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The Conceptual Heat Exchanger Design for Heat Pipe Cooled Micro Reactor

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1. Introduction

The micro reactors have been developed for a lot of purposes, such as space applications, transportable solution to access electricity. They are typically cooled by liquid metal heat pipes (HP), and the heat exchanger removes the heat from condenser region of heat pipes. But this condenser part of the micro reactors has some issues to solve. The heat exchanger (HE) typically has cross flow in some designs. Fig. 1 shows Westinghouse eVinci micro reactor which has cross flow in the primary heat exchanger system. Because of the non-uniform velocity and temperature distribution, the cross flow can become less efficient than the parallel and counter flow. Moreover, high temperature peaks cause unexpected deformation of structure materials, and lead to a related accident. The heat exchanger needs to provide sufficient cooling to the core by heat pipes. So, a uniform flow can either protect the core against overheating or provide a better mechanical strength. Another issue is that, in an overheating accident condition, as the temperature increases the pressure increases in the HPs which can cause some failure in it [1]. Additionally, the failure of heat exchanger tank results in the draining of coolant which means the loss of heat sink. In this condition, the core will not be able to remove its heat by the heat pipes and it will get heat up.

This study reassesses the flow type of heat exchanger and the safety of the reactor. The new conceptual heat exchanger design is suggested to give a solution for explained issues. In the section 2, the new conceptual design is presented, and 3D models are shown with flow paths. As presented in the section 3, the thermal analysis with using the Ansys CFX was performed to make comparison between representative cross flow and new designs. Finally, the safety features of new design are discussed in the section 4. This design concept provides more efficient flow and protection against failure of heat pipes and completely draining of coolant inside the heat exchanger.

2. New Conceptual Design

To provide uniform velocity and temperature distribution in the heat exchanger, the flow type is assumed as axial flow. Fig. 2 shows the representative one channel coolant flow paths of new design. The inlet and outlet of coolant flow are designed in the same direction with the heat pipe to have axial flow. Additionally, the Electric Actuated Ball Valves (EABV) were inserted in the inlet and outlet of insider coolant flow path. These valves are electrically controlled by the main controller depending on temperature change. In the normal operation, they are in an open position, the fluid flows in both the first and second flow paths. The coolant continues to flow in both paths and removes the heat from heat pipes until the heat pipe failure. To detect the temperature change of the first coolant flow path, thermocouples added the outlets of each channel first flow path.

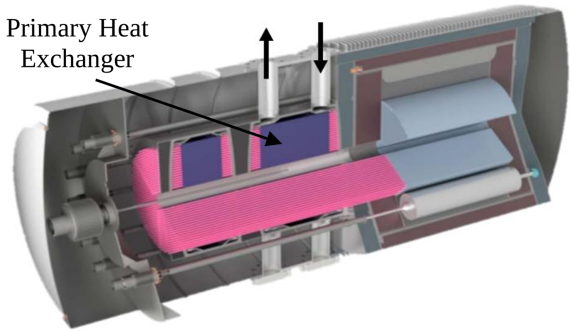

Fig. 1. Westinghouse eVinci micro reactor [2].

In the HP failure conditions, the thermocouples which are shown in the Fig. 2 detect the temperature increase and the EABVs are switched to closed position which is also mean they seal the first coolant flow path to restrain any leakage from heat pipe to energy conversion system. In this case, the coolant flows through second flow path, and it still continues to provide cooling for core by heat pipe and sealed first flow path.

Table I: Design and Flow Analysis Parameters

Parameter	Unit	Value
HP Inner Diameter [3]	cm	1.575
HP Outer Diameter [3]	cm	1.757
HP Average Temperature [4]	°C	627-727
HP Operating Pressure [5]	MPa	0.1
HP Working Fluid [5]		Potassium
HE Inlet Temperature [6]	°C	486.1
HE Inlet Pressure [6]	kPa	246.3
HE Inlet Flow Rate [5]	kg/s	0.020
Condenser Length [5]	cm	210
Material [5]		SS 316
Coolant [5]		Air
HP-to-HP Pitch [6]	cm	2.771

