Numerical Analysis for Design of Cryogenic Cooling System

a Sung-Kyun Kim, a Dong-Gyu Lee, a Kune-Woo Lee
a Korea Atomic Energy Research Institute, Dukjin-Dong, Yuseong-Gu, Daejeon, South Korea, sungkyun@kaeri.re.kr

1. Introduction

KAERI has been developing a new dismantling technology, we called "*cryogenic cutting technology*", that is cutting an object as injecting abrasive and liquid nitrogen simultaneously for decommissioning a high radioactive nuclear facility such as a hotcell, nuclear power plant, etc.. Now we have been developing a cryogenic high compressor unit for accelerating liquid nitrogen. However we are faced with a serious problem that most of liquid nitrogen was evaporated while passing through pipes and the high compressor unit due to the heat exchange between liquid nitrogen and the outside. To prevent the evaporation of liquid nitrogen, we have made a concept design of a cryogenic cooling system. In this paper it is described herein and representative results of CFD simulation for determining the design variables are presented.

2. Methods and Results

In this section the cryogenic cooling method for converting nitrogen gas to liquid nitrogen and the CFD procedure and results are described.

2.1 Cryogenic Cooling System

In order to cool the vaporized nitrogen we came up with a double pipe cooling system. As shown in Fig. 1 the coil double pipe is placed in an airtight container filled with liquid nitrogen. The double pipe consists of an inner pipe and outer pipe. The vaporized nitrogen passes through the inner pipe and also the liquid nitrogen moves through the outer pipe. During the nitrogen gas is moving in the pipe, the heat transfer occurs between liquid nitrogen area and nitrogen gas area. Consequently, nitrogen gas cools down and becomes liquid nitrogen when the temperature of it approaches to 77 K. The cooling fluid moving in an outer pipe may happen to be vaporized because of the heat transfer between the cooling fluid and nitrogen gas so in order to prevent the vaporization the double pipe is placed in a container filled with liquid nitrogen.

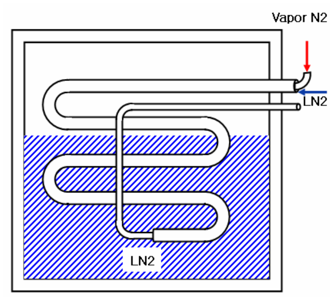

Fig. 1. The scheme of the cryogenic cooling system

2.2 Construction of mesh

A CFD simulation was performed for determining design variables such as an inner diameter, outer diameter, and length of pipe, an input velocity of cooling fluid.

In order to perform the CFD simulation we built the mesh structure as shown in Fig. 2 by using GAMBIT software and Table 1 shows its configuration. The mesh was created to 2D model and total 432,000 cells were used.

Table 1. Configuration of the double pipe

Configuration	Unit	Value
Inner diameter	mm	10
Outer diameter	mm	40
Length	mm	400
Number of coil	EA	8

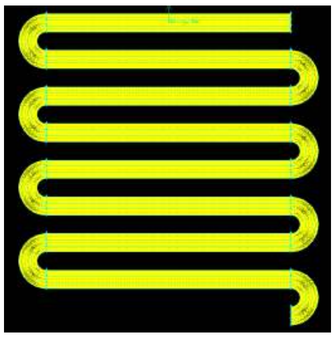

Fig. 2. Structured mesh for the cryogenic cooling system

2.2 *Preparation of Simulation*

In this CFD simulation the Spalart-Allmaras model one equation was used as a turbulent model, for the spatial discretization the first order upwind scheme was used, and for the pressure discretization the standard scheme was used. For setting up B. C.(boundary condition), the inner pipe and outer pipe entrance is set as velocity inlet B. C. each with a normal velocity of 600 m/s and temperature of 150 K, and a normal velocity of 10 m/s and temperature of 77 K. The exit of inner and outer is set as outflow B. C. (with zero gradient in normal direction and some constraints of mass flow conservation) with outflow ratio equals to 1(this means that all the inflowing flow passes here to outside). Inner walls of pipe are set as non-slip wall. Material properties for pipes are set as aluminum and material properties of the fluids are all set as nitrogen.

2.3 *Simulation*

Fig. 3 shows the CFD simulation results. As you can see nitrogen gas passing through the inner pipe is cooling down along the pipe line and the exit temperature of nitrogen gas dropped down to 95.3 K. According to the T-S diagram this temperature is bounded in the liquid region so we conclude that the selected design variables of the cryogenic cooling system are reasonable.

