© June 2019 | IJIRT | Volume 6 Issue 1 | ISSN: 2349-6002

Review of the Investigation of heat and fluid flow in a square duct using turbulators

Mayank Kumar Dwivedi[1], Abhishek Kumar[2]
[1]*M.Tech. Scholar, Mechanical Engineering Department, KNP College of Science and Technology, Misrod, Bhopal MP*
[2]*Assistant Professor, Mechanical Engineering Department, KNP College of Science and Technology, Misrod, Bhopal MP*

Abstract- **The use of rib roughness in numerous forms, shapes and sizes is the utmost common and effective way to increase the thermohydraulic performance of a rectangular duct. Investigators reported various rib roughness shapes in the literature for studying fluid flow and heat transfer in rectangular duct. A number of experimental and CFD studies carried out on rib roughened rectangular duct for their performance analysis were reported in the literature. This comprehensive review of literature reveals that a lot of work has been described on design of rectangular duct by experimental approach. This review also reveals that rare studies have been done on CFD analysis of rectangular duct.**

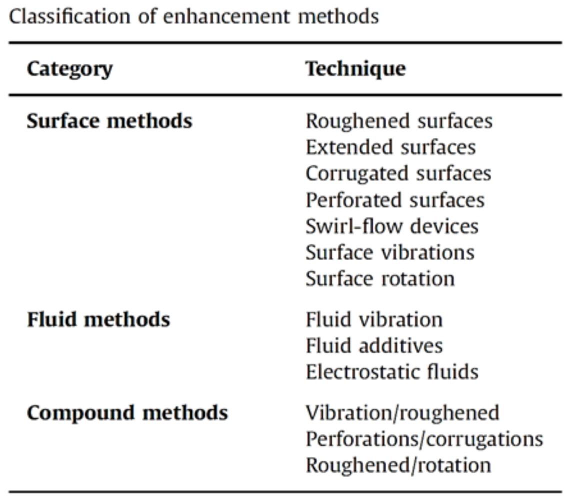
Index Terms- Ribs, Nusselt Number, Heat transfer, Pressure Drop, CFD

I. INTRODUCTION

Applications of heat transfer enhancement concepts can be found in gas turbine airfoils, solar air heaters, electronic cooling, etc. A common technique to enhance heat transfer is by installing turbulence promotors (rib turbulators) on the smooth walls. The rib turbulators generate secondary flows which increase near-wall shear in the vicinity of the ribs and these secondary flows also interact with channel side walls to increase turbulent transport of energy from relatively hotter walls by forming vortex or vortices. One application of rib turbulators as heat transfer enhancement technique is found in gas turbine airfoils. The gas turbine airfoils are subjected to elevated heat loads on both pressure and suction side walls. Hence rib turbulators are installed on pressure and suction side internal walls to increase heat transfer in order to increase the heat transfer rates between internal walls and coolant. Rib turbulators also result in increase in wetted surface area which enhances the overall conductance. Several studies have been carried out in the past on heat transfer enhancement by various cooling designs, such as, ribbed channel with bleed holes, ribbed channel with grooves, rib dimpled compound channels, jet impingement, jet impingement with effusion holes, dimpled channel, jet impingement onto dimpled target surface etc. The use of artificial roughness on a surface is an effective technique to enhance heat transfer coefficient also has good application in design and development of efficient solar air heaters. Many investigations have demonstrated the effects of different rib configurations on heat transfer coefficient between absorbers plate and air flowing in solar air heaters, numerically and experimentally, in order to improve the heat transfer capability of solar air heater ducts. Heat transfer enhancement due to rib turbulators is affected by several parameters such as rib angle-of-attack, channel aspect ratio, rib pitch-to-height ratio, blockage ratio, and rib shape. Investigations on these aspects of rib turbulator design have been reported. In the past, researchers have studied the flow characteristics of ribbed duct, both, experimentally and numerically. Some studies focused on the relative arrangement of ribs, e.g. parallel, staggered, and criss-cross. Several investigations have been carried out in the past on rib turbulator as a method of enhancing heat transfer [1-11].

