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NUMERICAL INVESTIGATION OF PISTON COOLING USING SINGLE CIRCULAR OIL JET IMPINGEMENT

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ABSTRACT

Thermal loading of piston in diesel engine has increased more in recent years due to applications of various technologies to meet low emission and high power requirements. If the heat is not dissipated, it would result in cracking and deformation of the piston material. An oil jet impinges on the bottom surface of moving piston with high velocity which in turn cools the piston to a uniform temperature and provide a longer service life of the piston. The objective of present work is to perform numerical investigation and to analyze heat transfer characteristics of single circular oil jet impingement on the bottom surface of a piston by varying the piston position from TDC to BDC and oil jet velocity [10,15 ,20 and 25 m/s] . The heat transfer distribution along the piston surface is found to be strongly dependent on jet speed and vertical distance of bottom surface of piston from nozzle exit. The numerical simulations are carried out using commercial StarCCM+ software using the k-epsilon turbulence model.

Keywords: Circular oil jet impingement, jet diameter (d), nozzle to bottom surface of piston distance (Z), Top dead centre (TDC), Bottom dead centre (BDC)

INTRODUCTION

Pistons in today's motor vehicle engines perform a wide range of functions, e.g., they transmit the force generated by combustion gases to the connecting rod, they support the normal force applied against the cylinder walls while the cylinder pressure is conveyed to the connecting rod and together with their sealing elements, they seal the combustion chamber from the crankcase. The combustion chamber is the hottest part of the engine. The piston is the bottom of the combustion chamber and it is the only part of the chamber that is not cooled by the standard cooling system. Most of the heat is dissipated from the piston through the piston rings to the cylinder walls.

In the automotive industry, there is demand for increasing engine performance by decreasing free space in the engine compartment. Oil jet piston cooling is an alternative way to cool the piston. The oil jet splashes the oil on to the underside surface of the piston, thus removing the heat from the piston and effectively cooling it.

Gulati et al [1] carried out experimental work and studied the effects of the shape of the nozzle and Reynolds number on the local heat transfer distribution to normally impinging jet on flat surface.They reported that at high Re and low (Z/d) ratio local Nusselt number distribution exhibit an occurrence of the secondary peak which is shifted away

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from stagnation point. The formation of secondary peak with increase in turbulence intensity directly enhances the heat transfer rate. Lee et al [2] carried out the effect of jet diameter on heat transfer and fluid flow for round turbulent jet impinging on flat surface.They found that increase in nozzle diameter turbulent intensity becomes more which in turn increase heat transfer rate.

Chougule et al [3] carried out numerical simulation to analyze fluid flow and heat transfer characteristics of multi air jet array impinging on a flat plate. They observed that higher heat transfer is observed for lower Z/d ratio because of reduction in impingement surface area. In case of low Z/d ratio the same amount of fluid spreads is lesser. In case of higher Z/d ratio, there is mixing of jet before impinging on the flat plate which indirectly affects the heat transfer rate.So for given low jet to plate spacing (Z/d) and high Reynolds number, net amount of fluid that comes out of the jet is also higher which causes better heat transfer performance. Madhusudhana et al [4] carried out the numerical simulation on conjugate heat transfer study of turbulent slot impinging jet by varying nozzle to plate spacing (Z/d) from 4 to 10.They reported that increase of nozzle to plate spacing fluid has to travel more distance in ambient fluid medium thereby losing its momentum which in turn dissipate less amount of heat from the impinging plate surface. So, Nusselt number distribution goes on decrease with increase of nozzle to plate spacing (Z/d). Jambunathan et al [5] studied the survey on the impingement cooling of single air jet. They have been observed that simple correlation for local heat transfer coefficient is function of the Reynolds number, nozzle to plate spacing (Z/d), and Prandtl number.

Mohammad et al [6] had studied heat transfer coefficient and temperature at bottom of the piston by effect of some parameter such as relative oil velocity and piston position. Lytle and Webb [7] studied the effect of very low nozzle to plate spacing ratio (Z/d<1) on heat transfer distribution by circular air jet impinging on flat plate. They have been observed that there is a maximum Nusselt number value shifted from stagnation point which was found at low nozzle to plate spacing and higher Reynolds number.Mani bijoy et al [8] has numerically evaluated the performance of piston cooling when an oil jet (SAE-5W30) impinges perpendicular on the moving piston. The present study is to heat transfer distribution at piston bottom and piston temperature were investigated by effect of piston position and oil velocity using numerical techniques.