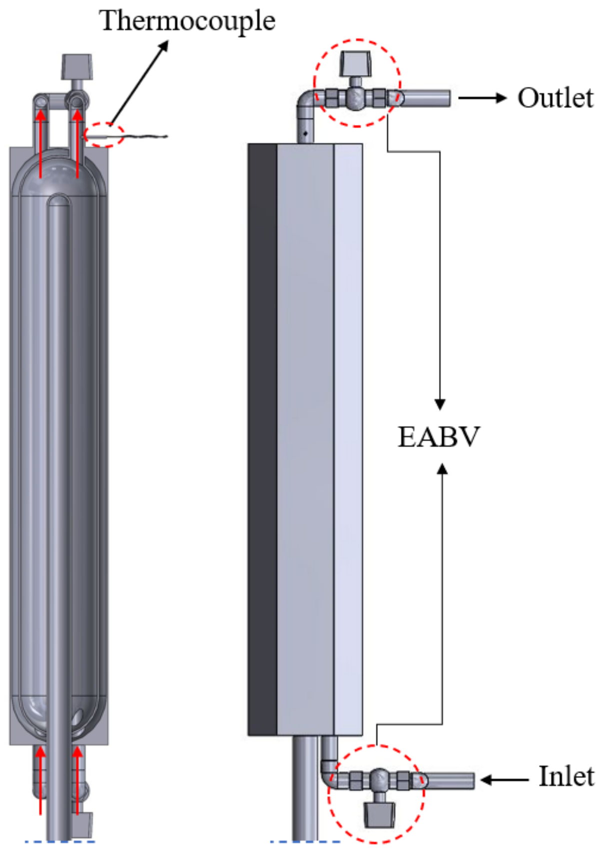

Fig. 2. Flow direction of coolant in new heat exchanger design.

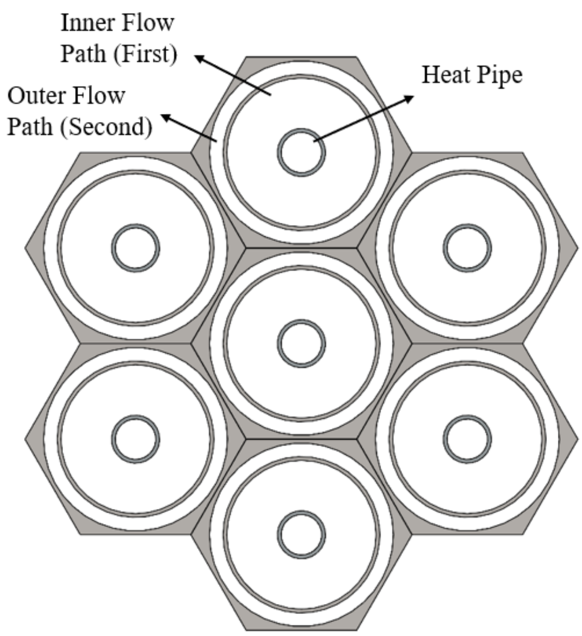

Fig. 3. Midplane view of conceptual design.

As shown in the Fig. 3**,** instead of filling all heat pipes in one heat exchanger tank, it was divided in channels. Each heat pipe has one flow channel which has two coolant flow path which become active and inactive according to conditions. This divided design also provides a protection against the draining of coolant tank completely by separate coolant flow paths. Fig. 4 shows the representative 7 heat pipe channel model of this design which is not included the core parts. In the multi channel design, inlet and outlet of each channel's flow paths are separately connected to same flow line. EABVs just control the inner flow path while outer flow path has flow continuously.

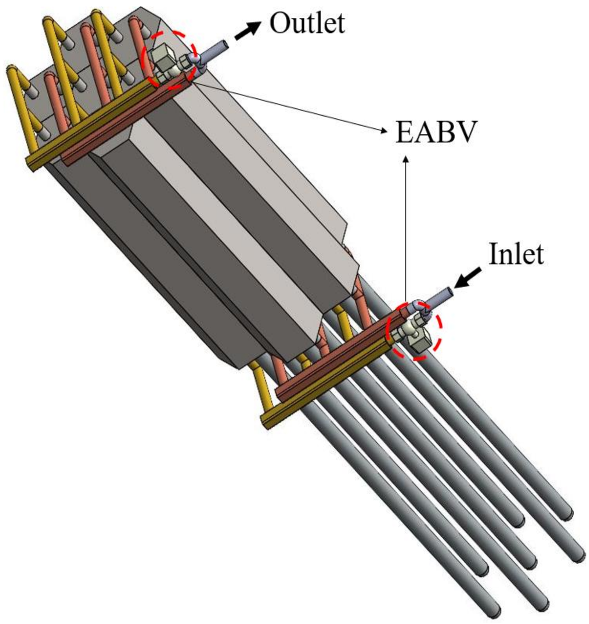

Fig. 4. The conceptual heat exchanger design which consist 7 heat pipes channels.

