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Numerical Investigation to Enhance Heat Transfer in Rectangular Channel by solid Trapeziodal Vortex Generators for Turbulent Fully Developed

دراسة عدديه لتعزيز نقل الحرارة في قناة مستطيلة باستخدام شبه منحرف الصلب كمولد دوامة في تدفق المضطربة بالكامل.

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ABSTRACT

A numerical investigation was achieved to study the heat transfer enhancement by using vortex generators in a rectangular channel and the air as the working fluid for three-dimensional and turbulent fully developed flow . The optimum trapezoidal vortex generators are mounted in a staggered arrangement on a flat plate with pitch 5cm and then fixed this plate in the bottom of the channel . Tests were achieved of a rectangular channel (50cm,6cm,3cm) and the wall thickness of the channel was 1.5mm , the vortex generators longitudinal pitch (p) to vortex generators height(e) ratio p/e=10, vortex generators height (e) to its length (a) ratio was e/a= 0.5 and the height of vortex generators to the hydraulic diameter of the channel (Dh) was e/ Dh= 0.136. Reynolds number of 7250,8840 and10300 were used with constant outside wall temperature of 400°C as the boundary condition. The problem is solved by using ANSYS FLUENT VERISON 18.2and the numerical part consist of modeling and meshing. Results showed that with a usage of the solid trapezoidal vortex generators thermal performance factor enhanced by 15%,25% and 45% times,to that rectangular channel with a solid trapezoidal compare to the smooth channel with respect to Reynolds number values. The friction factors were 0.05,0.04and 0.02 for smooth channel and for the channel with vortex generators were 0.09, 0.07 and 0.03 with respect to Reynolds number values.

KEYWORDS :heat transfer enhancement , internal flow , rectangular channel, vortex generators.

الخلاصة

تم إجراء تحقيق عددي لدراسة تعزيز نقل الحرارة باستخدام مولدات دوامة في قناة مستطيلة لتدفق ثلاثي الأبعاد ومضطرب بالكامل.ان الشكل الأمثل لمولدات دوامة على شكل شبه منحرف الصلب التي وضعت في ترتيب مبعثرعلى لوحة مسطحة .والمسافه بين واحده واخرى هي 5سم وثم تثبيت هذه اللوحة في الجزء السفلي من القناة. تم اجراء الاختبار لقناة مستطيلة (50 سم ، 6 سم ، 3 سم) وكان سمك الجدار للقناة 1.5 مم ،ونسبة المسافه الطوليه للمولدات الدوامه الى ارتفاع مولد الدوامه (10) وارتفاع مولدات الدوامة (e) إلى طولها (a) كانت النسبة e / a = (0.5) وارتفاع المولدات الدوامة إلى القطر الهيدروليكي للقناة Dh(e / Dh = 0.136). تمت الاختبارات لا رقام ينولد 840،7250 و 10300 مع درجة حرارة الجدار الخارجي ثابتة 400 درجة مئوية كشرط الحدود. تم حل العمليات باستخدام ANSYS FLUENT VERISON 18.2 والجزء العددي يتكون من النموذج والتشبيك. أظهرت النتائج أن معامل نقل الحرارة وعدد Nusselt زاد مع زيادة عدد رينولد باستخدام مولدات دوامة شبه منحرف الصلب. تم تحسين عامل الأداء الحراري بمقدار 2.5،1.5 و 4.5 مرة للقناة التي تحتوي على مولدات دوامة مقارنة بالقناة الملساء نسبة الى أرقام رينولدز. كانت قيم عامل الاحتكاك 0.05،0.04 و 0.02 للقناة الملساء وللقناة ذات المولدات الدوامة كانت 0.09 و 0.07 و 0.03 نسبة الى ارقام رينولدز.

Nomenclature:

L length of the duct
W width of the duct
t thickness of the channel
p longitudinal pitch of vortex generators
e height of vortex generators
a length of vortex generators
Dh hydraulic diameter of channel
Re Reynolds number
Nu Nusselt number
h heat transfer coefficient
Eh enhanced ratio
f friction factor
f/f0 thermal performance factor
Γ molecular thermal diffusivity
Γ_t turbulent thermal diffusivity
ρ air density
u velocity of air in x-direction
v velocity of air in y-direction
w velocity of air in z-direction

1-INTROUDICTIN

Increasing requirements on the performance of heat exchangers such a power system plant, air conditioning plant, electric circuit in electronic chip cooling, vehicle industry and refrigerant application for purpose of compactness, production cost effectiveness and higher efficiency lead to used heat transfer method. Heat exchangers were firstly advanced to usage smooth heat transfer surfaces.

Heat transfer enhancement is the process of raising the effectiveness of heat exchangers. This can be attained, when the heat transfer power of a given a tool is increased or when the pressure losses produced by the tool are reductive. A kind of heat transfer techniques used to influence, including producing a strong secondary flows or augmentation boundary layer turbulence. Heat transfer enhancements are classified into three different types [1]**.**

1-passive type
2- active type
3- compound type

Passive type do not needed to any outside power input. In the convective of transfer of heat, one of the methods to enhance the transfer rate of heat is to augment the active surface region and seat time of the heat transfer fluids. By means of this method causes the whirl in the bulk of fluid and disturbs the real boundary layer, which augments the active surface area, time and heat transfer coefficient in a present system. Active techniques are utilized actively to control the secondary flow and pressure drop to meet the demeaned heat transfer rates even that the cost of improved pumping power. There's little realize used of this approach in heat exchangers since operating cost is very high and compound techniques a compound augmentation approach is the only in which greater than one of the above cited techniques is utilized in combination with the motive of further enhancing the thermo-hydraulic overall performance of a heat exchanger**.**

2-LITERATURE REVIEW

Numerical researchers studied the effects of shapes and positions of vortex generators in heat exchangers:

Wa and Tao.(2007)[2] made a numerical study in three-dimensional and turbulent flow to show the effects of delta winglet vortex generators inside a rectangular channel .Reynolds number 1600 and the angle of attack 30° and 45. Air was used as the working fluid and a constant in heat flux as the boundary condition, numerically simulations using the soft ware ANSYS FLUENT . Results showed that the maximum Nusselt numbers were discovered by increasing in Reynolds number and the angle of attack. Anshuman and singh.(2014)[3] three-dimensional numerical simulations are performed in a rectangular channel with a usage triangular vortex generators .Reynolds number is 1000 and the angle of attack 15°, 30° and 45 .Results showed the vortex generators have more significant on heat transfer and the Nusselt number increased with increasing in Reynolds number , friction factors decreased with increasing in Reynolds number . Amit and Sunil. (2014) [4] presented a numerical study the effects of isosceles triangles as the longitudinal winglet vortex generators inside a rectangular channel and the vortex generators arranged in staggered arrangement in turbulent and three dimensional flow, Reynolds numbers depended on the hydraulic diameter 2000 to 22000 with uniform heat flux under the forced convection, used air as the working fluid and the angle of attack 60°,45° and 30° and the aspect ratio (AR=10), numerical used ANSYS FLENT CFD. Results showed that vortex generators have more significant on heat transfer are compared with channel without a vortex generators. .Saeed and Alireza. (2017) [5]investigated a numerical studied the effects of curved blocks and triangle blocks in a rectangular channel. The blocks arranged in in-inline arrangement and Reynolds numbers varied from 25 to 150, the numerical part used ANSYS FLUENT. Results showed that heat transfer increased with augments in Reynolds number and Nusselt number increased with used the curved blocks are compared to that channel with triangular blocks. Parkpoom and Paranee.(2017)[6] presented a numerical studied in turbulent and three –dimensional flow inside a rectangular channel with used the baffles arranged in –inline arrangement. Reynolds numbers ranged from 12000 to 35000 and the angle of attack 30°,45° and 60.Air was used as the working fluid and it is steady and incompressible flow .Results showed the higher heat transfer rate found at e/H= 0.3 and angle of attack 45° with Reynolds number 12600,Nusslet number increased with increasing in Reynolds number .Farhan et al .(2018)[7] made a numerical studied in turbulent and three-dimensional flow inside an elliptical passage with different rib configurations. Reynolds numbers varied11000, 13500 and 1600 , air was taken as the working fluid and the temperature of surrounding hot air is 673k with inlet air temperature is 300k , different aspect ratios (AR=1,1.3,1.6 and 2).Numerically simulation was done by using ANSYSYS FLUENT version 16.2 .Results showed that for using ribs increasing in coolant air temperature at center line of elliptical passage so decreased in the channel wall temperature .Average Nusselt number and friction factors increased with increasing in Reynolds number.

3- GEMOETRY MODELS , MESH GENERATION AND COVERNING EQUESTIONS

The dimensions of rectangular channel are (60mm x 30mm) and the length of a rectangular channel is L=500mm with winglet vortex generators are 10mmx 3mm x5mm and the angle of attack for winglet vortex generators is taken 90° as show in (figure.1).The material of the channel and the winglet vortex generators are taken as stainless steel.

Mesh generation, ANSYS FLUENT verison18.2Work bench was used and it was used to generated the mesh. Tetra-hard meshing was used for the domain of air and the winglet vortex generators because its usefully for complex geometry and time consuming as show in (figure.2). Refine meshing is need at the near wall of rectangular channel to shows the effects of boundary layers and the sub layer and the number of nodes and elements for the smooth case and the case with solid winglet vortex generators 456871 , 298734, 876532 and 1087652 respectively

the inlet temperature and Reynolds numbers of air inside a rectangular channel were 27°C ,7250,8840 and10300and the outside wall-temperature is fixed at 400c°.And the governing equations, in this study Navier-Stokes equation were used, which are the best equation in fluid dynamic and heat transfer. Navier-Stokes equation is governed by continuity, momentum, and energy equations.

continuity equation[8]

$$\left(\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z}\right)=0 \qquad \ldots(1)$$

momentum equations[9]

X – Component

$$\rho\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)=\rho f_x-\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right) \qquad \ldots(2)$$

Y- Component

$$\rho\left(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}\right)=\rho f_y-\frac{\partial p}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right) \qquad \ldots(3)$$

Z- Component

$$\rho\left(\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}\right)=\rho f_z-\frac{\partial p}{\partial z}+\mu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right) \qquad \ldots(4)$$

4-Validate ANSYS Results for the smooth channel

Its important to ensure the vality and accuracy of the obtained from the numerical data acomparison of the numerical result for Nusselt number with literature P.Sriromreun et al [10] for the case of smooth channel .Figure 3 show the deveiation between the result of present work and literature is around 3.5% for average nusslet number which gives agood indicates to the accuracy of the result .

