section by digital air speed flow meter.

2. The converging nozzle

The converging nozzle (300 mm) long to connect the blower with Entrance channel, the beginning of the channel is circular and its exit has an elliptical cross section of entrance channel.

3. Entrance channel

Entrance channel is manufactured with an elliptical cross-section as same as the dimension of the cross section area of the channel test section with a length of (2m). The importance to ensure that the coolant air was having thermal and hydraulic fully development entrance length the hydraulic entrance length is Le= 0.818 m according to correlation (4.1)] [56].

= 4.4 / ... (4.1)

Other authors give much longer entrance length Le=1.48m according tore commends as in [55].

Le=40 × (4.2)

And the thermal fully development entrance equation (4.3) to be L = 0.37 m as in [57].

≈ - $L_{th}e$

Where: $L_{th}e$ = thermal entrance length And L = Entranc length

length can be calculated according to

(4.3)

So in this experiment the entrance length was taken equal to 2 m which is suitable to ensure the fully thermal and hydraulic entrance length.

Heating system

Figure (4)shows the heating system which consists of oven which consists of a rectangular box with a length of 700 mm, 500 mm width and the height of 500 mm. Oven walls were insulated with alumina as a good insulator so as to avoid the losses of heat energy to the surrounding of the box. As shown in the figure (4 a) heat was produced by heaters around the channel to assuring constant surrounding hot air temperature of (673K). The total power of the heaters is (6600 W). The temperature is restrained by a CTE (control thermostat electric) as showing a figure (4 c) which designed and built to maintain a constant hot air temperature on the outer surface of the channel test section. The circuit was designed for a load voltage of 0 - 220 V, with a maximum current of 20 A. A controller thermocouple was used to maintain a constant temperature on the outer surface of the main channel test section.

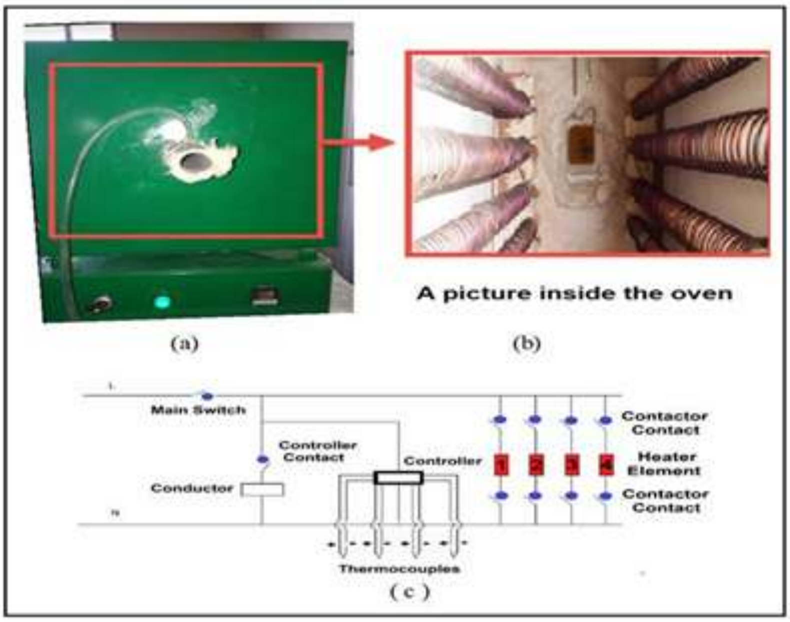

Figure (4): Heating system: a) Front view of the oven b) Inside section view of the oven c) thermostat electric circuit

Ribs

Elliptical stainless steel ribs (physical properties listed in the table (1)) with different geometries were manufactured in the Mechanical Industries factory in Tehran by CNC machine as shown in figure (5) fitted in the channel by the following procedures:

- Drilling holes in the upper wall along the channel with 50 mm apparatus then use it to fix the ribs in place. For facilitating shifting the rib inside the channel and because the channel and their ribs were manufactured with high precision using the CNC machine, the tolerance is very low between the external diameter of the ribs and the inner diameter of the channel. Therefore, liquid nitrogen was used for the purpose of cooling the ribs and thus to reduce its dimensions temporarily.
- After cooling the rib, pushing the first rib by a Teflon rod fitting until it reached to the final location. The rib was then screwed in position.
- Re-doing step 2 to fit all other ribs. At attack angle of 90^{+} to the coolant airstream, as shown in figure (7) ribs were being placed.

