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A CFD Assessment of a Compact High Temperature Heat Exchanger

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1. Introduction

New concepts based on a Very High Temperature gas cooled Reactor (VHTR) have become of interest for an energy source with a thermo-chemical process for a hydrogen production. The NHDD (Nuclear Hydrogen Development and Demonstration) plant being developed at KAERI also has the same concepts. A baseline candidate of a thermo-chemical process for the NHDD is the Sulfur Iodine (S-I) Cycle. This cycle consists of three chemical reactions to dissociate water, which needs only water and heat to be added to the cycle. A high temperature above 850℃ is required to split the water. Figure 1 shows a concept of the S-I cycle by using the process heat from a NHDD reactor [1].

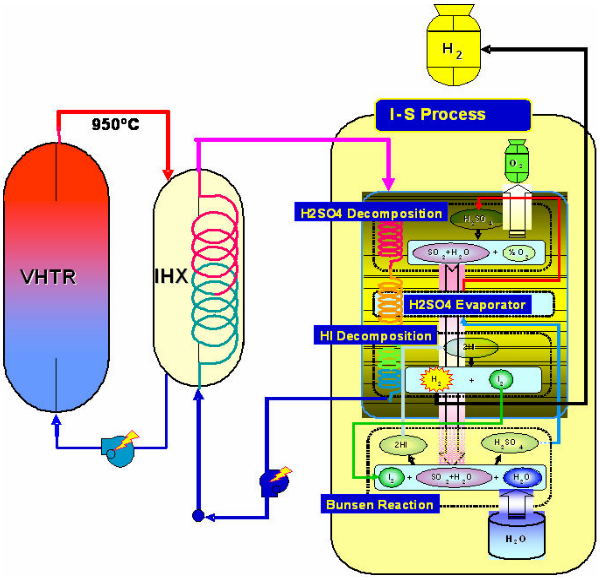

Figure 1. A Concept of NHDD Plant

The intermediate Heat Exchanger (IHX) transfers the high temperature heat coming from the VHTR to the I-S process. Compact heat exchangers of the plate-fin or printed-circuit types have a large heat transfer area per volume and they are expected to be used as the IHX. The type of the IHX for the NHDD has not been decided as yet but several studies for selecting a proper type have been conducted. Design of the IHX needs a large amount of studies and experiments with regards to the heat transfer performance, secondary coolant and material selection, and the structural integrity etc. Due to the inherent high temperature operation of the IHX, a design approach by experiments has encountered many restrictions. Computational Fluid Dynamics (CFD), called numerical experiments, could be a useful tool for an assessment and optimization of the IHX thermal design.

The purpose of this study is to assess the feasibility of CFD as a tool for a performance analysis of the designed IHX. The offset strip fin type has selected a baseline model in this study by using the CFX commercial CFD software. To begin with, a CFD computation is performed for the offset strip fin geometry and it is compared with a known experimental correlation of the pressure drop. Then, a high temperature heat exchanger developed in UNLV (University of Nevada, Las Vegas) is selected for the feasibility study. The results are quantitatively analyzed and some parameters are compared with the CFD analysis of UNLV.

2. Numerical Simulation

2.1 Pressure Drop Prediction

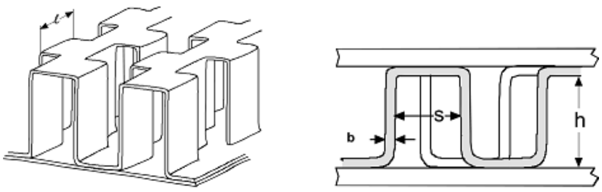

Figure 2. Geometry of the offset strip fin

A typical geometry of the offset strip fin is provided in Figure 2. The hydraulic diameter is defined as follows:

$$D_h = \frac{4shl}{2(sl + hl + bh) + bs}$$

where s is the fin width, l the fin length, h the fin height, and b the fin thickness. The parameters selected for the present calculation are

h = 2mm, s = 2mm, l = 5mm, b = 0.2mm, D_h = 1.942.

These values are within the range of the experimental correlation by Manglic & Bergles [2].

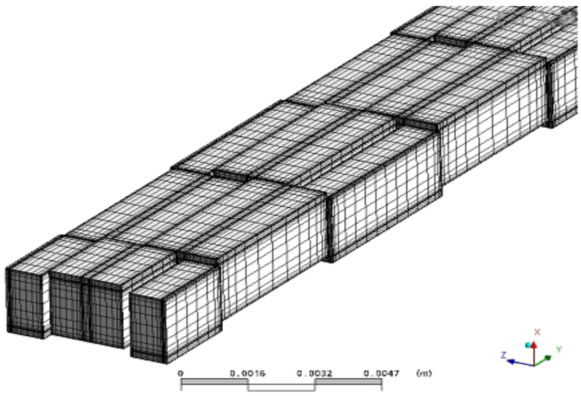

Figure 3. Grid system for the offset strip fin

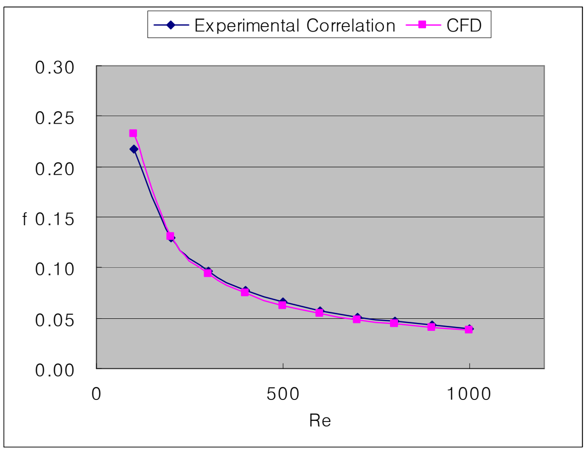

Figure 4. Comparison of friction factor with Reynolds number

Figure 3 shows a part of the computational grid system for 15 modules. One module consists of two strips. In the transverse direction, the domain is established to be able to apply a periodic boundary condition. The computations were performed for the Reynolds numbers from 100 to 1000 with a interval of 100. The flow is assumed as a laminar flow.

