A study on the heat transfer enhancement for air flow through a duct with various rib inserts (Review)

Pradip Ramdas Bodade
Research Scholar
Department of Mechanical Engineering, SIRT Bhopal

Dinesh Kumar Koli
Assistant Professor
Department of Mechanical Engineering SIRT Bhopal

Abstract-Many industries are utilizing thermal systems wherein overheating can damage the system components and lead to failure of the system. The excessive heat so generated must be dissipated to surroundings to avoid such problems for smooth functioning of system. This is especially important in cooling of gas turbine blades, process industries, cooling of evaporators, thermal power plants, air conditioning equipments, radiators of space vehicles and automobiles and modern electronic equipments. In order to overcome this problem, thermal systems with effective emitters such as ribs, fins, baffles etc. are desirable. The need to increase the thermal performance of the systems, thereby affecting energy, material and cost savings has led to development and use of many techniques termed as "Heat transfer Augmentation". This technique is also termed as "Heat transfer Enhancement" or "Intensification". Augmentation techniques increase convective heat transfer by reducing the thermal resistance in a heat exchanger.

Many heat augmentation techniques has been reviewed, these are (a) surface roughness, (b) plate baffle and wave baffle, (c) perforated baffle, (d) inclined baffle, (e) porous baffle, (f) corrugated channel, (g) twisted tape inserts, (h) discontinuous Crossed Ribs and Grooves. Most of these enhancement techniques are based on the baffle arrangement. Use of Heat transfer enhancement techniques lead to increase in heat transfer coefficient but at the cost of increase in pressure drop.

This review paper is based on different types of baffles and their different arrangements. Studies show that there are some economical heat transfer enhancement techniques.
.Keywords – Enhancement, Baffles heat transfer and turbulent flow.

I. INTRODUCTION

Heat transfer enhancement or heat transfer intensification is of very importance in the applications of thermal systems where overheating can damage the components or assemblies of the system. Hence, in order to avoid such type of problems, some heat transfer intensification techniques are being used in industrial applications. There are following three methods for heat transfer enhancement;

1. *Active method* – In this method, some external power source is required to enhance the heat transfer e.g. induction pulsating of cam and reciprocating plunger, use of magnetic field to disturb particles of flowing fluid, stirring the fluid or vibrating the fluid.
2. *Passive method*- Here no external power is required for augmentation e.g. treating surface, roughness surface, external surface, using various inserts.
3. *Compound method*-This method is based on combination of active and passive methods. .

Passive method:

Passive method is widely used to intensify the heat transfer as no external power is required. In this method, modification of the surface and the geometry of the duct is used. However, for augmentation of heat transfer use of resistance to fluid flow is required. This method is used in designing of nuclear reactors, heat exchanger, in industries

II. DIFFERENT METHODS OF INTENSIFICATION:

Following are the methods used to enhance the heat transfer

II.I Surface Roughness:

Soo Wban Abn and Kang Pil Son [1] found that the heat transfer can be enhanced by the use of rough surfaces. Four different shapes such as semicircle, sine wave, trapezoid, and arc were suggested to investigate the heat transfer enhancement and friction factor on rectangular duct. They measured the friction factor and heat transfer enhancement on smooth duct and compared it with the results. Square shape geometry gave the highest value because of its strongest turbulence mixing caused by rib. Non circular ducts such as equilateral triangle, Square and rectangular ducts have lower frictional factors and heat transfer as compared to circular ducts this increase in the friction factor and heat transfer depends upon properties and size of the fluid molecules

II.II Baffle

Hamidou Benzenine , Rachid Saim and Said Abboudi, Omar Imine [2] studied that the turbulent flow can increase heat transfer in complicated component such as design of nuclear reactors, heat exchangers, cooling industrial machine and electronic components . Various authors studied turbulent flow produced due to baffle for heat transfer augmentation *Wilfried et al* [1] Authors focused on impact of baffle on the heat transfer and geometry of heat exchangers. *Rajendra et al.* [2] calculated the heat transfer and friction factor on asymmetrical rectangular pipe with perforated baffle. *Gupta et al.* [3] used helical shaped baffles, thermal and hydrodynamics parameters were investigated. *Yong-Gang Lei et al.* [4] studied flow passing thought a channel with only single helical baffle.

