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ARTIFICIAL ROUGHNESS ENHANCEMENT ON THE ABSORBER PLATE OF SOLAR AIR HEATER DUCT FOR PRESSURE DROP CHARACTERISTICS

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ABSTRACT- The aim of the present work is to study the pressure drop characteristics of a roughened solar air heater duct. The computer simulation of pressure drop and air flow in a rectangular duct with constant heat flux has been carried out to visualize and study the effect of rectangular ribs on the performance of air heater using 'ANSYS' software. Te following research has been conducted in the present work:

- Study of effect of geometry of roughened surface i.e. relative pitch (ratio of pitch and rib height).
- Study of effect of mass flow rate. Change of mass flow rate causes change in the Reynolds number which enables to study the effect of Reynolds number on convective heat transfer coefficient.

Keywords: Heat Transfer, Simulation, Ansys, Reynolds Number, Nusselt Number

1. INTRODUCTION

Energy in various forms plays an important role in the development and economic progress of a country. The growth of population coupled with rising material standards of living has increased the rate of energy usage, which has created crisis of energy, especially in the developing countries. This has necessitated our dependence on non-conventional resources of energy, viz. solar energy, geothermal energy, wind energy etc. Of various alternatives, solar energy seems to be the brightest long term resource for meeting continuously increasing demand of energy.

For harnessing solar thermal energy, different types of collection devices are in use e.g., flat plate collectors for low temperature below 90 ^{0}C and focusing collectors for high temperature applications above 90 ^{0}C. Generally, water heating and air heating is done using solar flat plate collectors. Solar air heaters are very popular among solar thermal applications due to their simple design and low cost. Some engineering applications of solar thermal technology are domestic water heating, space heating, space cooling and refrigeration, distillation and drying of agriculture products etc.

The thermal efficiency of a solar air heater is generally less because of low heat transfer coefficient between absorber plate and air flowing in the duct. To make solar air heater more effective, thermal efficiency needs to be improved by using enhancement techniques. There are several methods which can be used to increase the efficiency of solar air heaters. Various surfaces used to improve efficiency of air heater are finned surface, corrugated surface, and surface with artificial roughness etc. In the current scenario, the focus of researchers is on adding artificial roughness to absorber plate due to its several advantages over other methods. Artificial roughness can be increased by using various type of ribs, of which rectangular ribs are preferred due to ease of manufacturing and placement on absorber plate, better strength and due to convenience in optimization of roughness parameters. Due to better strength, the ribs are not disturbed in the high turbulent region.

On the basis of surface configuration roughness can be divided into two categories. First category corresponds to geometry where the gap between two ribs is small because of which re-circulating flow occurs. The other category where the gap between two ribs is large eddies form only behind the roughness elements.

Several experimental investigations and numerical studies have been performed to study the effects of ribs of different geometry. The computer simulation pressure drop and air flow in a rectangular duct with constant heat flux has been carried out in the present work to visualize and study the effect of rectangular ribs on the performance of air heater by using ANSYS, an analysis and simulation software. Main parameters studied in this work are mass flow rate and relative pitch (ratio of pitch and rib height).

1.1 Solar Air Heater

A solar air heater is a simple device to heat air by utilizing solar energy, which has many applications in drying agricultural products, such as seeds, fruits and vegetables, and as a low-temperature energy source. Also, solar air heaters are utilized for heating buildings with auxiliary heaters to save energy in winter-time. Solar air heaters can also be used for industrial purpose. Solar air heaters are simple in design and maintenance. Depending upon the air passage in the solar air heater the air heaters can be classified in the following ways:

1.1.1 Single glass cover air heater

In this type of air heater there is only one glass surface on the top and the absorber is below the glass plate as shown in Figure.1.1. The air flows below absorber plate.