5- RESULTS AND DISCUSSION

The best results were found at Reynolds number 10300 with boundary condition of working fluid inlet temperature was 27°C and outside channel wall temperature 400c° .Figures (4) and (5) represent the contours of temperature distribution for the working fluid (air) inside the smooth channel (channel without winglet vortex generators) and channel with winglet vortex generators. Winglet vortex generators affected a clear disturbance whenever compared with smooth channel (channel without winglet vortex generators). These winglet vortex generators made a wakens developed into vortices. It's cleared that the temperature was increased in the channel with solid winglet vortex generators are creating the vortices behind the winglet vortex generators which is leaded to disturb the actual boundary layer and enhance in heat transfer.Figures (6) and (7) shows the contour of velocity distribution for the working fluid inside a smooth rectangular channel and channel with winglet vortex generators configuration. The velocity of working fluid was increased and decreased through the channel due to the contraction and expansion for usage a winglet vortex generators.The case (channel with solid vortex generators) is the best one because of this case have a perfect shape to make a more vortices and disturb the boundary layer and this enhance the heat transfer from the channel channel inner wall to the working fluid. Figures (8) and (9) represents the velocity vector along the smooth channel and the channel with winglet vortex generators configuration. Winglet vortex generators caused flow separation and reattachment. The actual boundary layer was disturbs and the turbulence of flow augmented because of the separation and reattachment. This mixing of the working fluid near the wall of channel with the cooler of the working fluid at the centerline of channel caused enhancement in heat transfer. Figure (10) shows the Nu varying with Re for smooth channel and channel with solid trapezoidal winglet vortex generators. Nu increasing with Re.channel with solid trapezoidal the Nusselt number increasing by 46%, 50%and55% with respect to Reynolds number .Figure (11) represented the thermal performance factor(f/fo) varying with Reynolds number .It can be seen that thermal performance factor goes on increasing with increased in Reynolds number. The maximum performance factor was(4.5) found at Re= 10333.

6-CONCOLUISON

In this research the heat transfer and flow characteristics in a rectangular channel with solid winglet vortex generators at different Reynolds number (7250,8840 and 10300) are numerically studied with 400c° the outside wall temperature as a boundary condition and compared with smooth duct case.

1. The temperature of the channel inner –wall decreased by 18.3% with using the vortex generators while the temperature of the working fluid in centerline of channel increased by 13% and this caused increasing in heat transfer .
2- An acceptable increments were happened for the drop of pressure and the friction factors for the case of modified channel.
3- The solid winglet vortex generators caused a good heat transfer enhancement of 45%

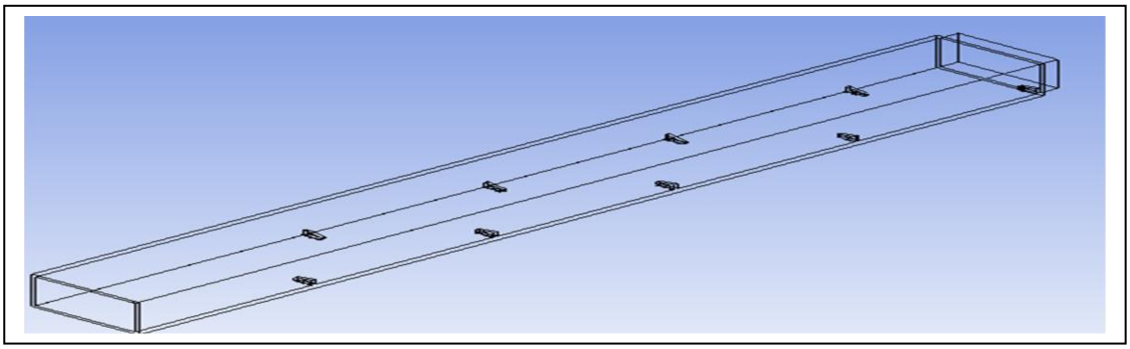
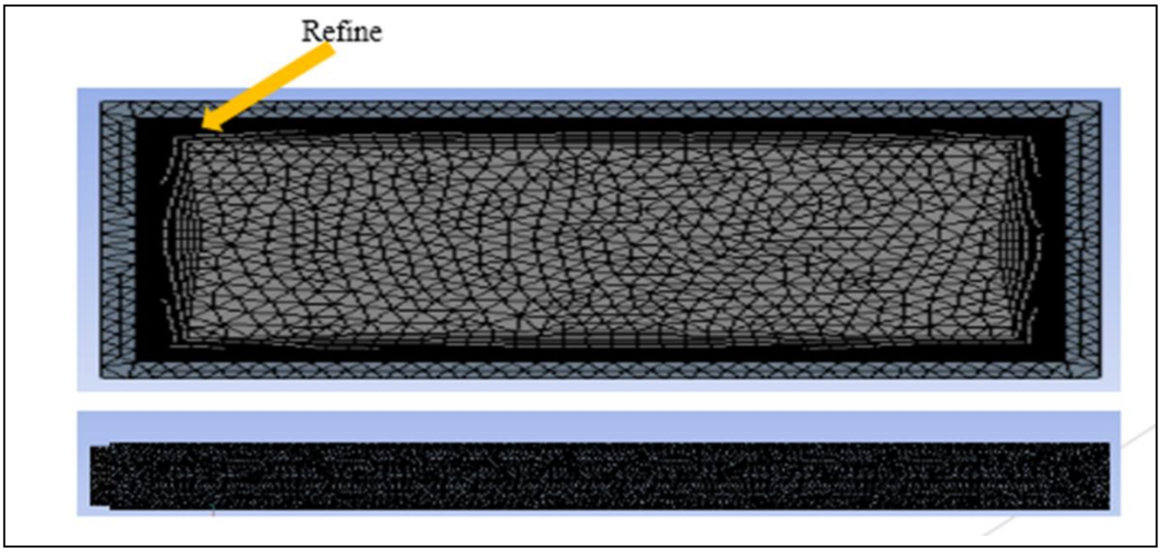


