HEAT TRANSFER ANALYSIS OF TURBULENT FLOW IN CONICAL DIFFUSER USING INTERNAL SPIRAL SQUARE

تحليل الانتقال الحراري للجريان المضطرب في منشر مخروطي بأستخدام حلزون داخي ذو مقطع عرضي مربع

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Abstract

The work presents a numerical investigation of heat transfer characteristics of conical diffuser with specific dimensions, using internal spiral square rib, with air as the working fluid. The Reynolds number range based on the bulk flow rate and hydraulic diameter is 1.759×10^5 to 4.36×10^5. The conical diffuser was subjected to uniform rates of heat flux and different inlet air velocity(0.02, 0.04 and 0.06) m/s, respectively. Results show that the spiral square rib enhanced heat transfer for (ΔT=40, 38 and 35 K) corresponding to the different inlet air velocity .The data obtained were compared with plain (without rib). The cone with internal spiral square rib was found to possess the highest performance factors for turbulent flow. The heat transfer coefficient enhancement for internal spiral square rib is higher than that for plain cone for a given Reynolds number. The use of internal spiral square rib improved the performance of cone. All studies where carried out using FlUENT14.5 package, by using K-ε model.

Keywords: cooling enhancement, conical diffuser , internal spiral square rib , heat transfer enhancement and turbulent flow.

الخلاصة

تمت في هذا البحث دراسة نظرية لانتقال الحرارة خلال ناشر مخروطي و باستخدام أضلاع داخلية حلزونية مربعة الشكل.المائع المستخدم (الهواء) أخذ مدى رقم رينولد للجريان 4.36×10^5 -$1.759x10^5$ وباستخدام حرارة ثابتة على سطح الناشر وبسرعات مختلفة لمائع التشغيل(0.02, 0.04 , 0.06) m/s على التوالي. وقد أظهرت النتائج إن استخدام الإضلاع الحلزونية ادى الى تحسين انتقال الحرارة للدرجات (ΔT=40, 38 ,35 K) مقارنة بالأنبوب بدون أضلاع. وان استخدام الأضلاع يحسن من معامل انتقال الحرارة مقارنة بالمخروط الأملس ولنفس مدى رقم رينولد في الجريان الاضطرابي. تم استخدام برنامج فلونت 14.5 لكافة الحسابات باستخدام نموذج K-ε .

Nomenclature

A	Heat transfer area, m^2	Cp	Specific heat of air, J/kg.K
D_h	Hydraulic diameter, m	f	Frictional factor
g	Acceleration due to gravity ,m/s^2	h	Heat transfer coefficient, W/m^2 k
p	Pitch of rib, m	h/h_o	Thermal enhancement Factor
L_t	Length of test section, m	R_e	Reynolds number
m	Mass flow rate, kg/s	u	Velocity of flow , m/s
Q	Heat transfer rate, W	ρ	Density of air, kg/m^3
q	Heat transfer per unit area W/m^2	q	Heat flux,w/m^2
μ	Viscosity of air , N s/ m^2		
T	temperature ,K		

Introduction

Among numerous heat transfer enhancement techniques ribs are most widely employed to augment the heat transfer performance inside cooling channels. The mechanism of the heat transfer enhancement by the conventional ribs is based on the flow separation and reattachment as can be well demonstrated by the transverse ribs (ribs perpendicular to the main flow direction) that induce two-dimensional flow phenomenon. When heat is transferred from the wall to the flowing fluid inside the flow channel, fluid temperature in the core region is always lower than that near the wall. Accordingly, if the cold and higher momentum fluid in the central core region of the channel is by some means carried to the hot area near the wall, heat transfer will be enhanced. In other words, if the secondary flow occurs, the thickness of both velocity and thermal boundary layers on the wall where the flow from the channel core region hits will become thinner and the heat transfer in that region will be augmented[1].

Amro et al. [2] conducted an experimental study of heat transfer in a ribbed cooling channel. They show that the rib arrangement for leading edge cooling is a rib with a 45^o angle and double-sided, fully-overlapped ribs in the arc area. The ribs provide uniform heat transfer in the arc area and result in high values for the heat transfer coefficients in the channel. Jia et al. [3] reporting on a numerical analysis of heat transfer enhancement in square ducts with V-shaped ribs. They show that, both downstream and upstream of the bend, V-shaped ribs result in better heat transfer enhancement than transverse straight ribs in ducts. Sewall and Tafti [4] carried a large eddy simulation of a 180^o bend in a stationary ribbed duct. The domain studied includ three ribs upstream and three ribs downstream of the bend region of the bend with an outflow extension added to the end. They found that heat transfer increased with the presence of a rib. Including a ribs in the bend which increases the friction factor by 80%, and it increases the heat transfer augmentation by approximately 20%.

Rajendra Karwa and B. K. Maheshwari [5] study the heat transfer and friction in an rectangular duct with some solid and perforated baffles with relative roughness. For the solid baffle the friction factor was found between 9.6-11.1 times than smooth duct which decreases in perforated baffle.

Prashanta Dutta and Akram Hossain [6] Studied the effect heat transfer local , friction factor and perforated baffles in a rectangular pipe with inclined. Used Two baffles in this experiment, one which mounted at the top and another one varied to identify optimum configuration to enhancement of heat transfer.

C. Yildiz et al. [7] Placed twisted narrow, thin metallic strips in inner pipe of a concentric double-pipe heat exchanger and studied the effect it on heat transfer and pressure drop in parallel and countercurrent flow. These turbulators prepared by twisting the strips through certain angles to touch the inside wall at each step.

Kenan Yakut et al. [8] investigated flow-induced vibration characteristics of conical-ring turbulators for heat transfer enhancement in heat exchangers experimentally. The conical- rings, having 10, 20 and 30 mm pitches, were inserted in a model pipe-line through which air was passed as the working fluid. It was observed that as the pitch increases, vortex shedding frequencies also increased and the maximum amplitudes of the vortices produced by conical-ring turbulators occur with small pitches.

In this paper, the effect of fitting spiral square rib in conical diffuser at constant surrounding air temperature and different inlet air velocity on fluid flow and heat transfer will be investigated.

