Conjugate Heat Transfer (CHT) simulation of Argon Gas Heater for Argon Recirculation and Purification System in Pyroprocessing facility

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Introduction

PyroProcessing Research and Development Facility (PPRDF) is a facility being setup to develop pyroprocessing technology in IGCAR. This facility consists of a large argon cell attached with an argon recirculation and purification system. Once through Argon gas heater is an important process equipment in Argon Recirculation and Purification System (ARPS) to heat argon from room temperature to 100°C. The heated argon is used for effective regeneration of catalyst bed. The conjugate heat transfer (CHT) simulation of the gas heater using heat transfer module of COMSOL was carried out. The objective of this study was to validate the design, to know the set point for heater surface temperature, input power and to obtain the temperature of individual heating elements to avoid hot spots.

Main characteristics of Argon gas heater

The once through Argon heater consists of rectangular duct of 0.5m height, 250mm width and 300mm breadth. Argon heating is done with a series of 24 finned U shaped electric heaters, placed in 6 rows and 4 columns. SS fins with a gap of 1 cm are fitted over each heater. The outer diameter of the heater and fin is 11 and 31.75 cm respectively. Nichrome wire is used as the heating element at the centre of each electric heater. Dry MgO power is filled in between the nichrome wire and the SS sheath of each heater. The argon gas enters at the bottom of the rectangular duct at room temperature and exits from top at around 100°C. The total electric power of all the heating elements in the duct is 18KW and flow rate of the argon in 525 Nm^3/h. Figure 1 shows the 2-D view of the argon gas heater.
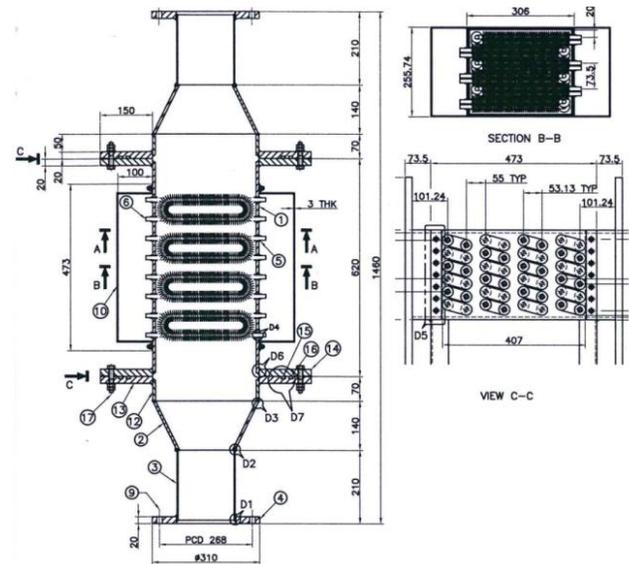
Fig.1: 2-D view of the argon gas heater

Geometrical Model

As argon gas heater is of cuboidal shape, 3-D geometrical model is selected for the simulation. The simulation model considered only the heating zone where heater is placed. To minimize size, help of symmetrical plans parallel to the flow direction is taken in model. Figure 2 shows the schematic view of the computational model.
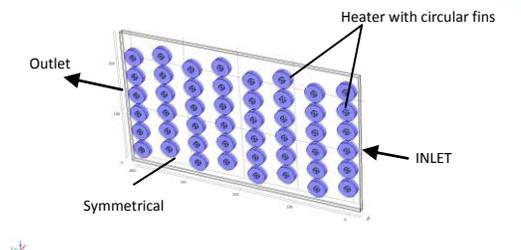
Fig.2: Computation model of Argon gas heater

Mathematical modeling and boundary condition

The study used CHT 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. Initially only fluid domain was considered in modeling. The heater surface was constrained with constant temperature boundary condition. The surfaces of circular fins were constrained with highly conductive and internal wall boundary condition. Temperature and velocity boundary condition were given at the inlet. The outlet of gas heater was constrained with pressure and outflow boundary conditions. Other surfaces of the model were constrained with Symmetry, insulation and wall boundary conditions. Later on heat conduction equation in each electric heater was introduced in the simulation with constant linear power input at the centre of each heater. Table 1 shows the input parameter to the model.