Figure (1):Geometry models for solid trapezoidal inside channel



Figure(2) :Tetra-hard meshing for air, rectangular and winglet vortex generators

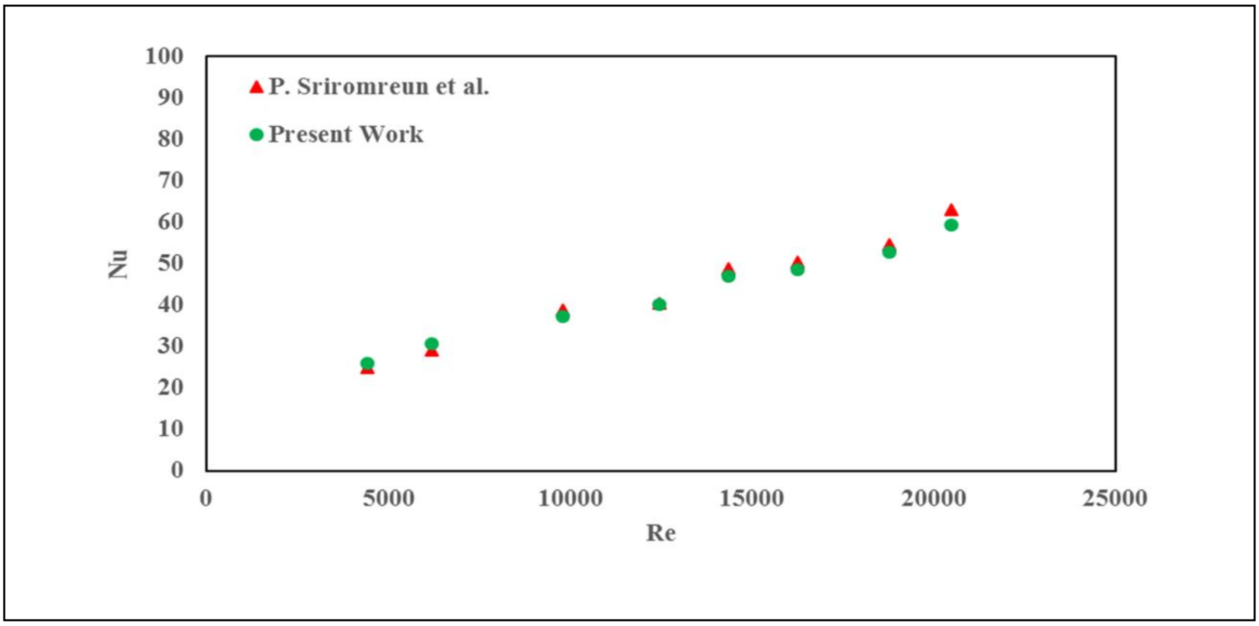


Figure (3): Validation between average Nusselt number with Reynolds number for smooth channel

