Parametric Design Study for Cooling System of Fuel Transfer Cask of the PGSFR

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1. Introduction

One of the refueling components for the Prototype Gen IV Sodium Fast Reactor (PGSFR) is the Ex-Vessel Transfer Machine (EVTM). EVTM contains the fuel transfer cask (FTC) holding the spent fuel assembly which radiates 2 kW of decay heat. The location of FTC is shown in Fig. 1. [1]

As shown in Fig. 2 of the conceptual FTC, the spent fuel assembly is wrapped with the lead shield of the cask which blocks the radioactive rays. The lead shield and the containment cylinder make the air pathway to cool off the containment, while argon gas flows in the containment cylinder as a purging gas to provide inert space to avoid the sodium-water reaction. Argon gas is purged from the top of the containment cylinder. The main reason to purge the argon gas is to mitigate the sodium vapor accumulation and cool down the decay heat. The direction of the air is in the opposite of the argon gas flow in this design. [2]

To design FTC various dimensions should be estimated. Moreover, the heat removal capacity of the argon purging system was taken into account. 773 K is temporarily suggested as the maximum allowable temperature for the fuel assembly because the maximum allowable temperature of the cladding of the fuel assembly is limited to 773 K.

The purpose of the parametric study is to figure out the effect of dimensions of the FTC internal basket adaptor to meet the allowable temperature 773 K for the fuel assembly.

In this paper, the finite volume method was considered. The commercial code, STAR-CCM+ was employed. [3]

2. Methods and Results

2.1 Simulation domain

The FTC is assumed to be cylindrical so that 2D axisymmetric model is used to speed up the calculation. And a simple convective condition is considered in air cooling boundary for the heat removal performance of the internal purging system.

The simulation domain and the boundary conditions are shown in Fig. 3. Inlet and outlet mass flows have 2 kg/min, respectively, and the temperature of the inlet flow is 373.15 K. The direction of the X-axis is the origin for the axisymmetric condition. On the outside of the containment cylinder, a convection boundary is applied with 293 K of the temperature of cooling air and 1 W/m^2 of the heat transfer coefficient. The spent fuel is assumed as a porous medium. Lower active region of the spent fuel generates the energy source of 2 kW, and the simulation is assumed steady-state.

Polyhedral mesh and prism layer mesh were used to generate the mesh elements.

Fluid physic model for argon gas, [4]

- Ideal gas
- K-Epsilon Turbulence
- All Y+ wall treatment
- Segregated flow model
- P_i = 4.95 kg/m^4 for porous media
- P_v = 106.86 kg/m^3-s for porous media

Solid physics model for FTC,

- Constant density
- Segregated energy

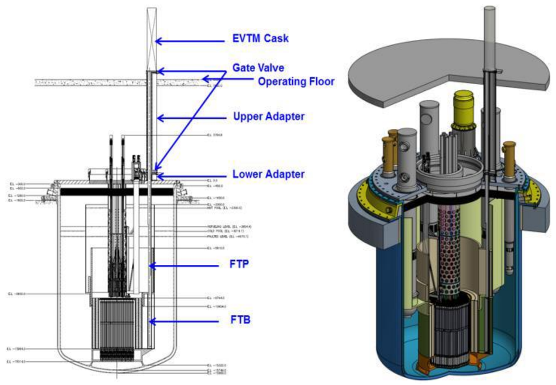


Fig. 1. Location of FTC in the PGSFR

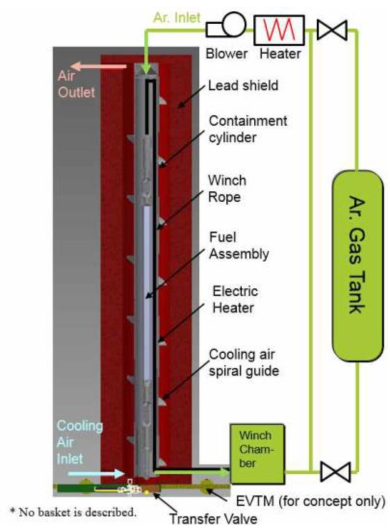


Fig. 2. Schematic diagram of the fuel transfer cask [1]

