Turkish Online Journal of Qualitative Inquiry (TOJQI)
Volume 12, Issue 6, June 2021:286-292

Research Article

Computatıonal Studıes On The Thermo-Hydraulıc Performance Of Dıfferent Pıpe Geometrıes Of Compact Tubular Aır To Aır Heat Exchangers Used In Low Bypass Ratıo Turbofan Engınes

Dr. A Revanth Reddy[1], M S S Santosh Kumar[2*], B V Shailendranath Reddy[3], K Durga Venkata Siva Prasad[4], G V Surya Teja Varma[5], Dr Chellapa B[6], Fazil Ahmad[7], Dr Kannan B T[8]

Abstract

In this research paper, the thermo-hydraulic performances of the different shapes of the pipes that can be used in the compact air to air heat exchangers of the gas turbine engines have been studied. The standard design/control design has been taken as the cylindrical U bend pipe of diameter 6mm, having a length of 726mm. Three different elliptical pipes of different eccentricities but having equivalent areas are designed to check if the change in design is able to improve the heat transfer characteristics of the heat exchanger, while reducing the pressure losses of the cooling gases. In addition to these two geometrical shapes of the pipes, a new design of pipe which combines the geometries of both the models has been put forth in this paper and its performance has also been studied computationally. The computational calculations are performed using ANSYS CFX. The change in temperature of the hot gases inside the pipes are measured in CFX Post and the effect of the pipe geometry on the pressure drop in the cooling air on the outside of the pipes have also been tabulated and studied.

Keywords: *Compact air to air heat exchangers, U bend pipes, Gas turbine engines, Pipes of combined geometry*

---

[1] School of Aeronautical Sciences, Hindustan Institute of Technology and Science, Padur,Chennai, India
[2] School of Aeronautical Sciences, Hindustan Institute of Technology and Science, Padur,Chennai, India, ssivam1659@gmail.com
[3] School of Aeronautical Sciences, Hindustan Institute of Technology and Science, Padur,Chennai, India
[4] School of Aeronautical Sciences, Hindustan Institute of Technology and Science, Padur,Chennai, India
[5] School of Aeronautical Sciences, Hindustan Institute of Technology and Science, Padur,Chennai, India
[6] School of Aeronautical Sciences, Hindustan Institute of Technology and Science, Padur,Chennai, India
[7] School of Aeronautical Sciences, Hindustan Institute of Technology and Science, Padur,Chennai, India
[8] Department of Aerospace Engineering, College of Engineering and Technology, SRM Institute of Science and Technology, SRM Nagar, Kattankulathur, Kanchipuram, Chennai, TN, India

Introduction

Heat exchangers are a kind of systems used to transfer heat between two or more fluids and to prevent the mixing of fluids the two fluids in the heat exchangers are separated using a solid wall. These can be used in both heating and cooling purposes. Making of turbines is a challenging task as the temperature of the blades should be cooled to make the turbines work effectively. These cooling methods determine the reliability and life of a gas turbine engine. Reduction of temperature of turbine blades is highly depended on how the cold air is effectively used for this purpose. O.K. Krasnikova et al.,[1] have worked on heat exchangers used in Cryogenic helium plants which require compact devices with a high efficiency i.e., to ensure that the heat exchangers are operated with small temperature differences between forward and return helium flows and they focused on heat exchangers to make them more reliable, inexpensive and easy to manufacture. R. Hosseinnejad et al.,[2] have worked with heat exchangers with twisted tape and these models are examined in the fluent software to solve the governing equations. Y. Sano et al.,[3] have worked on effects of thermal dispersion on heat transfer in cross flow tubular heat exchangers, these were investigated in both analytical and numerical methods. They get to know that in addition to the molecular thermal diffusion, there is significant mechanical dispersion in heat and fluid flow in a fluid saturated porous medium, as a result of hydrodynamic mixing of the interstitial fluid particles passing through pores. A. A. Konoplev et al.,[4] demonstrated that efficiency of the heat transfer in the tubular heat exchangers may depend on open flow area of inter tubular channel. This dependence can show itself in different ways for smooth and ribbed tube heat exchangers. Bo Wang et al.,[5] have newly developed compact multi tubular heat exchanger is made of linear metal cellular material. Nidal et al.,[6] have introduced new types of internal fins and the effect of Reynolds and Prandtl number as well as geometrical variables have been discussed. Morteza Khoshvagt et al.,[7] have worked on twisted tapes and twisted tubes and made four different combinations using twisted tapes, twisted tubes and straight tubes and these four tubes are compared to a equivalent straight tube to know the best performing tube.

