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Enhancement of horizontal jet impingement heat transfer analysis on vertical flat plate

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Abstract:

In this paper determination of heat flux for horizontal jet impingement on vertical flat plate is found out. Experiment work is compared with CFD analysis. Diameter of jet is fixed to be 12mm and the gap between jet to plate was set to be 6, 12, 18 and 24mm. Jet to plate distance (e) Ratio ranging from 0 to 2 and Re for turbulent flow is considered in this analysis. Air and CO_2 are compared by experimental and CFD simulation. It was found that CFD simulation can give close to experimental results.

Keywords: Computational fluid dynamics, vertical plate, Heat flux, H/D, Re

1. Introduction

Impinging jets have more demand in industrial applications viz. heating of metals etc. Keyon et al. [1] explained the impact of fluid flow on flat plate. The results shows that as the blowing ratio is greater, greater is the cooling effectiveness. Gokulnath. [2] explained about Jet impingement cooling mechanism. The results shows that heat transfer is to be obtained from the heat transfer coefficients with limited area. Khudheyer. [3] studied computationally for the impingement heat transfer for the inside channel. It is concluded that the heat flux is enhancing. It is also found out that as the jet size increases heat transfer also increases.

Akshay. [4] explained about theoretical and experimental developments in heat transfer. The results shows that jet impingement method provides best way of getting more heat transfer rate. Muhsincan. [5] described the effects of different phase heat transfer improvements through impact of jet cooling. The results shows that use of nano rods enhances surface area of the plate. Pallavi and Ashish. [6] experimented and simulated to achieve an elementary perceptive. Results shows that heat transfer is increased by varying the parameters. Vipin et al. [7] studied enhancement of heat transfer in pulsed jet impingement cooling at different frequencies. Results shows that there is a considerable increase in average Nusselt number. Mahesh. [8] studied different CFD techniques used. The results are, r_{ib} with more perforation gives enhancement of Nusslet number. Chaina. [9] numerically studied the single impinging jet on concave surface. The results shows that more in Re gives increase in Nusselt number. Reji Kumar. [10] determined the cooling of impinging jet to increase the temperature. Results shows that cooling is used for more density applications. In this paper comparing heat transfer rate for CFD and experiment for air and CO_2 has been found out. K. Siva Satya Mohan & S. K. Bhatti [11] studied and compared analysis of heat flux for an inclined jet, which impinges on stationery vertical and horizontal flat. CFD simulation and experimental investigation were performed to analyse the heat transfer performance of a hot fluid in a cylindrical impinging jet on a flat surface. From results, it is found that heat flux of air is more than CO2. Also inclined jet

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with horizontal plate has better results than vertical plate. K. Siva Satya Mohan & S. K. Bhatti [12] performed numerical simulation to study the heat transfer performance of a hot fluid in a confined impinging jet on a flat heated surface. The tests were realized for the following ranges of the governing parameters: the jet thickness is 2m and the distance of horizontal jet to heated surface was set to 1 to 3 m. Three different cases are considered in this analysis. They are H/D = 0.5,1 and 1.5. Fluids like Acetylene and Acetyl chloride are compared in this analysis. Turbulent models considered for this analysis are Spallart Almaras, k-ω and k-ε. Out of these three k- ω model has more heat transfer characteristics. The plate is considered to be stationery. Horizontal Jet with convergent nozzle is considered and compared in this analysis. Results shows that Surface Nusselt number, Surface Heat Transfer coefficient plays vital role for better heat transfer calculation. Sajja Ravi Babu et al. [13] conducted experiments on the preparation of water-alumina nanofluid for volume fractions between 0.01% and 0.1%. After preparing the nanofluid, the measurement data of viscosity and thermal conductivity of the prepared nanofluid is taken for different volume fractions and this data was used for training the ANN model. Results found that 70 percent of the data was used for training, while the remaining 30 percent was used for testing. Validation was done by taking the values from data randomly. K.P.V.K.Varma et al. [14] carried out CFD analysis on a double pipe heat exchanger fitted with perforated tube inserts under fully turbulent flow regime. k-€ turbulence model along with enhanced wall functions was used to capture the near wall region effects. Mass flow rate and temperatures at the inlet of the test section were maintained as 0.1 kg/s and 333K. Analysis was carried out to analyse the temperature, velocity, pressure and turbulence contours of double pipe heat exchanger fitted with perforated tubes and modified geometry perforated tubes. Results shows that there was a change in heat transfer by inserting the perforated tubes and geometry modified tube inserts inside the tubes of the heat exchanger. B. Kirankumar et al. [15] examined the machinability of AISI P20+Ni steel using Wire Electrical Discharge Machining (WEDM) process. Various cutting wires are investigated, including zinc-coated brass wire, cryogenically treated zinc-coated brass wire and brass wire with ultrasonic vibration (UVBW). Optimal machining conditions for high productivity in terms of material removal and surface quality in terms of minimum roughness value are determined using Response Surface Methodology (RSM) and the Search and Rescue Optimization Algorithm (SAR), considering factors such as servo voltage, pulse off time, pulse on time and peak current. Experimental findings identify UVBW as the most effective wire electrode for machining of AISI P20+Ni, achieving a desirability of 0.722 through RSM and after 87-92 iterations with SAR. A comparison of prediction techniques, including Deep-Belief-Neural-network (DBN), hybrid DBN-SAR and RSM methods, gives the superior accuracy of the hybrid DBN-SAR approach in predicting WEDM process parameters, for enhancing machining process efficiency and precision.