Governing equation

The continuity equation states the conservation of mass, which for all but nuclear-reaction environments is valid. The conservative form is:

$$\frac{\partial \rho U_i}{\partial x_i} = 0 \qquad (1)$$

The energy equation as displayed above is however seldom used and instead the simplified temperature equation is applied:

$$\frac{\partial \rho C_p U_i T}{\partial x_j} = \frac{\partial}{\partial x_i}\left(\frac{\mu C_p}{\mathrm{Pr}}\frac{\partial T}{\partial x_i}\right) \qquad (2)$$

The heat-transfer rate is the amount of heat that transfers per unit time (usually per second).

$$Q = hA\Delta T \qquad (3)$$

D_h is the hydraulic diameter express as:

$$D_h = \frac{4A}{P} \qquad (4)$$

Reynolds number express as:

$$R_e = \frac{\rho u D_h}{\mu} \qquad (5)$$

The definition of mass flow is important for correlations. Mass flow is defined in equation :

$$m = \rho u A \qquad (6)$$

The energy-balance equation express as follows:

$$Q = mc_p(T_o - T_i) \qquad (7)$$

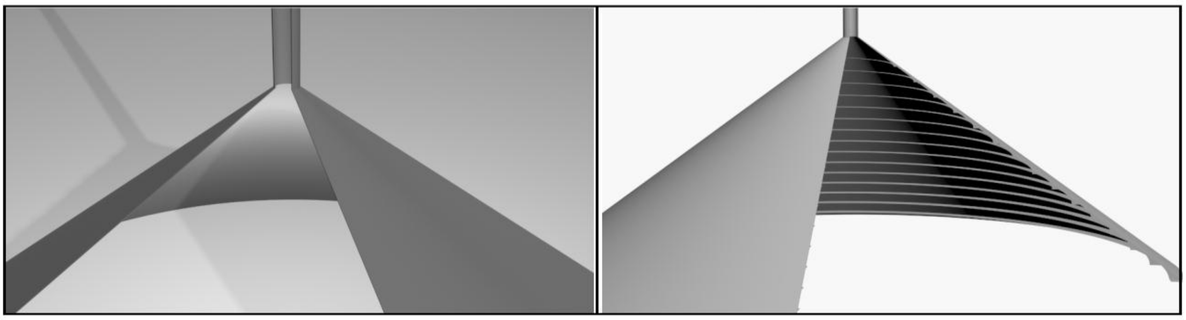
Furthermore ***Q*** is the total heat transferred to air by forced convection and is given by:

$$q = Q / \pi DL \qquad (8)$$

$$h = q/(T_{w,x} - T_{w,bx}) \qquad (9)$$

System Descriptions

The suggested conical diffuser is of 1.2 cm thickness, 150 cm inlet diameter and 75 cm cone height. The pipe which connected to the cone is of 150 cm height with diameter of 3 cm. Another conical diffuser was suggested and simulated which contain a spiral of square cross section (0.5x0.5) cm and 3 m pitch as shown in Figure (1).



A B

Fig. (1): Simulated conical diffuser : A. smooth cone
B. Spiral cone

Boundary Conditions

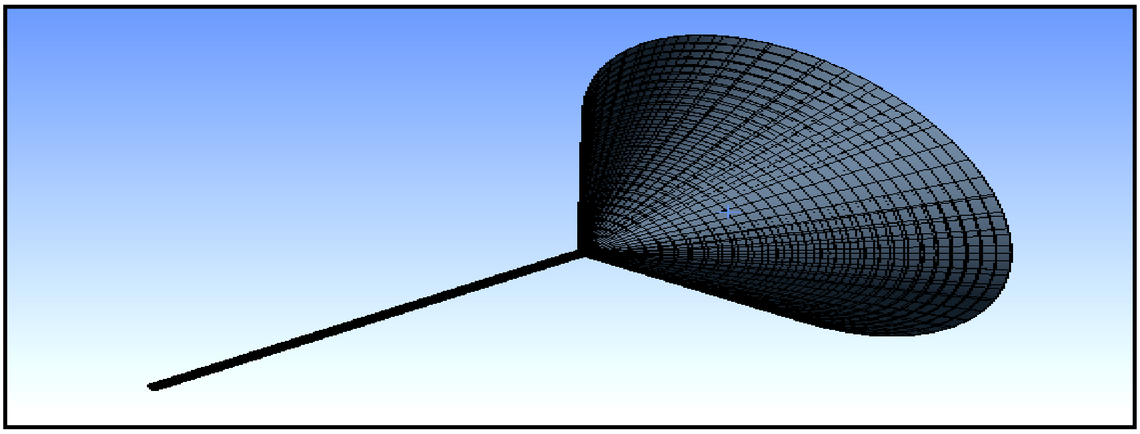
Fluid inlet boundary conditions

Air enters a computational domain is specified to have a uniform velocity values of (0.02, 0.04 and 0.06) m/s. The coolant air inlet temperature is specified to be (300 K). The velocity component in the y and z directions is considered to be zero.

Fluid outlet boundary conditions

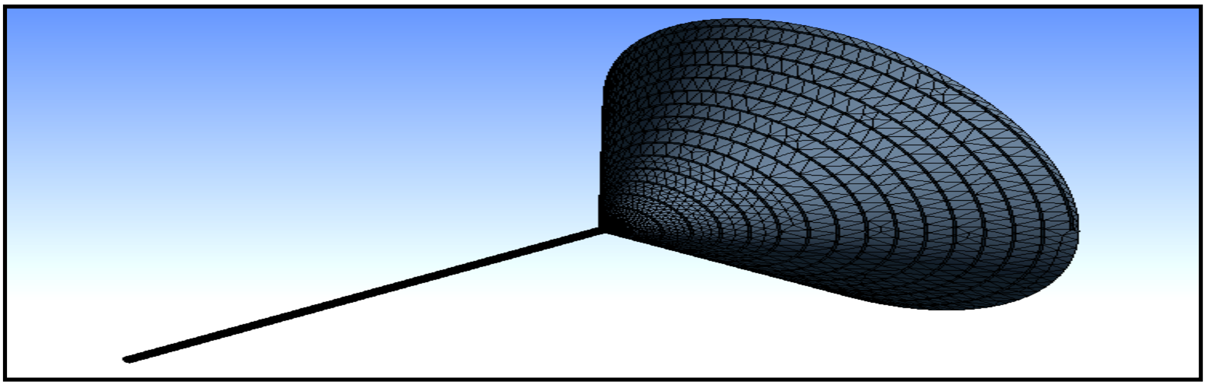
The outlet boundary condition were determined using FUENT 14.5, including: temperature for coolant air at diffuser centreline and air velocity at diffuser centreline.