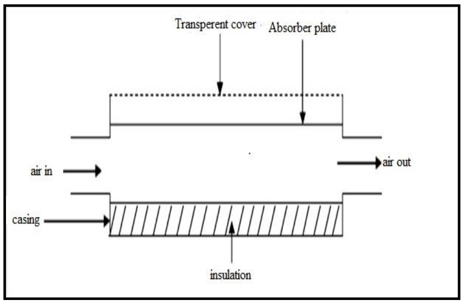


Figure.-1.1 Solar Air Heater

1.2 Performance Enhancement Techniques for Solar Air Heater

The performance of a flat plate solar air heater has been found to depend strongly on the rate of incident solar radiations, the losses from the absorber surface and the rate of heat transfer from absorber plate to the air. The following are some performance enhancement techniques for solar air heaters:

- Enhancement of intensity of solar radiation incident upon the solar collector
- By lowering convective as well as radiative heat loss
- By using alternate medium or vacuum in the gap space
- By selective absorber surfaces
- Improvement of heat transfer from absorber plate
- By Increasing the Area of Heat Transfer without Effecting the Convective Heat Transfer CoefficientSuch surfaces are termed as 'extended
- By Increasing Convective Heat Transfer Coefficient Using Artificial Roughness

1.3 Concept of Artificial Roughness

In order to attain higher heat transfer coefficient, it is desirable that the flow at the heat-transferring surface is to be made turbulent. Surface roughness is one of the first active techniques to be considered as means of augmented forced convection heat transfer. However, energy for creating such turbulence has to come from the fan or blower and this excessive turbulence leads to excessive power requirement to make the air flow through the duct. It is therefore desirable that the turbulence must be created only in the region very close to the heat transferring surface i.e. in the laminar sub-layer region only where the heat exchange takes place and the flow should not be unduly disturbed so as to avoid excessive friction losses. This can be done by keeping the height of the roughness element to be small in comparison with the duct dimensions. Although there are several parameters that characterize the arrangement and shape of the roughness, the roughness element height (e) and pitch (p) are the most important parameters. These parameters are usually specified in terms of dimensionless parameters, namely, relative roughness height, e/d (the ratio of height of roughness element to the equivalent diameter of the duct) and the relative roughness pitch, p/e (the ratio of pitch to height of roughness elements). The roughness elements can be two dimensional ribs or three dimensional discrete elements, transverse or angled ribs or continuous or broken ribs. Although square ribs are the most commonly used geometry but chamfered, circular, semi-circular and grooved sections have been investigated in order to get most beneficial arrangement **Han and Zhang [1992**]

Some important geometry and the parameters that characterize the geometry and substantially influence the performance are given in table below.

1.4 Some Important Roughness Geometries

The use of artificial roughness in solar air heaters owes its origin from the several investigations carried out in connection with the enhancement of heat transfer in nuclear reactor, cooling of gas turbines blades and electronics equipment. These are few important geometries used in above mention application are given in figures below.

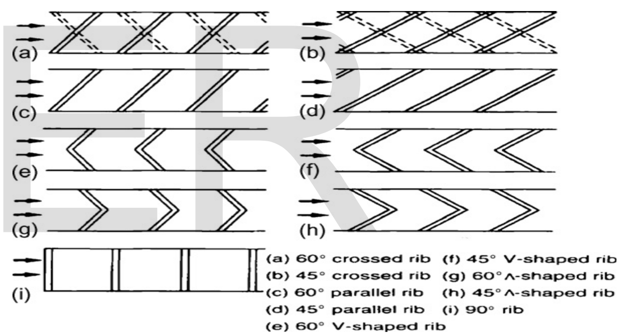


Figure- 1.2 Different configuration of Ribs used by Han and Zhang Hans *et al* [2010]

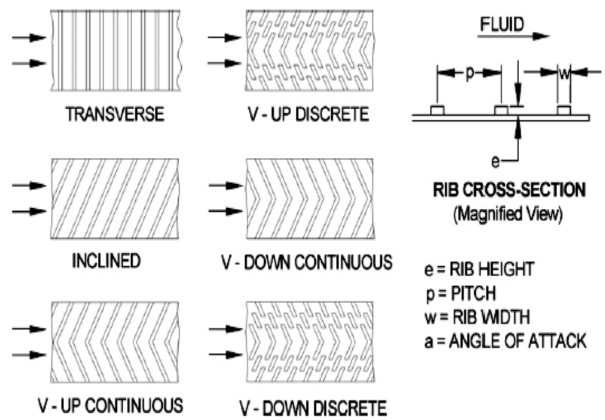


Figure-1.3 Different configuration V-Shaped Ribs Muluwork [2000]

Table 1 Various Types of Roughness Geometries and Parameters Hans *et al* [2009]

