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COOLING OF TURBINE BLADE TIP BY SHAPE MODIFICATIONS TO THE COOLING U SHAPE CHANNEL OF BLADE

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ABSTRACT - The main components of a gas turbine engine are compressor, combustor and turbine. It is important to develop highly efficient gas turbines using the latest state-of-the-art technologies. One of the traditional methods used to improve the efficiency of a gas turbine is to increases the inlet temperature; thereby increasing the power output and, in turn, the efficiency. The problem associated with increasing the inlet temperature of a gas turbine is the failure of material due to excessive thermal stresses. This brings in the concept of cooling of turbine blades to incorporate the increase in the inlet temperature. The cooling should be optimized, as lack of cooling will cause failure of material and excess cooling will cause a decrease in efficiency of the turbine. The two main methods of cooling are internal and external cooling. The turbine blades are exposed to a continuous flow of gas that may enter the turbine at a temperature between 850° C to 1700°C which is far beyond the melting point of current material technology. The life of blade can be increased if an attempt is made to decrease the temperature of the turbine blade by various means. This research deals with cooling of the turbine blade by various methods of applying different geometries of fins at the tip of turbine blade so that enhancement of heat transfer is done and cooling can be done efficiently. In present work three types of fin geometries with different arrangements were used viz. two rectangular fins placed at the tip blade and twisted fin at the tip. All the three configurations were analyzed for three different velocities viz. 10 m/s, 12m /s and 14 m/s. Simulation was performed in ANSYS fluent and CAD models were created using CATIA. Results were compared between the pressure drop and temperature contours for all the cases using post processing. It was found that the rectangular fin provides better heat transfer considering all the velocities and fin geometries.

1. INTRODUCTION

Developed gas turbines working at very high temperatures for increasing the efficiency and performance of the turbines. But very high temperatures may exceed the material melting temperature of the turbine blades. Hence advance cooling systems must be employed for the cooling of the turbine blades for their long life.At present, so many cooling technologies are available for the internal and external cooling of the turbine blades are in practice. Fig 1. shows the most common cooling techniques for the cooling of internal and external regions of the turbine's blades. The outer edge of the turbine blade is cooled by using impingement cooling with gas-film cooling, the middle portion is cooled by using rib tubulated cooling and the trailing edge is cooled by using pin fin cooling with ejection. The cooling of the turbine blades must include all the regions of the blade exposed to hot gases. One such region of a blade in the case of high-pressure turbines is the tip of the blade. For the mechanical and thermal expansion of the turbine blades, a clearance gap is provided between the turbine blade tip and the shroud/ fixed casing of the turbine. But from this clearance gap, leakage of hot gases occurs mainly due to the difference between the pressure side and suction side of the blade.There are several publications available discussing the effects of providing fins / twisted / pin fins inside these serpentine passages which improve the heat transfer by considerable amount.[1]

