Transactions of the Korean Nuclear Society Autumn Meeting
Yeosu, Korea, October 25-26, 2018

Preliminary Design of Intermediate Heat Exchanger for High Temperature Gas-cooled Reactor

Byung Ha Park [a*], Eung-Seon Kim[a]
Korea Atomic Energy Research Institute, 111, Daedeok-Daero, Yuseong-Gu, Daejeon, Korea
[*]Corresponding author: bhpark@kaeri.re.kr

1. Introduction

An intermediate heat exchanger (IHX) is a key component for high temperature gas-cooled reactor (HTGR). This component transfers heat from the primary loop to the secondary loop. It will be operated at temperature up to 950 ℃ with pressurized helium up to 7 MPa. KAERI considers a printed circuit heat exchanger (PCHE) as a candidate for the IHX. A PCHE is a very compact heat exchanger. Moreover, it has the merit of wide operating range.

350MWt HTGR is a candidate design for industrial heat application and hydrogen production. There is a dimensional limitation for a conventional PCHE manufacturing technique. The dimension of a PCHE plate is limited by the capacity of press machine and vacuum furnace. A conventional PCHE may cover several MW. A large number of PCHE are required for 350 MWt. A single PCHE module will be connected to each other in a pressure vessel. The connected PCHEs form a PCHE assembly.

A PCHE module is preliminary designed with the requirements such as pressure drop and capacity. The pressure drop is defined by the operating pressure and the specific ratio, the ratio of the discharge pressure over the suction pressure. It is related to the operating cost. The capacity is related to the arrangement of PCHEs, including the number of PCHEs and pressure vessel size. It is related to the capital cost.

We suggest design process and an example of optimized design for the IHX.

2. Methods and Results

The power is 350 MWt. The inlet temperature of the primary helium is 950 ℃ and that of the secondary helium is 460 ℃. The operating pressure of primary and secondary helium is 7 MPa. The specific ratio of a blower is assumed as 1.04. Therefore, the pressure drop of entire system is less than 280 kPa. It was assumed that the quarter of the allowable pressure drop is applied for the IHX. We initially assumed the number of PCHE modules with rough calculation and modified the number with an iterative method. The obtained unit capacity of a PCHE module is 1.75 MW and two hundred modules are required for the IHX.

Two lumped methods, the effectiveness method and the logarithmic mean temperature method (LMTD), and finite difference method (FDM) were utilized for designing a module. The FDM method evaluates the module with two-dimensional configuration.

FDM calculation was verified with comparing calculation results from the LMTD method and FDM. The channel shape is straight and the flow regime is laminar. The metal between hot channel and cold channel is very thin to ignore effect of longitudinal conduction. Table I summarizes the operating condition for the verification.

Table I: Operating condition of a heat exchanger for verification of the FDM calculation

Fluid	Helium
Temperature	200°C (In) / 400°C (Out)
Pressure	2 MPa
Channel mass flow rate	3.5e-5 kg/s
Channel length	400 ㎜
Channel diameter	1 ㎜
Channel horizontal pitch	1.01 ㎜
Channel vertical pitch	0.51 ㎜

Fig. 1 shows node sensitivity and verification results. The deviation ratio is the capacity ratio of LMTD method result over FDM result. Properties used in the LMTD method were the mean of the inlet and outlet. The deviation ratio is about 2% when the unit node size is less than 5 mm [1].

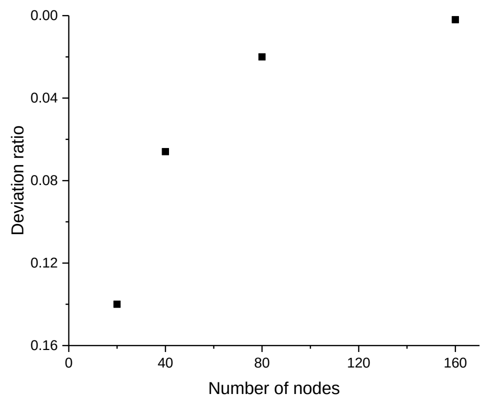

Fig. 1 Node sensitivity in terms of the deviation between FDM and LMTD method

2.1 Design of a PCHE module

Each micro channel is designed as a pressure boundary. It prevents incidents caused by the pressure difference between the primary and secondary. The shape of channel is wavy and its angle is 45 °. The material of a PCHE is alloy 617.