II. LITERATURE REVIEW ON RIB TURBULATORS FOR HEAT TRANSFER ENHANCEMENT

Many investigations [12–21] have demonstrated the effects of different rib configurations on heat transfer coefficient between absorbers plate and air flowing in solar air heaters, numerically and experimentally, in order to improve the heat transfer capability of solar air heater ducts. Fig. 1 Shows the classification of enhancement methods.



Classification of enhancement methods

Category	Technique
Surface methods	Roughened surfaces Extended surfaces Corrugated surfaces Perforated surfaces Swirl-flow devices Surface vibrations Surface rotation
Fluid methods	Fluid vibration Fluid additives Electrostatic fluids
Compound methods	Vibration/roughened Perforations/corrugations Roughened/rotation

Fig 1 classification of enhancement methods

It is well known that in a turbulent flow a laminar/viscous sublayer exists in addition to the turbulent core. The artificial roughness on heat transfer surface breaks up the laminar boundary layer of turbulent flow and makes the flow turbulent adjacent to the wall. The artificial roughness that results in the desirable increase in the heat transfer also results in an undesirable increase in the pressure drop due to the increased friction; thus, the design of the flow duct and absorber surface of duct should, therefore, be executed with the objectives of high heat transfer rates and low friction losses. 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 viscous sub-layer only where the heat transfer takes place and the core flow should not be unduly disturbed so as to avoid excessive friction losses. This can be done by keeping the height of the roughness elements to be small in comparison with the duct dimensions. Different types of ribs are shown in fig. 2-11.