A comparative study between three different channels was conducted by the authors. In the first case, a channel without any baffle was examined. In the second case, the same channel with only one helical baffle was considered. And in the third case, the same channel with two helical baffles was examined. *Kang-Hoon et al.* [5] determined the mean heat transfer coefficients in a rectangular channel with porous obstacles. From this work, it can be concluded that use of porous baffles increase heat transfer as compared to no baffle. *Molki and Mostoufizadeh*[7]] evaluated heat transfer and pressure losses in a rectangular channel with baffles. The author concluded that baffles raise the pressure losses as well as heat transfer coefficients.

Thermo hydraulic parameters in a rectangular channel which were heated by perforated fins of different heights were investigated .The effects of turbulent flow with rectangular pipe containing the different shapes of baffles were studied.

Schematic diagram of the experimental setup.

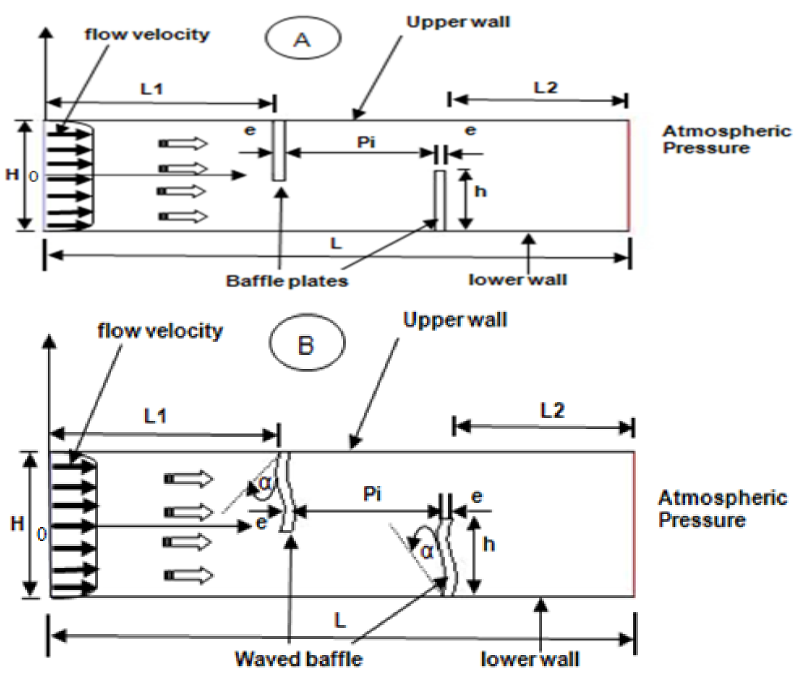


Figure. The geometry of the system under investigation
(A) Plate baffles (B) Waved baffles

II.III Perforated baffle:

Rajendra Karwa and B. K. Maheshwari [3] studied the heat transfer and friction in an asymmetrical rectangular duct with some solid and perforated baffles with relative roughness. The friction factor for the solid baffle was found between 9.6-11.1 times than smooth duct which decreases in perforated baffle. The baffle which has an open area gives the highest heat transfer. Maheshwari [1] examined the effect of change in pitch ratio and open area on mass transfer. Perforated baffle has 47% mass transfer which is greater than that of solid baffle i.e 26 %. Hwang and Liou[2] calculated the heat transfer and friction factor in rectangular pipe using solid and fully perforated baffles. For solid rib, nusselt number ratio (nu/nus) was increased with increase in roughness and then decreases, vice versa in case of perforated rib. Tanasawa et al. [3] studied half perforated rib situated on two opposite wall of rectangular duct. Half perforated baffle has greatest heat transfer effects than solid and fully perforated baffle. The nusselt number increases for fully perforated baffle while friction factor is 2.98-8.02 times than that is for smooth duct. However, nusselt number and friction factor ratio increases with decreasing roughness pitch from 28.8 to 7.2.

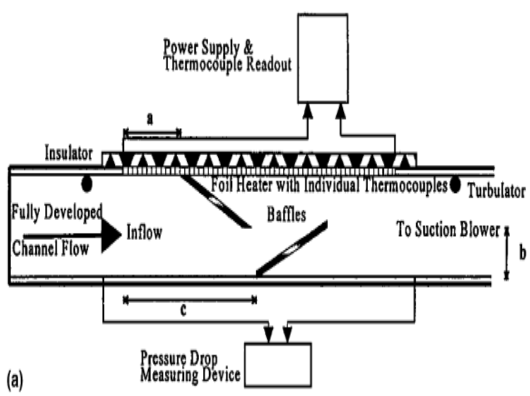
II. IV Inclined baffle :

Prashanta Dutta and Akram Hossain [4]

Studied the the effect of local heat transfer and friction factor in a rectangular pipe with inclined and perforated baffles. Two baffles were used in this experiment, one was mounted at the top and another one varied to identify optimum configuration for enhancement of heat transfer. Relevant article by Sparrow and Tao (1983) on augmentation of heat transfer by insert rod. Chandra and coworkers experimentally investigated the heat transfer and friction factor by varying number of ribs.