Table.1: Input Parameter

Parameter	Value
Inlet velocity	1.94 m/s
Inlet temperature	$30\,^oC$
Heater surface temperature	$100\,^oC$ to $300\,^oC$
Linear heat input (W/m)	100, 200, 500, 1000
Fluid	Argon
Heater surface material	SS
Turbulent Intensity at inlet	0.1
Turbulent Length scale	0.01m

Meshing and Solver setting

Prism mesh is used in this simulation. Triangular mesh was first created at one of the symmetrical plan of the model and then swept mesh feature was used to create mesh on whole domain. Total number of mesh elements in the model is around 0.1 million and the corresponding degree of freedom is around 0.7 million. The maximum and minimum quality of the mesh was around 0.8 and 0.4 respectively. Figure 3 show mesh inside the model domain.
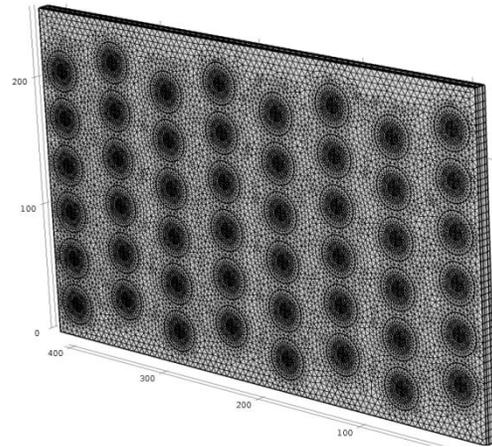
Fig.3: Meshing of simulation model

Stationary study with parametric sweep was carried out. Heater surface temperature was used for the parametric study. Iterative solver was used in the simulation for solving linear and nonlinear systems of equations. Segregated approach instead of fully coupled one was selected to solve the coupled physics to take advantage of iterative solver.

Study and results

Two type of study was done, one as constant heater surface temperature as an input and other as constant heater power as an input. The heater surface temperature was varied from $100\,^oC$ to $300\,^oC$, where as the heater power was varied from 100W/m to 1000W/m. Figure 4 shows the argon temperature at outlet of the gas heater for different heater surface temperatures. From the analysis it was seen that the average argon outlet temperature reaches to the required value of $100\,^oC$ when we maintain the surface temperature of the heater to around $200\,^oC$.

Temperature and Velocity distribution of argon over the plane passing between the two fins is shown in figure 5 & 6 respectively. From the temperature distribution result it was seen that argon temperature gradually increases along the length of the gas heater and reaches the required value at the outlet. Some level of cold argon

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bypass from the gap at top and bottom surface of gas heater is also seen in the result. From the velocity distribution result it is seen that there is stagnation zone behind each heater which was overcome by using helical fins in the final design instead of transverse fins as used in the model.
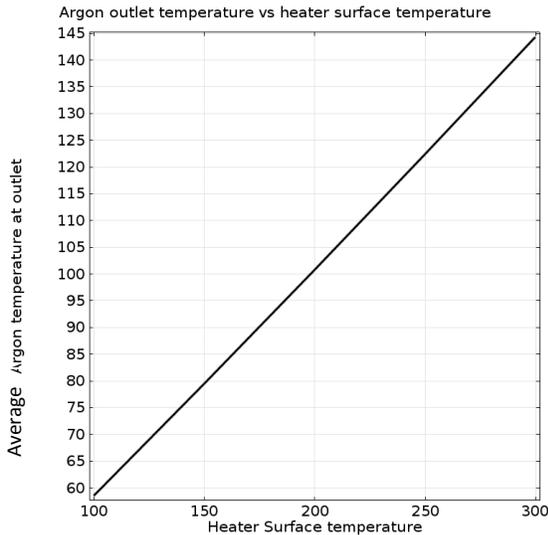
Fig.4: Argon temperature (^{o} C) at outlet for different heater surface temperature (^{o} C)
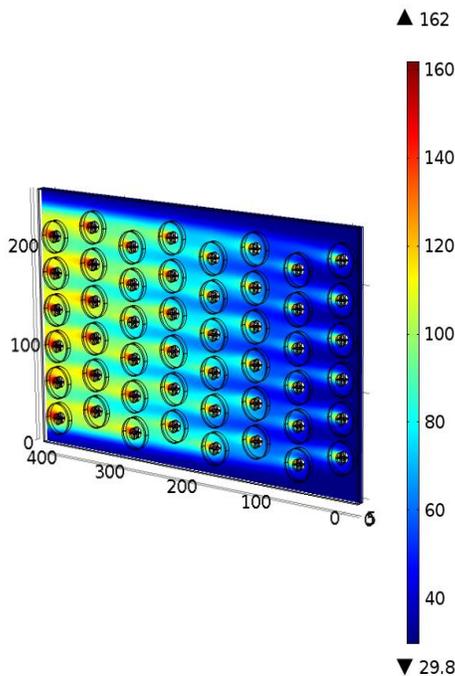
Fig. 5: Argon temperature (^{o}C) distribution over the plane for the heater surface temperature maintained at 200°C
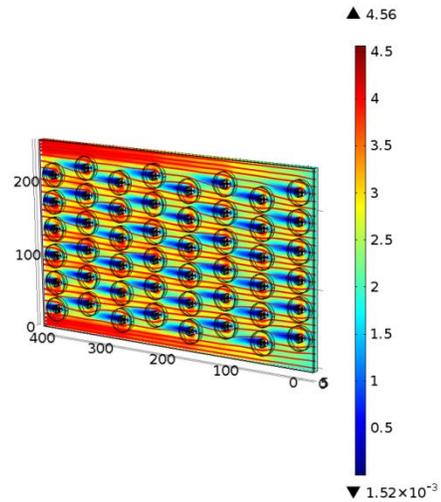
Fig, 6: Argon velocity (m/s) distribution over the plane passing between two fins.