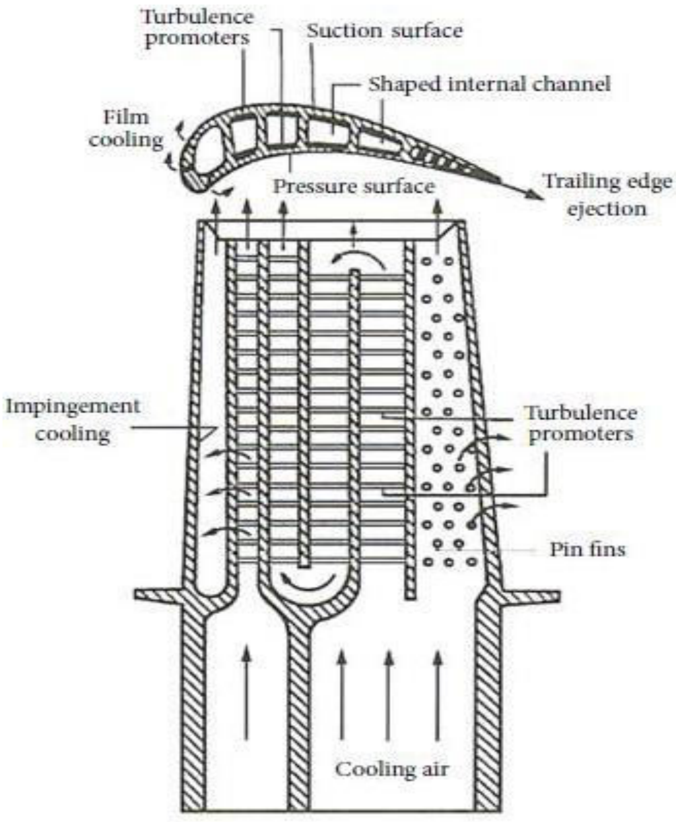


Fig 1: Typical cooling techniques for turbine blades

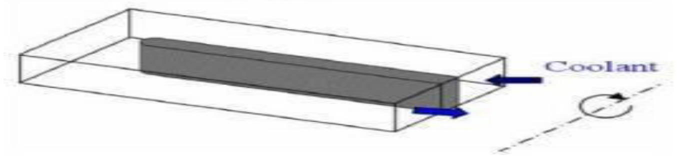
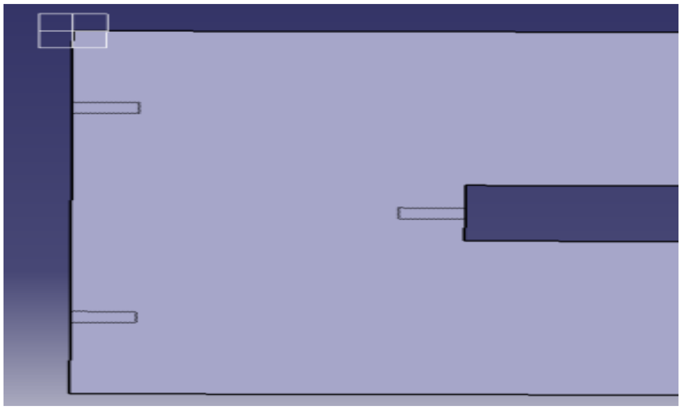


Fig 2: A twopass serpentine passage insidea turbineblade

2. METHODOLOGY

The earlier cases studied include the results for the smooth tip of the turbine blade tip internal surface. In order to improve the turbulence near the tip, there has to be some provision over the tipsurface.Based on these observations and studies the tip surface was modified by adding pins at various locations over the tip internal surface. Three different cases were tested and the results for various Reynolds numbers were studied. The two cases considered are asshown in fig. 3 and 4.



Fins at both side of cannel

Fig 3: Shows Fins in channel (3Fins)

Twisted Tape

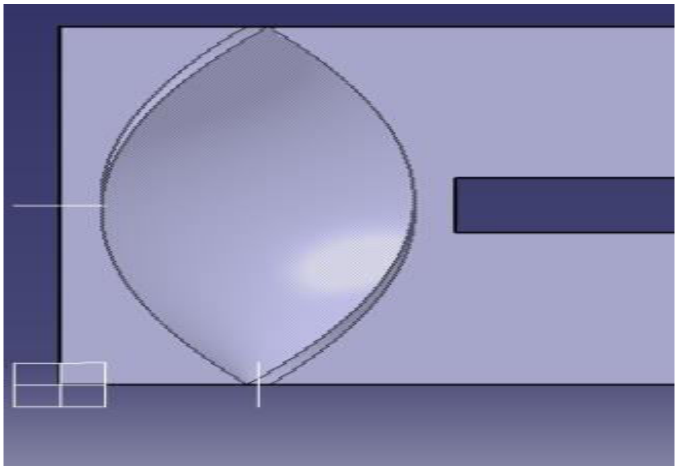


Fig 4: Shows a Twisted insert in channel

The governing equations used in simulations are as described:
Continuity equation

$$\frac{D\rho}{Dt} + \rho\nabla . V = 0 \qquad (1)$$

Momentum Equations

X Component:

$$\rho\frac{Du}{Dt} = -\frac{\partial p}{\partial x} + \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} + \rho f_x \qquad (2)$$

