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CFD Analysis of Argon Cell for Pyrochemical Processing

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Abstract: R&D activities on pyroprocess started at IGCAR, with setting up of a laboratory scale facility to carry out lab scale studies on separation of heavy metals. However, it is necessary to develop the technology expeditiously. Hence it is planned to scale up the process studies and set up engineering scale facilities at Fast Reactor Technology Group (FRTG), IGCAR. This inactive demonstration facility is named as High Temperature Electrorefiner (HTER). Majority of the important equipments of this facility will be inside an Argon cell where high purity argon gas atmosphere will be maintained at ambient temperature. This paper describes the studies on the argon flow and thermal characteristics inside the Argon cell for ensuring safe operation. These safety studies will be considered as the basic requirement for design of HTER.

Keywords: Argon cell, Pyroprocess, COMSOL.

1. Introduction

Pyrochemical reprocessing or Pyroprocessing is the suitable method for reprocessing spent metallic fuel from fast breeder reactors. This technique can be used for reprocessing short cooled and high burn-up fast reactor metal fuels. Pyroprocessing installations are more compact based on aqueous reprocessing methods.

R&D activities on pyroprocess started at IGCAR, with setting up of a laboratory scale facility to carry out lab scale studies on separation of heavy metals. However, it is necessary to develop the technology expeditiously. Hence it is planned to scale up the process studies and set up engineering scale facilities at Fast Reactor Technology Group (FRTG), IGCAR. This inactive demonstration facility is named as High Temperature Electrorefiner (HTER). Majority of the important equipments of this facility will be inside an Argon cell where high purity argon gas atmosphere will be maintained at ambient temperature. This paper describes the studies on the argon flow and thermal characteristics inside the Argon cell for ensuring safe operation. These safety studies will be considered as the basic requirement for design of HTER.

This HTER facility will be equipped with several types of pyroprocess equipment such as electrorefiner, salt and cadmium distillation equipment, scraping equipment and tilting equipment inside an Argon cell. The argon cell size is approximately of 16.5m (L) ×4.6m (W) × 6m (H). Fig.1 shows the layout of the argon cell with process apparatus. The electrorefiner in this process, produces a cathode deposit, which contains dendrites of heavy metal and occluded salts or cadmium. Distillation in vacuum is essential for recovery and consolidation of heavy metal. This is carried out in a high temperature vacuum retort also termed Cathode Processor (CP). Cathode processing involves loading the cathode deposit with salt/cadmium in to a crucible and subsequently placing the crucible in the cathode processor. Further the crucible is heated under vacuum to distill the salt /cadmium from the crucible. The crucible is further heated to melt and consolidate the heavy metal. The crucible is then cooled forming a heavy metal ingot in the crucible mold.

To operate the argon cell safely, all generated heat in the argon cell should be removed effectively by circulating argon gas and also there should not be any abnormally high temperature regions. The cell is ventilated via twelve 100mm × 200mm rectangular duct on the top ceiling and bottom of the argon cell. The argon is supplied to the argon cell at the temperature of 30^{0}C from top and comes out from bottom of argon cell. The temperature of all the walls of the process apparatus has been defined with constant temperature of 100^{o}C. The Argon flow and thermal characteristics are studied for addressing the safety issues. COMSOL-Multiphysics simulation tool is used for this purpose. The k-ε turbulence model along with heat transfer model has been used to calculate the argon velocity profile, temperature profile inside the argon cell.