Figure (5): Photographic of ribs machining processes

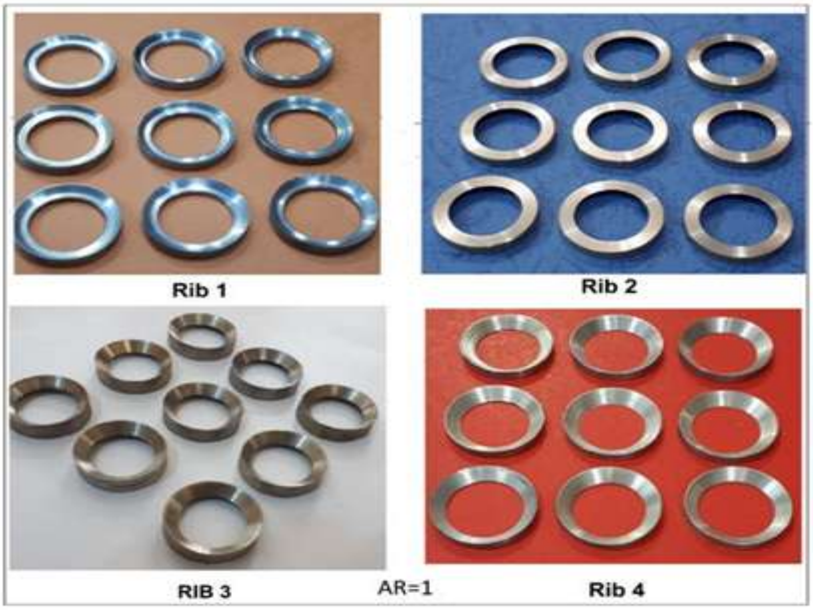

Figure (6) displays Photographic view of the ribs with aspect ratio 1and 2

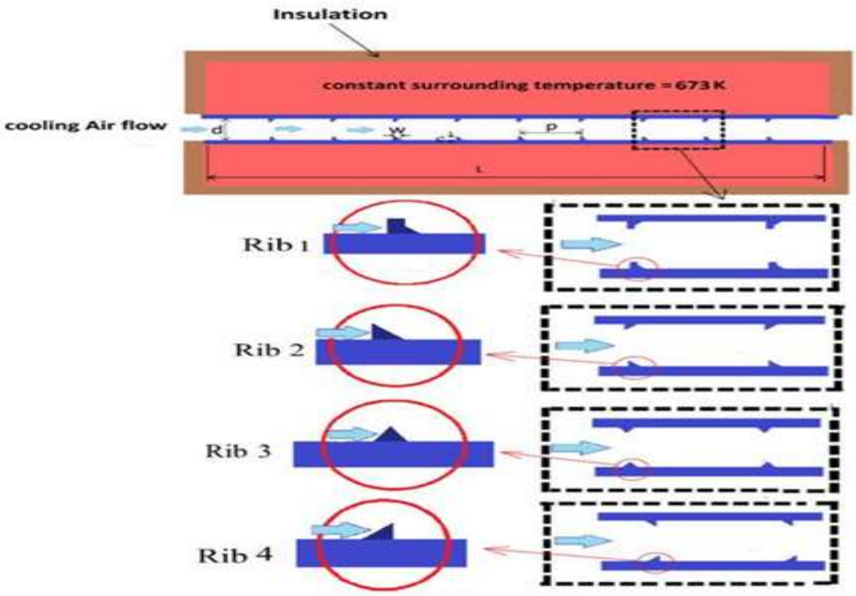

Figure (7): Location of ribs inside the channel

Measuring procedures

The experiment is performed as described in the following steps:

- The blower was switching ON and its speed was regulated by the control switch until the desired flow rate at a required Reynold number (Re=11000). And the airspeed is measured by the anemometer.
- Switching ON the heaters which installed in the oven by the power switch and then set up the temperature control panels at a temperature of 673 k, which will control the work of heaters, and that will distribute the temperature inside the oven so that the temperature remains constant inside the oven and thus ensure that the temperature of the internal air on the oven will remain constant and the external channel wall surface temperature would be constant. Thus, the conditions on the surface of the channel wall will be simulating the passages in the gas turbine blade.
- Keep on the blower and the heaters working for a sufficient period of time until the readings are stabilized. This period takes about 40 minutes and after that, the temperature and pressure readings are taken.
- Regulate the blower gate to obtain the required flow rate (Re=11000).