FLOW DIAGRAM OF PISTON COOLING CIRCUIT

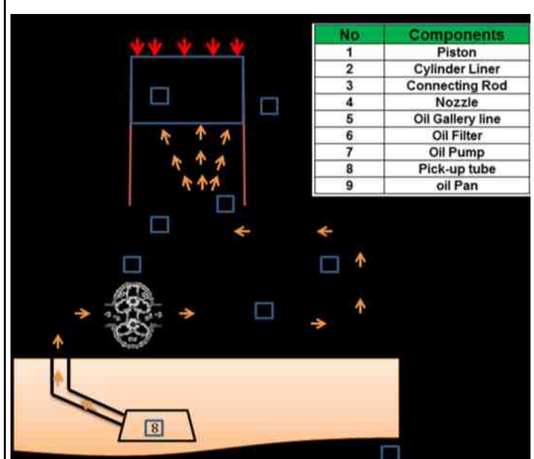

Figure: 1 Schematic sketch piston cooling using oil jet

Working:

Oil is drawn from oil pan by gear or rotor type oil pump and passed on to oil-filter. The Oil filters which remove the dust particle present in oil and allow the oil to flow through gallery line with high pressure. Then oil is released at high pressure from a nozzle mounted on the cylinder block on the bottom surface of the piston. The oil jet produces a high heat transfer coefficient between oil wetted piston surfaces. The drained oil from cylinder flows downward through separate passage and finally gets collected in oil pan where it is

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cooled by air flowing around. The cooled oil is then reticulated.

COMPUTATIONAL DOMAIN:

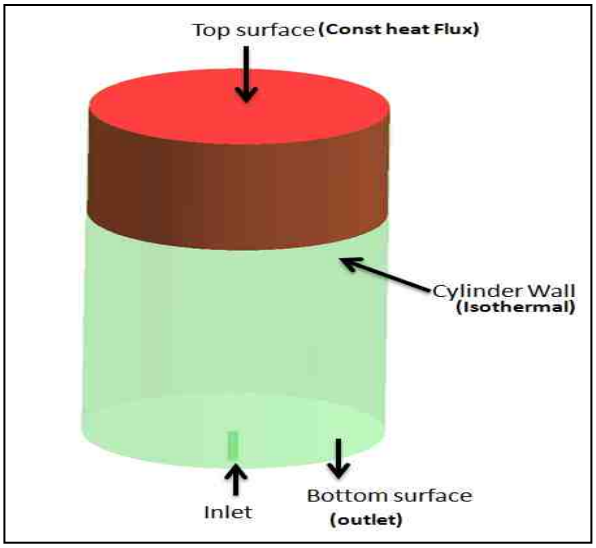

Figure: 2.1 Computational domain of single jet impingement

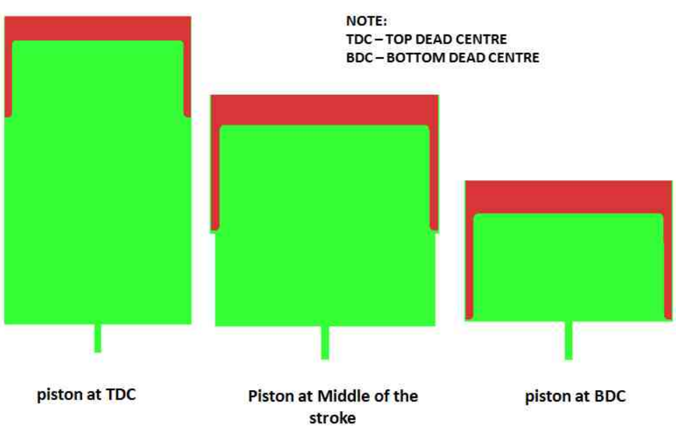

Figure: 2.2 Section view of piston position in the domain.

IMPORTANT ASSUMPTIONS:

- Oil is Isothermal and incompressible
- Constant properties for oil and piston material
- Heat transfer across the side of the Piston surface and liner are neglected

BOUNDARY CONDITIONS

- Inlet: u=0; v= V_{Jet} ; T_{Jet}=100°C
- Top surface: Q_{Flux} = Constant
- Side Surface : $T = T_{wall}$
- Bottom Surface : $P = P_{atm}$

Note:

Top surface - Piston crown contact with hot combustion gas.
Side surface – Piston liner contact surface.
Impingement surface - Piston exposed to oil jet.
Outlet- Oil gets drained.