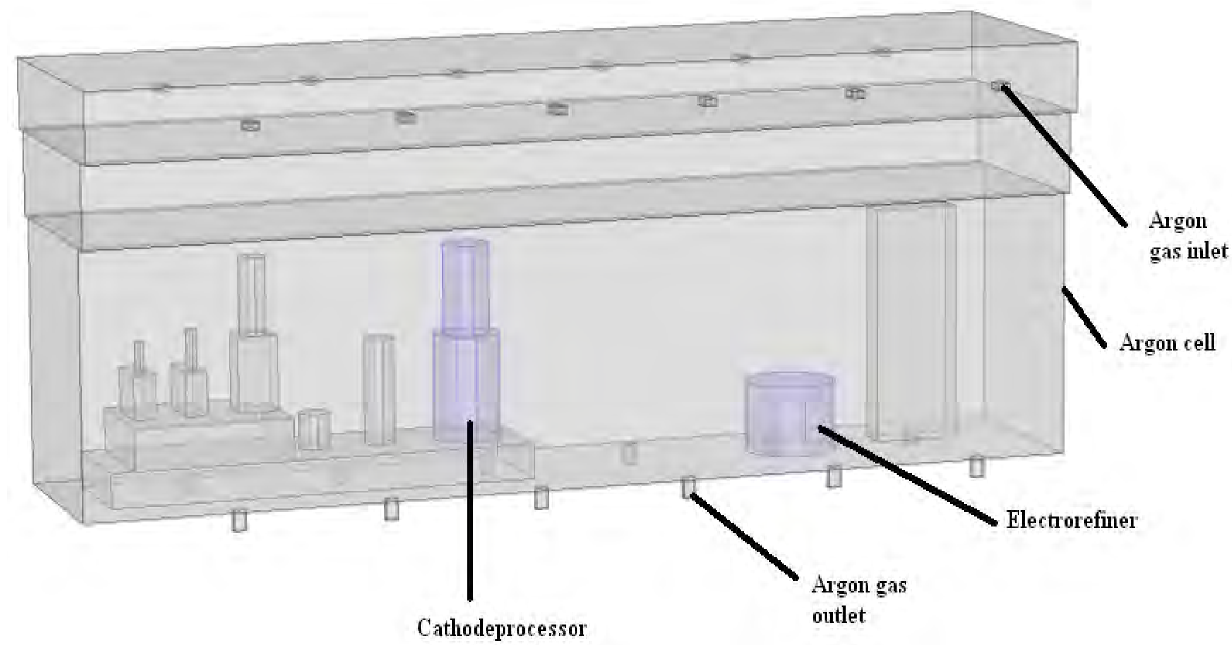


Fig. 1: Layout of the argon cell with process apparatus

2. Mathematical Model

The study used Non Isothermal model with turbulence flow. It uses Reynolds Averaged Navier Stokes (RANS) equations as the Turbulence model type for solving the mean velocity field and pressure. The closure scheme used for solving RANS equation in this problem is k-ε model. The heat conduction equation in solid is used for solving the temperature inside the solid domain. Whereas heat conduction equation used in fluid domain include the turbulence effect for solving the temperature inside the fluid domain.

3. Geometrical Model

To simplify the geometrical model of argon cell, the cell is assumed as a simple rectangular box with 16.5m (L) ×3.5m (W) × 6m (H) dimension. Since Cathode processor and electrorefiner are only process equipments that will act as the vital heat source inside the argon cell, so they are only included inside the cell. The shape of both the equipments i.e. electrorefiner and cathode processor are assumed cylindrical and approximate sizes were taken from the conceptual design of the equipments. Twelve 100mm × 200mm rectangular duct on the top and on the bottom of the argon cell are also included in the geometrical model. To further simplify the geometrical model, the argon cell was cut into two halves along the symmetrical plane (zx plane). Fig.2(a) shows geometrical model with plane of symmetry. The final simplified geometrical model of th argon cell used for COMSOL simulation is shown in Fig.2(b).