Heat transfer augmentation was studied in a fully developed square channel with V-shaped rib. (Han et.al 1991) used another augmentation technique of impingement cooling that uses high velocity jet to cool the surface. Lin et al. (1997) examined heat transfer behavior of single impingement on large region required to cool the surface. Goldstein and seol (1991) studied the heat transfer characteristics from circular air jet. Beitelmal et al. (2000) studied the impinging effect of the jet inclination in cooling uniform heated plates. Other than ribs and impingement method, internal flow swirl ,tape twister, baffle were also used for intensification. However, enhancement in heat transfer by using inclined baffles in channel was recommended. Dutta and Dutta (1998) experimented the enhancement of heat transfer with inclined solid and perforated baffle. The effect of baffle size, position, and orientation were studied for heat transfer augmentation. The conclusion of this study is that the heat transfer and friction factor is maximum in two inclined baffles than the single baffle.

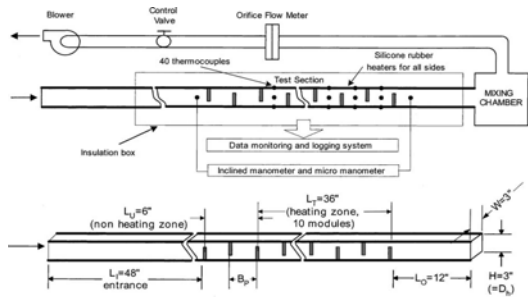
Schematic diagram of the experimental setup.



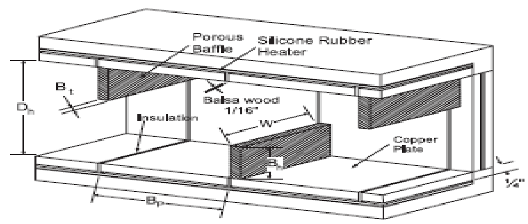
II.V. Porous baffle

Kang-Hoon Ko and N.K. Anand [5] attached the baffles was at top and bottom of wall. Some merits of porous baffle are, (a) more heat escape (b) due to light weight it is used in aerospace application. Similar article by kon and stevens[1] on enhancement of cooling by using porous baffle which reduces the temperature of wall. Kue and Tien [2] they found that in porous baffle heat transfer increases 2 to 4 times than that of solid baffle. Rachedi and Chikh [3] used porous baffle in their study that dropped temperature nearly to half as compared to solid baffle. Hwang and Chao [4] packed bed experiment using porous baffle to increase heat transfer. Kim [5] packed bed experiment using foam materials to increase heat transfer. Lion and Chen [6] used the perforated baffle; they found that nussult number increases as compare to simple baffle. Hwang [7] attached porous baffle mounted on top and bottom of wall in zigzag manner that increases heat transfer.

Schematic diagram of the experimental setup.



II.VI. Corrugated channel



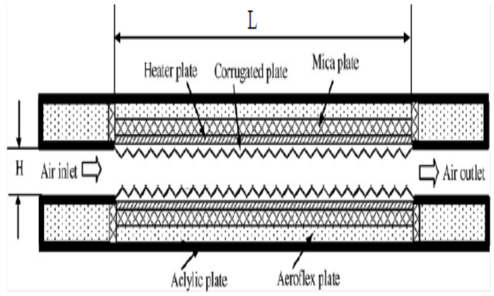
Schematic diagram of the test section.

II.VI. Corrugated channel

Waleed Mohammed Abed and Mohammed Abed Ahmed [6] used corrugated channel in the heat exchanger as these have high heat transfer efficiency and turbulent flow with low velocity. Some of the inventors studied flow and heat transfer of corrugated channel. Focke (1985) [1] investigated inclined angle between plate and overall flow direction and found maximum heat transfer rate at an angle of 80^0. Flow pattern are less effective for heat transfer at higher angle .Tanda and Vittori (1996) [2] investigated laminar fully developed flow and heat transfer in a two dimensional wavy channel, which was characterized by a wavy wall. It was heated at uniform heat flux, and compared with that of an opposite wall which was flat and adiabatic. It was seen that pressure drop in wavy channel was greater than that for straight ducts. Depending on geometry of wavy plates heat transfer may be increase or decrease. Blomerius and Mitra (2000) [3] Studied fluid flow and heat transfer in corrugated ducts and investigated Reynolds number (600-2000) from the numerical solutions of the Navier-Stokes equations. Corrugations and the main stream direction have been considered at an angle of 45^0 and 90^0.