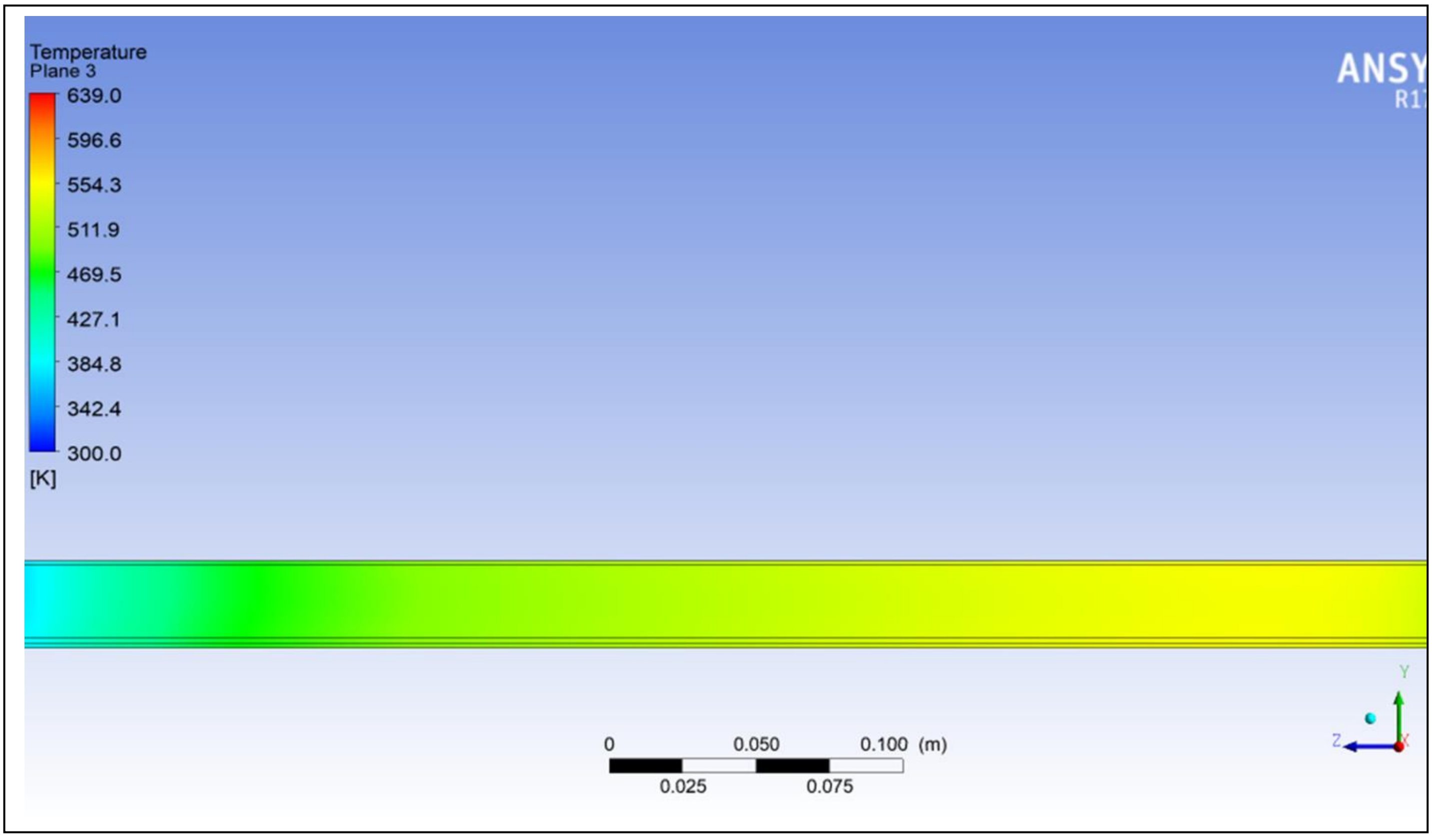


Figure (4):Temperature contour for smooth channel at Re=10300

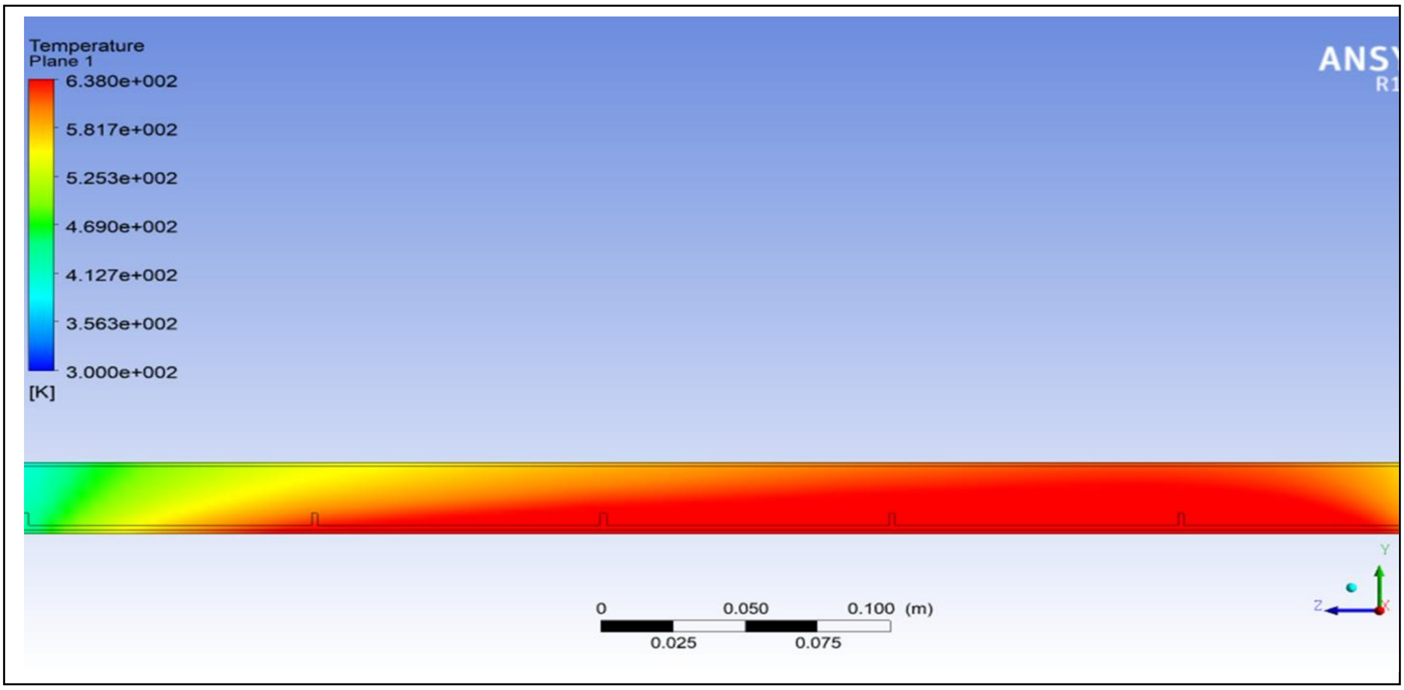
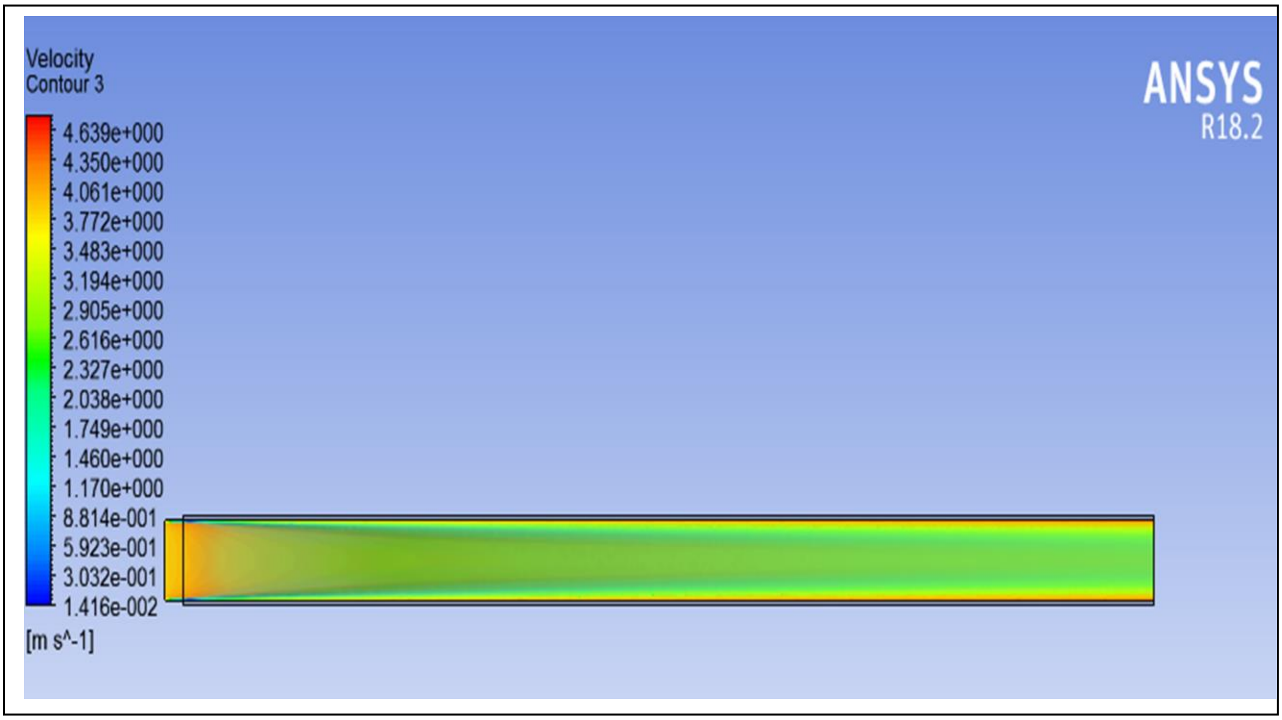
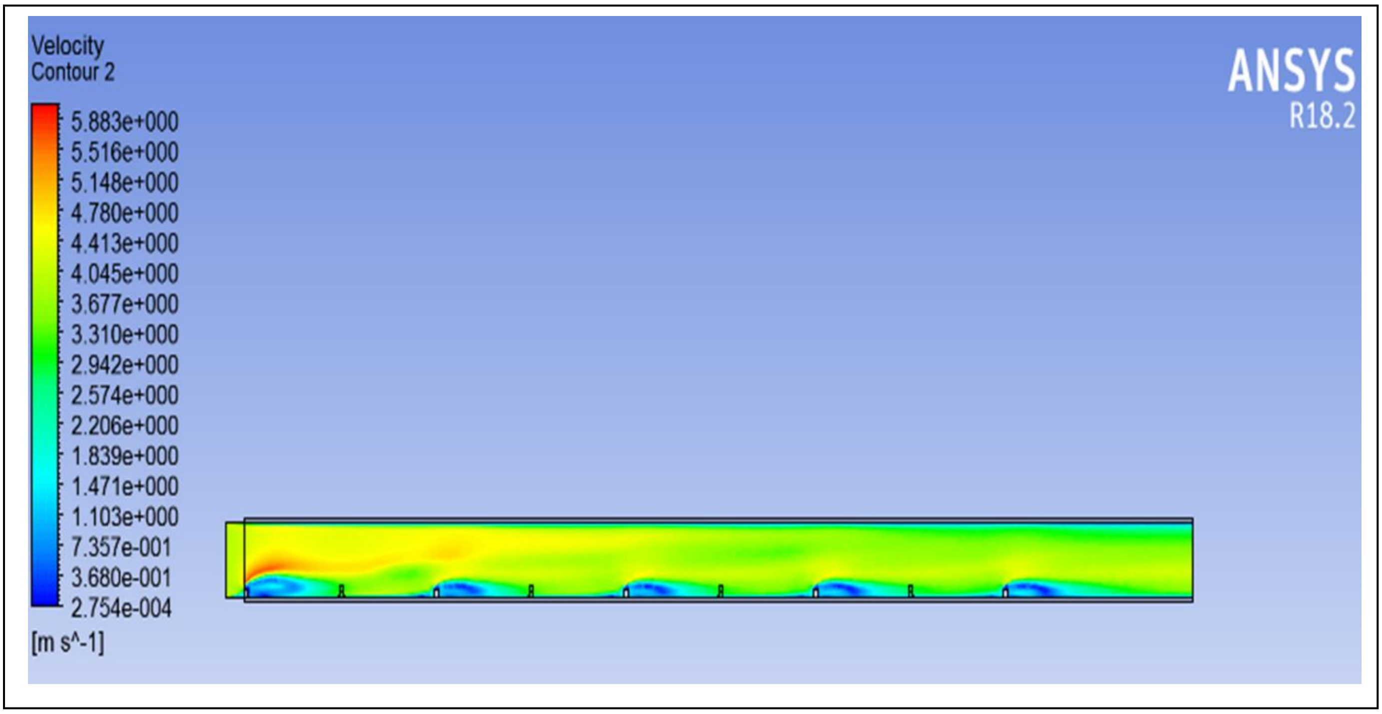