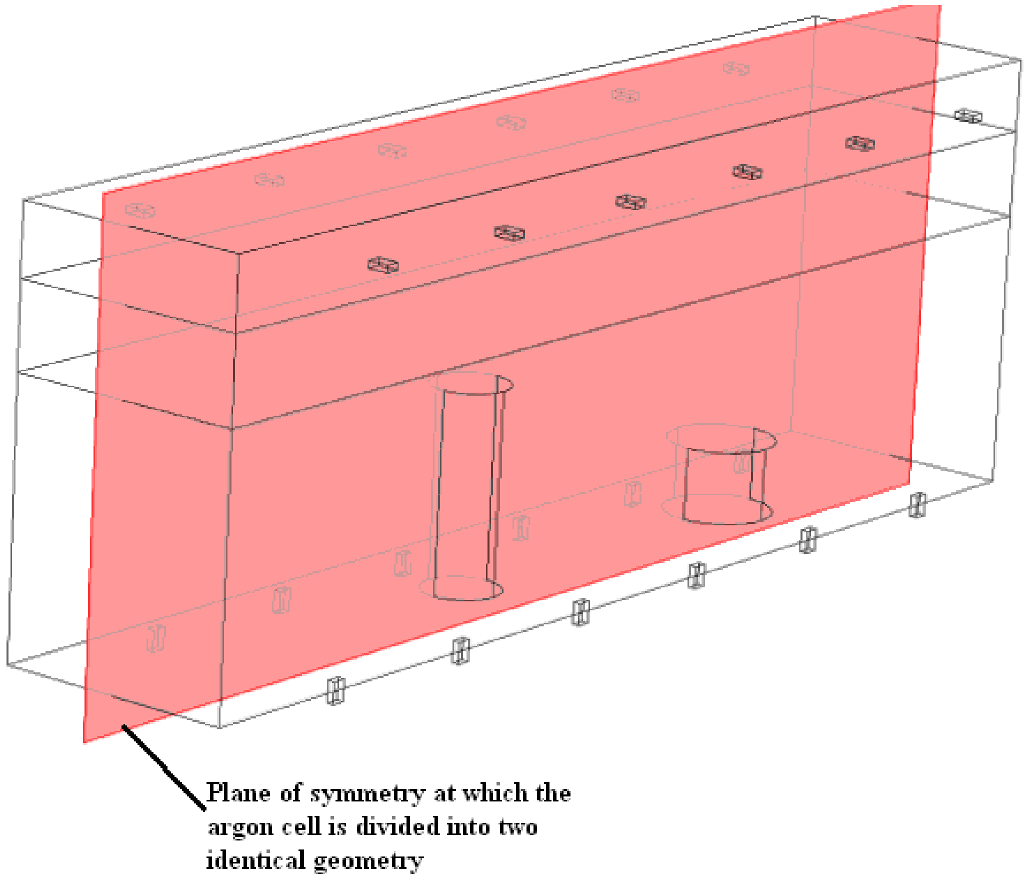


Fig. 2 (a): Geometrical model showing the plane of symmetry.

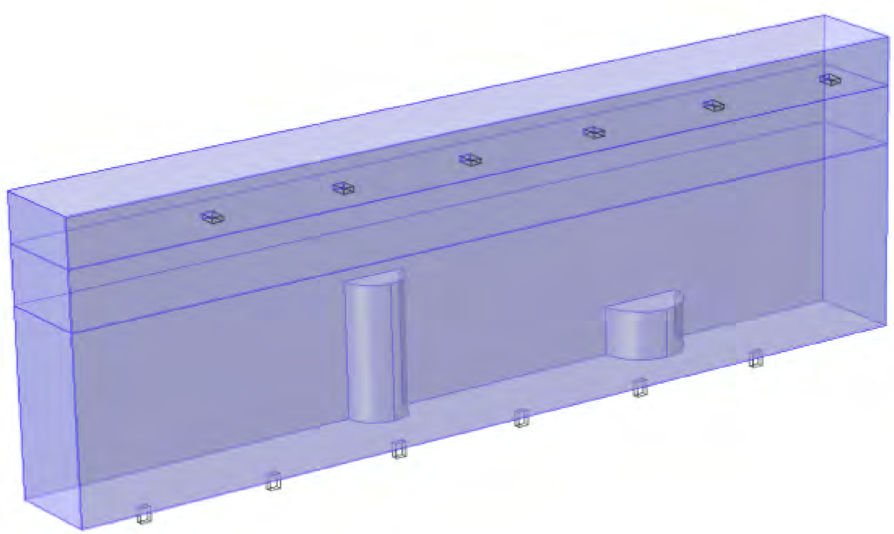


Fig. 2(b): Simplified argon cell model used for simulation in COMSOL

4. Boundary condition

Boundary condition to each surface inside and outside the argon cell is given based on process requirement. Fig 3(a) and 3(b) shows the different boundary given to solve the fluid flow and heat transfer equations respectively.