2. Materials and methodology

The components used, their materials and working fluids used for the present analysis were as shown in Table 2.1. Three different jets were fabricated with different diameters. Parameters considered and their ranges are pivoted in Table.2.

Specifications of the jet and plate used for the analysis were pivoted in Table 2.2. Thermal properties of fluids at 30^{0}C temperature are shown in the Table 2.3. It shows that thermal conductivity of air is more than that of CO_2.

Table 1 Materials and working substance

Component	Material	Working substance
Cylinder and jet	Steel	Air
Plate	Copper	CO_2

Table 2.1 Parameters and their ranges

Parameter	Value
Surface temperature range, $T_{s,\infty}$ °C	30- 80^{0}C
Nozzle diameter, mm	10 - 14
Nozzle to plate distance to jet diameter (H/D)	0.5 – 2

Table 2.2 Specifications of jet and plate

D_1	L_1	D	H	H/D	L_2

mm	mm	mm	mm		mm
76	140	10, 12 and 14	5, 6 and 7	0.5	180
76	140	10, 12 and 14	10, 12 and 14	1	180
76	140	10, 12 and 14	15, 18 and 21	1.5	180
76	140	10, 12 and 14	20, 24 and 28	2	180

3. Experimental set up and procedure

Fig 1 Pictorial view of horizontal jet on flat plate

Fig.1 shows the proposed experimental set up for Horizontal jet impingement on vertical flat plate

Heat flux can be calculated from the mathematical equation from Heat Transfer. Table 4, 5 and 6 shows the calculated values of heat transfer coefficient from e=0.5 to 2.

Table 4 Reynolds number of air and CO_2 for ɵ =90^0, α =$0^0$and ɵ =0^0, α =90^0at D=10mm

		Re		h, W/m^2K	
	Fluid	Air	CO_2	Air	CO_2
e	0.5	6.25 x 10^5	8.54 x 10^5	2527	1903
	1	9.38 x 10^5	12.81 x 10^5	3497	2633
	1.5	12.51 x 10^5	17.08 x 10^5	4399	3313
	2	15.64 x 10^5	21.35 x 10^5	5261	3962

Table 5 Reynolds number of air and CO_2 for ɵ =90^0, α =$0^0$and ɵ =0^0, α =90^0at D=12mm

		Re		h, W/m^2K	
	Fluid	Air	CO_2	Air	CO_2
e	0.5	5.21 x 10^5	3.07 x 10^5	1820	1370
	1	7.82 x 10^5	4.60 x 10^5	2517	1896
	1.5	10.42 x 10^5	6.14 x 10^5	3168	2386
	2	13.03 x 10^5	7.68 x 10^5	3788	2853

Table 6 Reynolds number of air and CO_2 for ɵ =90^0, α =$0^0$and ɵ =0^0, α =90^0at D=14mm

		Re		h, W/m^2K	
	Fluid	Air	CO_2	Air	CO_2
e	0.5	4.47 x 10^5	6.10 x 10^5	1380	1039
	1	6.70 x 10^5	9.16 x 10^5	1907	1437
	1.5	8.94 x 10^5	12.21 x 10^5	2401	1809
	2	11.17 x 10^5	15.25 x 10^5	2870	2162

4. Flow diagram in CFD

Figure 3 and 4 shows model and meshing of horizontal jet impinging on vertical plate.