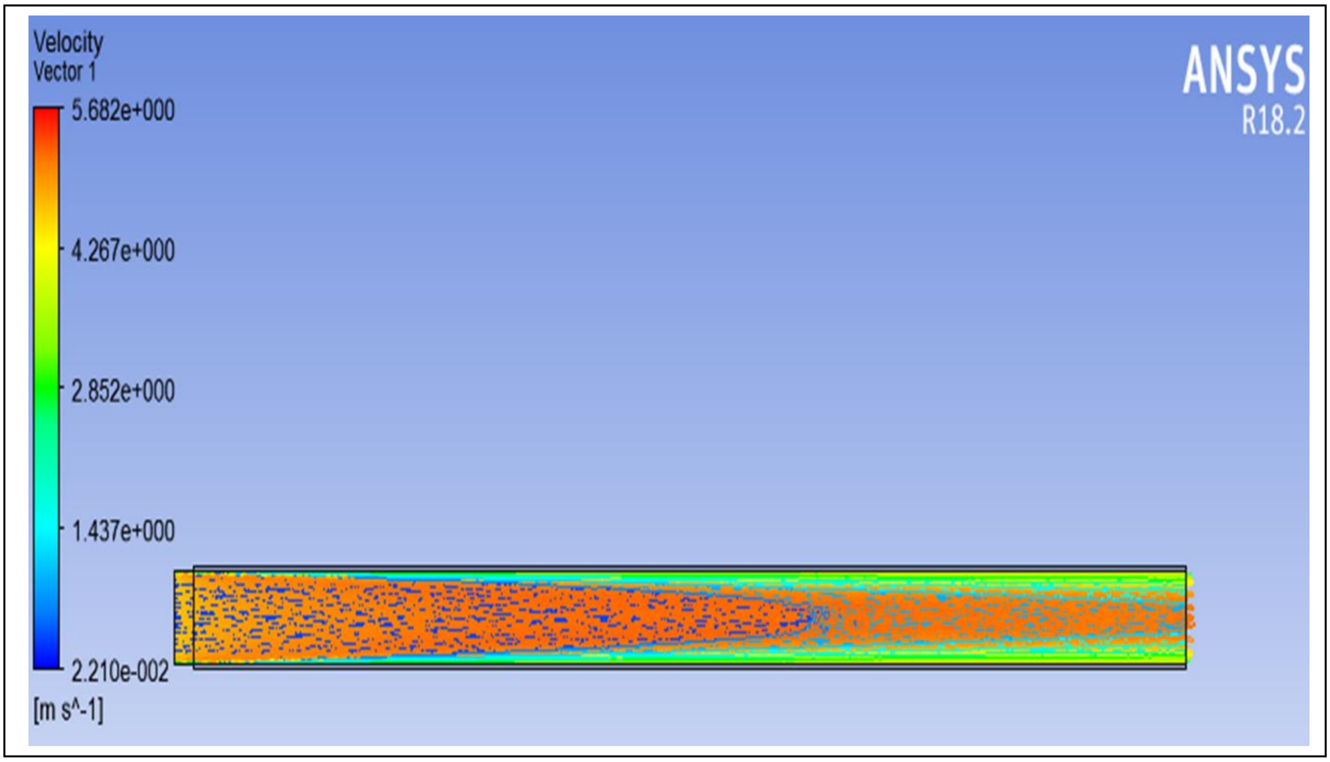
Figure (5):Temperature contour for channel with solid trapezoidal at Re=10300