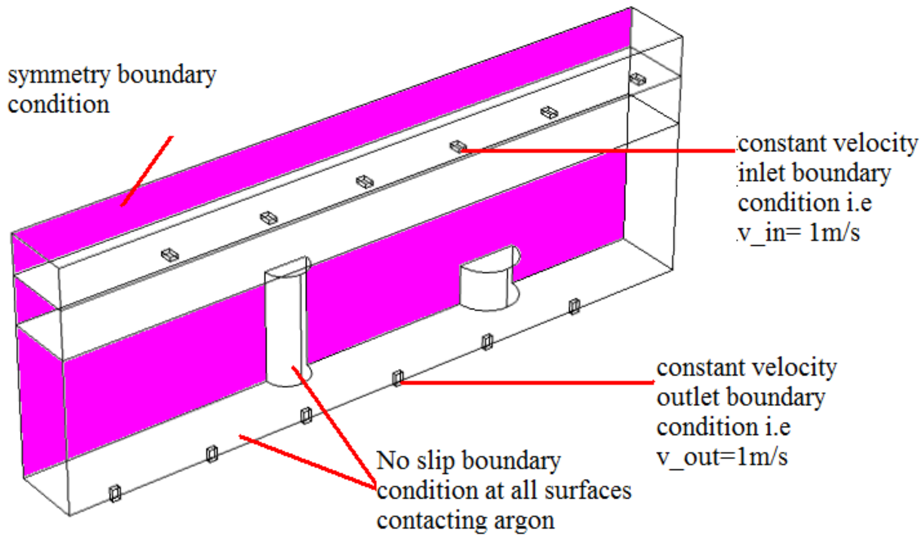


Fig. 3(a): Fluid flow boundary condition given to the model.

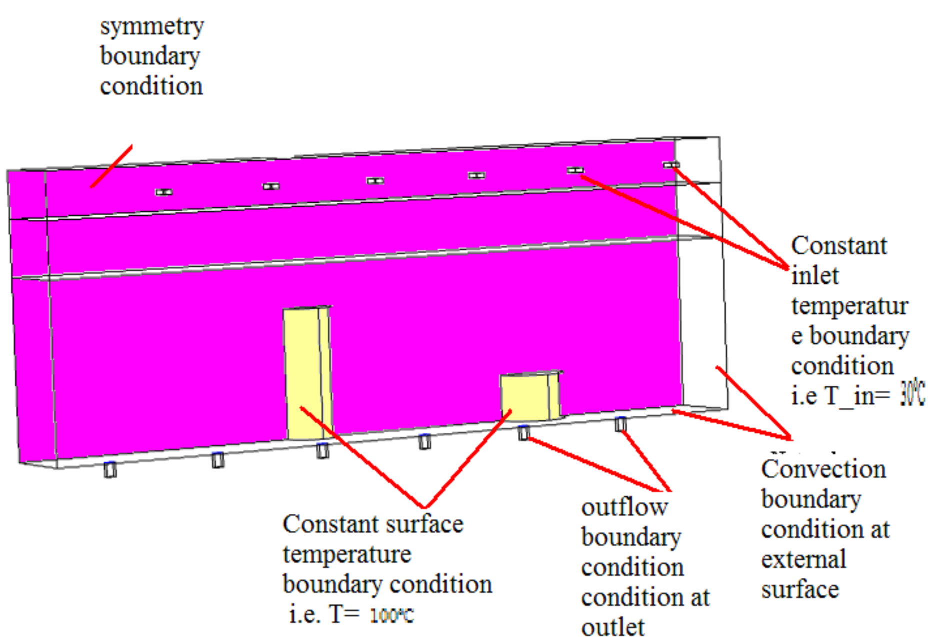


Fig. 3(b): Heat transfer boundary condition given to the model.