Y Component:

$$\rho\frac{Dv}{Dt} = -\frac{\partial p}{\partial y} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{zy}}{\partial z} + \rho f_y (3)$$

Z Component:

$$\rho\frac{Dw}{Dt} = -\frac{\partial p}{\partial z} + \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z} + \rho f_z \qquad (4)$$

Energy Equation:

$$\rho\frac{D}{Dt}(e + \frac{V^2}{2}) = \rho\dot{q} + \frac{\partial}{\partial x}(k\frac{\partial T}{\partial x}) + \frac{\partial}{\partial y}(k\frac{\partial T}{\partial y}) + \frac{\partial}{\partial z}(k\frac{\partial T}{\partial z}) - \frac{\partial}{\partial x}(up) - \frac{\partial}{\partial y}(vp) - \frac{\partial}{\partial z}(wp) + \frac{\partial(u\tau_{xx})}{\partial x} + \frac{\partial(u\tau_{yx})}{\partial y} + \frac{\partial(u\tau_{zx})}{\partial z} + \frac{\partial(v\tau_{xy})}{\partial x} + \frac{\partial(v\tau_{yy})}{\partial y} + \frac{\partial(v\tau_{zy})}{\partial z} + \frac{\partial(w\tau_{xz})}{\partial x} + \frac{\partial(w\tau_{yz})}{\partial y} + \frac{\partial(w\tau_{zz})}{\partial z} + \rho f.V \qquad (5)$$

BOUNDARY CONDITIONS:

Table 1: Boundary conditions

Inlet	Velocity inlet
Wall	Constant heat flux
Outlet	Pressure outlet

MESH:

The methodology adopted during the study. Model is created in Catia software and imported in Ansys. Initially coarse mesh generated. Later fine mesh is generated by using edge sizing. In this, edges and the regions of high pressure and temperature gradients are finely meshed.

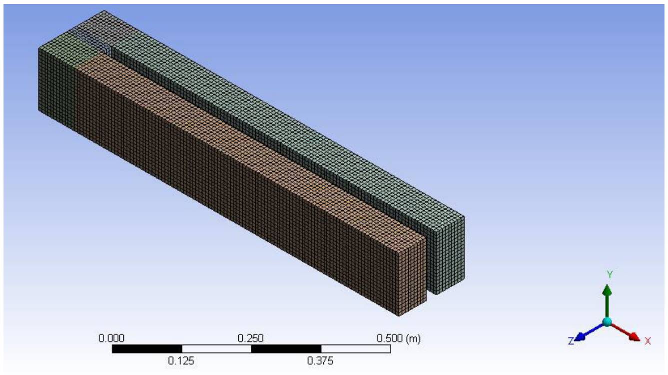


Fig. 5: Mesh model

I. RESULTS & DISCUSSIONS

Before finalizing the simulation and processing further calculations we need to validate the results. The turbulent heat transfer in the smooth tip two pass channels has been computed.

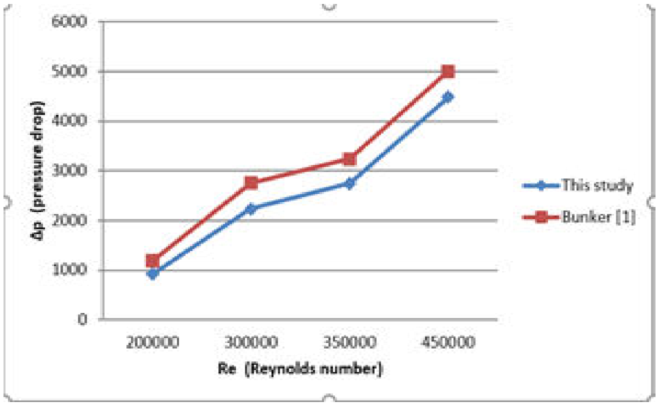


Fig. 6: Comparison of pressure drop for current study and Bunker's [1] experimental results for a smooth tip two pass channel