S. No	Rib Geometry	Parameters
1.	Transverse ribs	e/d , p/e
2.	Continuous Angled ribs	e/d, p/e, α
3.	V-shaped ribs	e/d, p/e, α
4.	Angled ribs with gaps	e/d, P/e, α, g/p, d/W
5.	Transverse-chamfered ribs	e/d, p/e, ϕ
6.	V-shaped staggered discrete ribs	e/d, p/e, α, B/S, p′/p, S′/S
7.	Grooved- ribs arrangement	e/d, p/e, g/p
8.	Arc shaped ribs	e/d, p/e, α
9	W-Shaped discrete ribs	e/d, p/e, α
10	Wire mesh	e/d, p/e, L/e, S/e

On the surface configuration, one can divide the roughness into two different categories. The first category corresponds to a geometry where the gap between the two ribs is small and is occupied by a re-circulating flow. This type of roughness is known as "*d* type" roughness. The second type refers to a situation where the gap between the ribs is larger. This type of roughness is characterized by eddies that form behind a roughness element. This type of roughness is known as "*k*-type" roughness.

2. METHOLOGY

The following methodology is adapted for modelling and analysing heat transfer in the duct in simulated condition: **Selection of flow domain, Flow regime, creating the finite element mesh, Applying boundary conditions, Setting FLOTRAN, analysis parameters, solving the problem examining the results.**

2.2 Terms Used in Analysis

- Hydraulic equivalent diameter
- Reynolds number (Re)
- Nusselt number (Nu)

2.3 Introduction to ANSYS

ANSYS is general-purpose finite element analysis (FEA) software package. Finite Element Analysis is a numerical method of constructing a complex system into very small pieces called elements. The software implements equations that govern the behavior of these elements and solves them all; creating a comprehensive explanation of how the system acts as a whole. These results then can be presented in tabulated or graphical forms. In the present work FLOTRAN CFD is use to 2-D analysis of air flow in a rectangular duct with constant heat flux on one side.

2.4 The Basics of FLOTRAN Analysis

2.4.1 Types of FLOTRAN analyses

These types of FLOTRAN analyses can be done using FLOTRAN elements: Laminar or turbulent, Thermal or adiabatic Free surface Compressible or incompressible Newtonian or Non-Newtonian Multiple species transport

2.4.2 Characteristics of the FLOTRAN elements

The ANSYS FLOTRAN elements, FLUID141 and FLUID142, solve for 2-D and 3-D flow, pressure, and temperature distributions in a single phase viscous fluid. For these elements, the ANSYS program calculates velocity components, pressure, and temperature from the conservation of three properties: mass, momentum, and energy.

2.5 Parameter Analysis

Artificially roughened solar air heater has been considered for the analysis of different performance parameters having different types of roughness and geometries on the underside of the absorber plate. The details of roughness, operating parameters and range of flow has been given in Table 2 and a schematic diagram of experimental setup of solar air heater has been presented in Figure 2.1.

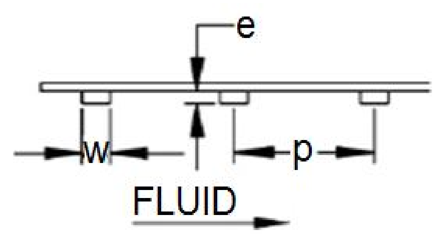


Figure- 2.1: Absorber Plate Showing the Roughness Element

Table 2 Value of Different Parameters

S.NO	PARAMETERS	VALUES
1	Relative roughness pitch(P/e)	6-25

2	Rib height (e)	3.4 mm
3	width (b)	5.8 mm
4	Relative Roughness height (e/D_h)	0.0442
5	Duct aspect ratio (W/H)	25
6	Duct height(H)	.04 m
7	Reynolds number (Re)	4000-16000

4. RESULTS

When fluid enters a closed channel at a uniform velocity, the fluid particles in the layer in contact with wall of the channel come to complete rest. This layer also causes the fluid particles in the adjacent layers to slow down gradually, as a result of friction. To make up this velocity reduction, the velocity of the fluid at the mid-section of the rectangular duct has to increase to keep the mass flow rate through the rectangular duct constant. As a result, velocity gradient develops along the channel. As the roughness element lies under the absorber plate, the flow becomes turbulent because of reattachment points or breakage of hydrodynamic boundary layer at regular intervals. In this process heat transfer coefficient, friction factor and pumping power of fluid increase due to the presence of this artificial roughened rectangular duct. The results show the behavior of Nusselt number with different operating parameters of solar air heater having rectangular ribs on the backside of the absorber plate. The effect of roughness and operating parameters on the heat transfer coefficient has been examined and a comparison of performance of roughened solar air heater with that of conventional solar air heater having smooth duct has been made.