In this work, we have taken U bend pipes of three different cross sections having circular, elliptical and combined geometry (combination of both elliptical and circular cross sections) which have equivalent cross sectional area to the corresponding circular tube and having the same wall thickness of 0.3mm. The effectiveness of the pipes has been compared with different cross sections of pipes. Ten different cross sectional pipes have been chosen. One pipe is with a circular cross section of diameter 6mm. Six pipes are constructed with different elliptical cross sections which are equivalent to the circular cross section. These six elliptical cross sections can be divided into two different sets, one is with three different cross sections and are named as horizontally elongated tubes as shown in fig. 3 and other three are made in a way that their cross section is perpendicular in the same plane to the horizontally elongated tubes and are named as vertically elongated tubes as shown in fig. 4. For the other three designs, a new kind of design is introduced in this work which is a combination of circular and elliptical pipes. The reason for selecting such kind of pipes is the ease of manufacturing. When we press a circular U bend pipe at the central region which contains of straight tube, it will be converted into elliptical cross section at the straight path and will have circular cross section at the bending path which results in a combination of two different cross sections elliptical and circular. In the fig.1 isometric, front view and side view of a combined tube of ellipse with major and minor axis 4mm and 2mm respectively and circular cross section of 6mm is shown and this pipe is denoted as combined(2,4). Ellipses are denoted as ellipse (a, b), for horizontally elongated ellipse a<b and for vertically elongated ellipse a>b. In fig. 3 and fig.4 a horizontally and vertically elongated ellipses are shown.

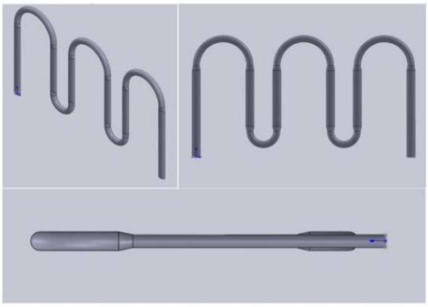

Fig. 1 Isometric, front and Side view of combined(2,4) pipe.

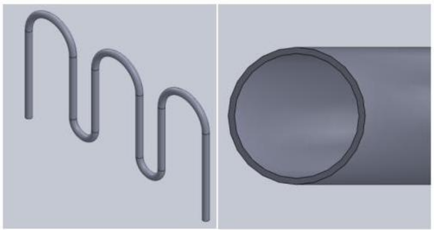

Fig. 2 Isometric view and cross section of circular pipe.

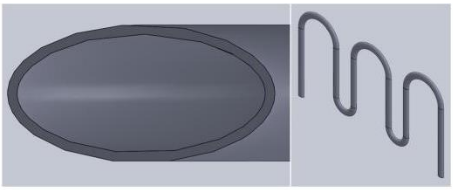

Fig. 3 Isometric view and cross section of ellipse(2,4) pipe.

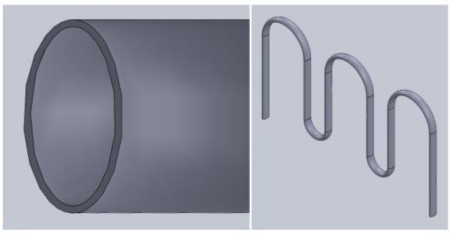

Fig. 4 Isometric view and cross section of ellipse(4,2) pipe.