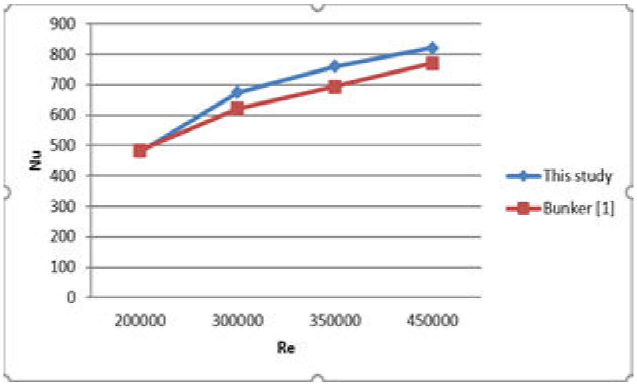


Fig. 7: Comparison of Nusselt number for current study and Bunker's [1] experimental results for a smooth tip two pass channel

A good agreement between the experimental results and the current computational model has been achieved which is shown in the plot 6 and 7. This validates our numerical simulations. After the model validation the results have been computed for different configurations of the tip i.e. by modifying the surface of the tip with arrangement of pins at different locations.

Twisted Tape

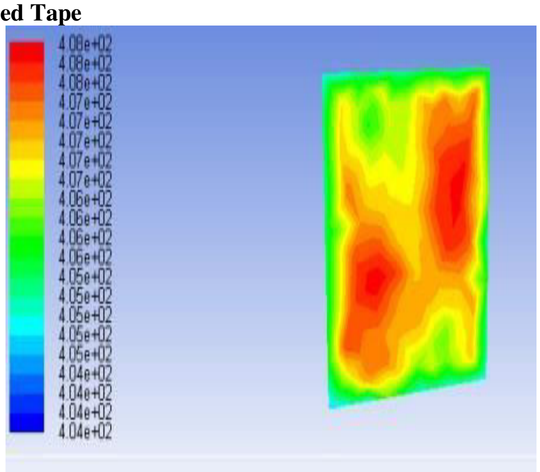


Fig. 8: Temperature contour for twisted tape at velocity 10m/s

Fig 8 shows the temperature contour for the U shape. The upper half portion represents the inlet while the lower half portion represents the outlet region. It is seen from the figure that the middle portion of the face is relatively hotter as compared to the end portions of the tip which is because the heat is dissipated faster from the outer surfaces as more area is exposed to environment due to which the convective heat transfer takes place. It can be observed that themaximum temperature is 408K and minimumtemperature is 404Kwhich was 323K and 299K for the case without fins from this we can say that the temperature of tip has increased considerably which will allow the heat to be transferred by convection easily.

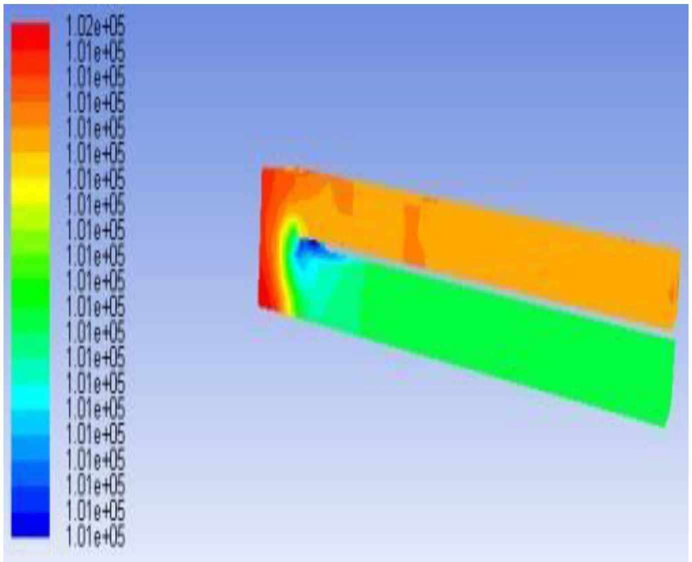


Fig 9: Pressure contour for twisted tape at velocity 10m/s

Fig 9 shows the pressure contour for the full channel. The upper half portion represents the inlet while the lower half portion represents the outlet region. It is seen from the figure that due to twisted insert at U bend pressure the pressure of fluid after passing over the twisted insert has decreased tremendously which is a good effect as if the pressure is lower will be better heat transfer.