First, the effectiveness method was used to calculate the number of transfer units (Ntu). Counter flow configuration has it over cross flow configuration in terms of Ntu when the ratio of stream capacity rate is equal to one. Ntu was obtained with inverse Ntu-effectiveness relationships [2].

$$Ntu = \frac{\varepsilon}{1-\varepsilon} \quad (1)$$

Required overall conductance of heat exchanger is:

$$UA_s = Ntu \cdot C_{min} \quad (2)$$

Second, the required overall conductance of heat exchanger is obtained by the LMTD method:

$$UA_s = \dot{Q}/\Delta T_m \quad (3)$$

FDM calculation, based on the required overall conductance, was iteratively conducted to match the required capacity. Heat transfer area and heat transfer coefficient were obtained. The obtained design parameters are summarized in Table II. Overall heat transfer coefficient was calculated based on the heat transfer area, which is obtained by FDM. The overall heat transfer coefficient by FDM was assumed as following:

$$\frac{1}{UA_S} = \frac{1}{(hA_S)_h} + \frac{t}{kA_{sw}} + \frac{1}{(hA_S)_c} \quad (4)$$

The metal thickness, *t*, is averaged value from hot channel to cold channel.

Table II: IHX module design parameters

Effectiveness (%)	93.9
NTU (Counter flow)	15.3
Stream capacity rate (W/K)	3806
Required overall conductance , effectiveness method (W/K)	58356
LMTD (K)	30
Required overall conductance by LMTD method (W/K)	58333
Heat transfer area by FDM (m^2)	37
Overall heat transfer coefficient by effectiveness method (W/m^2K)	1576
Overall heat transfer coefficient by LMTD method (W/m^2K)	1576
Overall heat transfer coefficient by FDM (W/m^2K)	1923

The overall heat transfer coefficient of FDM is higher than that of the lumped methods. The correction factors, such as real configuration, longitudinal conduction, because the difference between the lumped methods and two dimensional FDM. We selected the FDM result to design the module. Thermal margin is not considered in present step.

2.2 Design of IHX

The IHX assembly was design based on the module design. The detailed design parameters are summarized in Table III. All PCHE modules are connected in parallel. Those will be contained in the IHX pressure vessel and maintain a compact arrangement to minimize the size of the vessel, which is related to the capital cost. Several PCHE modules will be vertically stacked and share piping. On the other hand, sufficient room is required for installation and maintenance.

Table III: IHX assembly design parameters

Total Number of Modules	200
Module height (m)	0.64
Module length (m)	0.96
Module width(m)	0.4
Total heat transfer area (m^2)	7403
Primary helium flow rate (kg/s)	0.733
Primary helium average Reynolds number	1050
Primary helium inlet temperature (°C)	950
Primary helium outlet temperature(°C)	490
Primary helium inlet pressure (MPa)	7
Primary helium pressure drop (MPa)	0.056
Secondary helium flow rate	0.733
Secondary helium average Reynolds number	1071
Secondary helium inlet temperature (°C)	460
Secondary helium outlet temperature (°C)	920
Secondary helium inlet pressure (MPa)	7
Secondary helium pressure drop (MPa)	0.053
Effectiveness (%)	93.9

3. Conclusions

The PCHE type IHX for 350 MWt HTGR was preliminary designed. We utilized the lumped methods and FDM, iteratively. We design the unit capacity as 1.75 MW. Two hundred PCHE modules compose the IHX.

Acknowledgement

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (Grant Code: 2017M2A8A1014758).

REFERENCES

[1] B. H. Park, I. J. Sah and E. S. Kim, Thermal Performance of a Printed Circuit Heat Exchangers considering Longitudinal Conduction and Channel Deformation, Transactions of the

Korean Society of Pressure Vessels and Piping, Vol. 13, No 1. pp. 8-14, 2018
[2] JE. Hesselgreaves et al., Compact Heat Exchnagers: selection, Design and Operation, Elsevier (2017)