4.1 Validation of ANSYS results for the Smooth Duct

Pressure Drop (ΔP) for smooth duct

The pressure drop across duct length obtained from ANSYS has been compared with that obtained from Blasius equation, indicated by Eq. 4.2. The comparison has been shown in Fig. 4.2. It has been observed from the ANSYS results that the variation between predicted and ANSYS results lie within 9%.The reason for variation in values obtained by Blasius equation and ANSYS results is that the ANSYS results also include minor pressure loses at the entrance and exit sections which are not included in Blasius equation. The comparison indicates that the results obtained through ANSYS are reliable and in good agreement with those by Blasius equation.

$$f = 0.085Re^{-0.25}$$

$$headloss = \frac{4fLV^2}{2dg}$$

$$\Delta P = headloss \times \rho \times g$$

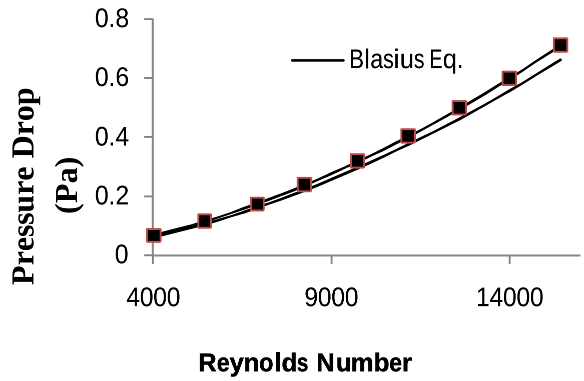


Figure-4.1 Comparison of pressure droppredicted by ANSYS and estimated by Blasius-equation for smooth duct

Effect of Reynolds number on pressure drop in the duct

Figure 4.2 shows the variation of pressure drop in the ductwith varying Reynolds numbers. Results show that for all plates, pressure drop increase with increase in Reynolds number for rough as well as smooth plate. Similar trend in the variation of pressure drop in the duct has been obtained for all plates having different relative roughness pitch. This is due to the fact that pressure drop in the duct is significantly frictional pressure drop. As Reynolds number increases the velocity gradient in the duct also increases which increase frictional force and hence pressure drop.

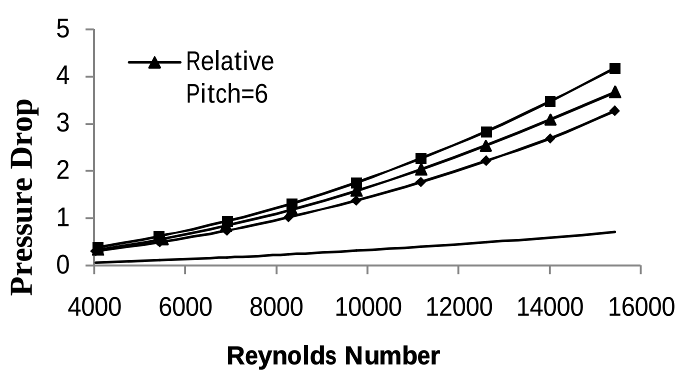


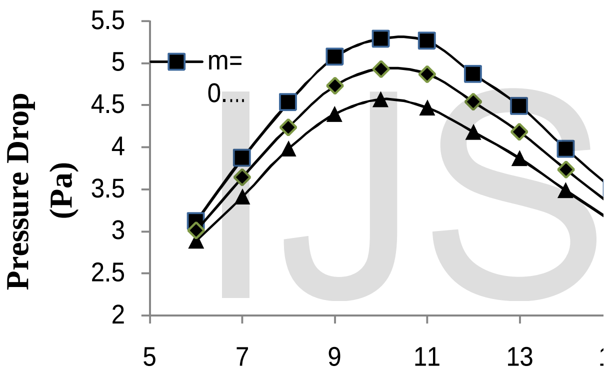
Figure-4.2 Comparison of Smooth and Roughened Plates for Different Values of Pressure drop in duct