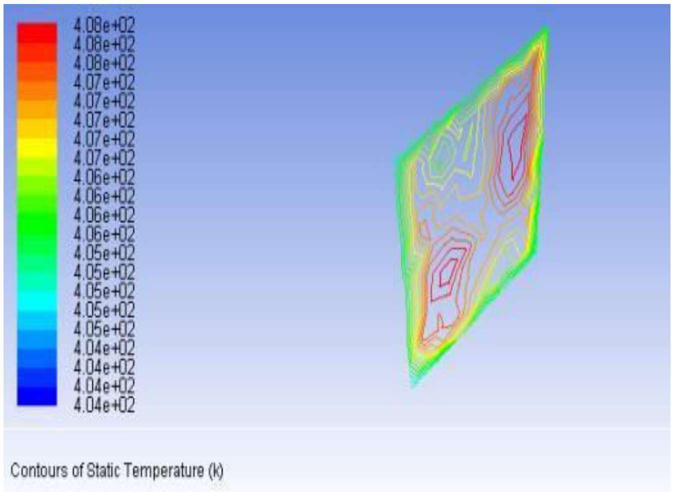


Fig. 10: Temperature contour for twisted tape at velocity 12m/s

Fig 6 shows the temperature contour for the U shape. The upper half portion represents the inlet while the lower half portion represents the outlet region. It is seen from the figure that the middle portion of the face is relatively hotter as compared to the end portions of the tip. Maximum temperature is 408K and minimum temperature is 404K from this we can observe that even while we change the velocity we are not getting change in the temperature values this means that there is no effect on temperature after changing the velocity from 10 m/s to 12 m/s.

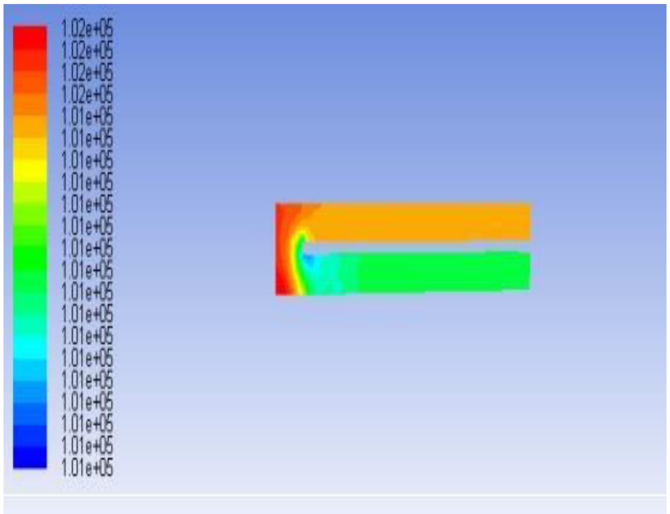


Fig 11: Pressure contour for twisted tape at velocity 12m/s

Fig 11 shows the pressure contour for the full channel. The upper half portion represents the inlet while the lower halfportion represents the outlet region. It is seen from the figure that due to twisted inter at Ubendpressure in higher at that point at exist point pressure is minimum. Here also we do not get any difference in pressure even after changing the velocity the pressure remains the same as that of previous case.