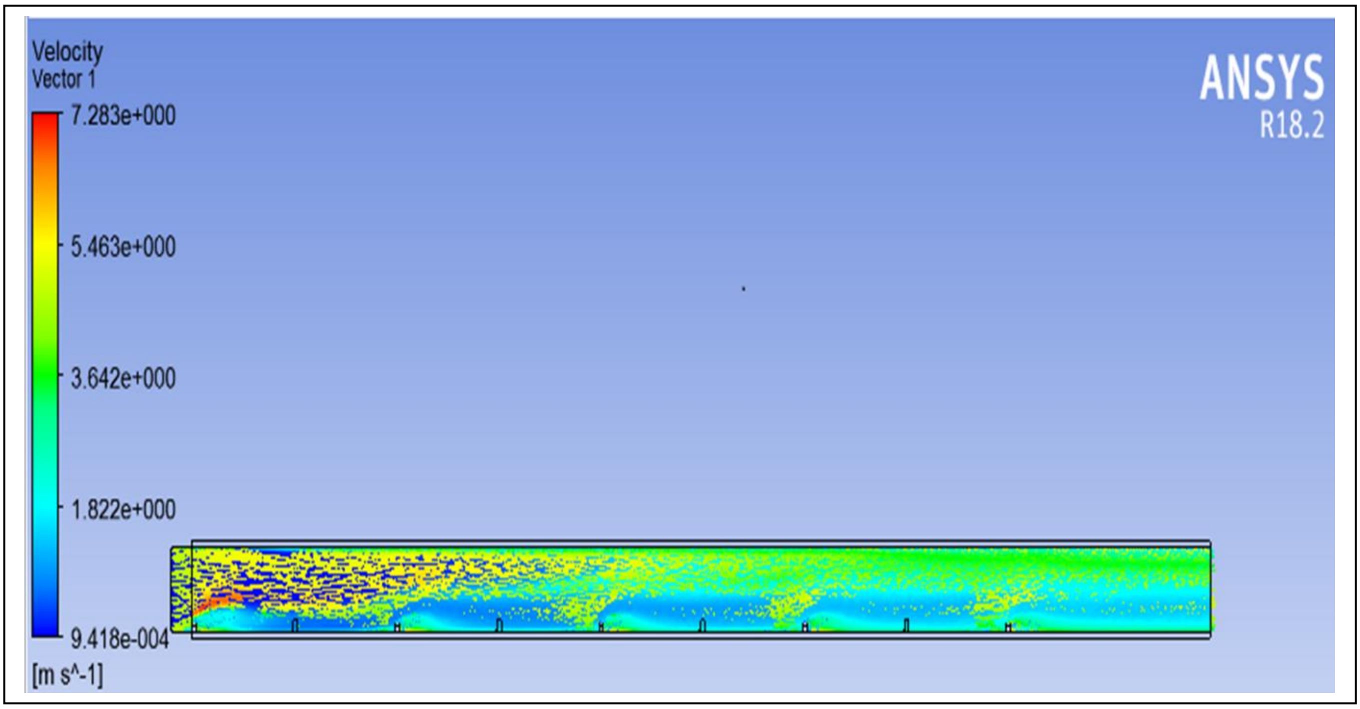
Figure(6):Velocity contour for smooth channel at Re=10300