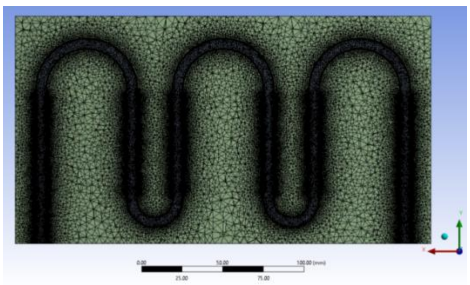

Fig. 5 Hybrid Mesh of the geometry and the domain.

Boundary Conditions:

The input boundary conditions and the theoretical calculations have been performed by Nesterenko in [8]. We will be using the same boundary conditions as mentioned in afore mentioned paper. The hybrid mesh generated for the geometry and the domain is shown in fig. 5. The inflation to account for the boundary layer near the walls for the fluid domain is also shown in the figure. The boundary conditions have been entered in CFX Pre and the solver has been run to achieve a convergence criterion of 1x10^-5.

Results and discussion:

The results of the ΔT values and the ΔP values for the circular pipe, elliptical pipe and combined pipes which are equivalent to the circular pipe of diameter 6mm are shown in Table 1 and the comparison graphs have been shown in fig 6&7.

The comparison of the ΔT for the pipes shows a general trend in the reduction of temperature as the diameter of the pipe passage decreases. From the graphs of pressure drop of the flow in the outer section of the pipes we can conclude that there is a high amount drop in pressure when vertically elongated elliptical tubes are used and pressure drop is least when horizontally elongated elliptical tubes are used. The temperature difference is high for the elliptical cross sectional tubes when compared with any other tubes.. From the comparison graphs of temperature difference we can conclude that ΔT is more for elliptical pipes when compared to circular and combined pipes.

Dimensions	Temperature difference (ΔT) (K)	Pressure drop(ΔP) (MPa)
circle(dia=6mm)	97.81	0.0018
ellipse(2,4)	134.2	0.0011
ellipse(2.25,3.75)	125.7	0.0012
ellipse(2.5,3.5)	118.6	0.0013
ellipse(4,2)	136.1	0.0041
ellipse(3.75,2.25)	124.5	0.004
ellipse(3.5,2.5)	118.8	0.0038
combined(2,4)	116.43	0.0013
combined(2.25,3.75)	111.98	0.0015
combined(2.5,3.5)	107.59	0.0017

Table 1: Temperature difference of the hot flow/inner flow for pipes and pressure drop of cold flow/outer flow for pipes