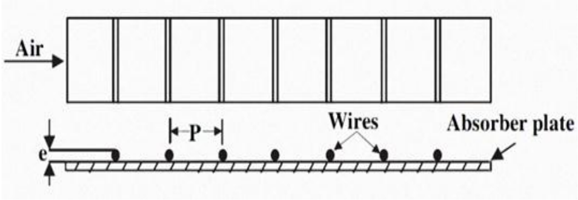


Fig 2 Transverse wire rib roughness

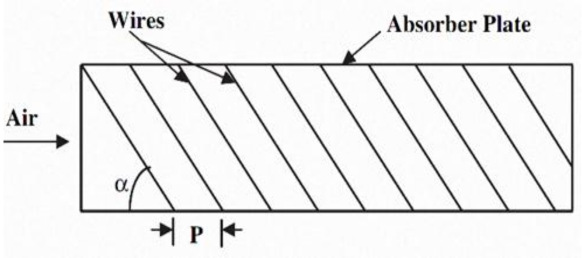


Fig 3 Transverse wire rib roughness

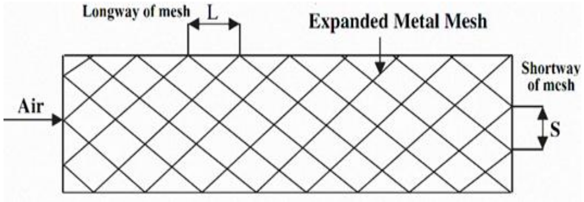


Fig 4 Expanded metal mesh roughness

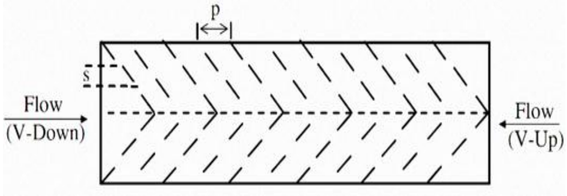


Fig 5 Staggered discrete V-shaped rib roughness

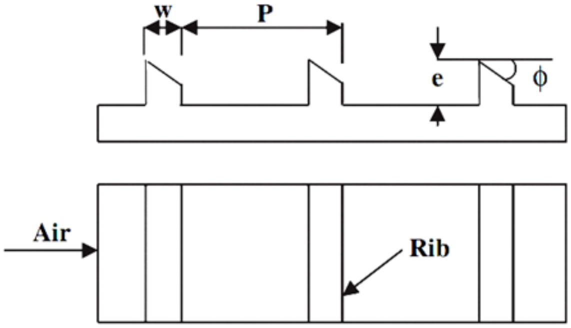


Fig 6 Chamfered rib roughness

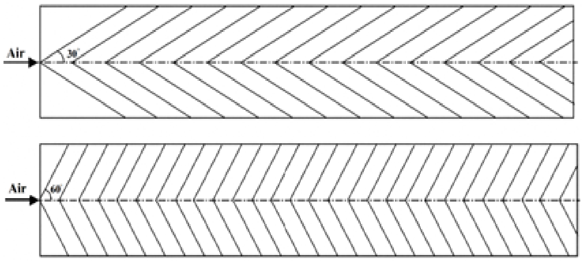


Fig 7 V-shaped rib roughness

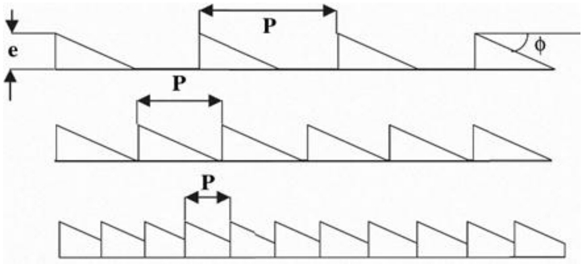


Fig 8 Transverse wedge shaped rib roughness

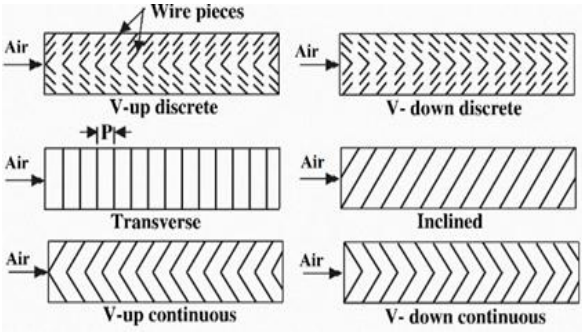


Fig 9 Transverse, inclined, V-up continuous, V-down continuous,

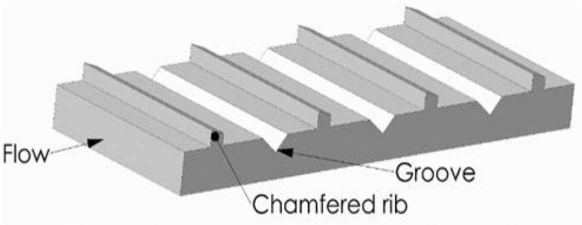


Fig 10 Chamfered rib-grooved roughness

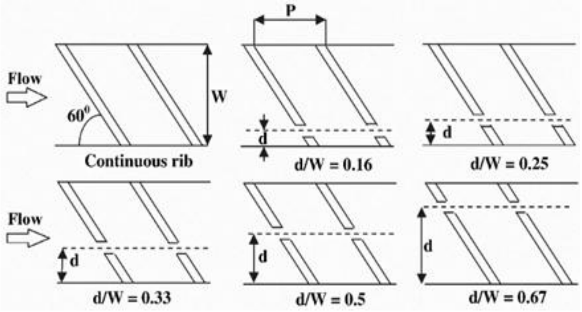


Fig 11 Inclined continuous rib roughness with gap

Heat transfer enhancement due to rib turbulators is affected by several parameters such as rib angle-of-attack, channel aspect ratio, rib pitch-to-height ratio, blockage ratio, and rib shape. Investigations on these aspects of rib turbulator design have been reported in [22–31]. In the past, researchers have studied the flow characteristics of ribbed duct, both, experimentally and numerically [32–37]. Some studies focused on the relative arrangement of ribs, e.g. parallel, staggered, and criss-cross [38–40]. Gao and Sunden [38] used particle image velocimetry to reveal the flow characteristics in rectangular channels with aspect ratio of 1:8. Six different rib configurations were experimentally investigated, namely staggered parallel ribs, staggered-single parallel ribs, inline parallel ribs, crossed ribs, V-ribs pointing downstream, and pointing upstream. Ekkad and Han [39] performed a detailed study on heat transfer characteristics with all rib parallel to each other in a non-rotating square channel using transient liquid crystals technique. Lee et al. [40] used naphthalene sublimation technique to measure detailed heat transfer enhancement contours using heat-mass transfer analogy. They tested continuous V shaped ribs and discrete V shaped ribs. Several investigations have been carried out in the past on rib turbulator as a method of enhancing heat transfer.

In past, several numerical investigations have been carried out to understand turbulent heat and fluid flow in rib roughened ducts. Murata and Mochizuki [41] carried out numerical investigation of laminar and turbulent heat transfer in a square duct featuring angled rib turbulators. Lu and Jiang [42] carried out experimental and numerical study on a rectangular channel featuring angled rib turbulators. The authors concluded that the SST k- turbulence model was more suitable for the prediction of turbulent heat transfer compared to RNG k-ε model. Al-Qahtani et al. [43] used Reynolds Stress turbulence model in conjunction with near-wall second –moment turbulence closure to study heat transfer in rotating rectangular channels with rib turbulators. Eiamsa-ard and Promvonge [44] studied four turbulence models for prediction of heat transfer in a rectangular duct featuring grooves. The authors carried out computations using standard k-ε, RNG k-ε, standard k, SST k-ω turbulence models and found that the k-ε model was better than the other turbulence models. For computations of heat transfer in a square duct roughened by discrete V-shaped ribs, Promvonge et