- After attaining the steady stage record thermocouples reading (T1, T2, T3, T4 and T5) which represent the inner wall surface temperature of the smooth channel (without ribs), and record thermocouples reading (T6, T7, T8, T9 and T10) which represent air cooling temperature at the channel centerline.
- Record the pressure reading from the digital manometer.
- The above steps were done for elliptical smooth channel with aspect ratio from 1 to 2.
- The previous steps are repeated after fitted ribs 1.
- Repeat the above steps for cases of ribs 2,3, and 4. For AR=1and AR=2.
- Repeat the above steps for another flow rate of (Re=13500 and 16000).
- Repeat all the above steps using a thermal barrier coating around the channel test section for the best case, which was found from the result the case of rib 1 fitted in channel with AR=2.

Data Reduction

All experimental data were either measured and recorded by hand, the experimental resultscan be reduced to get the average wall inner surface temperature, average air temperature at centerline, mass flow rate and Reynolds number. These data were then used to calculate the heat transfer coefficient, friction factor, and Nusselt number. The mean wall inner surface temperature Tw is calculated by the average of five recorded temperatures at various locations on the inner wall surface and is given as the net heat transfer rate from the wall which can be calculated as follows:

,-.,/.,0.,1.,2

,- = 2 (1)

The mean (average) air temperature T mean is the arithmetic mean of the measured values of air temperature at the entry and exit to the test section,

$$T_{mean} = \frac{T_O + T_i}{2}$$

(2)

The mass flow rate can be calculated as follows:

$\dot{m} = \rho u A$ (3)

c

$$\left(A = \frac{\pi \times a \times b}{4} \right) \qquad (4)$$

Where, ρ = air density, u= air flow velocity and A_c = channel cross sectional area , a =

major diameter of elliptic ,b = miner diameter of elliptic .

The pressure drop (ΔP) will be determined across the test section length and then used to find the friction factor using the following equation:

/ 4 Δ6 789: /

3 = / (5)

; <=

The heat transfer coefficient and Nusselt number can be calculated from the equations (6), (7), and (8).

>

9,(,@A,<BC

8 = D) (6)

Where Q is the heat transfer and

> = <=:6(,° − ,H) (7)

IJ = K (8)

The Reynolds number is calculated as follows:

L

×78

Re = (9)

M

Where, D_h = channel hydraulic diameter, u= air flow velocity and υ = kinematic viscosity.

9N

OBPH<B

78 = QBP (10)

Where as in [58] perimeter of elliptic

6BPH<BQBP R3 BSSHOQHN = T C/.V/

× U / (11)

Where, ρ = air density, u= air flow velocity and A_c = channel cross section area.

II. Results And Discussion

Effect of rib geometry on inner wall surface temperature

Figure (8) reveals the inner wall surface temperatures for different rib configurations and channel aspect ratio (2). The inner wall surface temperature for ribbed channel is lower than smooth one for all cases. Where the rates of decreasing percentage of temperatures of the inner wall surface of ribbed channel with rib1 as compared with smooth one is (5.7%,5.3%,4.5%, and 3.8 %) for (rib1, rib2, rib3, and rib4), respectively. This is because ribs make wakes which develop to vortices. This rises the heat transfer from the duct wall to the coolant air, i.e., decreases the inner wall temperature and increase temperature of coolant air. Therefore, the best condition in cooling the inner wall surface of the channel is the case of rib 1 fitted in channel with AR=2.