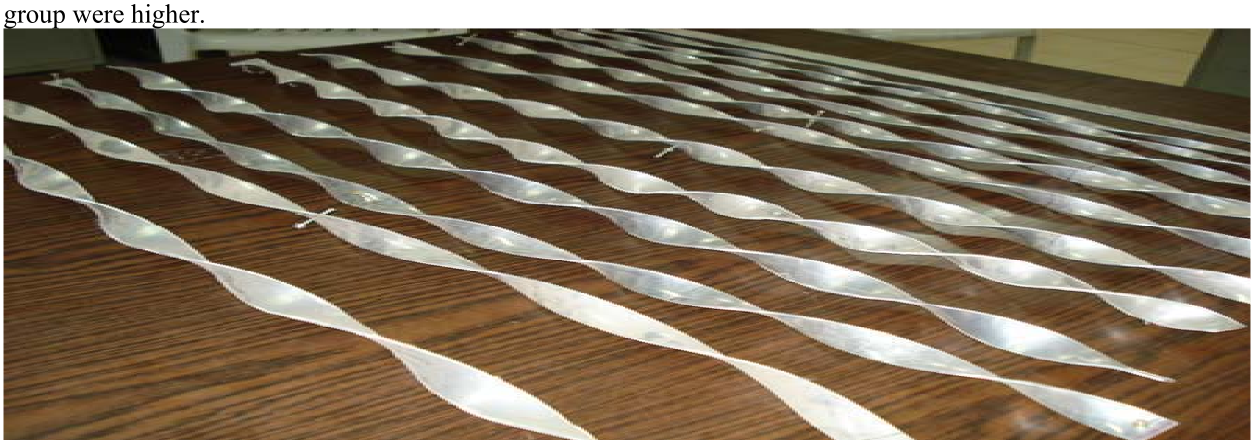
Numerical solutions for laminar forced convection in two-dimensional and three-dimensional sinusoidal corrugated ducts maintained at uniform wall temperature or uniform heat flux, were considered by Kundu (2001) [4]. For the two-dimensional problem, numerical solutions were obtained for different corrugation aspect ratios, plate spacing ratio, and flow rates. Hossain and Islam 2004 [5] investigated the fluid flow and heat transfer characteristic corrugated channel with two different types of surface wavinesses, one with sinusoidal channel and another with triangular channel numerically. The results shown that these types of wavinesses in channel increases heat transfer by mixing the fluid near the wall with main flow due to vortex, which also increase friction factor. Paisarn N. (2007) [6] studied V-corrugated channel upper and lower plates at constant heat flux, heat transfer characteristics and pressure drop as shown in fig. Corrugated plates with three different corrugated tile angles of 20°, 40° and 60^0 were analyzed. The experiments were performed for Reynolds number ranges of 2000–9000. He showed the effect of corrugated surface on the enhancement of heat transfer and pressure drop. The heat transfer coefficients obtained from the channel with the corrugated surface are higher than those with the plain surface. The pressure drop also increased on corrugated surface. Wahad and Yousif (2008) [7] investigated the fully developed laminar forced convective heat transfer and fluid flow characteristics inside two dimensional triangular wavy channels. Calculations were performed for Reynolds number range of ($50 \le Re \le 1000$).If Reynolds number increases the heat transfer as well as pressure drop increases. It totally depends on triangular wavy dimensions. When fluid flow compared with straight channel, heat transfer in triangular wavy channel was intensified.