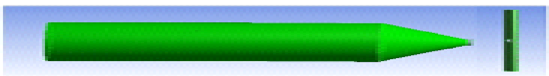


Figure 2 Horizontal jet & plate

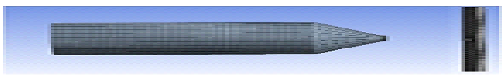


Figure 3 Meshing

2.7 BOUNDARY CONDITIONS IN CFD

Boundary conditions are the input and output conditions for which analysis is to be done.

3. RESULTS AND DISCUSSION

3.1 Experimental results and discussion

3.1.1 Experimental results and discussion for air at D=10mm

Fig. 4 shows the heat transfer rate enhancement at various e ratios and at various Re

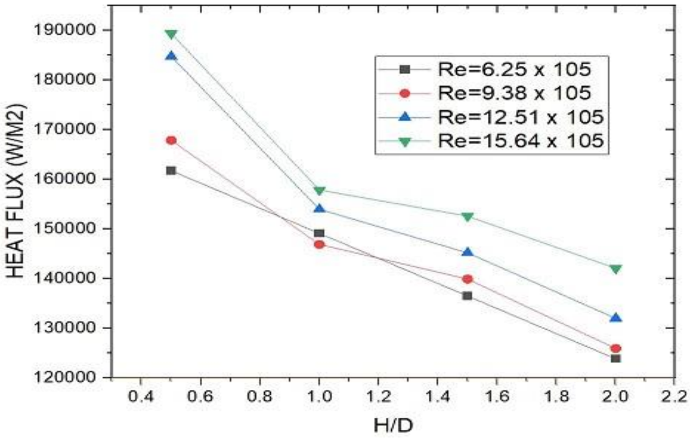


Fig. 4 heat transfer rate vs H/D at different Reynolds numbers at D=10mm

3.1.2 Experimental results and discussion for CO_2 at D=10mm

Fig.5 shows the heat transfer rate enhancement at various H/D and Re

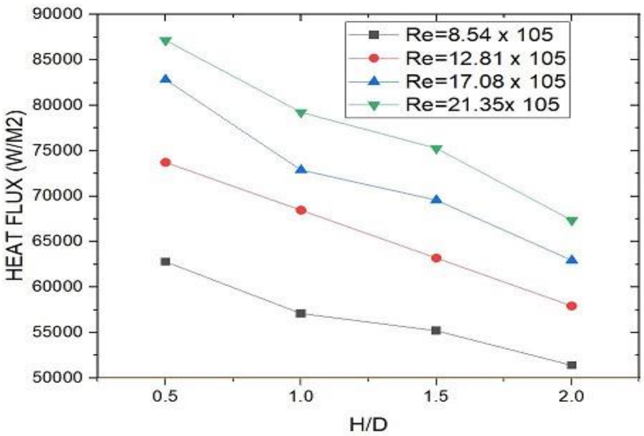


Fig. 5 heat transfer rate vs H/D at different Reynolds numbers at D=10mm

3.1.3 Experimental results and discussion for air at D=12mm

Fig.6 shows the heat transfer rate enhancement at e ratios and at various Re

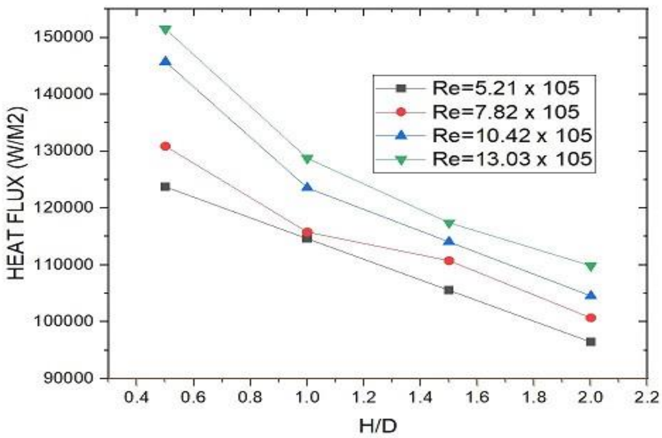


