Transactions of the Korean Nuclear Society Autumn Meeting
Pyeongchang, Korea, October 30-31, 2014

Verification of Heat Exchanger Design Code KAIST_HXD by Experiment

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1. Introduction

One of the generation VI reactors, Sodium-Cooled Fast Reactor (SFR) has received worldwide attention since it operates near atmospheric pressure with passive safety and reduces high-level radioactive wastes. However combination with conventional steam Rankine power conversion cycle faces the problem of violent Sodium-water reaction. Thus Supercritical Carbon Dioxide (S-CO_2) Brayton power conversion cycle has been suggested for the SFR due to the relatively mild Sodium-CO_2 interaction. The S-CO_2 power conversion cycle can achieve not only high safety but also high efficiency with SFR core thermal condition. For comparing the various cycles, important bases are the cycle total efficiency and overall physical size. In order to estimate the physical size of the power conversion system realistically, KAIST research team developed a heat exchanger design code KAIST_HXD. Thus, the KAIST_HXD code is attempted to be verified through an experiment with the existing facility; KAIST S-CO_2 pressurizing experiment (S-CO_2PE) facility.

2. In-House Code and Experimental Facility

To calculate the cycle total efficiency, it is important to estimate each component performance properly. In addition, appropriate sizing of a heat exchanger is also important. Especially in the S-CO_2 power cycle, heat exchanger occupies most of the power conversion system.

However, the most proposed cycle configuration has been calculated with assuming performance and the size of heat exchanger. Pressure drop in the heat exchanger was also simply neglected.

In this section KAIST_HXD code and S-CO_2PE facility are described.

2.1 Introduction of KAIST_HXD

In order to estimate the performance and the size of a heat exchanger reasonably, KAIST research team developed a heat exchanger core design code, KAIST_HXD. KAIST_HXD is a MATLAB based in-house code which applies the Dostal's concept of estimating the heat exchanger performance [1].

For the S-CO_2 power cycle application, a Printed Circuit Heat Exchanger (PCHE) has been suggested due to its capability to operate at high pressure and high temperature condition.

Currently, KAIST_HXD code is available for a heat exchanger core design of a PCHE with counter-current flow type.

From the geometry of each channel and the operating condition of each side, the KAIST_HXD code computes the required active length of heat exchanger to meet the target performance. The following figure is an algorithm of KAIST_HXD code.

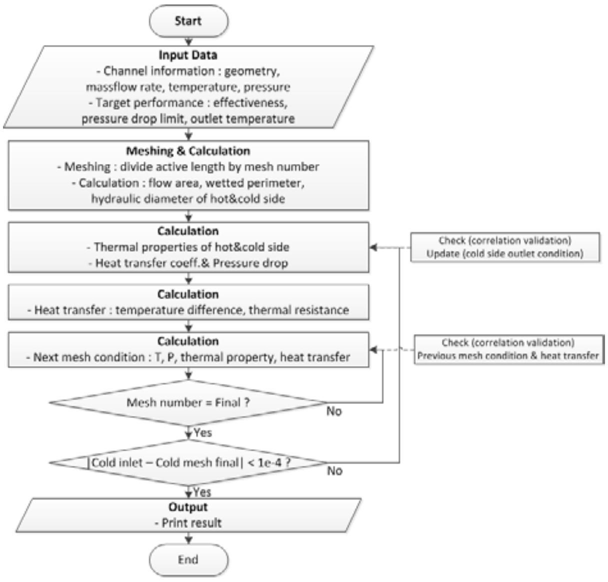

Fig. 1. KAIST_HXD algorithm.

The overall computation is interpreted from the set of representative hot and cold unit channel. For the stepwise calculation, the heat transfer area is divided to small steps from the beginning of the heat exchanger to end. To calculate the amount of heat transfer in each step, KAIST_HXD uses 2-dimensional heat transfer modeling [1].