LIST OF INPUT PARAMETERS FOR NUMERICAL SIMULATION:

The lists of input parameters for simulation are given below:

Piston diameter (D)	89 mm
oil jet impinging distance from BDC (z)	55 mm
Diameter of jet (d)	2.3 mm
oil temperature	100 °C
Oil type	SAE 15W40
Oil flow rate (Q)	4.8 LPM
Specific heat of oil (Cp)	2219 J/kgK
Oil thermal conductivity (K)	0.137 W/mK
Density of oil (ρ)	847 kg/m3
Kinematic viscosity of oil (ν)	14.1*10-6 m2/s
Aluminum thermal conductivity (K)	137 W/mK

Table 1: Section view of single confined circular jet

CFD model:

- Software: Star CCM+10.06
- Unsteady analysis of single jet impingement on the Bottom surface of the piston.
- Dimension Bore and stroke length of cylinder
- Diameter of nozzle jet (3 mm)
- Oil Jet velocity 10,15,20 and 25 m/s

The computational domain is modeled as a 3D steady system in the present investigation. Single circular jets are impinging on the piston bottom surface. The Conjugate method allows for a coupled heat transfer solution between the solid and fluid, and thus predicts the heat transfer coefficient more

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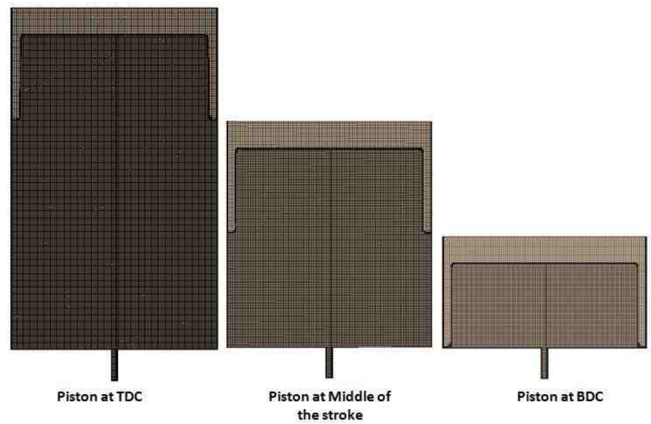
accurately than a decoupled solution. The conjugate heat transfer technique is used in the present simulations to estimate the heat transfer coefficient on the solid surface due to the impingement of the oil jet.

In the CHT approach, two separate simulations are set up, one for the fluid analysis and another for the solid thermal analysis. Using an assumed temperature on the wall boundaries, the fluid flow problem is solved to determine local heat transfer Coefficients and their corresponding fluid reference temperatures on the walls. The wall temperatures are fed to the solid thermal simulation to evaluate the temperature distribution in the piston, completing one cycle of the iteration. The wall temperatures predicted by the solid thermal simulation are then fed back to the transient flow Simulation and applied to the wall boundaries, and this process continues until a steady state condition is reached. The mixture multi-phase model with Volume of fluid (VOF) approach is used for this analysis. The VOF model provides an approach to capture the movement of theinterface between the fluid phases.The primary fluid is oil and secondary fluid is air.

Grid independence study:

Grid independence test for different piston position as shown in fig 3.8. The grid independence study is necessary to improve the accuracy of numerical result. The grid independency on heat transfer characteristics is checked by changing mesh from 8 million to 16 million which follows that 10 million was good enough for the For piston at TDC position present analysis. Similar Grid independence was checked for piston position at Middle of the stroke and BDC So cell count for piston at BDC 5.6 million and Middle of the stroke is about 8 million was considered for the analysis.



3: Section view of unstructured polyhedral mesh for different piston position

RESULTS AND DISCUSSIONS:

EFFECT OF OIL JET VELOCITY OF TEMPERATURE DISTRIBUTION AT PISTON BOTTOM:

The variation of temperature distribution of piston bottom surface by varying oil jet velocity and different piston position has shown in fig .4, 5and 6. It is observed that temperature distribution lower at stagnation zone when piston position at BDC as shown in fig 6.Thereby more amount of oil impinging on the piston bottom surface which results in higher heat transfer rate. Similarly, temperature distribution is higher at stagnation zone when piston position at TDC as shown in fig 4.Lower heat transfer performance is observed for piston position at TDC due to less exposure of oil impingement on the piston bottom surface. The minimum piston temperature occurred at piston position at BDC with velocity of 25 m/s which result in removal of more amount of heat from piston bottom surface.The maximum piston temperature observed at piston position at TDC with velocity of 10 m/s which decreases the heat transfer rate from piston bottom surface.