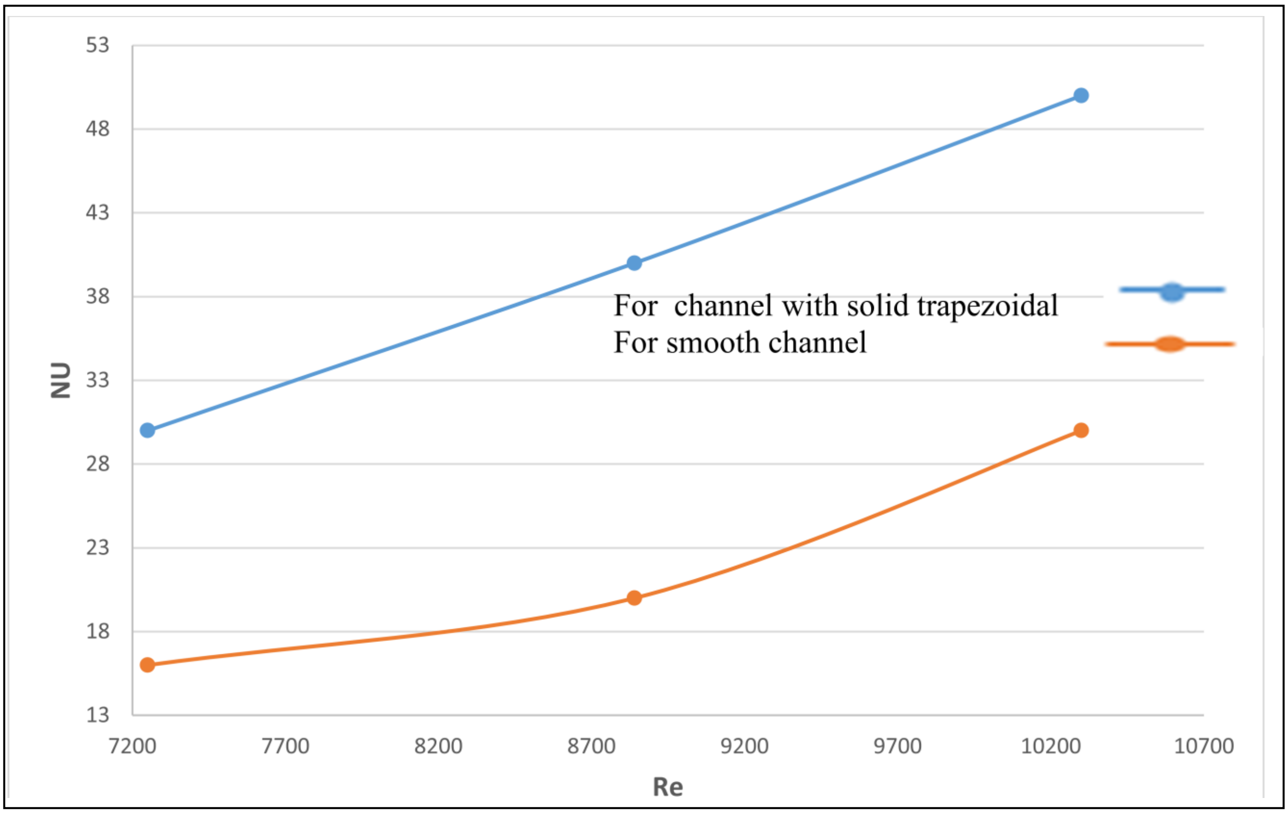
Figure(7) :Velocity contour for channel with solid trapezoidal at Re=10300



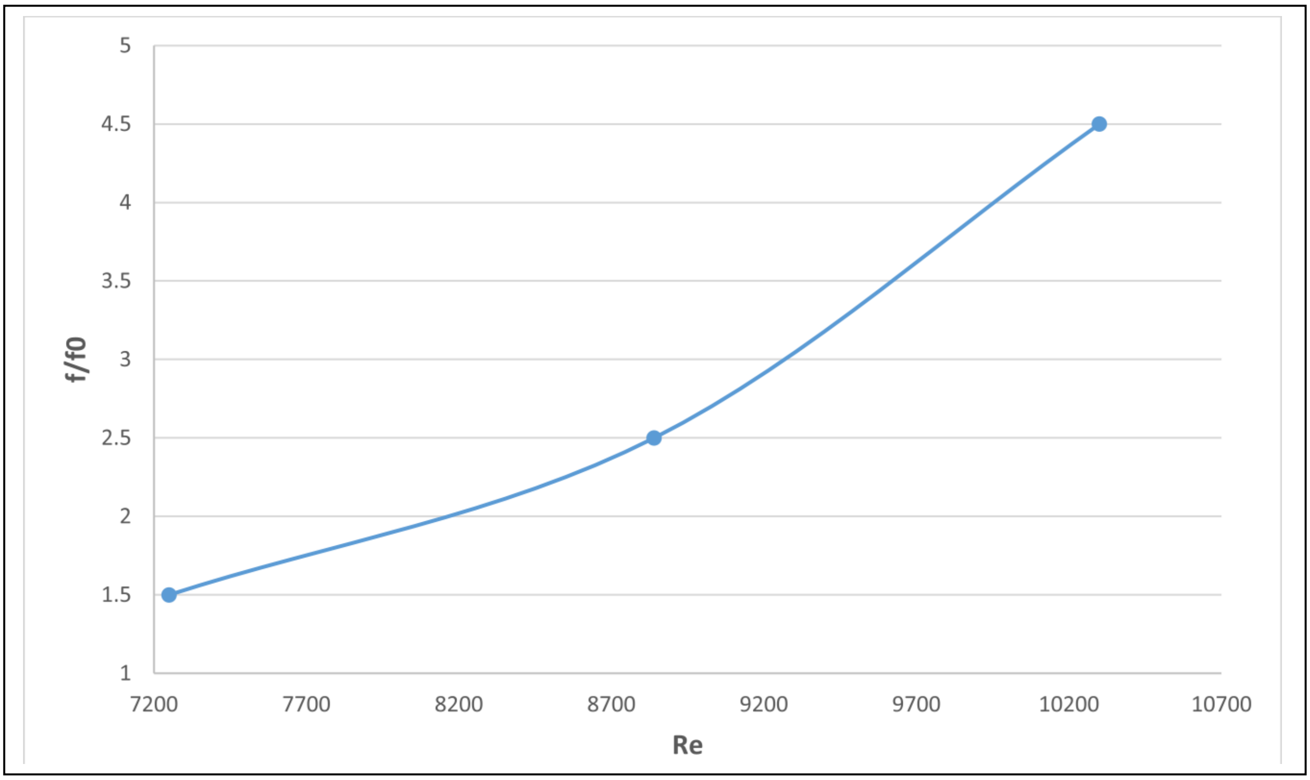
Figure(8) :Velocity vector for smooth channel Re= 10300



Figure(9):Velocity vector for channel with solid trapezoidal at Re=10300



Figure(10) :Nusselt number variation with Reynolds number



Figure(11):Thermal performance factor with Reynolds number

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