Figure 7 shows the argon temperature at outlet of the gas heater for different heater power. The power input to each heater is constant. The result from the analysis shows that for constant heater power of 500 W/m the outlet temperature of argon from gas heater reaches to 100°C. However for this constant power source in each heater, the surface temperature of the heater at the outlet reaches to 500°C as shown in figure 8, which is not advisable. To overcome this problem the heater power along the length should be decreased gradually and an optimum heater input for each heater bank has to be found out. So of the two mode of heater operation constant temperature mode was found to be more suitable.
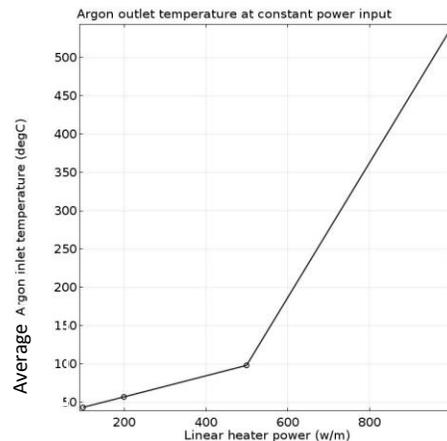
Fig.7: Argon temperature (^{o} C) at outlet for different heater power (W/m)
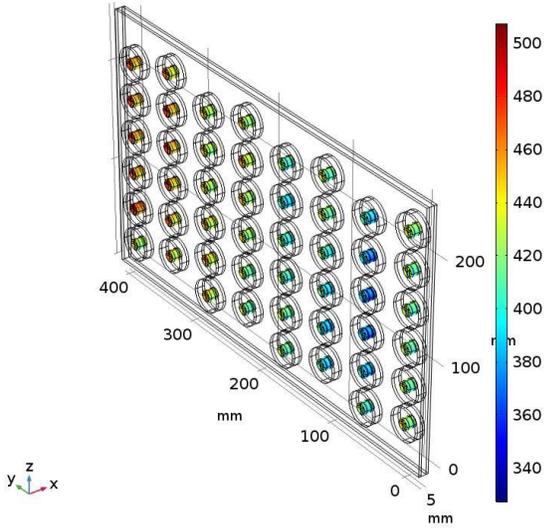
Fig, 8: Temperature distribution over each heater surface for constant heater power input of 500W/m.

Conclusion

From the simulation results it was found that the once through gas heater is capable of raising the argon temperature to above $100^{\circ}C$. Set point temperature for each heater surface was found. Of the two mode of heater operation, constant temperature mode was found to be more suitable. From the analysis, some improvement in the design was also found out. The encouraging results have given the confidence for the finalization of the final heater elements arrangement for the gas heater and for giving final clearance to fabrication.

Reference

1. Bird, R.B., et al., *"Transport phenomena"* Wiley publication, India (2006)
2. COMSOL user manual.