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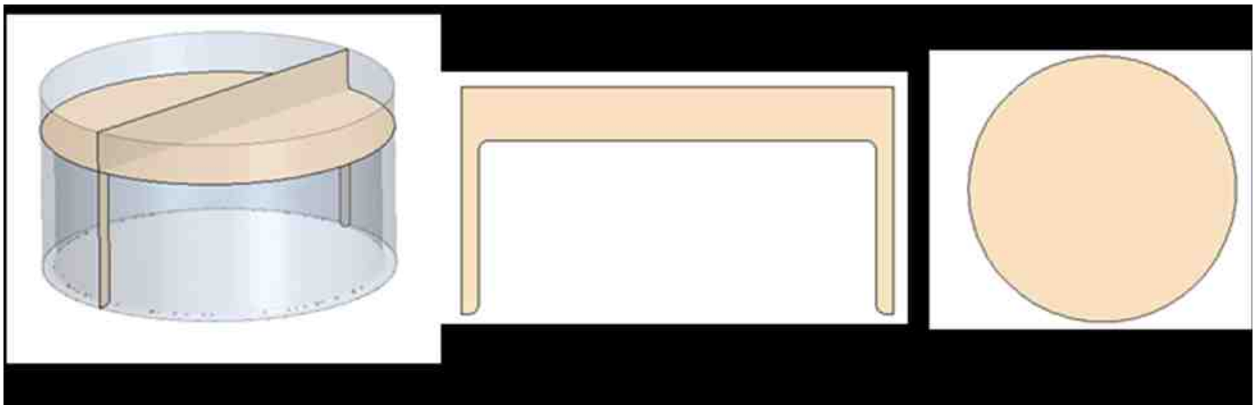