Fig Schematic diagram of experimental test section



II.VII. Twisted tape inserts

S. Naga Sarada, A.V. Sita Rama Raju, K. Kalyani Radha and L. Shyam Sunder [7] reported that in most of enhancement techniques, a variety of inserts have been used in circular channel, particularly when turbulent flow was considered. They used coil wire inserts, brush inserts, mesh inserts, strip inserts, twisted tape inserts etc. In order to enhance heat transfer in internal flow, tape is inserted in channel. Many industries apply this technique. Monheit (1987) made a comparative study of the thermal performance of ordinary full-width full-length twisted tapes with tapes having modified surface configurations. Dasmahapatra and Rao (1991) studied augmentation of heat transfer to viscous non- Newtonian fluids in laminar flow using full width interrupted twisted tapes under the uniform wall temperature condition. Al- Fahed and Chakroun (1996) investigated the effect of tube-tape clearance on heat transfer under fully developed turbulent flow. *Sarada et al.* studied conditions of heat transfer in a horizontal isothermal tube. Investigations were carried out on twisted tape inserts in viscous flow in a horizontal tube (Manglik and Bergles, 1992). Experimental data were obtained for water and ehtylene glycol with snug-fit tape inserts of three different twist ratios, y=3.0, 4.5, and 6.0; the tape thickness in each case was 0.483 mm. In continuation of their research, an extended review of the application of twisted-tape inserts in tubular heat exchangers and their thermal-hydraulic performance was discussed (Manglik and Bergles, 2003). To determine the heat transfer enhancement in a tube with twisted tape in the Reynolds number ranging from 5000 to 25000 (Chang *et al.*, 2007).Characteristics of laminar flow such as heat transfer and pressure drop in rectangular channel and square duct and ducts with twisted-tape inserts were experimentally investigated by (Saha and Mallick, 2005). Circular tube fitted with full-length helical screw element of different twist ratio, and increasing and decreasing order of twist ratio set have been studied with uniform heat flux (Sivashanmugam and Suresh, 2006). They performed their experiments for various values of Reynolds numbers and the obtained experimental data and compared with those previously reported in the literature. They reported better performance of the helical twisted insert in comparison to the twisted tape insert. Modification of twisted tape was made by focusing in increase of heat transfer rate rather than the reduction of friction loss, for example, the jagged (Rahimi *et al.*, 2009) broken (Chang *et al.*, 2007) and serrated (Chang and Jan, 2007) twisted tapes. The tapes in this group were designed to offer stronger swirl flow and better mixing than the typical one. However, the enhanced heat transfer by the use of the twisted tapes in the group was certainly accompanied by the rise of friction factor. In general, the performance factors of twisted tapes in this group were higher.



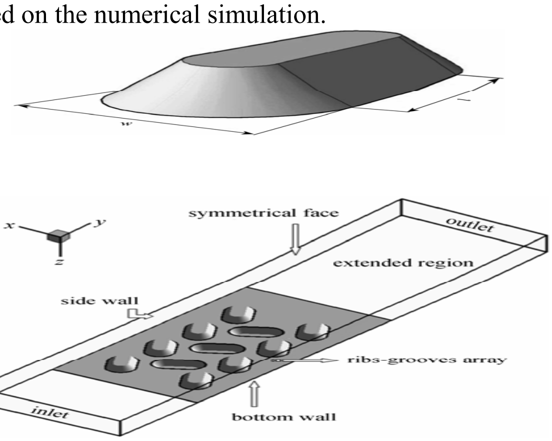
Photographs of twisted tape insert

Table 1. Shows the different types of inserts used

S. NO.	**Twist Ratio (T.R)**	**Width of Tape insert (mm)**
1	**3,4,5**	**26,22,18,14 and 10**
2	**Straight tape**	**26,22,18,14 and 10**
3	**Plane tube**	**--------------------------------**

II.VIII. Discontinuous Crossed Ribs and Grooves:

TANG Xinyi and ZHU Dongsheng [8] studied the turbulent flow and heat transfer enhancement in ducts or channels with rib, groove or rib-groove tabulators. Hu and Shen [3] carried out detailed distributions of internal heat transfer coefficients in a convergent cooling passage with a staggered array of 45° discrete ribs, and combination of ribs with grooves. For discrete ribs the area average enhancement factors were found to be 3-4 and that of combined discrete ribs with grooves were 2.5-3.2. Eiamsa-ard and Promvonge [4] performed experimental work on the turbulent forced convection heat transfer and friction characteristics in a rectangular duct with three types of rib-grooved turbulators (rectangular-rib and triangular-groove, triangular-rib and rectangular-groove and triangular-rib with triangular- groove). They found that lower Reynolds number (*Re*) gives higher enhancement index and as compared to smooth duct, all rib-groove arrangements significantly enhance the heat transfer up to 80%, 60%, and 46%, respectively with use of tabulators. The friction factors were found to be approximately 6.9, 5.5 and 4.8 times above the smooth duct, respectively. Eiamsa-ard and Promvonge [5] reported the heat transfer enhancement in a heat exchanger with delta-wing tape inserted. Kaewkohkiat *et al*. [6] studied the heat transfer and friction characteristics in a rectangular channel with rib-groove tabulators experimentally and reported that decrease in pitch ratio increases both nusselt number and friction factor. Bilen *et al*. [7] experimentally studied heat transfer and friction characteristics of a fully developed turbulent air flow in different grooved tubes (circular, trapezoidal and rectangular) and reported that heat transfer enhancement is up to 63% for circular groove, 58% for trapezoidal groove and 47% for rectangular groove, in comparison with the smooth tube at the highest Reynolds number of 38000. Nusselt number and friction factor in a chamfered ribbed duct with V-groove having chamfer angles of 5°, 12°, 15°, 18°, 22°and 30 were calculated by Layek et al[8,9]. They found that the performance parameter increases with increase in Reynolds number. Overall mechanism of heat transfer enhancement by the ribs is based on the flow separation, reattachment and secondary flow. Numerous investigations on the flow and heat transfer for the discrete inclined ribs have been carried out in order to reduce flow resistance in channel with ribs [10, 11]. In their work, the inclined discrete ribs have been used as longitudinal vortices generator and the heat transfer rate is increased by 150%-300% over the plain duct with less pressure loss compared with transversal ribs. Inclined discrete ribs can generate longitudinal vortices and give less blockage of the channel, thus increasing the heat transfer rate of the channel with less pressure drop. Use of the artificial grooves is widely used in modern heat exchangers, because they are very effective heat transfer augmentation. In this work, the combination of crossed and discontinuous ribs-grooves array was used to enhance heat transfer with less pressure loss and the better thermal performance is expected. The analysis pays particular attention to the effects of geometric parameters and complex flow structures on heat transfer enhancement based on the numerical simulation.



(a) Single rib **(**b) Boundary
(b) **3-D views of rectangular channel with ribs and grooves**

III. CONCLUSION

In this paper, the following heat transfer intensifiers are described and reviewed: (a) surface roughness, (b) plate baffle and wave baffle, (c) perforated baffle, (d) Inclined baffle, (e) porous baffle,(f) Corrugated channel,(g) Twisted tape inserts, (h) Discontinuous Crossed Ribs and Grooves. Different inventer's works about each one have been reviewed and many methods that assist their augmentation effects have been extracted from the literature. Among of these methods presented in the literature are half porous baffle, found that more attention should be made toward porous baffle heat transfer enhancement. Many researchers work related to Passive enhancement technique.

REFERENCES

[1] Soo Wban Abn and Kang Pil Son "An Investigation on Friction Factors and Heat Transfer Coefficients in a Rectangular Duct with Surface Roughness" *KSME International Journal* Vol 16 No.4, pp. 549-556, 2002.

[2] Hamidou Benzenine , Rachid Saim and Said Abboudi, Omar Imine " Numerical analysis of a turbulent flow in a channel provided with transversal waved baffles".

[3] Rajendra Karwa and B.K. Maheshwari "Heat transfer and friction in an asymmetrically heated rectangular duct with half and fully perforated baffles at different pitches" International Communications in Heat and Mass Transfer 36 (2009) pp. 264–268.

[4] Prashanta Dutta and Akram Hossain "Internal cooling augmentation in rectangular channel using two inclined baffles" International Journal of Heat and Fluid Flow 26 (2005),pp. 223–232

[5] Kang- Hoon Ko and N.K. Anand "Use of porous baffles to enhance heat transfer in a rectangular channel" International Journal of Heat and Mass Transfers 46 (2003) pp. 4191– 4199.

[6] Waleed Mohammed Abed and Mohammed Abed Ahmed "Numerical Study Of Laminar Forced Convection Heat Transfer And Fluid Flow Characteristics In A Corrugated Channel" Journal of Engineering and Development, Vol. 14, No. 3, September (2010) ISSN 1813-7822.

[7] S. Naga Sarada, A.V. Sita Rama Raju, K. Kalyani Radha and L. Shyam Sunder Enhancement of heat transfer using varying width twisted tape inserts International Journal of Engineering, Science and Technology Vol. 2, No. 6, 2010, pp. 107-118.

[8] Tang Xinyi and ZHU Dongsheng "Experimental and Numerical Study on Heat Transfer Enhancement of a Rectangular Channel with Discontinuous Crossed Ribs and Grooves" fliud dynamics and transport phenomena Chinese Journal of Chemiacal Engineering, **20**(2) 220— 230 (2012)