Mesh Generation



Volume meshing can be done by two ways of approaches in, structured and unstructured meshing. ANSYS-FLUENT can use grids comprising of tetrahedron or hexahedron cells in three dimensions. The type of mesh selection depends on the application as shown in Fig. (2).

a.Smooth cone



b. Spiral cone

Fig.(2): Mesh generation: a. smooth cone, b. spiral cone

Results and Discussion

Temperature Distribution

Figures (3, 5 and 7) present contour of air temperature distribution through smooth conical diffuser at surrounding air temperature of (315 K) and inlet air flow velocity of (0.02, 0.04 and 0.06) m/s, respectively. Air temperature distribution at conical diffuser centerline remains constant till the cone exit and increased near the wall.

Figures (4, 6 and 8) present contour of air temperature distribution through ribbed conical diffuser at surrounding air temperature (315 K) and inlet air flow velocity of (0.02, 0.04 and 0.06) m/s, respectively. It was shown that air temperature at the cone centerline was remain un-effected and increasing near the wall , this because of circulation generation and hence enhances heat transfer.

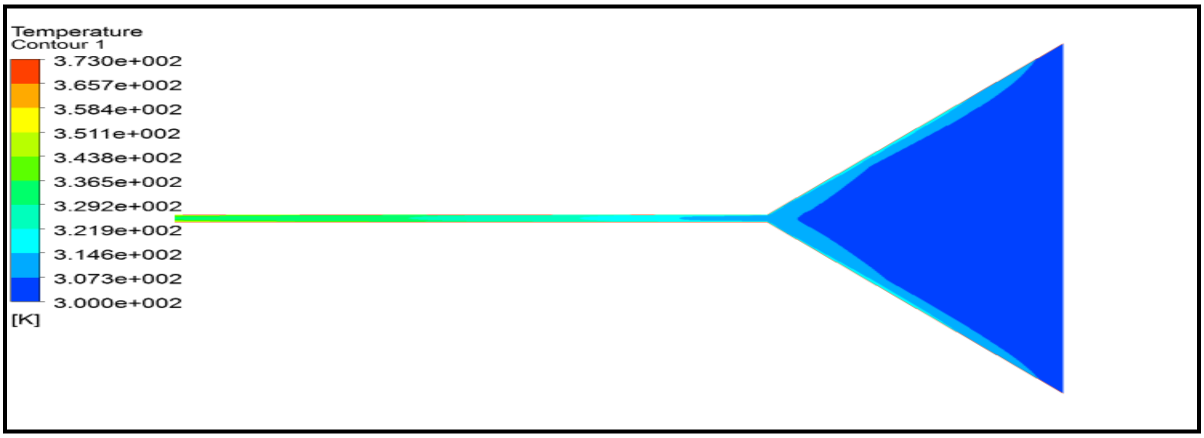


Figure (3): Contour of temperature distribution for smooth cone (without rib) at inlet air velocity 0.02 m/s

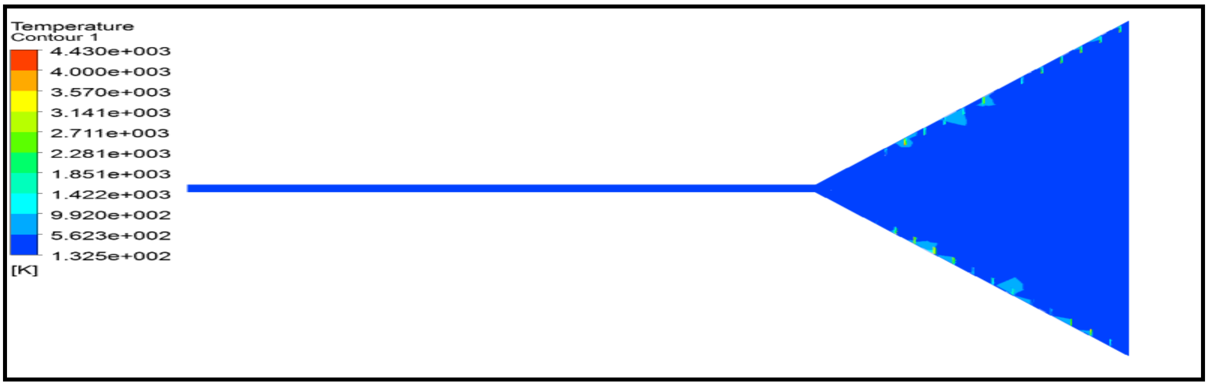


Figure (4): Contour of temperature distribution for cone with spiral square rib at inlet air velocity 0.02 m/s

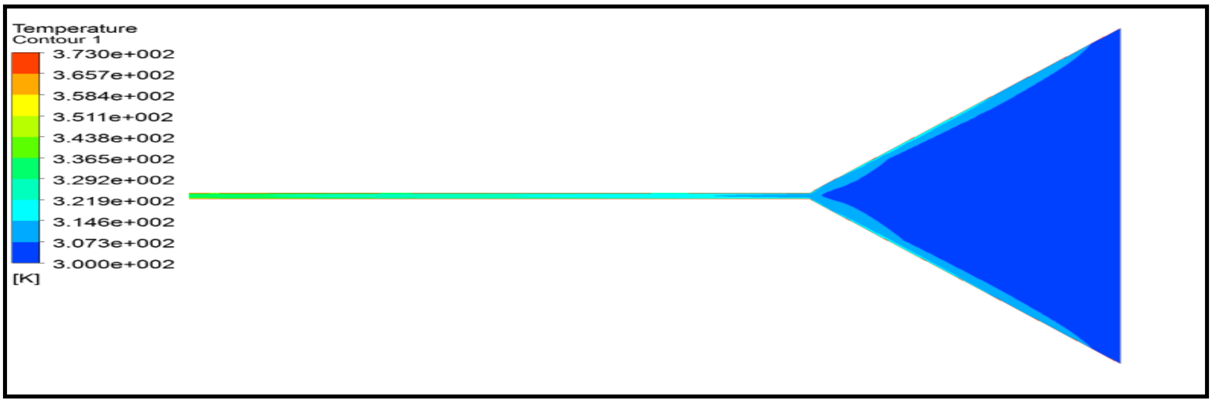


Figure (5): Contour of temperature distribution for smooth cone (without rib) at inlet air velocity 0.04 m/s