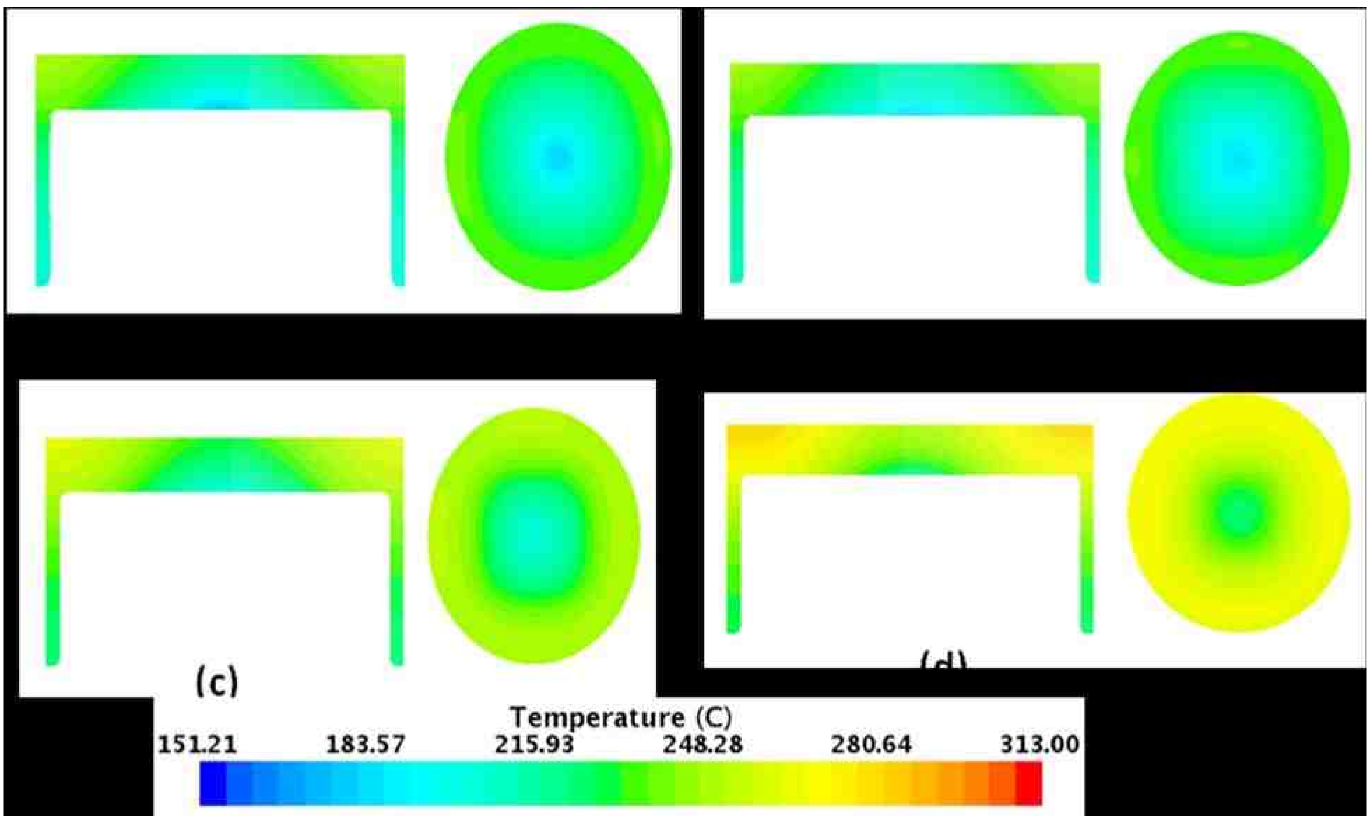

Fig.4 Temperature contour plot of piston at TDC with different oil jet velocity (a) 25 m/s (b) 20 m/s (c) 15 m/s (d) 10 m/s

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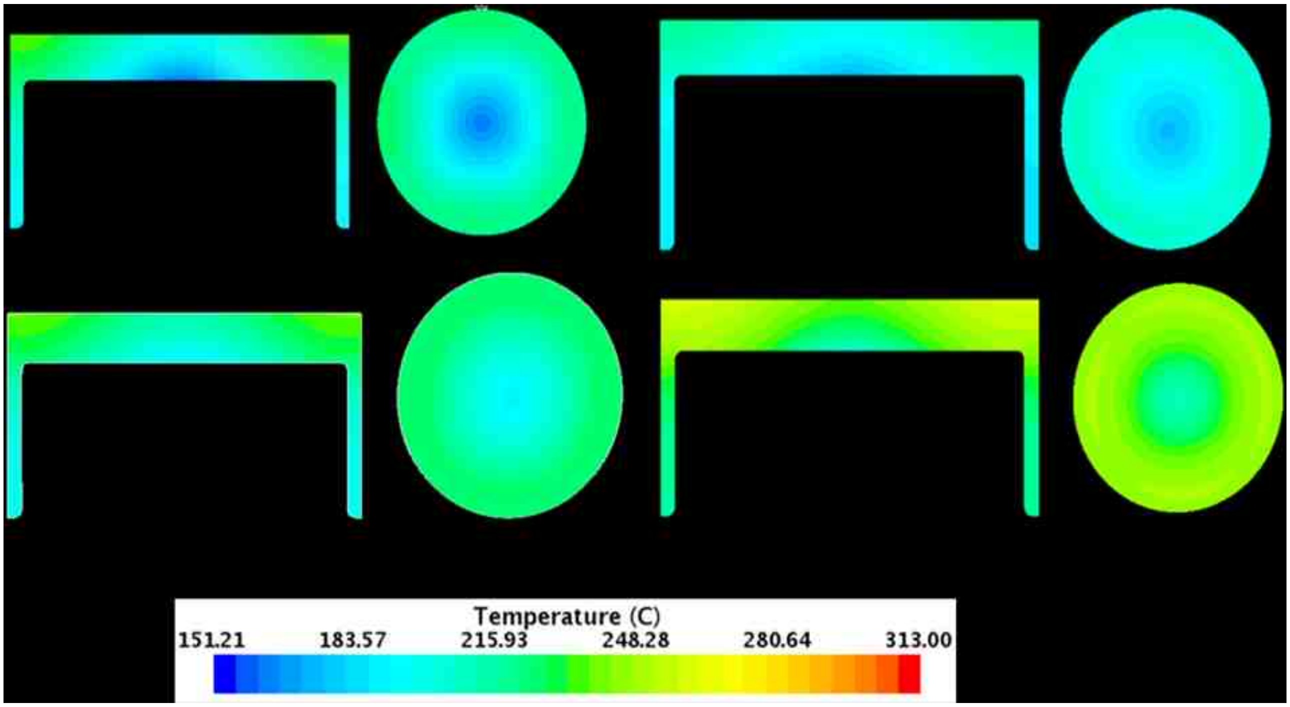

Fig.5 Temperature contour plot of piston at Middle of the stroke with different oil jet velocity (a) 25 m/s (b) 20 m/s (c) 15 m/s (d) 10 m/s