5. Result

Fig.4 shows the streamline plot for the 3D HTER facility COMSOL model. The distribution of velocity at „xy" plane at height of z =0.5m is shown in Fig.5. The velocity is ranging from about 0.03m/s to 0.01m/s. The 3-D temperature distribution of the argon cell at total flow rate of 864m^3/h is shown in Fg.6. Fig.7 (a) and 7(b) depicts the temperature distribution at the supply and exit duct section respectively. Fig.8 shows the temperature distribution in the center of the argon cell.

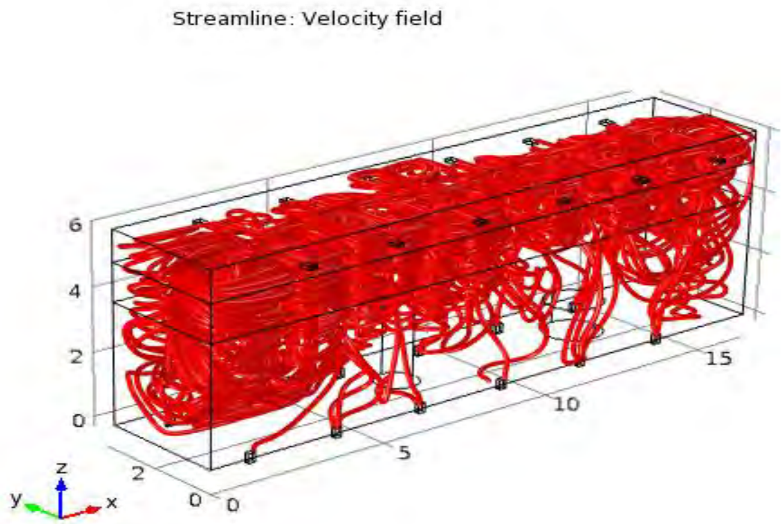


Fig. 4: Streamline plot for the argon cell

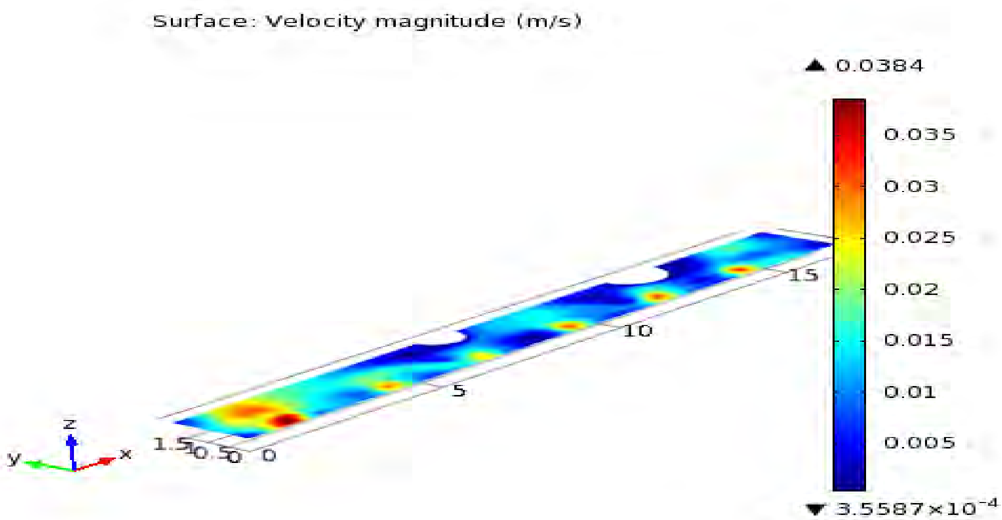


Fig. 5: Velocity distribution at xy palne at height z=0.5m.