al. [45] used RNG k-ε model. Acharya et al. [46] compared nonlinear and standard k-ε models for prediction of periodically developed heat and flow transfer in ribbed duct and concluded that the nonlinear model predicted realistic Reynolds stresses in the core flow region than the standard model. Peng et al. [47] studied different rib shapes numerically using SST k-ω turbulence model. Sewall and Tafti [48] carried out Large Eddy Simulations (LES) on a two-pass rib roughened duct featuring 90° rib turbulators and demonstrated that LES predicted flow and heat transfer was very accurate. However, LES comes at a significant computational cost. In order to maintain a balance between computational accuracy and cost, SST k-ω turbulence model was used in the present study. Further, the choice of the turbulence model in the present study is based on relative comparisons of heat transfer predictions by four other turbulence models and experimentally obtained heat transfer data.

III. CONCLUSION

This review is based on the different investigations in duct flow with rib turbulence promoters. It can be concluded that there is definite increase in heat transfer in duct when its surface is roughened. However, the different investigators find different values of increment in heat transfer with increase in friction factor for each experiment. We can see that the increase in heat transfer is achieved but the friction factor is also increasing simultaneously. The various correlations developed for the Nusselt number and friction factor for the range of parameters considered will give insight to the designers and other investigators in their work for finding out the optimum values. These correlations and heat transfer values can help the beginners of this field will help to know about the various geometries used till now and encourage them for investigating new roughness elements or even combinations of already existing elements for their work.

On the basis of the review of the literature and comparative study, the conclusion can be summarized as follows:

1. The use of artificial roughness on a surface is an effective technique to enhance heat transfer to fluid flowing in the duct. Artificially roughened duct have enhanced rate of heat transfer as compared to the smooth solar air heaters under the same geometric/ operating conditions.
2. It has been found that roughness geometries being used in solar air heaters are of many types depending upon shapes, size, arrangement and orientations of roughness elements on the absorber plate.
3. There are several parameters that characterize the roughness elements, but for duct the most preferred roughness geometry is repeated rib type, which is described by the dimensionless parameters viz. relative roughness height (e/D), relative roughness pitch, (P/e), angle of attack (α) and channel aspect Ratio (W/H) etc.
4. Transverse rib roughness enhances the heat transfer coefficient by flow separation and generation of vortices on the upstream and downstream of rib and reattachment of flow in the inter-rib spaces.
5. It can be concluded that the use of artificial roughness results in higher friction and hence higher pumping power requirements. It is desirable that design of solar air heater should be made in such a way that it should transfer maximum heat energy to the flowing fluid with minimum consumption of blower energy.