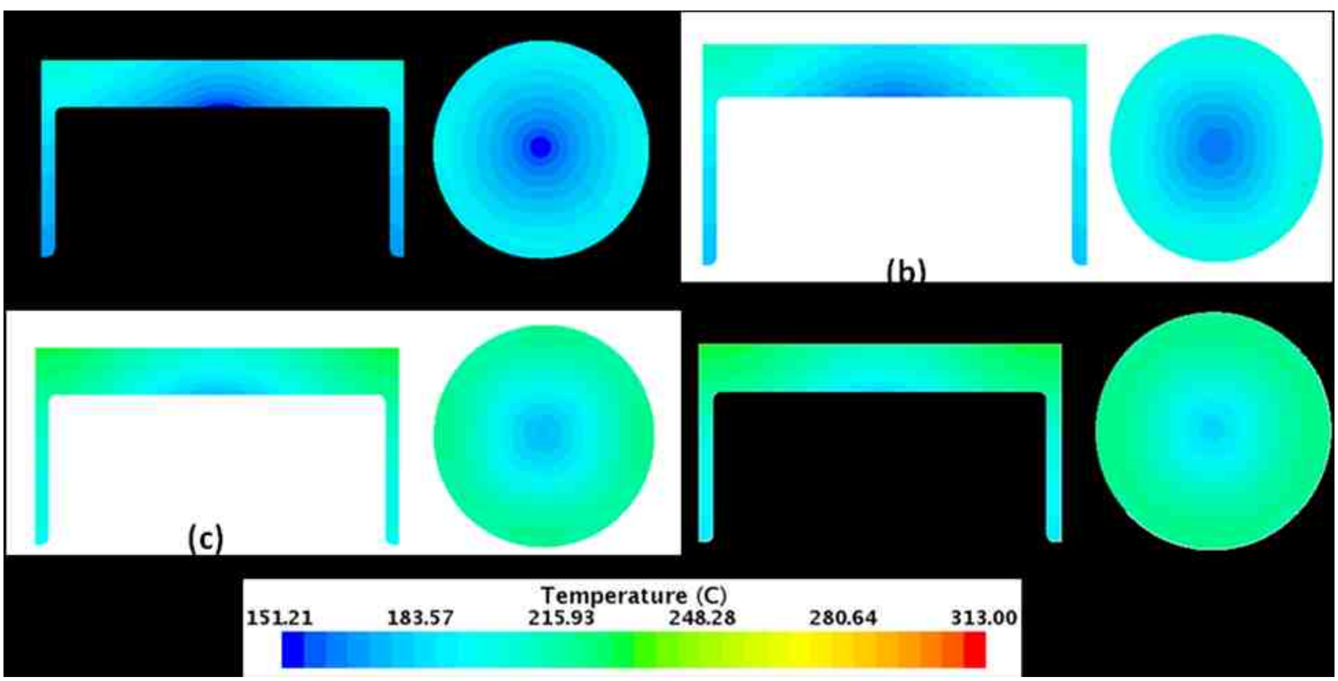

Fig.6 Temperature contour plot of piston at BDC with different oil jet velocity (a) 25 m/s (b) 20 m/s (c) 15 m/s (d) 10 m/s

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TEMPERATURE DISTRIBUTION AT THE PISTON BOTTOM SURFACE

Piston temperature contour for different position for given for oil jet velocity 25 m/s shown in fig 7.It is observed that for given oil jet velocity low heat transfer occurred at piston position at Top dead centre (TDC) due to oil has to travel more distance in the domain there by losing its momentum which in turn dissipate less amount of the heat. As the position of piston moves from TDC to BDC there is increase in heat transfer rate. The piston at BDC has higher heat transfer rate which shown in fig.7. Therefore heat transfer from piston bottom surface is directly related to oil flow rate.