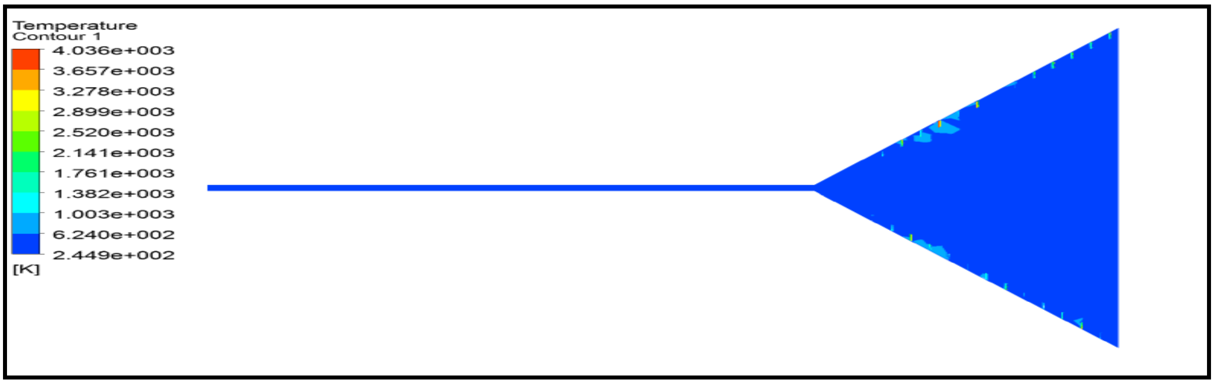


Figure (6): Contour of temperature distribution for cone with spiral square rib at inlet air velocity 0.04 m/s

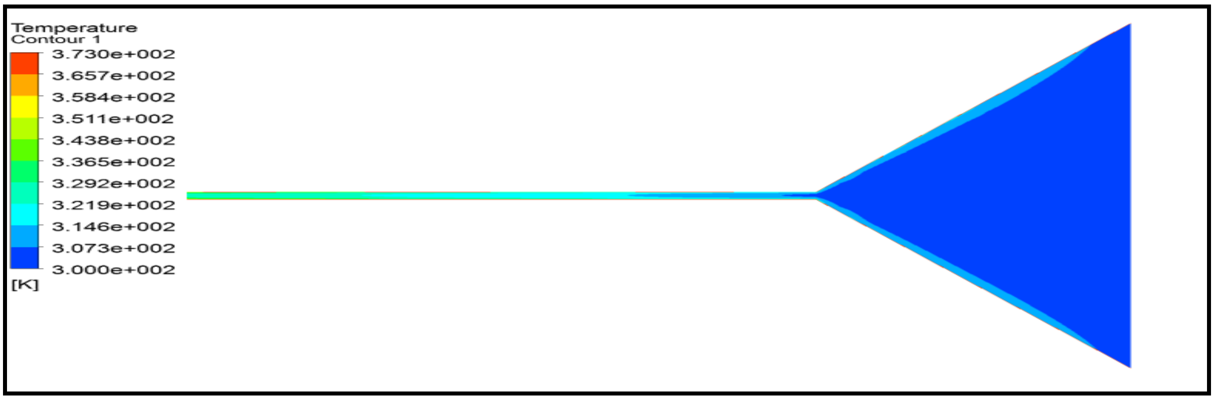


Figure (7):Contour of temperature distribution for smooth cone(without rib)with inlet air velocity of 0.06 m/s

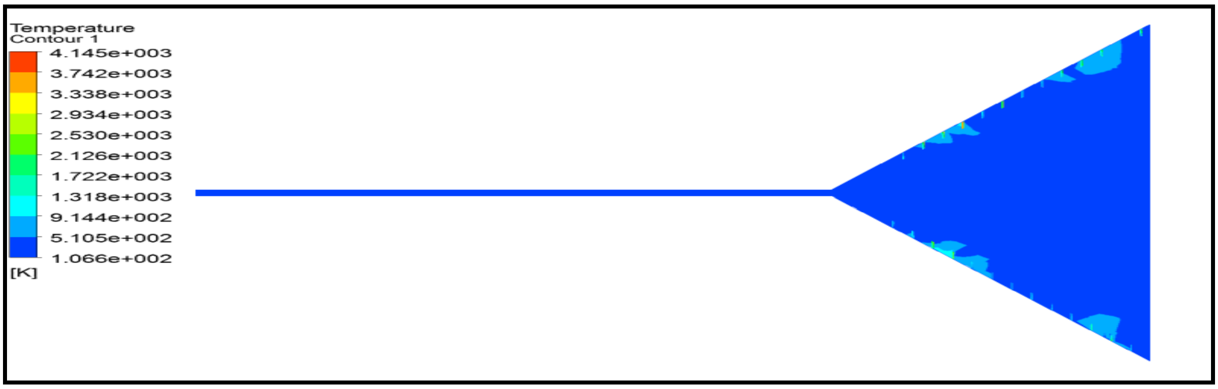


Figure (8): Contour of temperature distribution for cone with spiral square rib at inlet air velocity 0.06 m/s

Velocity Distribution

Figures (9, 11 and 13) show contour of velocity distribution through smooth conical diffuser at surrounding air temperature of (315 K) and inlet air flow velocity of (0.02, 0.04 and 0.06) m/s, respectively. It was shown that air velocity through the cone remains constant and suddenly increased in the throat.