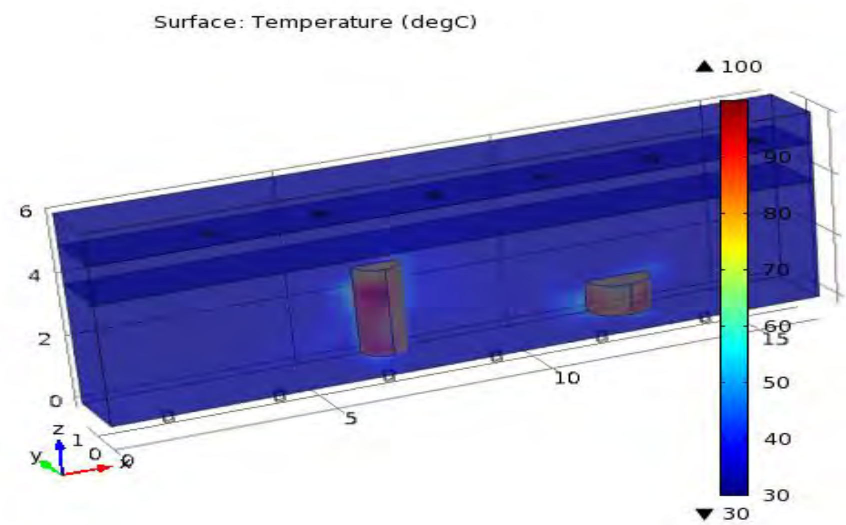
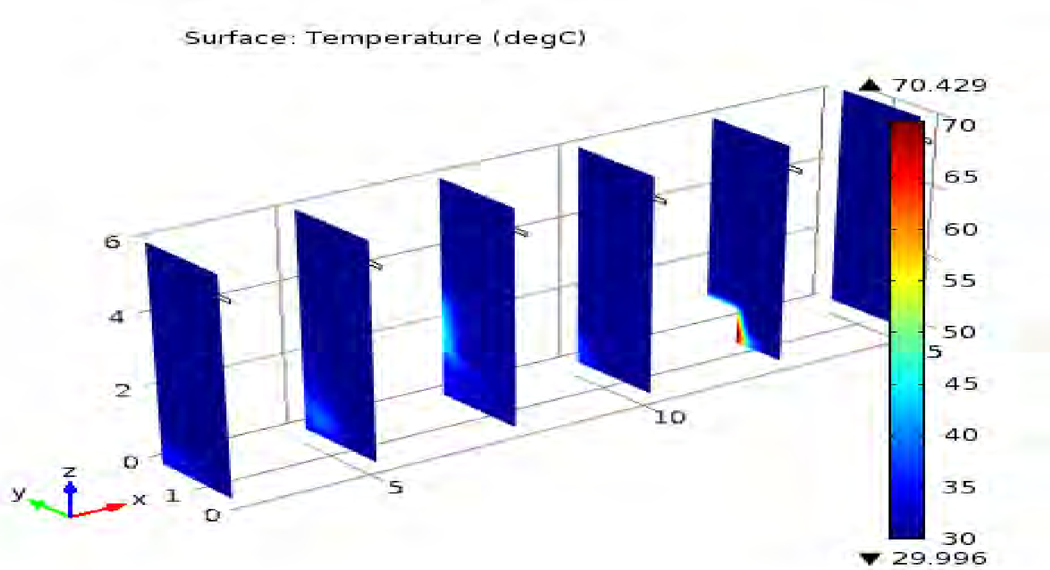
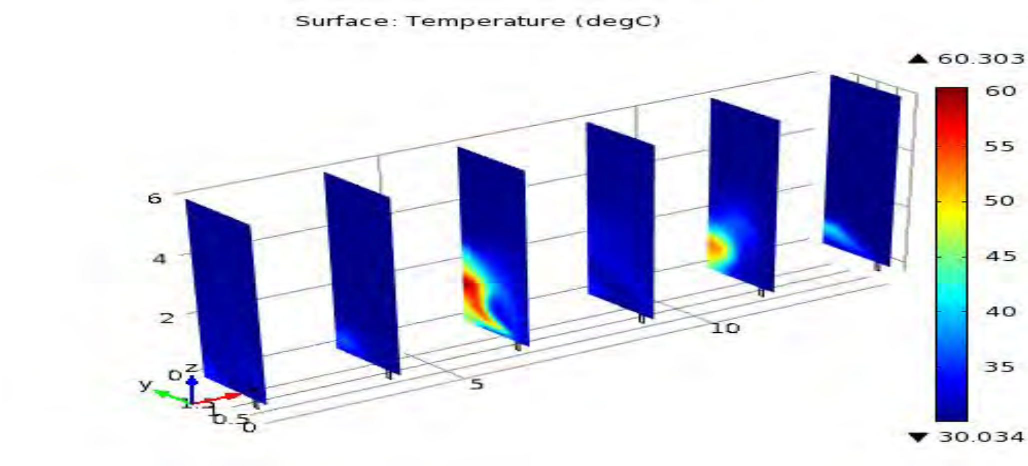