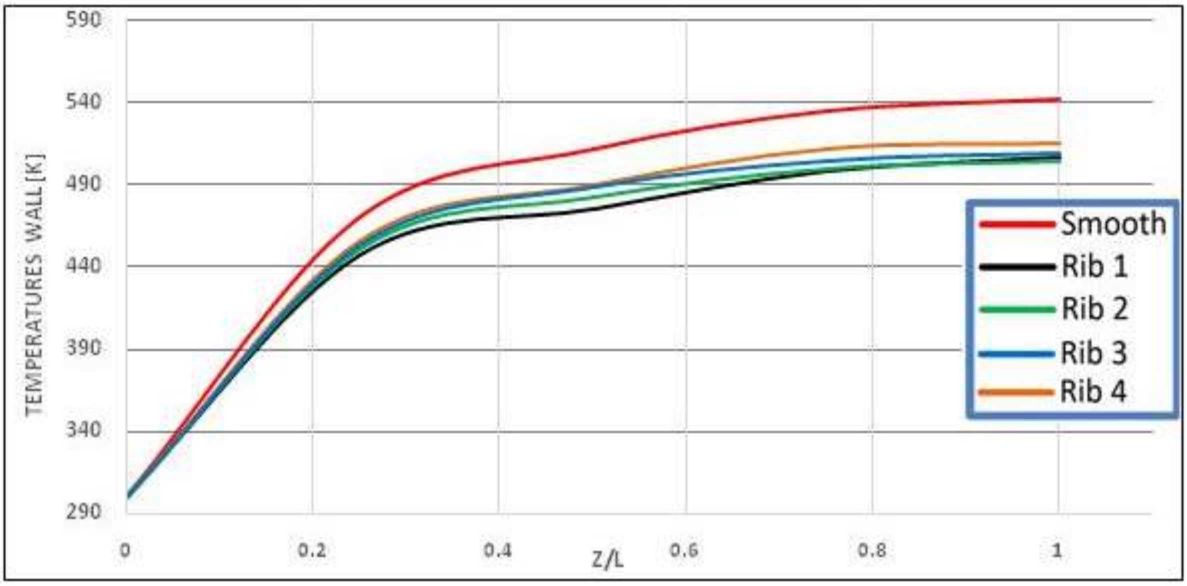

Figure (8): Temperature distribution for the inner wall surface channel with AR=2

Effect of rib geometry on coolant air temperature

Figures (9) presents the experimental results of coolant air temperature along the channel centerline for different rib configurations (rib1, rib2, rib3, and rib 4), and channel aspect ratio (2) compared with smooth channel at surrounding hot air temperature of (673 K) and coolant air flow of (Re=16000). Cooling air temperature for channel with ribs was higher than smooth channel because ribs make wakes which develop to vortices. This leads to increase the heat transfer from the channel wall to the coolant air, i.e., Increasing the coolant air temperature. For the channel with AR (2) if it compares the channel having ribs with the smooth channel it can be concluded that there is an increase in the temperature of the cooling air outside from the channel by the temperature of the cooling air inside air by increasing the percentage (17.7%,16.7%,8.3%, and 1.5%) and for case of (rib1, rib 2, rib 3, and rib 4), respectively. Case of rib1 have higher coolant air temperatures than the other cases, this indicates that this case have the perfect shape to accelerate the coolant air flow and thus increasing coolant air temperature. Therefor the case of rib1 fitted in channel with AR=2 is the most case in which there has been an increase in centerline air temperature, so it is the best case in heat transfer. So, rib 1 for all channel aspect ratio has higher coolant air temperatures than the other ribs, because they have the perfect shape to accelerate the coolant air flow and thus increasing coolant air temperature.

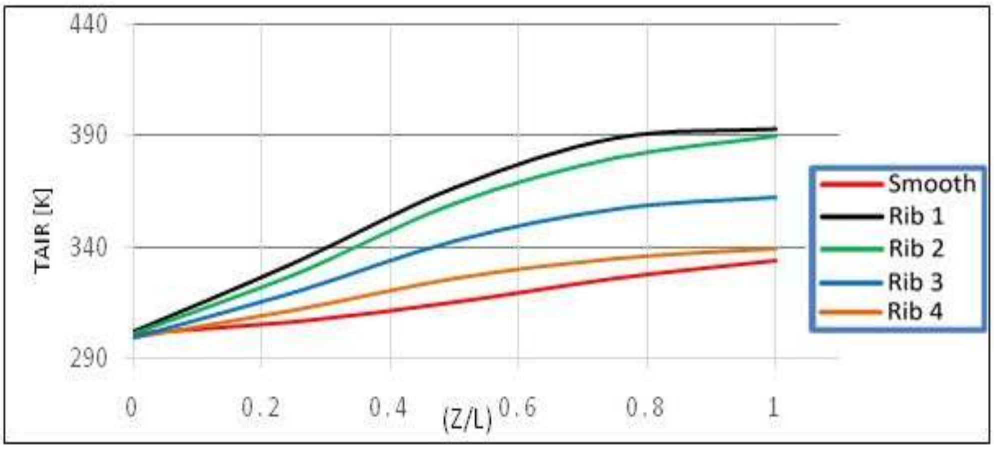

Figure (9): Air temperature distribution at the channel centerline for (Re=16000) and AR=2