REFERENCES

[1] E.Y. Choi, Y.D. Choi, W.S. Lee, J.T. Chung, J.S. Kwak, Heat transfer augmentation using a rib–dimple compound cooling technique, Appl. Therm. Eng. 51 (1) (2013) 435–441.

[2] S.W. Chang, T.M. Liou, K.F. Chiang, G.F. Hong, Heat transfer and pressure drop in rectangular channel with compound roughness of V-shaped ribs and deepened scales, Int. J. Heat Mass Transf. 51 (3) (2008) 457–468.

[3] S.V. Ekkad, Y. Huang, J.C. Han, Detailed heat transfer distributions in two-pass square channels with rib turbulators and bleed holes, Int. J. Heat Mass Transf. 41 (23) (1998) 3781–3791.

[4] S. Kumar, R.S. Amano, J.M. Lucci, Numerical simulations of heat transfer distribution of a two-pass square channel with V-rib turbulator and bleed holes, Heat Mass Transf. 49 (8) (2013) 1141–1158.

[5] Y.M. Zhang, W.Z. Gu, J.C. Han, Heat transfer and friction in rectangular channels with ribbed or ribbed-grooved walls, Trans.-Am. Soc. Mech. Eng. J. Heat Transf. 116 (1994), pp. 58–58.

[6] P. Singh, J. Pandit, S.V. Ekkad, Characterization of heat transfer enhancement and frictional losses in a two-pass square duct featuring unique combinations of rib turbulators and cylindrical dimples, Int. J. Heat Mass Transf. 106 (2017) 629–647.

[7] P. Singh, B.V. Ravi, S. Ekkad, Experimental investigation of heat transfer augmentation by different jet impingement hole shapes under maximum crossflow, in: ASME Turbo Expo 2016: Turbomachinery Technical Conference and Exposition, American Society of Mechanical Engineers, 2016, pp. V05BT16A018–V05BT16A018.

[8] P. Singh, S. Ekkad, Effects of rotation on heat transfer due to jet impingement on cylindrical dimpled target surface, in: ASME Turbo Expo

2016: Turbomachinery Technical Conference and Exposition, American Society of Mechanical Engineers, 2016, pp. V05BT16A010–V05BT16A010.

[9] P. Singh, S.V. Ekkad, Effects of spent air removal scheme on internal-side heat transfer in an impingement-effusion system at low jet-to-target plate spacing, Int. J. Heat Mass Transf. 108 (2017) 998–1010.

[10] B.V. Ravi, P. Singh, S.V. Ekkad, Numerical investigation of turbulent flow and heat transfer in two-pass ribbed channels, Int. J. Therm. Sci. 112 (2017) 31–43.

[11] P. Singh, S. Ekkad, Experimental study of heat transfer augmentation in a twopass channel featuring V-shaped ribs and cylindrical dimples, Appl. Therm. Eng. 116 (2017) 205–216.

[12] R.P. Saini, S.K. Singal, A review on roughness geometry used in solar air heaters, Sol. Energy 81 (11) (2007) 1340–1350.

[13] G. Tanda, Performance of solar air heater ducts with different types of ribs on the absorber plate, Energy 36 (11) (2011) 6651–6660.

[14] R.P. Saini, J. Verma, Heat transfer and friction factor correlations for a duct having dimple-shape artificial roughness for solar air heaters, Energy 33 (8) (2008) 1277–1287.