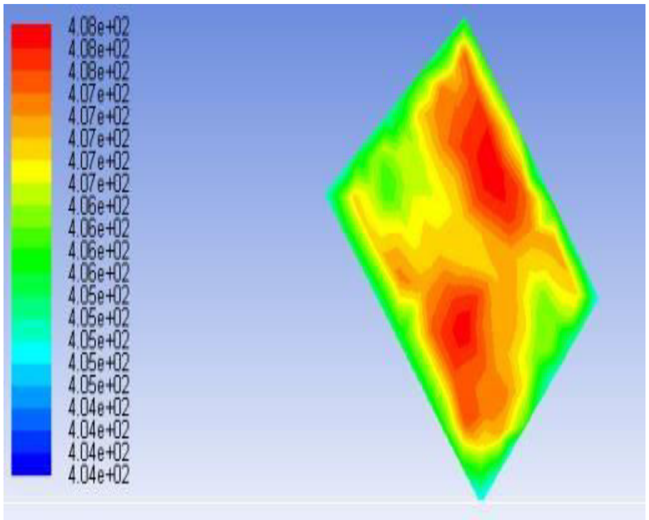


Fig.12: Temperaturecontourfortwistedtape at velocity14m/s

Fig 12 shows the temperature contour for the U shape. The upper half portion represents the inlet while the lower half portion represents the outlet region. It is seen from the figure that the middle portion of the face is relatively hotter as compared to the end portions of the tip. Maximum temperature is 408K and minimum temperature is 404K from this we can observe that even while we change the velocity we are not getting change in the temperature values this means that there is no effect on temperature after changing the velocity from 10 m/s to 14 m/s. It can be concluded now that there is no effect of changing velocity on the temperature profile hence, further any more cases of change in velocity are not considered.

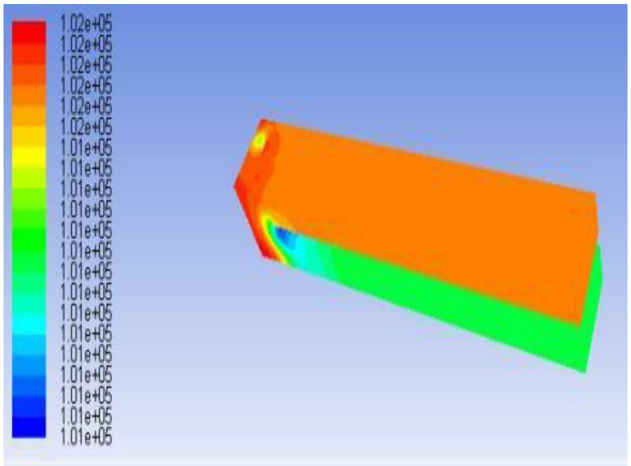


Fig 13: Pressure contour for twisted tape at velocity 14m/s

Fig13showsthepressurecontourforthefull channel. The upper half portion represents the inlet while the lower half portion represents the outlet region. It is seen from the figure that due to twisted inter at U bend pressure in higher at that point at exist point pressure isminimum. Even though we change the velocity we can observe that for twisted fin insert there is no change on pressure as well as temperature this means that there is no need for further analysis of change in velocity on pressure too.

Plate Fins Insert:

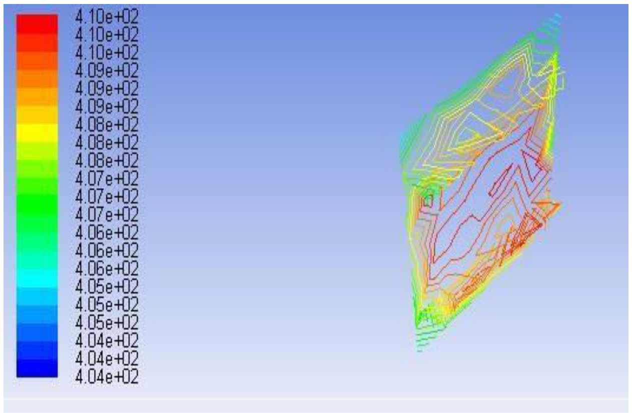


Fig. 14: Temperature contour for plate finat velocity 10m/s

Fig 14 shows the temperature contour for the U shape. The upper half portion represents the inlet while the lower half portion represents the outlet region. It is seen from the figure that the middle portion of the face is relatively hotter as compared to the end portions of the tip. Maximum temperature is 410K and minimum temperature is 404K which is favorable for better heat dissipation as there is rise in temperature it means that the heat from the fluid is transferred to the area where it is open to environment due to which there is a heat loss which is required objective.