Effect of rib geometry on the average Nusselt number

The average Nusselt number was increased with increasing Reynolds number. The reason is as Reynolds number increases the turbulent mixing is enhanced in the channel, which leads to effective removal of heat. Therefore, the Nusselt number ratio for all three Reynolds number follow a similar trend. Figure (10) present the experimental average Nusselt number varying with Reynolds number, it is noted from this figure that the highest value of the Nusselt number is when fitted rib 1 in channel and the lowest value is for the rib 4. That because heat transfer when using rib 1 is more than rib 4. Figure (11) presents the normalized Nusselt numbers and it shows that the channel with rib 1 has the higher value than the other ribs.

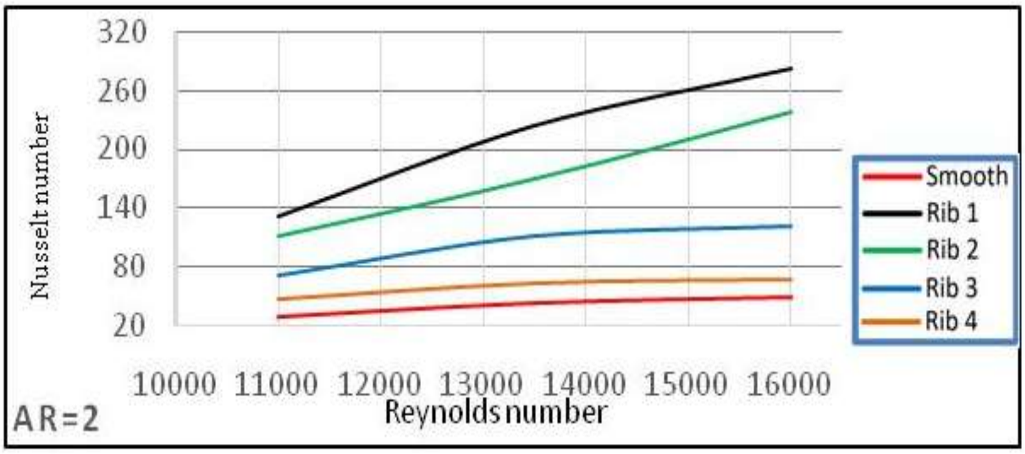

Figure (10): Nusselt number as a function of Reynolds number

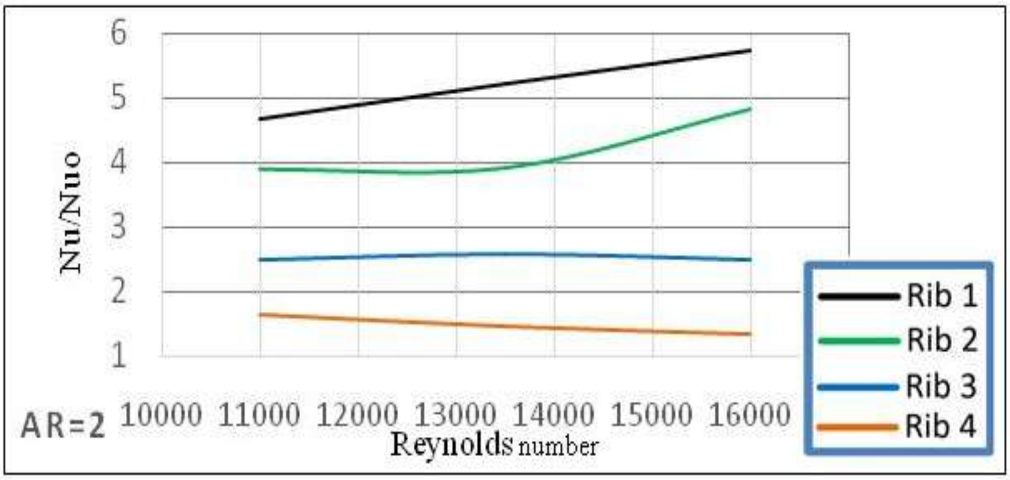

Figure (11) Normalized Nusselt number as a function of Reynolds number for AR=2

Effect of rib geometry on the friction factor ratio

Figure (12) presents the experimental friction factor ratio for all rib configurations and channel aspect ratio (2) with constant surrounding hot air temperature of (673 k) and Reynolds number of (11000,13500, and 16000). The friction factor ratio increases with increase Reynolds number and the lowest pressure drop (lower friction factor ratio) is found for rib1.