Fig. 6 heat transfer rate vs e at different Reynolds numbers at D=12mm

3.1.4 EXPERIMENTAL RESULTS AND DISCUSSION FOR CO_2 at D=12mm

Fig. 7 shows the heat transfer rate enhancement at e ratios and at various Re

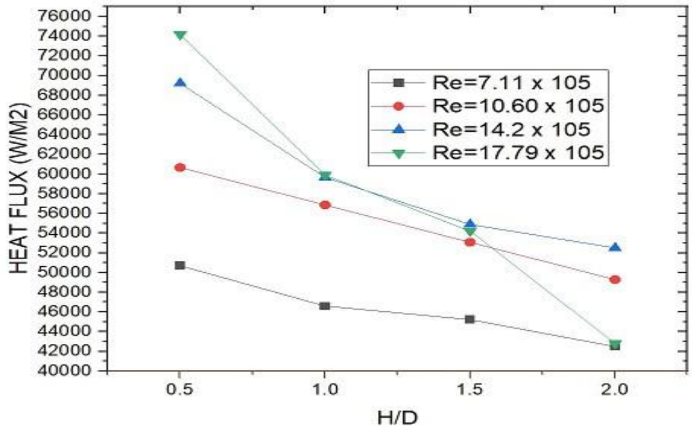


Fig. 7 heat transfer rate vs e at different Reynolds numbers at D=12mm

3.1.5 EXPERIMENTAL RESULTS AND DISCUSSION FOR AIR at D=14mm

Fig. 8 shows the heat transfer rate enhancement at various e ratios and at various Re

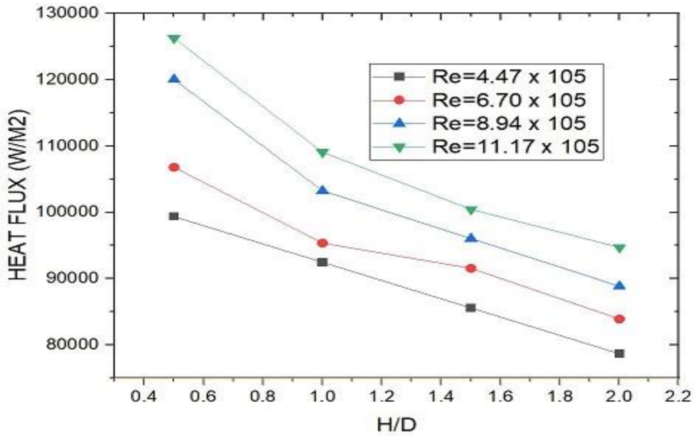


Fig. 8 heat transfer rate vs e at different Reynolds numbers at D=14mm

3.1.6 EXPERIMENTAL RESULTS AND DISCUSSION FOR CO_2 at D=14mm

Fig. 9 shows the heat transfer rate enhancement at various e ratios and at various Re

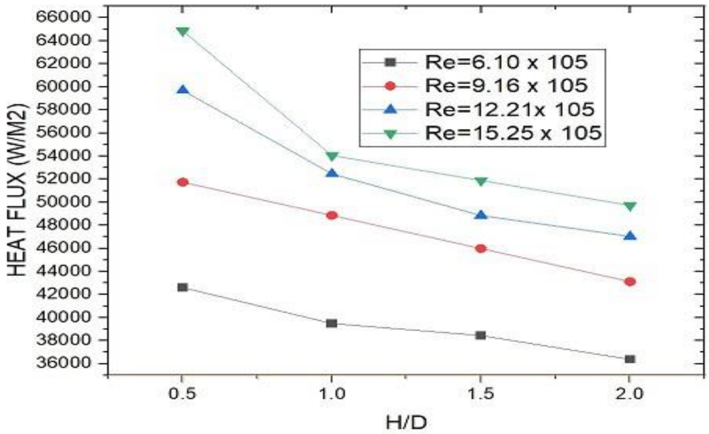


Fig. 9 heat transfer rate vs e at different Reynolds numbers for CO_2 at D=14mm

3.2 Cfd Analysis Results And Discussion

3.2.1 for air at D=10mm

Fig.10 shows the heat transfer rate enhancement at various e ratios and at various Re in CFD.