[15] B. Bhushan, R. Singh, A review on methodology of artificial roughness used in duct of solar air heaters, Energy 35 (1) (2010) 202–212.

[16] M.K. Mittal, R.P. Saini, S.K. Singal, Effective efficiency of solar air heaters having different types of roughness elements on the absorber plate, Energy 32 (5) (2007) 739–745.

[17] S. Singh, S. Chander, J.S. Saini, Heat transfer and friction factor of discrete Vdown rib roughened solar air heater ducts, J. Renew. Sustain. Energy 3 (1) (2011) 013108.

[18] A. Kumar, R.P. Saini, J.S. Saini, Numerical simulation of effective efficiency of a discrete multi V-pattern rib solar air channel, Heat Mass Transf. 52 (10) (2016) 2051–2065.

[19] A.S. Yadav, J.L. Bhagoria, A numerical investigation of square sectioned transverse rib roughened solar air heater, Int. J. Therm. Sci. 79 (2014) 111–131.

[20] R.S. Gill, V.S. Hans, J.S. Saini, S. Singh, Investigation on performance enhancement due to staggered piece in a broken arc rib roughened solar air heater duct, Renew. Energy 104 (2017) 148–162.

[21] A.M. Lanjewar, J.L. Bhagoria, R.M. Sarviya, Performance analysis of W-shaped rib roughened solar air heater, J. Renew. Sustain. Energy 3 (4) (2011) 043110.

[22] J.C. Han, Y.M. Zhang, C.P. Lee, Augmented heat transfer in square channels with parallel, crossed, and V-shaped angled ribs, J. Heat Transf. 113 (3) (1991) 590– 596.

[23] P.R. Chandra, M.E. Niland, J.C. Han, Turbulent Flow Heat Transfer and Friction in a Rectangular Channel With Varying Numbers of Ribbe Walls, Trans.-Am. Soc. Mech. Eng. J. Turbomach. 119 (1997) 374–380.

[24] J.C. Han, S. Ou, J.S. Park, C.K. Lei, Augmented heat transfer in rectangular channels of narrow aspect ratios with rib turbulators, Int. J. Heat Mass Transf. 32 (9) (1989) 1619–1630.

[25] J.S. Park, J.C. Han, Y. Huang, S. Ou, R.J. Boyle, Heat transfer performance comparisons of five different rectangular channels with parallel angled ribs, Int. J. Heat Mass Transf. 35 (11) (1992) 2891–2903.

[26] M.E. Taslim, T. Li, D.M. Karcher, Experimental heat transfer and friction in channels roughened with angled, V-shaped, and discrete ribs on two opposite walls, Trans.-Am. Soc. Mech. Eng. J. Turbomach. 118 (1996) 20–28.

[27] P. Singh, B.V. Ravi, S.V. Ekkad, Experimental and numerical study of heat transfer due to developing flow in a two-pass rib roughened square duct, Int. J. Heat Mass Transf. 102 (2016) 1245–1256.

[28] G. Tanda, Effect of rib spacing on heat transfer and friction in a rectangular channel with 45 angled rib turbulators on one/two walls, Int. J. Heat Mass Transf. 54 (5) (2011) 1081–1090.

[29] G. Tanda, Heat transfer in rectangular channels with transverse and V-shaped broken ribs, Int. J. Heat Mass Transf. 47 (2) (2004) 229–243.

[30] E.M. Sparrow, W.Q. Tao, Enhanced heat transfer in a flat rectangular duct with streamwise-periodic disturbances at one principal wall, ASME J. Heat Transf. 105 (4) (1983) 851–861.

[31] R. Jia, A. Saidi, B. Sunden, Heat transfer enhancement in square ducts with Vshaped ribs of various angles, in: Proceedings of the ASME Turbo Expo, vol. 3, 2002, pp. 469–476.

[32] T. Astarita, G. Cardone, Convective heat transfer in a square channel with angled ribs on two opposite walls, Exp. Fluids 34 (5) (2003) 625–634.