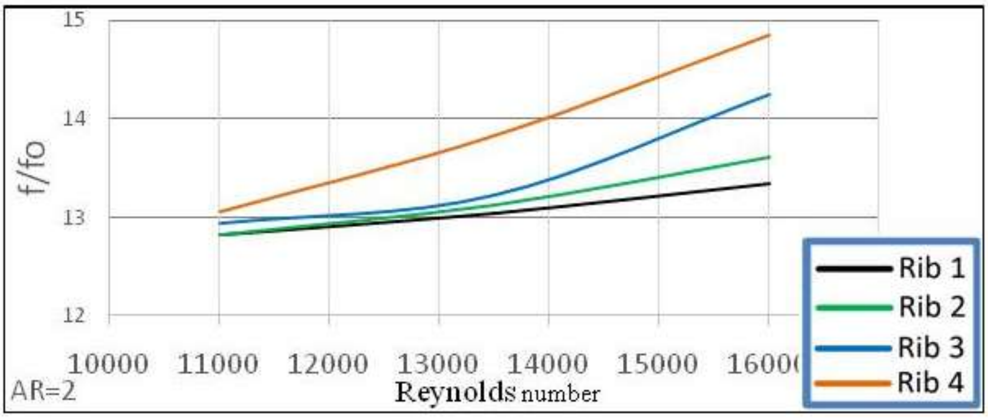

Figure (12): Friction factor ratio variation with Reynolds number for different rib configuration and AR=2

Effect of rib geometry on the thermal performance factor

By the averaged Nusselt number ratios and friction factor ratios, the thermal performance factor for each channel can be evaluated. Figure (13) shows the variation of the thermal performance factor for the ribbed channel with AR=2. The thermal enhancement factor varies between 0.53 and 2.12 depending on the rib configuration and Reynolds number. The maximum value of thermal enhancement factor was found at channel with AR=2 fitted with rib 1 at Re=16000.

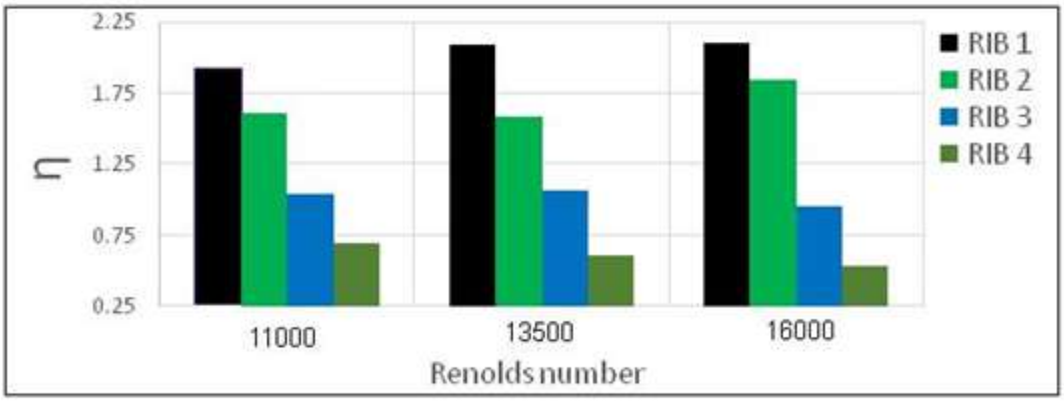

Figure (13): Enhancement factor as a function of Reynolds number

III. Conclusions

- Average Nusselt number increased with increasing Reynolds number, and the highest value was found for using rib 1 and channel aspect (2).
- Increasing coolant air flow velocity decreases the coolant air temperature at channel centerline, so decreases the inner wall channel temperature.
- Using ribs decreases the inner wall channel temperature and increases the coolant air temperature at channel centerline.
- Increase the aspect ratio of elliptical channel decreases the inner wall channel temperature and increases the coolant air temperature at channel centerline.
- Friction factor ratio increase with increase Reynolds number and the lower pressure drop (lower friction factor ratio) is found for rib 1 at all aspect ratio.

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