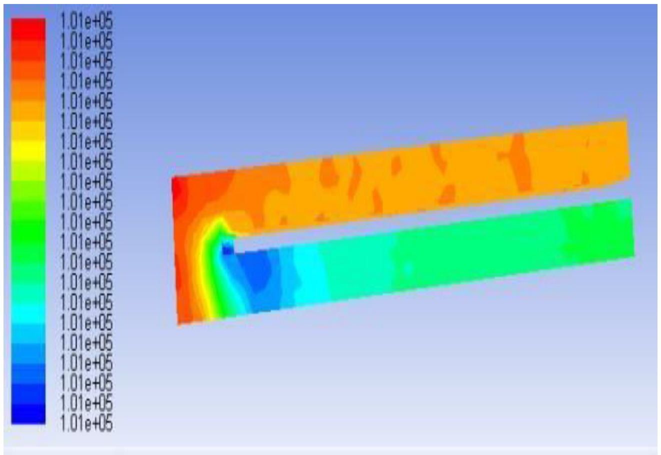


Fig 15: Pressure contour for plate fin at velocity 10m/s

Fig 15 shows the pressure contour for the full channel. The upper half portionrepresents the inlet while the lower half portion represents the outlet region. It isseen from the figure that due to twisted inter at U bend pressure in higher at that point at exit point pressure isminimum. It can be observed that at the end of U channel and towards outlet direction there is very less pressure drop due to this the stresses at U channel will decrease and this will further lead to increase in life of the U channel.

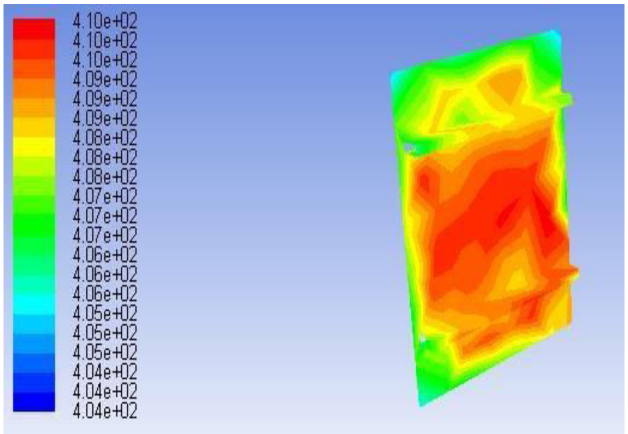


Fig. 16: Temperature contour for plate fin at velocity 12m/s

The upper half portion represents the inlet while the lower half portion represents the outlet region. It is seen from the figure that the middle portion of the face is relatively hotter as compared to the end portions of the tip. Maximum temperature is 410K and minimum temperature is 404K. Now it can be noted that there is no change in the temperature distribution at the turbine blade tip even after changing the velocity from 10 m/s to 12 m/s.

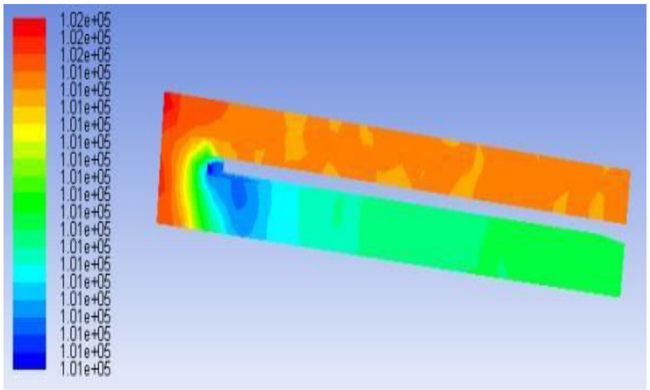


Fig 17: Pressure contour for plate finat velocity 12m/s

Fig 17 shows the pressure contour for the full channel. The upper half portion represents the inlet while the lower half portion represents the outlet region. It isseen from the figure that due to twisted inter at U bend pressure in higher at that point at exist point pressure isminimum. The pressure contour for this case is similar to previous from which we can conclude that there is no effect of velocity change on pressure drop.