Figures (10, 12 and 14) present contour of velocity distribution through ribbed conical diffuser with spiral at surrounding air temperature of (315 K) and inlet air flow velocity of (0.02, 0.04 and 0.06) m/s, respectively. Vortex was generated because of spiral and thus generating disturbance which enhances heat transfer rate.

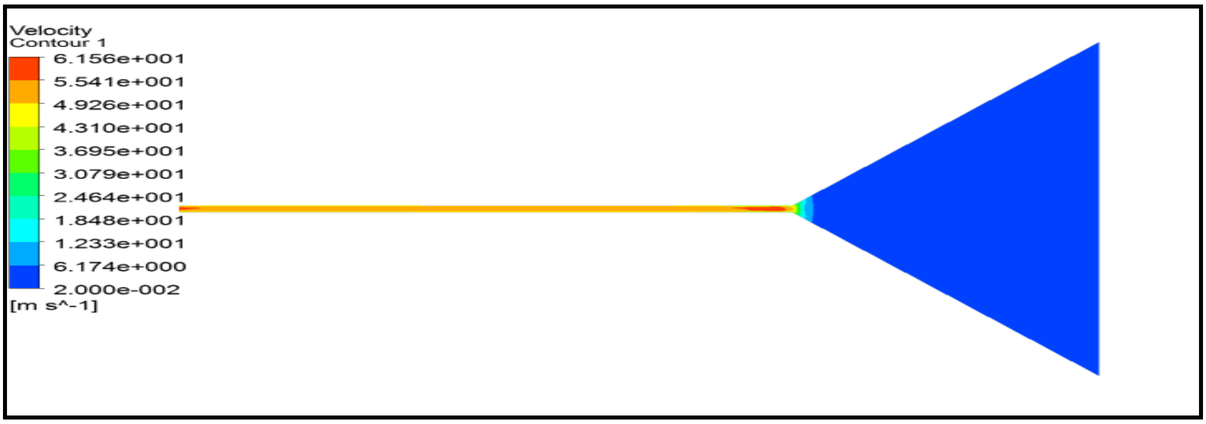


Figure (9): Contour of velocity distribution for smooth cone (without rib) at inlet air velocity 0.02 m/s

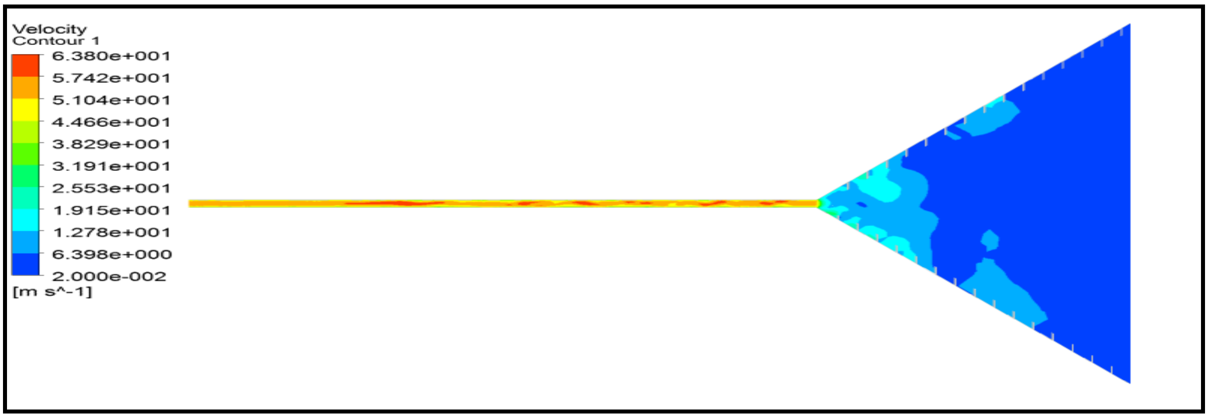


Figure (10): Contour of velocity distribution for cone with spiral square rib at inlet air velocity 0.02 m/s

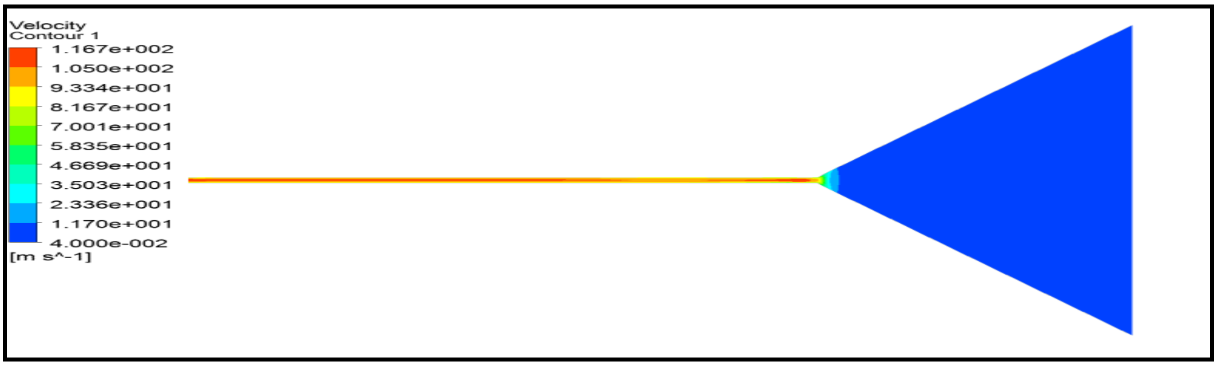


Figure (11): Contour of velocity distribution for smooth cone (without rib) with at air velocity 0.04 m/s

Figure (12): Contour of velocity distribution for cone with spiral square rib at inlet air velocity 0.04 m/s