Effect of relative roughness pitch on pressure drop in the duct

Fig. 4.3 shows the variation of pressure drop in the duct with relative roughness pitch parameter. It has been observed that with increase in the value of p/e, pressure drop inthe duct first increase up to p/e=10 then it starts decreasing for all the plates under study. Maximum pressure drop is found for p/e ratio 10. In duct with smooth plate, laminar sub layer is formed adjacent to surface; hence a part of flow remains laminar. But in presence of ribs this laminar flow is disturbed and becomes turbulent.In flow simulation, maximum disturbance has been observed for relative roughness pitch p/e=10, hence maximum pressure drop occur at p/e=10.

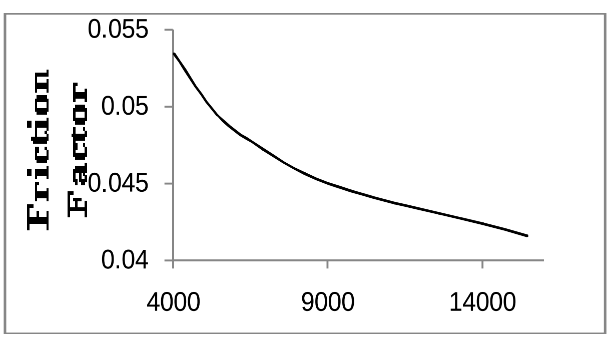
Variation of friction factor with Reynolds number

The plot for variation in friction factor with Reynolds number has been shown in Fig. 4.4 and Fig.4.5 for smooth and roughened plate respectively. Friction factor for smooth as well as roughened plate's decreases as Reynolds number increases.



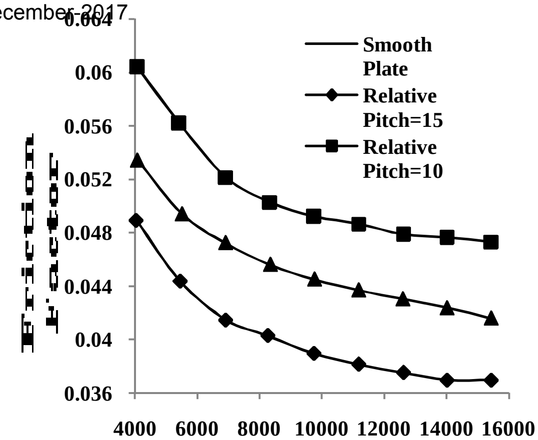
Relative Pitch

Figure-4.3 Variation of pressure drop in duct with relative pitch



Reynolds Number

Figure-4.4 Variation of friction factor with Reynolds number for smooth plate



Reynolds Number

Fig. 4.5Variation of friction factor with Reynolds number for different relative Roughness pitch

4.2 Flow Pattern Studies

On the basis of graphical output of ANSYS the following effects were observed, by which above results can be explained.

4.2.1 Effect of ribs

The most important effect produced by the presence of a rib on the flow pattern is the generation of two flow separation regions, one on each side of the rib. The vortices so generated are responsible for the turbulence and hence the enhancement in heat transfers as well as in the friction losses takes place. A considerable influence of the presence of ribs is more pronounced in turbulence intensity distribution. Fig. 4.6 shows the pressure distribution to show flow separation region on each side of the rib.

4.2.2 Effect of relative roughness pitch

Fig. 4.6 to 4.8 shows the flow patterns as a function of relative roughness pitch. Due to flow separation downstream of a rib, reattachment of the shear layer does not occur for a pitch ratio of less than about 8. Maximum heat transfer has been found tooccur in the vicinity of a reattachment point. For relative roughness pitch considerably less than about 8, the reattachment will not occur at all, resulting in the decrease of heat transfer enhancement. However, an increase in pitch beyond about 10 also results in decreasing the enhancement.