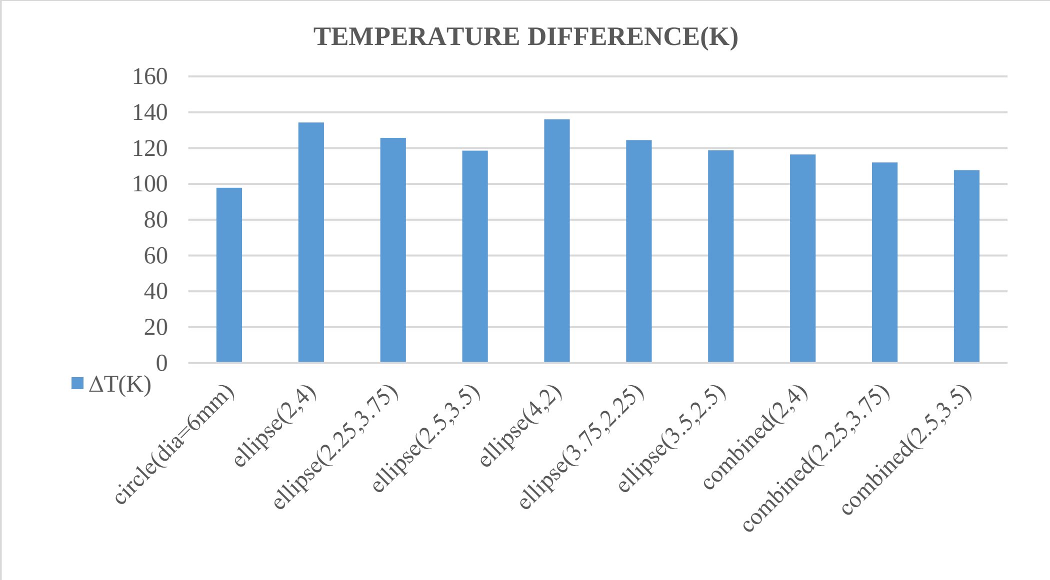

Fig.6 Comparison graph of temperature difference of the hot flow/inner flow for pipes which are equivalent to circular pipes with diameter 6mm.

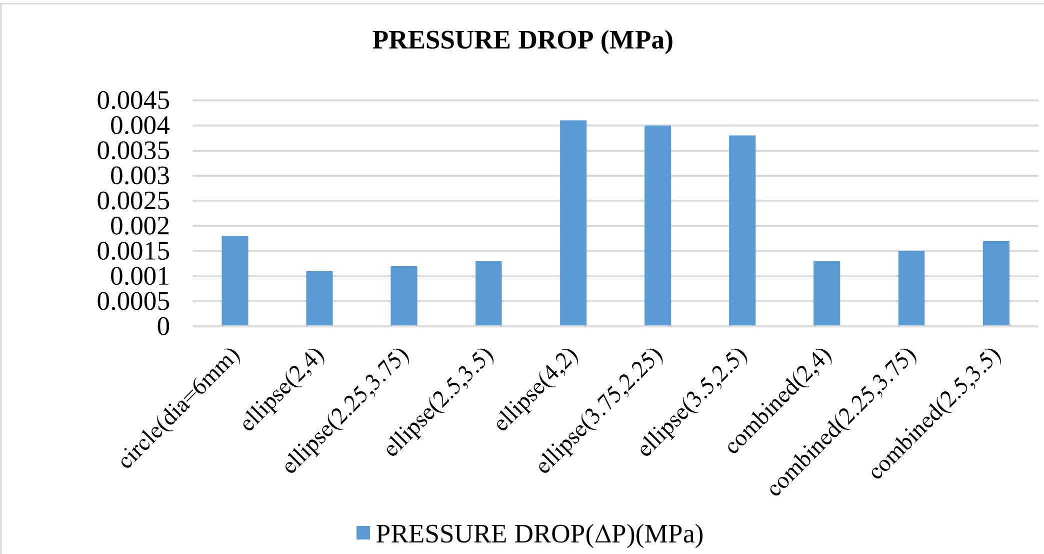

Fig.7 Comparison Graph of Pressure drop for the cold flow/outer flow for pipes which are equivalent to circular pipes with diameter 6mm.

Even though elliptical cross sections give more temperature drop when compared to other two pipes it should be noted that constructing a U bend tube having an elliptical cross section is a challenging task. So, we come up with new kind of pipes which contain elliptical cross sections at straight path of U bend tube and have circular cross section at curved path of the tube which gives us a good efficiency when compared with circular U bend pipe and which are easy to construct when compared to elliptical cross section U bend pipes.

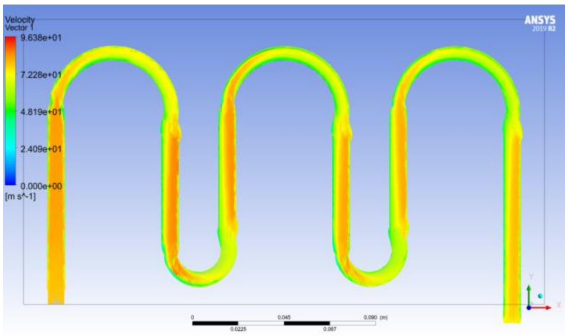

Fig.8 Velocity vector of flow inside the tube which is combination of circular and elliptical cross section which is equivalent with circle of diameter 6mm of length 726mm.