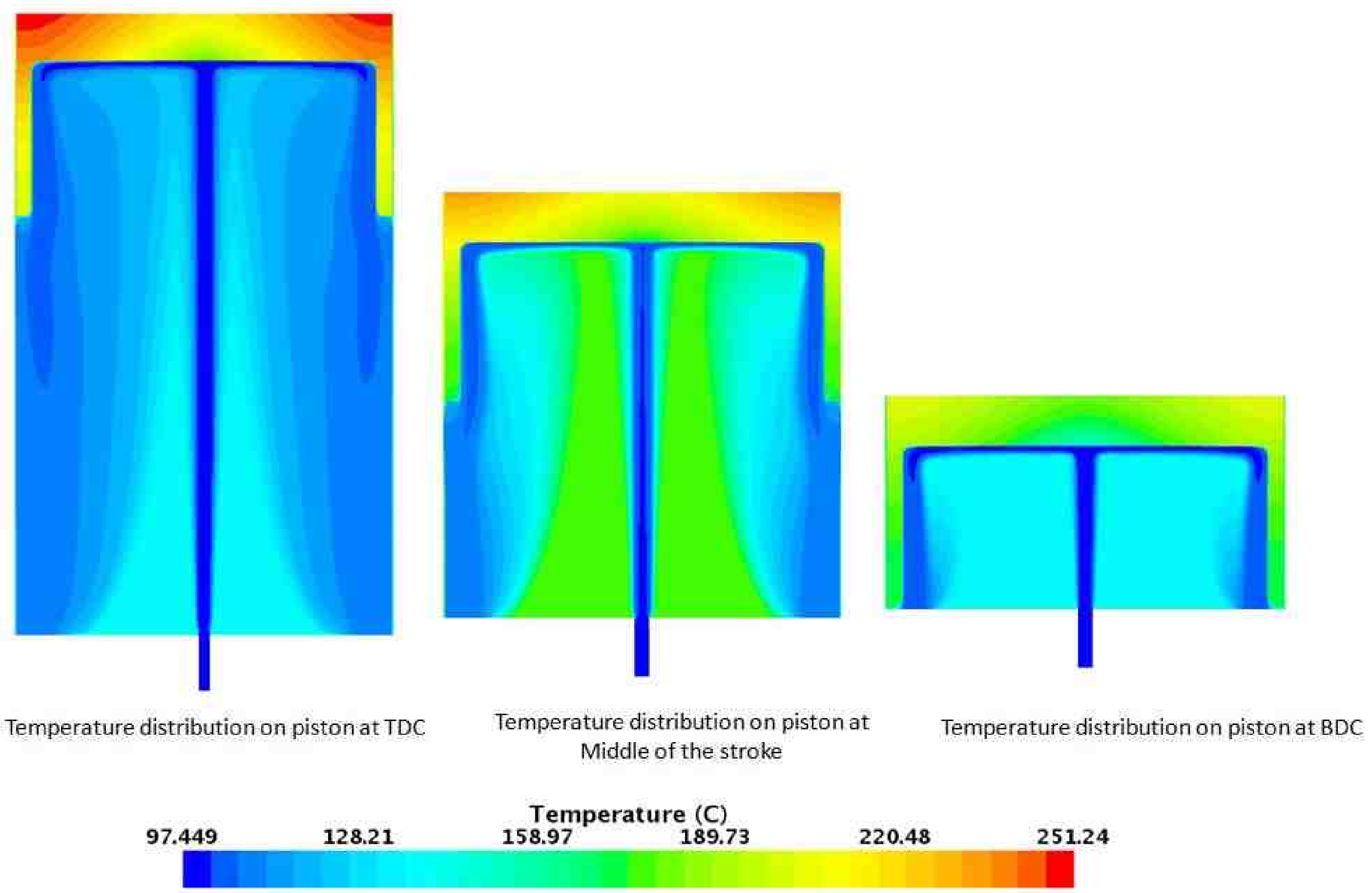

Fig .7 Temperature contour plots for piston at different position

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The variation in temperature along radial direction piston at middle of the stroke position has shown in Fig.8.It is observed that by increasing the oil velocity from 10 m/s to 25 m/s the piston temperature would be decreased which inturn increase heat transfer .There is higher heat transfer near stagnation point and its values get dropped along radial direction which shown below