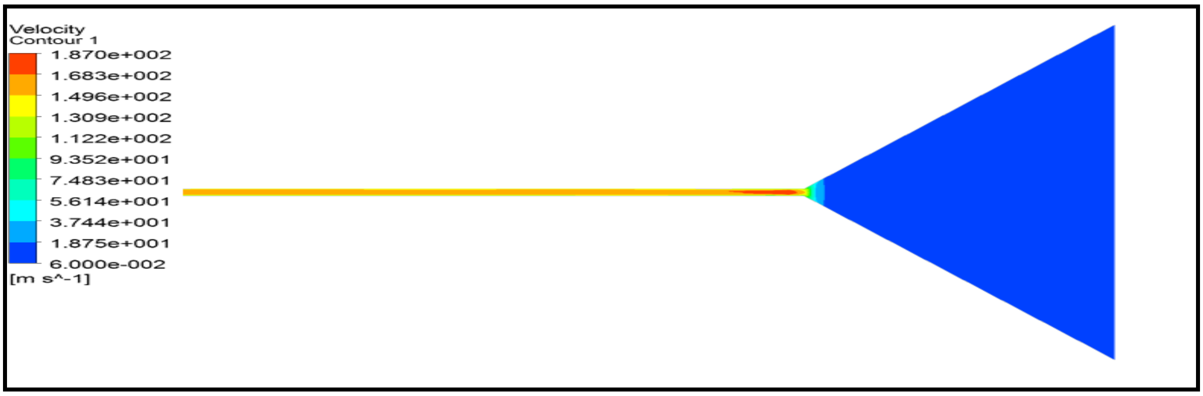


Figure (13): Contour of velocity distribution for smooth cone (without rib) at inlet air velocity 0.06 m/s

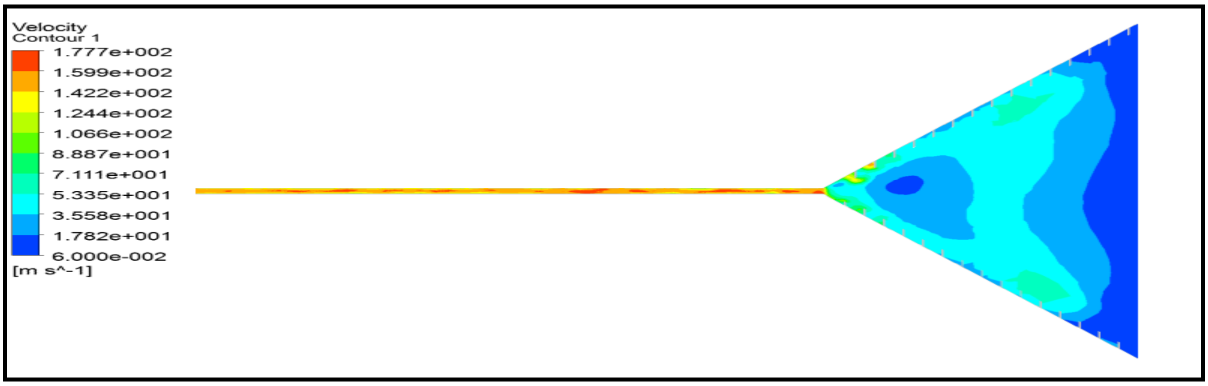


Figure (14): Contour of velocity distribution for cone with spiral square rib at inlet air velocity 0.06 m/s

Figures (15, 16 and 17) present temperature distribution at cone centerline compared with smooth cone (without spiral) at surrounding air temperature of (315 K)and inlet air flow velocity of (0.02, 0.04 and 0.06) m/s, respectively. Air temperature for cone with spiral be larger than smooth cone because ribs making wakes which developed to vortices this lead to increase the heat transfer from the pipe wall to the air stream i.e. increasing air temperature , the difference between the inlet and outlet temperature for smooth and ribbed cone is (ΔT=40 K)

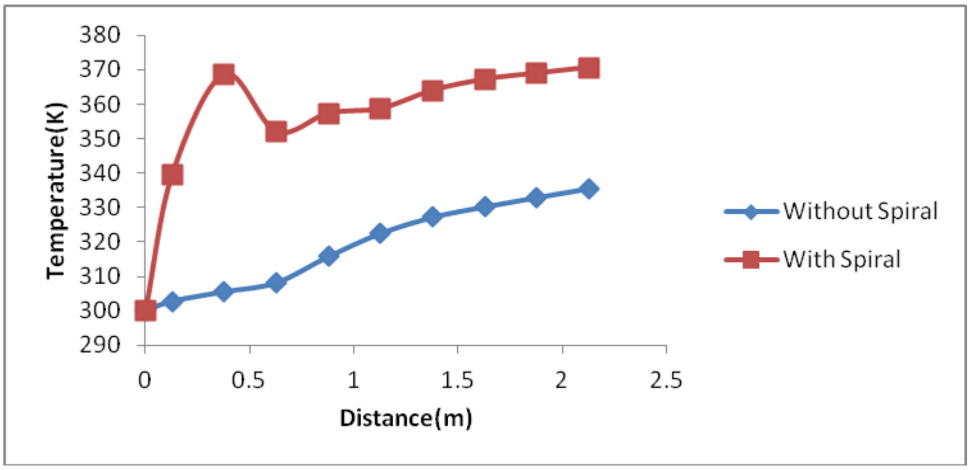


Figure (15): Temperature distribution along cone centerline for inlet air velocity of 0.02 m/s

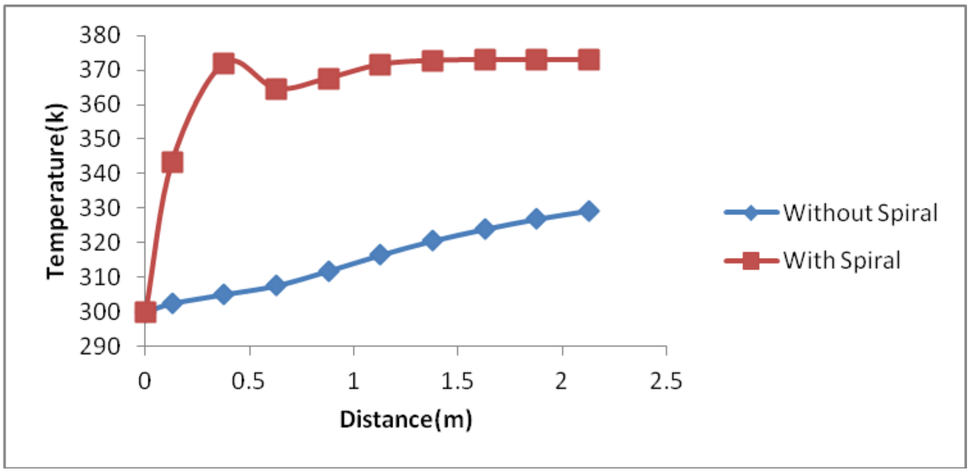


Figure (16): Temperature distribution along cone centerline for inlet air velocity of 0.04 m/s