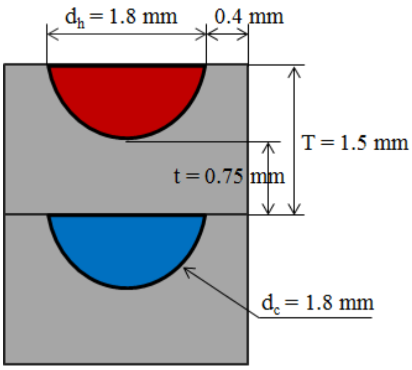

Fig. 2. Cross section of heat exchanger representative channel

$$Q = U\,A\,\Delta T = \frac{1}{R_{conv.Hot} + R_{cond} + R_{conv.Cold}}\,A\,\Delta T$$

$$= \frac{1}{\frac{1}{h_{Hot}} + \frac{t}{k_{cond}} + \frac{1}{h_{Cold}}}\,A\,\Delta T \qquad (1)$$

Each parameter is: heat transfer (Q), overall heat transfer coefficient (U), heat transfer area (A), temperature difference (ΔT), thermal resistance (R), plate thickness (t).

In 1-dimensional thermal resistance, the convection heat transfer coefficient was calculated from the previous experimental correlations [2].

The total volume and the pressure drop of a heat exchanger core are obtained from the calculated result. The required active length of a heat exchanger is used for calculating the total volume and the pressure drop.

2.2 S-CO_2PE Experiment Facility

The S-CO_2PE is the Supercritical Carbon Dioxide Pressurizing Experiment facility in KAIST. The main purpose of facility is S-CO_2 pump performance evaluation by utilizing a turbomachinery based on water pump. To explore the incompressible characteristic near the critical point of CO_2, a centrifugal water pump is adopted. To configure a loop, an expansion valve and a heat exchanger were added to simulate a turbine and a precooler of the actual power cycle. The pre-existing Spiral Tube Heat Exchanger (STHE) will be substituted with a PCHE.

Recently through cooperation of the vendor of the PCHE, KAIST research team designed a PCHE for the precooler in S-CO_2PE. To apply new component, S-CO_2PE experienced major modification during the maintenance time. The modified S-CO_2PE is shown figure. 3.

Fig. 3. Modified S-CO_2PE facility

Preparation for the experiment with PCHE, additional measurement devices are set at inlet and outlet point of every components. The calibration of thermometers and pressure gauges were also conducted.

3. Summary and further works

To overcome the limitation of Reynolds number of the experimental correlation of the heat transfer coefficient used in KAIST_HXD [2], Computational Fluid Dynamics (CFD) code was utilized to expand the correlation [3]. By using the KAIST_HXD code with updated correlations from CFD results, a PCHE was newly designed to substitute the precooler in S-CO_2PE. The following figure is the shape of heat exchanger core.

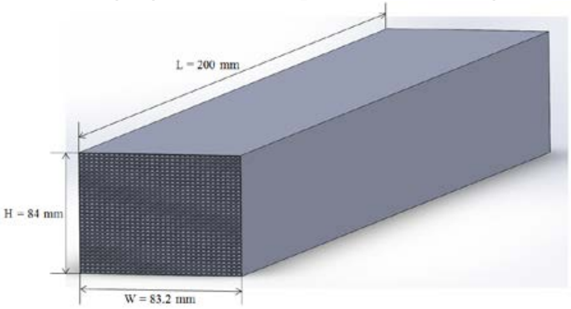

Fig. 4. Geometry of heat exchanger core

Table I: Parameters of heat exchanger core

Material		STS316L
Thermal conductivity (W/m·K)		15.3
Hot side	CO_2 Inlet Pressure (MPa)	7.8
	CO_2 Inlet Temp. (℃)	34
	CO_2 Flow rate (kg/s)	0.5
Cold side	Water Inlet Temp. (℃)	15
	Water Flow rate (kg/s)	0.5

The result of the experiment with manufactured PCHE may validate the KAIST_HXD code and correlation from CFD results.

In the PCHE design even distribution for each channel and pressure drop of header part are important design parameters. However, current heat exchanger design code does not include form losses and pressure drop of header part. The heat exchanger design code will be revised with the consideration of header section in the next phase.

ACKNOWLEDGEMENT

This research was supported by the National Research Foundation of Korea (NRF) and Innovation project of Korea Atomic Energy Research Institute (KAERI).

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