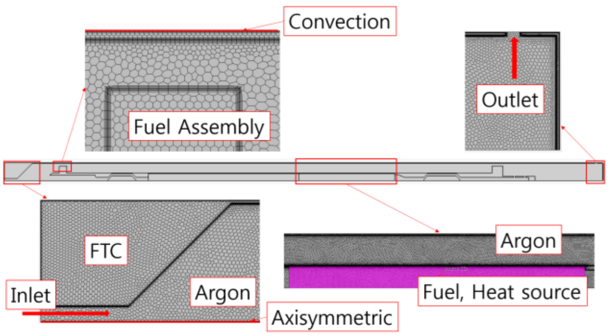


Fig. 3. Simulation domain and the boundary conditions.

2.2 Design parameter

Dimension A in Fig. 4 represents the design parameter to be determined. A is the gap between the inside of the containment cylinder and the fuel assembly. B is the inside hole size of the fuel assembly. C is the distance between the inlet and the fuel assembly. B and C are set to be constants.

A parametric design study for cooling system was performed for 10 cases by changing the gap size (A) from 0.0 mm to 59.0 mm. Cases are compared with respect to the size of the gap (A) in Table 1.

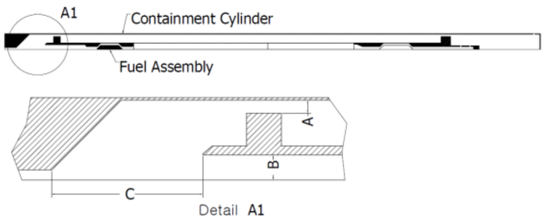


Fig. 4. The current A is 26 mm, B is 50 mm, and C is 304 mm

Table 1 Simulation cases for the dimensions in fig. 4.

Case #	A (mm)	B (mm)	C (mm)
1	0	50	304
2	1	50	304
3	3	50	304
4	5	50	304
5	8	50	304
6	10	50	304
7	11	50	304
8	13	50	304
9	26	50	304
10	59	50	304

2.3 Results

Analysis results are presented in Fig. 5 to Fig. 9 and Table 2. The result of case #9 shown in Fig. 5 was used as a reference. Streamline flows can be observed through the gap. It is noted that sealing the gap can improve the mass flow into the fuel assembly.

In Fig. 8.(a), the minimum temperature of fuel region is obtained when the gap (A) is 0.0 mm. The temperature of the spent fuel with the gap of 1.0 mm is 570.7 K, which is significantly lower than the target temperature of 773 K. For the case with the gap of 3.0 mm, the maximum temperature is exceeded the temperature limit. The maximum temperatures are observed to be asymtopically increased with the gap size (A).

From Fig. 8.(b) the heat transfer rates from the spent fuel to the argon gas(working fluid) are proportional to the mass flow rates into the fuel assembly. Insufficient mass flow rates cause to decrease the cooling capacity.

Fig. 9 represents the heat transfer from the spent fuel to argon gas and the convection from the purging gases to the duct. The ratio of the heat transfer to the duct and the working fluid are almost same over the gap size of 10.0 mm.

From the results, it can be observed that the sealing gap is crucial for the heat removal capacity from the spent fuel. The suggested geometry is illustrated in Fig. 10.

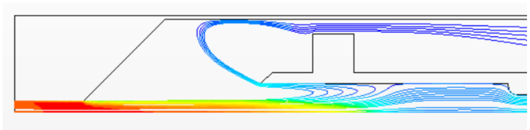


Fig. 5. Streamline with respect to the velocity. The maximum velocity is 21.57 m/s for Case #9.