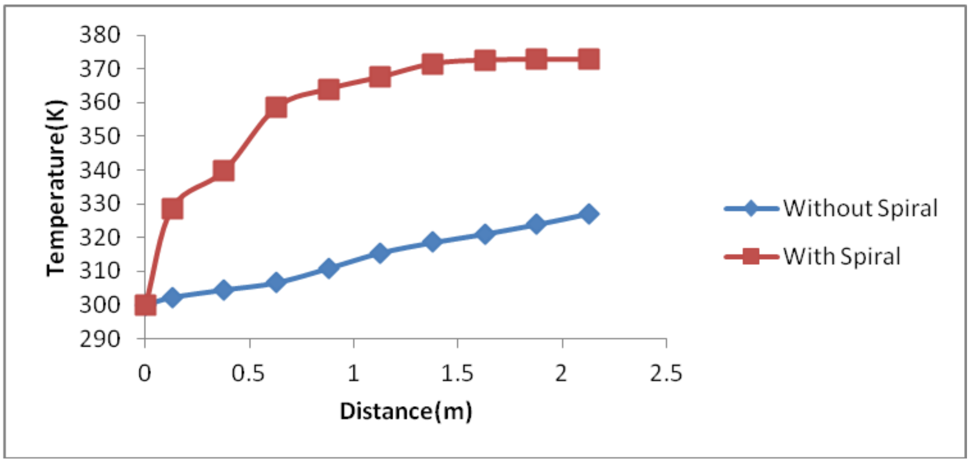


Figure (17): Temperature distribution along cone centerline for inlet air velocity of 0.06 m/s

Figures (18, 19 and 20) present air velocity along the ribbed(spiral) cone centerline compared with smooth cone (without spiral) at inlet air velocity of (0.02, 0.04 and 0.06) m/s, respectively and surrounding air temperature of (315 K). It was shown that increases inlet air velocity increases air velocity through the cone.

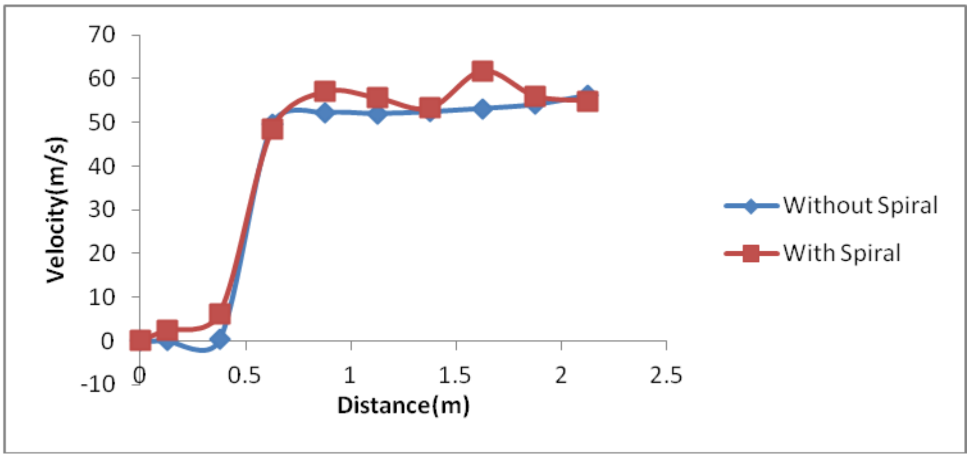


Figure (18): Velocity distribution along cone centerline for inlet air velocity of 0.02 m/s

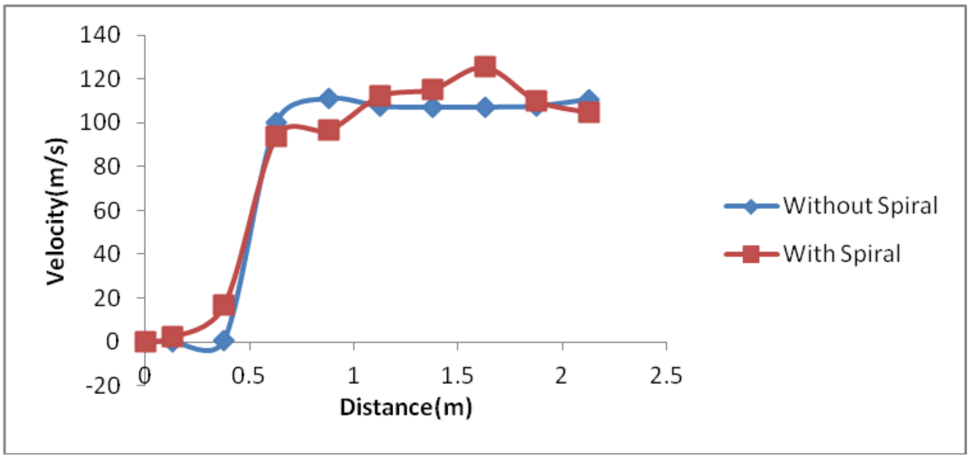


Figure (19): Velocity distribution along cone centerline for inlet air velocity of 0.04 m/s