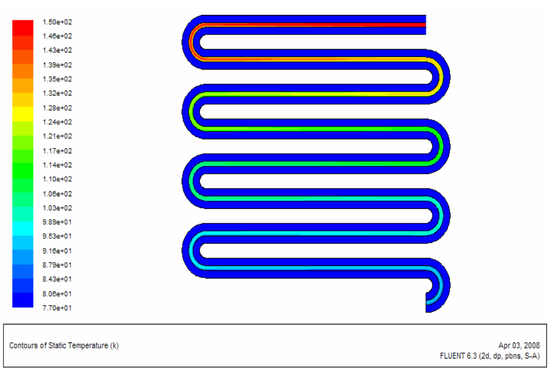

Fig. 3. Temperature distribution of cryogenic cooling system

Next, we examined the effect of the variation of the pipe length. Fig. 4 shows the temperature of pipe exit with respect to pipe length. When the pipe length is 400 mm the temperature of nitrogen gas is the lowest. We also investigated the effect of the velocity of the coolant but there is no temperature variation with respect to the velocity of the coolant.

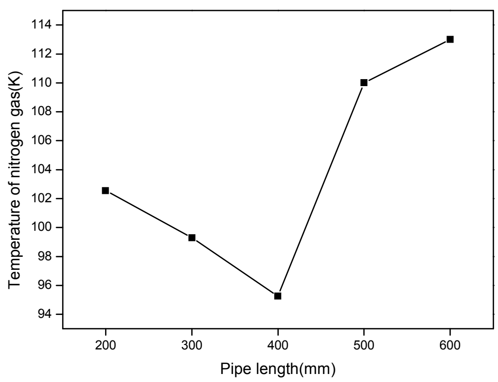

Fig. 4. Temperature of pipe exit with respect to pipe length

3. Conclusion

In this paper we performed the CFD simulation of the cryogenic cooling system. As a result of CFD simulation we were able to select appropriate design values and operation conditions for developing the cryogenic cooling system. Hereafter the design values and operation conditions will be used to make the experimental equipment. I think that CFD simulation is a very useful method to determine design variables in case of needing much money to build experimental equipment. I hope that engineers use CFD simulation technique as a tool for verifying design values

REFERENCES

[1] FLUENT User's Guide, Release 6.3, 2007.
[2] V. Kumar, S. Saini, M. Sharma and K.D.P. Nigam, Pressure drop and heat transfer in tube-in-tube helical heat exchanger, Chemical Engineering Science, Vol. 61, pp. 4403–4416, 2006.
[3] T.J. Rennie and V.G.S. Raghavan, Numerical studies of a double-pipe helical heat exchanger, Applied Thermal Engineering, Vol. 26, pp. 1266–1273, 2006.
[4] Yamamoto, T. Akita, H. Ikeuchi and Y. Kita, Experimental study of the flow in a helical circular tube, Fluid Dynamic Research, Vol. 16, pp. 237–249, 1995.
[5] M.A. Abdulla, A four-region, moving-boundary model of a once through, helical oil team generator, Annuls of Nuclear Energy Vol. 21, No. 9, pp. 541–562, 1994.
[6] Bai, L. Guo, Z. Feng and X. Chen, Turbulent heat transfer in a horizontally coiled tube, Heat Transfer Asian Research, Vol. 28, No. 5, pp. 395–403, 1999.
[7] S.A. Berger, L. Talbot and L.S. Yao, Flow in curved pipes, Annuls Review of Fluid Mechanics, Vol. 15, pp. 461–512, 1983.
[8] J.S. Jayakumar, R.B. Grover and V.H. Arakeri, Response of a two-phase system subject to oscillations induced by the motion of its support structure, International Communication Heat Mass Transfer, Vol. 29, pp. 519–530, 2002.
[9] V. Kumar, S. Saini, M. Sharma and K.D.P. Nigam, Pressure drop and heat transfer in tube-in-tube helical heat exchanger, Chemical Engineering Science, Vol. 61, pp. 4403–4416, 2006.
[10] Nandakumar and J.H. Masliyah, Bifurcation in steady laminar flow through curved tubes, Journal of Fluid Mechanics, Vol. 119, pp. 475–490, 1982.