Comparison of the friction factors (Fanning factors) between the computational results and the experimental correlation is provided in Figure 4. The computational results give smaller values than the correlation but they are reasonable when considering the complex flow. The larger value of the computational results at the Reynolds number of 100 is not of importance as the correlation is only valid for a Reynolds not less than 300.

2. High Temperature Heat Exchanger

A subject of the IHX performance analysis is an offset strip curved-fin type compact heat exchanger being developed in UNLV HTHX Project [3]. The heat exchanger is made of a liquid silicon impregnated carbon composite. The primary fluid is helium, the coolant of the VHTR, and the intermediate heat transfer fluid is a high temperature and low pressure Molten-Salt. The 3D geometry of the flow channels and the operating conditions are shown in Figure 5.

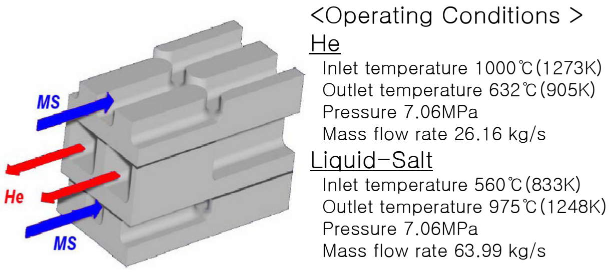

Figure 5. 3D geometry and operating conditions

A conjugate heat transfer is used in order to predict the overall thermal performance. A 3D computational domain that consists of 37 periodic modules is defined with a grid system. Details of the channel dimensions are given in reference [4]. A laminar flow and constant physical properties are assumed in the present simulation. Figure 6 shows the velocity and temperature distribution at the helium channel. A boundary layer is being developed along the fin, followed by a wake occurring with its separation at the fin end. This flow pattern is continuously repeated in the same way along the channel. The temperature of the helium is decreasing as it transfers the heat to the intermediate coolant.

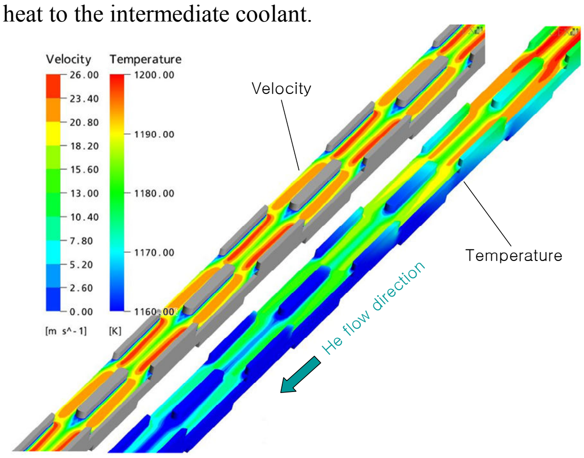

Figure 6. Velocity and Temperature distributions at the helium channel

Comparison of the performance parameters between the present and reference results is provided in Table 1. The present results predict a lower pressure drop than the reference in the He channel but a higher one in the MS channel. It is conjectured that the differences of the mesh number and the discretization scheme used in each cause somewhat different results. The present study used a half mesh number compared to the reference. The scheme used in this study is a high resolution but with an upwind in the reference. The present results predict higher outlet temperatures of the He and MS channels. The LMTD value of the present is closer to the design one than the reference.

Table 1. Comparison of performance parameters

Property	Present High-resolution (CFX)	Reference Upwind (FLUENT)	Reference Design Values
He side ΔP	15.1 (kPa)	16.7 (kPa)	NA
MS side ΔP	10.9 (kPa)	7.84 (kPa)	NA
He inlet/outlet Temperature(K)	1273/930	1273/896	1273/905
MS inlet/outlet temperature(K)	833/1257	833/1251	833/1248
LMTD(K)	44.9	39	44.4

3. Conclusions

CFD analyses were performed to investigate its feasibility as a preliminary IHX design tool for a performance prediction. Two problems, one is an offset strip fin with an experimental correlation and the other is a conjugate heat transfer problem for the offset strip curved-fin type of the UNLV, were selected. The result of the pressure drop calculation gives just a little lower value than the experimental correlation but very reasonable ones in view of the engineering aspects. The results for the conjugate heat transfer represent a little difference when compared to the reference one conducted in the UNLV. However, it showed that the CFD method gives physically reasonable results and it has the capability to deal with this kind of heat transfer problem. For a future use of the CFD method for the design of a high temperature heat exchanger, it is necessary to conduct not only profound numerical studies but also supporting experimental validation works.

Acknowledgement

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