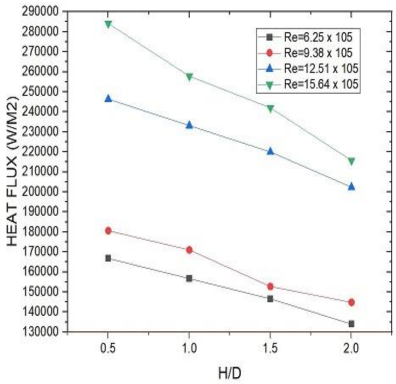


Fig. 10 heat transfer rate vs e at different Re

Fig.11 and 12 shows the temperature and heat flux of the jet and plate.

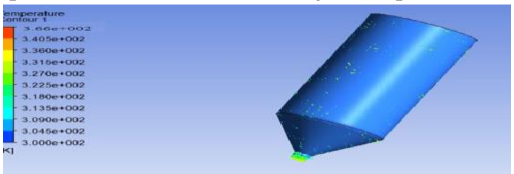


Figure 11 Outlet temperature of Jet

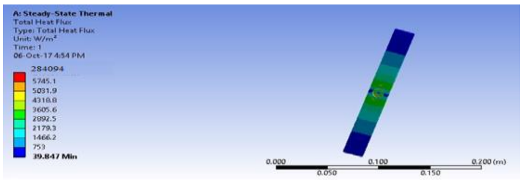


Figure 12 Total heat flux of flat plate

3.2.2 For CO_2 at D=10mm

Fig 13 shows the variation of heat transfer rate enhancement at various e ratios and at various Re in CFD.

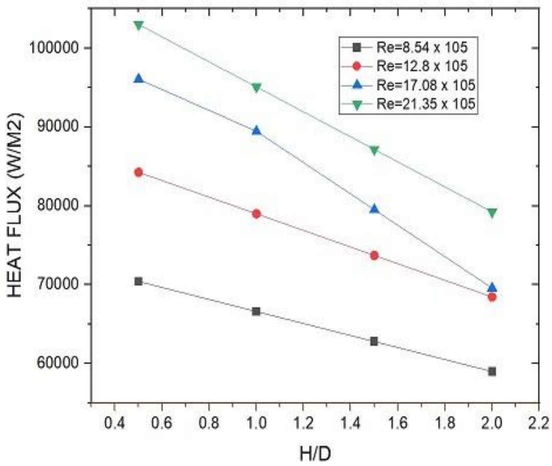


Fig. 13 heat transfer rate vs e at different Re

Fig.14 and 15 shows the temperature and heat flux of the jet and plate.

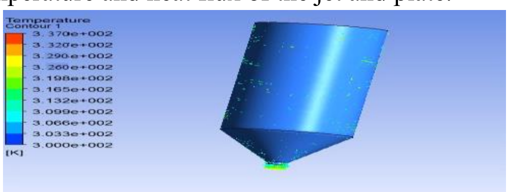


Fig. 14 Outlet temperature of jet

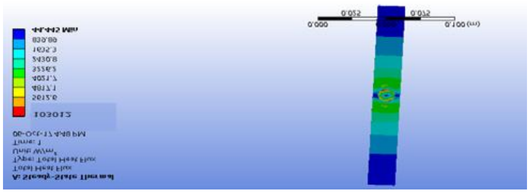


Fig.15 Total heat flux of flat plate

3.2.3 For air at D=12mm

Fig.16 shows the variation of heat transfer rate enhancement at various e ratios and at various Re in CFD.

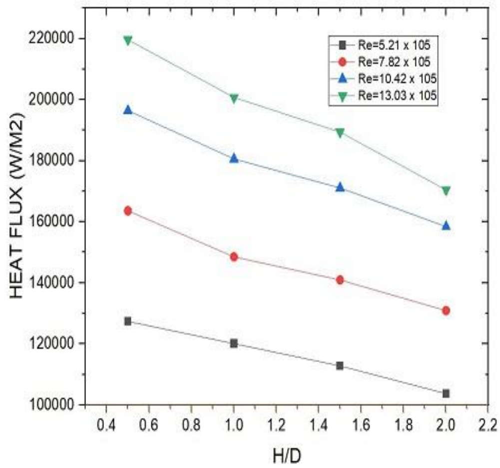


Fig. 16 heat transfer rate vs e at different Re

Fig.17 and 18 shows the temperature and heat flux of the jet and plate.