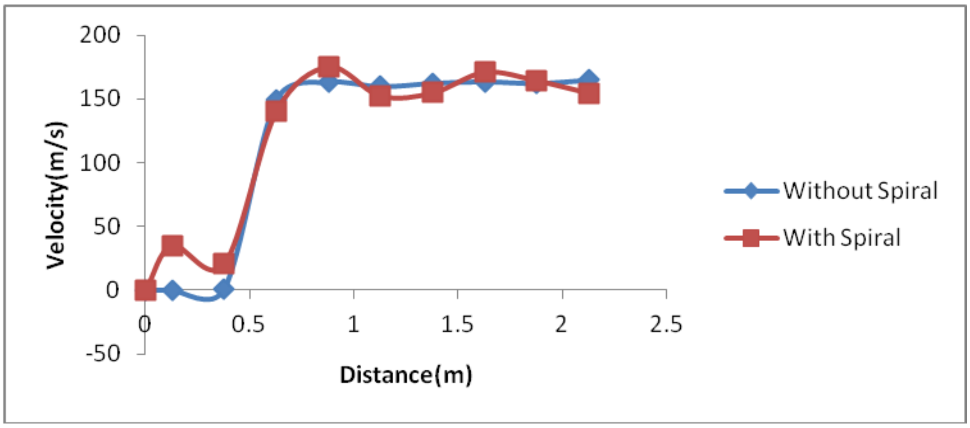


Figure (20): Velocity distribution along cone centerline for inlet air velocity of 0.06 m/s

The overall thermal performance (h/h_o) is shows in figures (21, 22 and 23) for inlet air velocity of (0.02, 0.04 and 0.06) m/s, respectively. The maximum value of thermal performance (h/h_o) is (3.9) at inlet air velocity (0.06) m/s ,because the maxing and turbulent flow. The thermal performance is greater than 1, meaning that the spiral performance always exceeds the smooth cone.

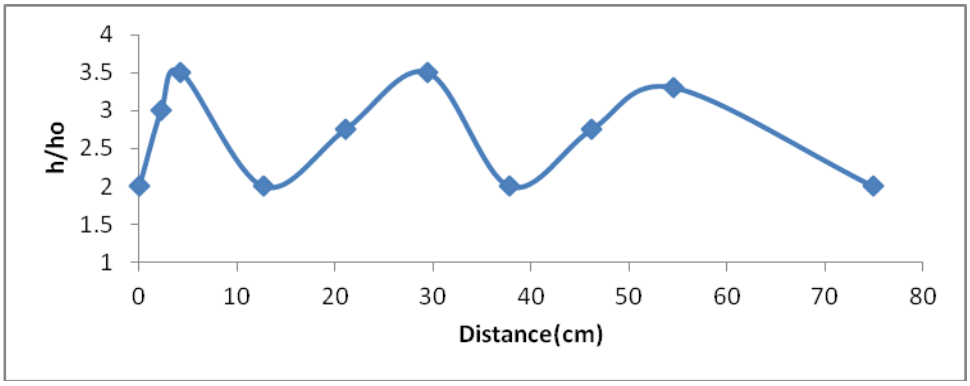


Figure (21): Thermal performance(h/h_o) for inlet air velocity of 0.02 m/s

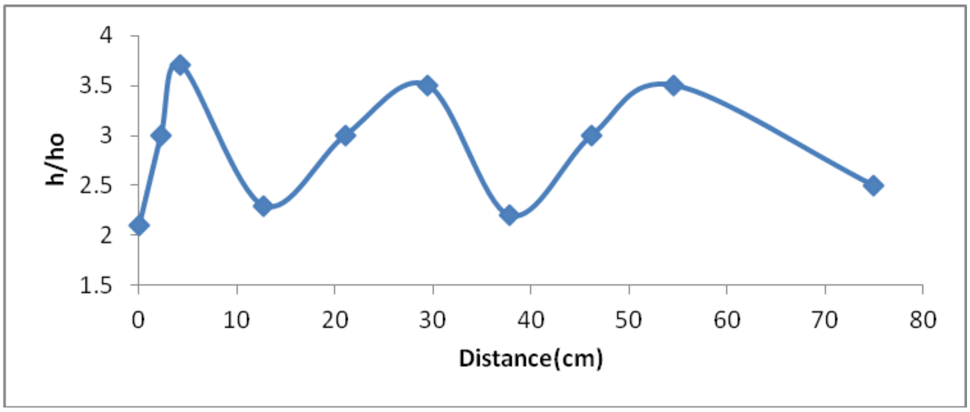


Figure (22): Thermal performance(h/h_o) for inlet air velocity of 0.04 m/s

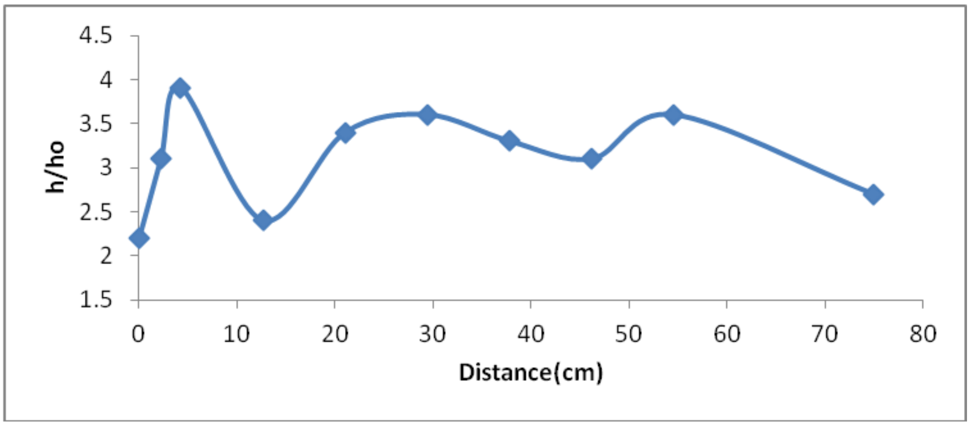


Figure (23): Thermal performance (h/h_o) for inlet air velocity of 0.06 m/s

Conclusions

From the present work the following conclusions were obtained:

1. Heat transfer was enhanced by increase ,12.69, 12.06 and 11.11 % in spiral cone at surrounding air temperature of (315K) and air flow velocity (0.02, 0.04 and 0.06) m/s, respectively.
2. Using spiral square rib enhances heat transfer coefficient more than smooth cone ,this because spiral will generate vortex enhances heat transfer.
3. The maximum value of thermal performance (h/h_o) is (3.9) at inlet air velocity (0.06) m/s , more than the other inlet velocities.
4. Increases inlet air velocity decreases air temperature at the cone centerline.
5. Using spiral square rib enhances fluctuation in air velocity and thus enhances heat transfer rate because of mixing effect and turbulence.

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