[33] G. Xie, J. Liu, W. Zhang, G. Lorenzini, C. Biserni, Numerical prediction of turbulent flow and heat transfer enhancement in a square passage with various truncated ribs on one wall, J. Heat Transf. 136 (1) (2014) 011902.

[34] B. Bonhoff, S. Parneix, J. Leusch, B.V. Johnson, J. Schabacker, A. Bölcs, Experimental and numerical study of developed flow and heat transfer in coolant channels with 45-degree ribs, Int. J. Heat Fluid Flow 20 (3) (1999) 311– 319.

[35] G. Xie, S. Zheng, B. Sundén, Heat transfer and flow characteristics in rib-/ deflector-roughened cooling channels with various configuration parameters, Numer. Heat Transf. Part A: Appl. 67 (2) (2015) 140–169.

[36] A.M.I. Mohamed, R. Hoettiba, A.M. Saif, The effect of the corrugation rib angle of attack on the fluid flow and heat transfer characteristics inside corrugated ribbed passage, J. Heat Transf. 133 (8) (2011) 081901.

[37] H. Sato, K. Hishida, M. Maeda, Characteristics of turbulent flow and heat transfer in a rectangular channel with repeated rib roughness, Exp. Heat Transf. Int. J. 5 (1) (1992) 1–16.

[38] X. Gao, B. Sundén, PIV measurement of the flow field in rectangular ducts with 60 parallel, crossed and V-shaped ribs, Exp. Therm. Fluid Sci. 28 (6) (2004) 639–653.

[39] S.V. Ekkad, J.C. Han, Detailed heat transfer distributions in two-pass square channels with rib turbulators, Int. J. Heat Mass Transf. 40 (11) (1997) 2525– 2537.

[40] D.H. Lee, D.H. Rhee, K.M. Kim, H.H. Cho, H.K. Moon, Detailed measurement of heat/mass transfer with continuous and multiple V-shaped ribs in rectangular channel, Energy 34 (11) (2009) 1770–1778.

[41] A. Murata, S. Mochizuki, Comparison between laminar and turbulent heat transfer in a stationary square duct with transverse or angled rib turbulators, Int. J. Heat Mass Transf. 44 (6) (2001) 1127–1141.

[42] B. Lu, P.X. Jiang, Experimental and numerical investigation of convection heat transfer in a rectangular channel with angled ribs, Exp. Therm. Fluid Sci. 30 (6) (2006) 513–521.

[43] M. Al-Qahtani, H.C. Chen, J.C. Han, A numerical study of flow and heat transfer in rotating rectangular channels (AR=4) with 45 rib turbulators by Reynolds stress turbulence model, in: Proceedings of the ASME Turbo Expo, 2002.

[44] S. Eiamsa-ard, P. Promvonge, Numerical study on heat transfer of turbulent channel flow over periodic grooves, Int. Commun. Heat Mass Transf. 35 (7) (2008) 844–852.

[45] P. Promvonge, W. Changcharoen, S. Kwankaomeng, C. Thianpong, Numerical heat transfer study of turbulent square-duct flow through inline V-shaped discrete ribs, Int. Commun. Heat Mass Transf. 38 (10) (2011) 1392–1399.

[46] S. Acharya, S. Dutta, T.A. Myrum, R.S. Baker, Periodically developed flow and heat transfer in a ribbed duct, Int. J. Heat Mass Transf. 36 (8) (1993) 2069– 2082.

[47] W. Peng, P.X. Jiang, Y.P. Wang, B.Y. Wei, Experimental and numerical investigation of convection heat transfer in channels with different types of ribs, Appl. Therm. Eng. 31 (14) (2011) 2702–2708.

[48] E.A. Sewall, D.K. Tafti, Large eddy simulation of flow and heat transfer in the 180-deg bend region of a stationary gas turbine blade ribbed internal cooling duct, J. Turbomach. 128 (4) (2006) 763–771.