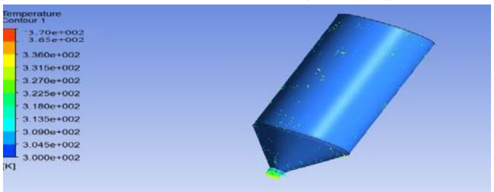


Fig. 17 Outlet temperature of Jet

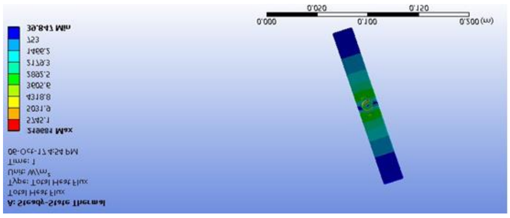


Fig. 18 Total heat flux of flat plate

3.2.4 For CO_2 at D=12mm

Fig. 19 shows the variation of heat transfer rate at various e ratios and at various Re in CFD.

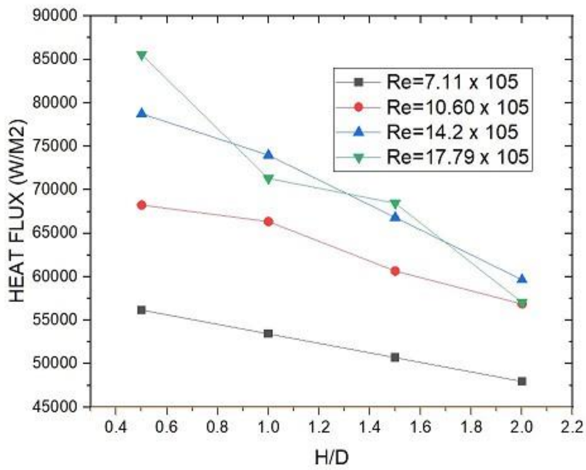


Fig. 19 heat transfer rate vs e at different Re

Fig. 20 and 21 shows the temperature and heat flux of the jet and plate.

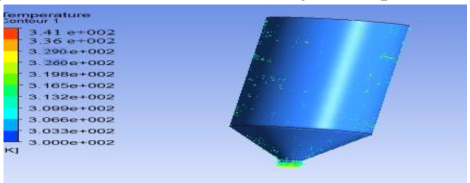


Figure 20 Outlet temp.of cylindrical jet

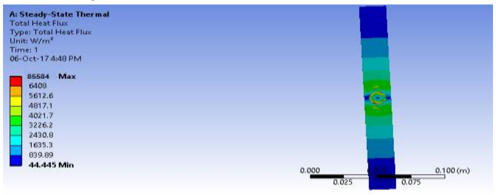


Figure 21 Total heat flux of flat plate

3.2.5 For Air at D=14mm

Fig.22 shows the heat transfer rate enhancement at various e ratios and at various Re in CFD.

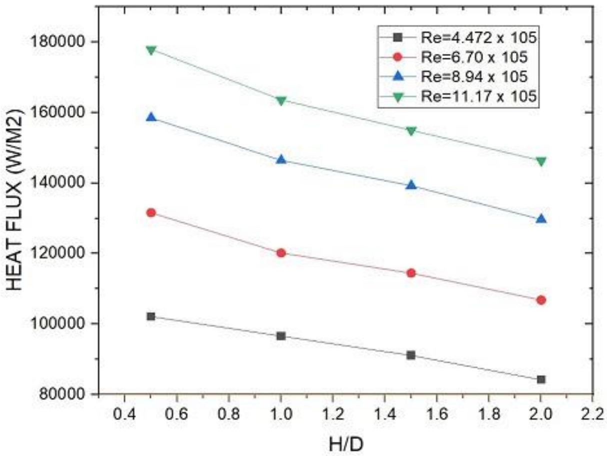


Figure 22 heat transfer rate vs e at different Re

Fig.23 and 24 shows the temperature and heat flux of the jet and plate.