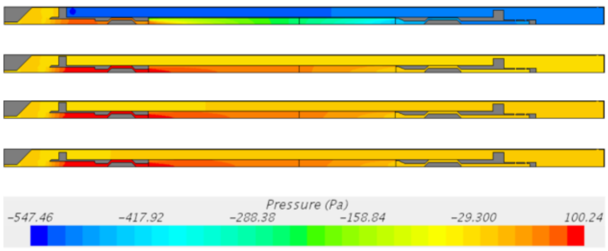


Fig. 6. Gauge pressure results for case #2, 4, 5, and 9

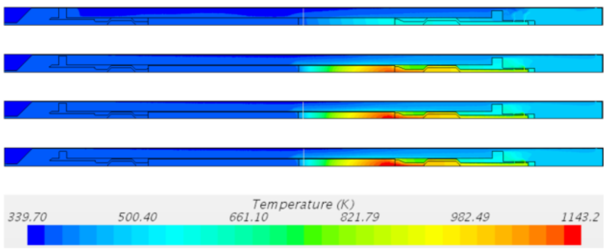
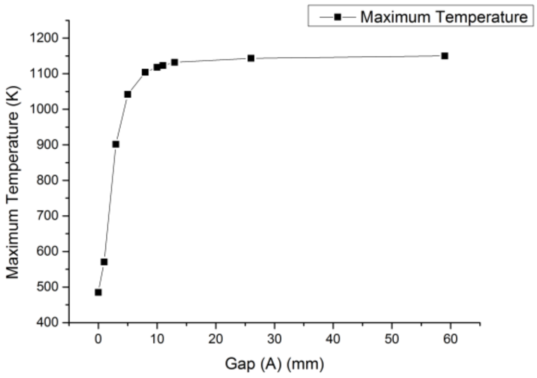


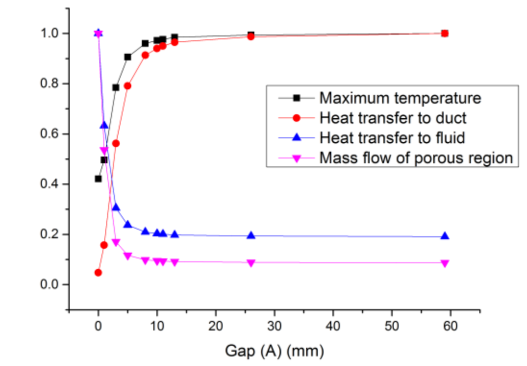
Fig. 7. Temperature results for case #2, 4, 5, and 9

Table 2 Results of the parametric study

Case #	Max. Temp. (K)	Mass flow (kg/s)	Convection to duct (W)	Convection to fluid (W)
1	484.8	3.330E-02	7.6	310.7
2	570.7	1.787E-02	25.0	293/3
3	901.8	5.697E-03	89.3	229.0
4	1041.9	3.901E-03	125.7	192.7
5	1104.3	3.288E-03	145.1	173.2
6	1118.1	3.166E-03	149.1	168.9
7	1122.8	3.125E-03	150.9	167.4
8	1132.2	3.044E-03	153.3	165.0
9	1143.2	2.965E-03	156.8	161.5
10	1150.0	2.905E-03	158.9	159.4



(a)



(b)

Fig. 8. (a) The maximum temperatures of the spent fuel for the cases, (b) Normalized mass flow rates and the maximum temperatures with respect to the gap size.

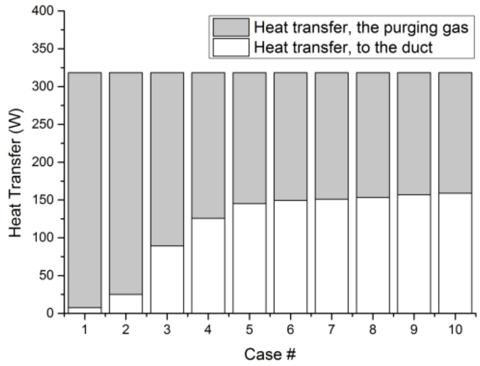


Fig. 9. Heat transfer rates of the purging gas and the duct.

Fig. 10. A suggested design modification concept geometry from the results.

3. Conclusions

For argon purging system of FTC, a parametric design study was performed. Case 2 with 1.0 mm of the gap satisfies the temperature requirement of the fuel assembly. It was confirmed that the gap between the FTC and the fuel assembly is the major factor for the mass flow into the fuel assembly. It was suggested a new geometry to improve the heat removal capacity of the internal purging system.

Parametric design studies for the various inlet mass flow condition with the air cooling system will be considered for the further work.

ACKNOWLEDGMENTS

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