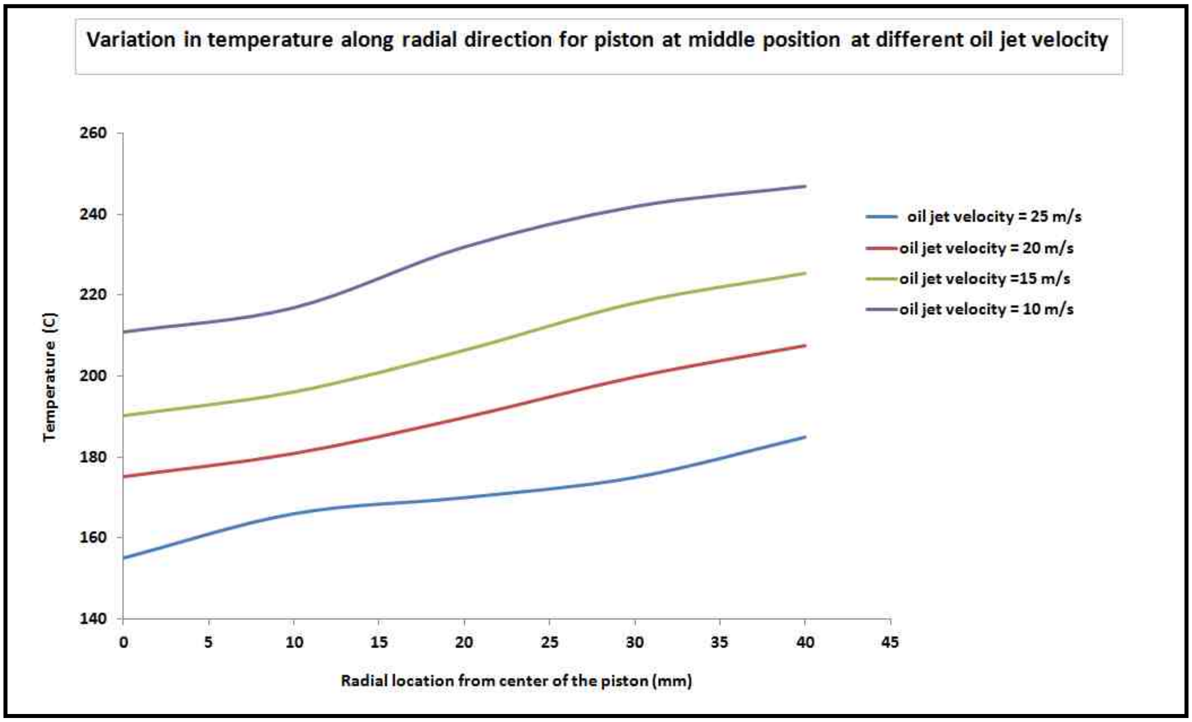

Fig.8 Variation in temperature along radial direction for different plots for piston at different position

EFFECT OF OIL EXPOSURE AT DIFFERENT PISTON POSITION:

The oil distribution of the area exposure at the bottom surface of the piston at different position is shown in Fig.9.For given velocity 20 m/s When position of piston at TDC less oil exposure about 1.5 ml on bottom surface which result in lower the heat transfer. The higher exposure of oil about 6 ml Piston at BDC which caused better heat transfer from the piston bottom surface. The heat removal rate from piston bottom depends on oil velocity and piston position.

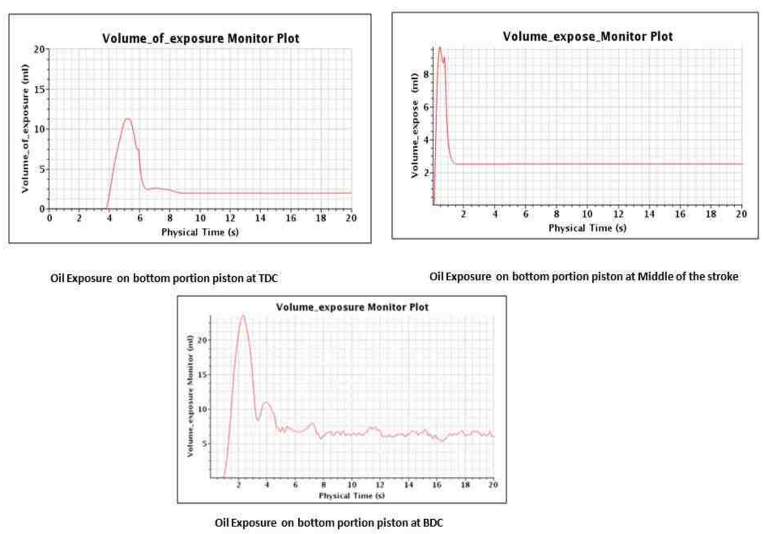

Fig.9 Volume of exposure of oil monitor plot for piston at different position

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RESULTS AND DISCUSSION:

The numerical study has been carried out to investigate the effect of oil jet speed and piston position on the heat transfer distribution on piston bottom surface by impinging the round circular oil jet .The numerical simulations were made for oil jet speed=10,15,20 and 25m/s and jet exit 3 mm in the diameter. The following conclusions have been drawn:

- The heat transfer distributions on piston bottom are dependent jet speed and piston position. Piston temperature was decreased by increasing oil jet velocity.
- Higher heat transfer rate is observed for piston position at BDC (Fig.6) because of more amount of oil impinging on the piston bottom.
- Lower Higher heat transfer performance is observed for piston position at TDC (Fig.4) due to less exposure of oil impinges on the piston bottom.
- Increase in Jet speed increases the heat transfer at all piston position.
- Heat transfer rate at stagnation zone is strongly depending on oil jet velocity. As the jet impinging velocity increased, the heat transfer rate increased. The heat transfer rate at stagnation zone is higher value and goes on decreases as move away from radial direction.

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