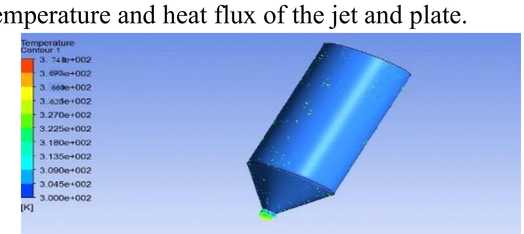


Figure 23 Outlet Temp. of cylindrical Jet

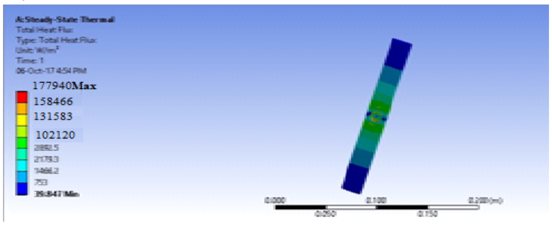


Figure 24 Total heat flux of flat plate3.2.6 For CO_2 at D=14mm

Fig 25 shows the heat transfer rate enhancement at various e ratios and at various Re in CFD.

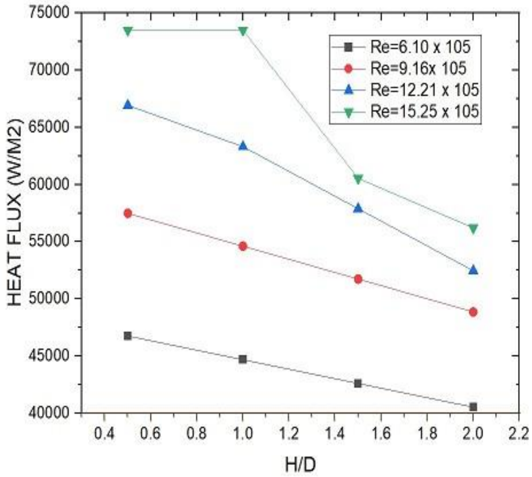
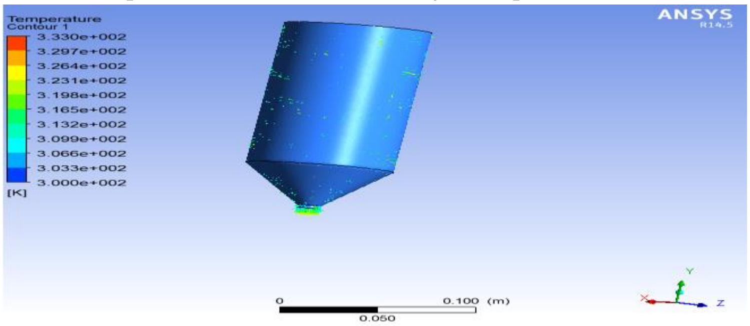


Fig. 25 heat transfer rate vs e at different Re

Fig.26 and 27 shows the temperature and heat flux of the jet and plate.



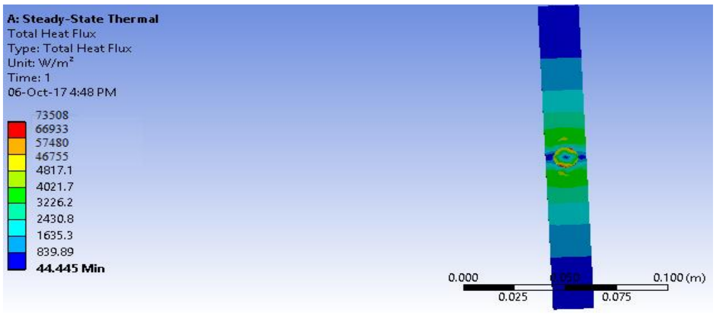


Fig. 26 Outlet temperature of cylindrical jet   Fig. 27 Total heat flux of flat plate

5. Conclusions and recommendations

- From results is is shown that e=0.5 gives more heat flux than e=1,1.5 nd 2.
- From results it is shown that at massflow rate of 0.25 kg/s gives more heat flux.
- It is concluded that CFD validation is correlated to exerimental value and is more for air.

Nomenclature

Re	Reynolds number
D_l	Diameter of cylinder
L_l	Length of the cylinder

D	Diameter of the jet
L_2	Length of the plate
H	Distance from nozzle exit to stagnation point
CFD	Computational fluid dynamics
H/D=e	jet to plate distance and diameter of jet

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