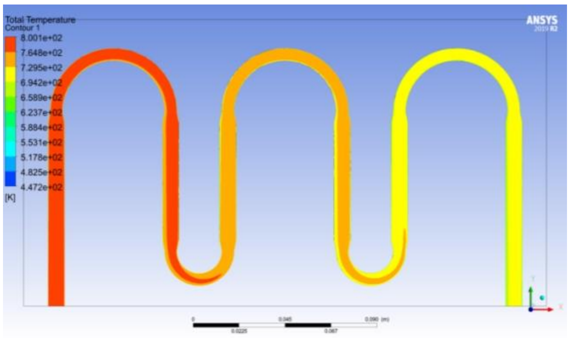

Fig.9 Temperature contour of flow inside the tube which is combination of circular and elliptical cross section which is equivalent with circle of diameter 6mm of length 726mm.

The velocity vector diagrams at the center of the tubes by taking a section plane at the center of the tube. Velocity vector of combined (2,4) pipe is shown in Figure. 8.

Temperature contour diagrams inside the tubes are taken at the center of the tube by taking a section plane at the center of the tube. Temperature reduction inside the pipes as the hot gases flow from one end of the pipe to the other end can be seen from this Figure 9.

Conclusion

From the studies performed on these different pipe designs, it can be seen that the elliptical pipes have the best thermo-hydraulic performance with regards to the fall in temperature on the inside of the pipes and the pressure drop on the outside. But as it was mentioned earlier, the manufacturing of a perfectly shaped elliptical pipes in the U bending section pose a major difficulty for the technologies that are available today. The combined pipes in turn can be compromising option in that they can be manufactured with relative ease and the thermal performance is better than the circular pipes and slightly less than the elliptical pipes and the same can be said about the pressure drop in the cooling flow in the outer section as well.

References

O. K. Krasnikova, T. S. Mishchenko, L. R. Komarova, O. M. Popov, and V. N. Udut.Coiled Tubular Heat Exchangers. Chemical and petroleum Engineering, Vol.38, Nos. 3-4, (2002).

R. Hosseinnejad, M. Hosseini, M. Farhadi; Turbulent Heat Transfer In Tubular Heat Exchangers With Twisted Tape; Akadémiai Kiadó, Budapest, Hungary (Published on: 23 June 2018).

Y. Sano, F. Kuwahara, M. Mobedi , A. Nakayam; Effects Of Thermal Dispersion On Heat Transfer In Cross-Flow Tubular Heat Exchangers. Heat mass transfer Vol. 48; 183-189 DOI 10.1007/s 00231-011-0865-x (2012).

A. A. Konoplev, G. G. Aleksanyan, B. L. Rytov, and A. A. Berlin; On The Compactness Of Tubular Heat Exchangers, Semenov Institute of Chemical Physics, Russian Academy of Sciences, ul. Kosygina 4, Moscow,119991,Russia(2011); DOI:10.1134/S0040579512060127.

Bo Wang, Geng Dong Cheng & Lei Jiang; Design Of Multi-Tubular Heat Exchangers For Optimum Efficiency Of Heat Dissipation. Engineering optimization Vol. 48, No. 8, (Aug 2008), 767-788.

Abu-Hamdeh NH, Bantan RAR, Alimoradi A, Study Of Heat Transfer Intensification Through New Types Of Tubular Heat Exchangers With Rod Bank Insert. Chemical Engineering and Processing - Process Intensification (2020).

Morteza Khoshvaght-Aliabadi, Amir Feizabadi; Performance Intensification Of Tubular Heat Exchangers Using Compound Twisted-Tape And Twisted-Tube. Published by Elsevier; Chemical Engineering and Processing- process intensification, (December 2019).

Nesterenko VG, AR Reddy, Improvement of the design and methods of designing tubular air-to-air heat exchangers cooling systems of gas turbines- *Proceedings of the 30th congress of ICAS*, 2016.