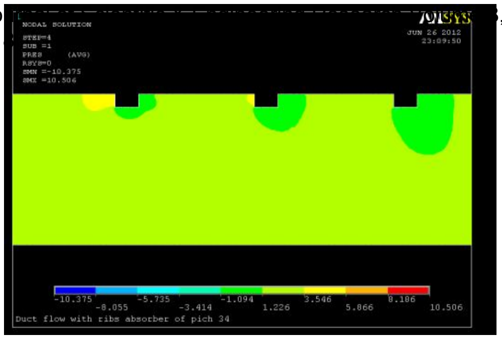


Figure- 4.6 Pressure distribution to show flow separation region on each side of rib

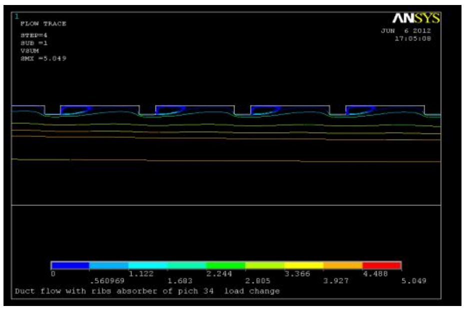


Fig. 4.7 Flow pattern as a function of relative roughness pitch 10

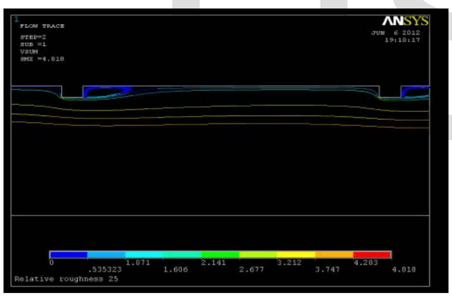


Figure4.8 Flow pattern as a function of relative roughness pitch

CONCLUSION

A computer simulation of transverse shape continuous type of artificial roughness geometry on the absorber plate of solar air heater duct has been carried out to investigate the pressure drop characteristics under simulated conditions using ANSYS. The pressure drop in the duct and thermal efficiency has been computed as a function of Reynolds number and mass flow rates for different artificial roughness (relative pitch) on the absorber plate of air heater duct. The relative roughness pitches considered in the study are varied from 6 to 15. The performance of roughened absorber plate has been compared with that of smooth plate and different results have been obtained, Reynolds number has been varied from 4000 to 16000 in the present study.

REFERENCES

[1] Aharwal, K. R., Gandhi, B. K. and Saini J. S. 2007. Experimental investigation on heat transfer enhancement due to a gap in an inclined continuous rib arrangement in a rectangular duct of solar air heater. *Renewable Energy.* 33: 585-596.

[2] Aharwal, K.R., Gandhi, B.K. and Saini, J.S. 2008. Experimental investigation on heat-transfer enhancement due to a gap in an inclined continuous rib arrangement in a rectangular duct of solar air heater. *Renewable Energy* 33: 585–596

[3] Aharwal, K.R., Gandhi, B.K. and Saini, J.S. 2009. Heat transfer and friction characteristics of solar air heater ducts having integral inclined discrete ribs on absorber plate. *Heat and Mass Transfer.* 52: 5970–5977

[4] Bevill, V.D. and Brandt, H. 1968. A solar energy collector for heating air. *Solar Energy*. 12(1): 19-29.

[5] Bhagoria, J.L., Saini, J.S. and Solanki, S.C. 2002. Heat transfer coefficient and friction factor correlations for rectangular solar air heater duct having transverse wedge shaped rib roughness on the absorber plate. *Renewable Energy*. 25(3): 341-369.

[6] Bhushan, B. and Singh, R. 2010. A review on methodology of artificial roughness used in duct of solar air heaters. *Energy* 35: 202–212

[7] Chaube, A., Sahoo, P.K. and Solanki, S.C. 2005. Analysis of heat transfer augmentation and flow characteristics due to rib roughness over absorber plate of a solar air heater. *Renewable Energy.* 31: 317–331

[8] Desrues, T., Marty, P. and Fourmigué, J.F. 2012. Numerical prediction of heat transfer and pressure drop in three-dimensional channels with alternated opposed ribs.*Applied Thermal Engineering* 45: 52-63

[9] Gregory, J.Z., Rogelio, L. and Louay, M.C. 2008. Linear correlation of heat transfer and friction in helically-finned tubes using five simple groups of parameters. *Heat and Mass Transfer* 51: 3548–3555

[10] Han, J.C. and Zhang, Y.M. 1992. High performance heat transfer ducts with parallel. crossed and V shaped broken ribs. *Heat and Mass Transfer* 35: 513-523.