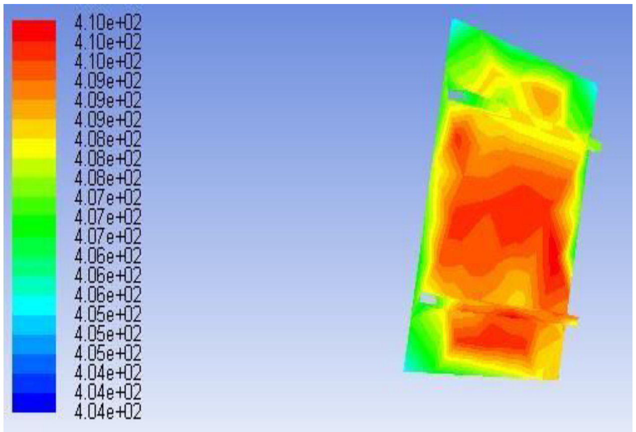


Fig. 18: Temperature contour for twisted tape at velocity 14m/s

Fig 18 shows the temperature contour for the U shape. The upper half portion represents the inlet while the lower half portion represents the outlet region. It is seen from the figure that the middle portion of the face is relatively hotter as compared to the end portions of the tip. Maximum temperature is 410K and minimum temperature is 404K. As there was no change observed for velocity change from 10 m/s to 12 m/s further the velocity is increased to 14 m/s and its effect on temperature is observed but even though the velocity increased the temperature did not change which justifies that there is no effect of velocity variation on temperature distribution at turbine blade tip.

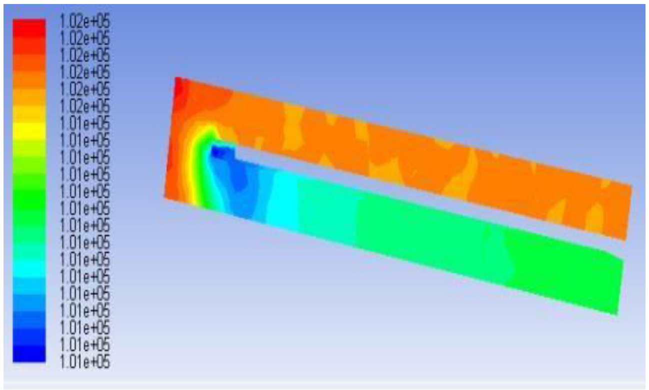


Fig 19: Pressure contour for twisted tape at velocity 14m/s

Fig 18 shows the pressure contour for the full channel. The upper half portion represents the inlet while the lower half portion represents the outlet region. It isseen from the figure that due to twisted inter at U bend pressure in higher at that point at exit point pressure isminimum. The pressure drop also remains same as that of analysis for the case of velocity as 10m/s from this it can be concluded that there is no change in pressure as well as temperature for variation in velocity. The temperature difference for the smooth, rectangular, and twisted insert are as shown in table 2

Table 2: Temperature in various condition

Model Type	Min. Temp (K)	Max. Temp (K)	Temperature Difference (K)
Smooth	299	323	24
Rectangular Fins	403	410	7
Twistedinsert	404	408	4

3. CONCLUSION

The pin fins placed at the corners and at the periphery of the tip force the vortices generated towards the tip wall thereby improving the turbulent mixing of theheated fluid with the incoming coldfluid.Rectangular fins can prove to be a great heat transfer enhancement tool if configured in proper numbers and arrangements over the Pin fins.ByusingRectangularfinsthereisnopressure drop at the U section of the cooling channel. The Rectangular fins provided also helpedin uniform distribution of heat over thetip.From the obtained result of the difference in temperature and pressure losses we can conclude that the Rectangular fin model gives us more heat transfer and it can be concluded better as compared to another model.

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