Fig. 6: Temperature distributions at a total argon flow rate of 864 m^3/hr

This inactive pyrochemical demonstration facility is designed with argon flow rate of 600m^3/h as per process calculation to maintain the required purity of argon inside the argon cell. The Average temperature of argon at outlet at this flow rate is around 35^{o}C. With this simulation it is found that the argon flow rate of around 900m^3/h is more suited since there is no appreciable rise in argon temperature inside the argon cell. And also the average outlet temperature of argon at outlet is 31^{o}C. This help in bringing down the cooling load of argon gas.



(a)



(b)

Fig. 7(a) and (b): Plot demonstrating temperature profile at the supply and exit duct section respectively.

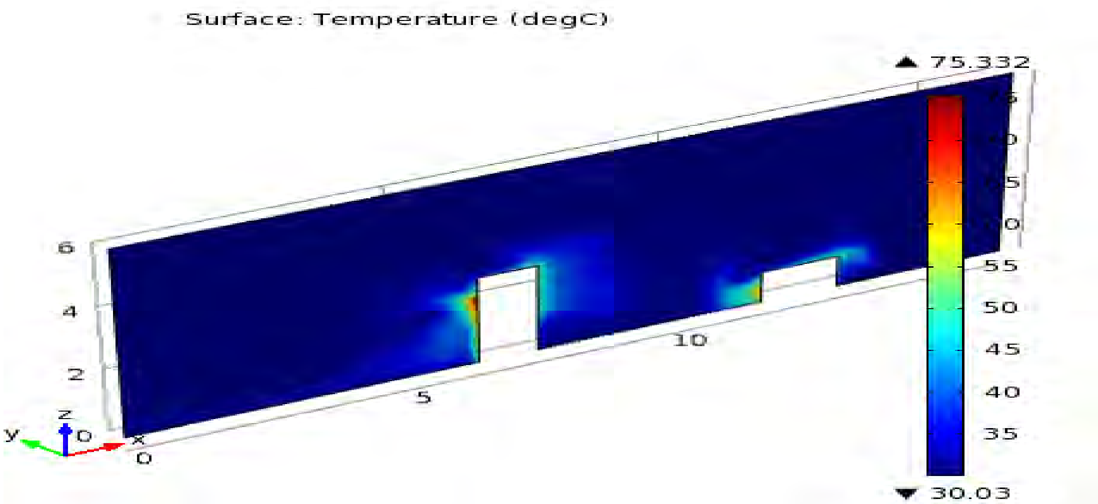


Fig. 8: Plot demonstrating temperature profile in the center of argon cell

7. Conclusions

CFD analysis of argon cell for inactive pyrochemical processing demonstration facility (HTER) is done using COMSOL code. The CFD analysis helped in finding out the velocity and temperature distribution of argon inside the cell at different argon inlet flow rate. It is concluded that that inlet flow rate of argon (900m^3/h) is sufficient to keep the argon temperature inside the cell almost constant to 30^{o}C.

8. References

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