3. Thermal Analysis Results

Simple model of the new heat exchanger design is modeled as one flow channel on Ansys CFX. Table I shows the design and flow analysis parameters. In the typical design which has cross flow, the maximum outlet temperature of air flow is around 675 °C [5]. Using the same design parameters, a representative cross flow heat exchanger channel which achieves the reference temperature output was designed to make a comparison between flow types and designs.

The temperature change throughout the HP of cross flow and new design can be seen in Fig. 5. The results obviously show that cross flow design has mixed flow because of the structural barriers. This causes a big velocity difference which also results in unwanted thermal increases in some regions. On the other hand, the suggested conceptual design has uniformly developed axial flow which provides more controllable velocity distribution. It also reduces unpredictable accident situations by regulating the temperature and velocity change. Furthermore, in the event of heat pipe failure, even if it doesn't have same temperature output, the coolant still continues to transfer heat via the second flow path.

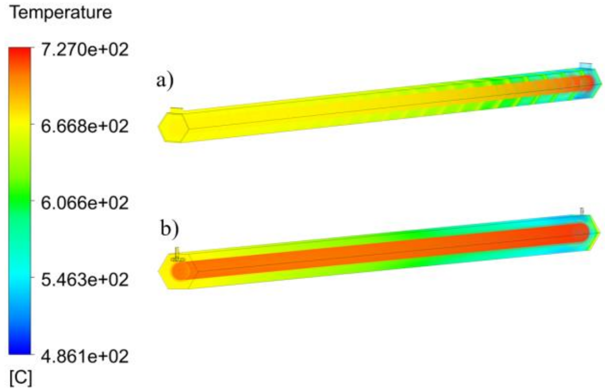

Fig. 5. Inlet and outlet temperature distribution of a) typical cross flow design, b) new design at normal operation.

Fig. 6 shows the coolant temperature change through the channel length for both cross flow design and new conceptual design. In the normal operation, the outlet temperature of the new design almost matches with the reference outlet temperature which is 675 °C. The fluctuation of the cross flow can be clearly seen in the graph.

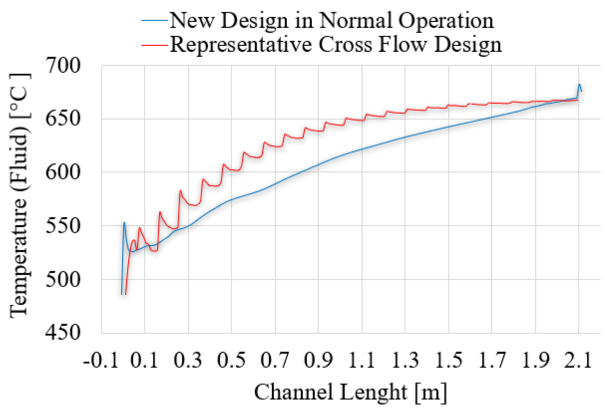

Fig. 6. Coolant temperature change through the channel length.

4. Safety Features of New Design

As presented in the previous sections, the new design has some safety benefits which can be a solution to protect the reactor against overheating or loss of heat sink scenarios. First of all, each heat pipe has its own channel which provides a separate flow process. Any failure condition in one channel will not directly affect the rest of them. In case of the faulty channel completely drained and there is no flow, the coolant continues to flow and remove heat from other channels. Secondly, the failure of heat pipe condenser regions doesn't block the energy conversion system because of the two stages coolant flow. In an accident condition, on the one hand the valves which are located in the inlets and outlets of the channels' inner flow path entirely close the first flow path and on the other hand they allow the coolant to flow through second flow path. In this process, the fluid inside heat pipe becomes stuck into the first flow path tube and doesn't leak to the conversion system. Additionally, the outer flow path continues to provide heat removal. The shutdown system gains more time to do its job by this process.

5. Future Work

Even if thermal analysis were completed on this design, some additional CFD analysis still needed to make detailed comparison. Moreover, it is also needed to investigate the thermal stress effect which can be result of big temperature difference. The safety analysis with using related codes also essential to make sure about safety features. It is also planned to produce this design, and make some experiments by related test facilities to have real time results.

6. Conclusions

In the normal operation, the representative cross flow design has fluctuant temperature profile while the new design has uniform distribution with axial flow. This chosen flow type and temperature profile provide more predictable accident conditions. Each heat pipe has its own heat exchanger channel which provides partially separate flow process, and prevents the fully drainage of the tank. One channel's failure will not affect the other channel directly. Lastly, in the heat pipe accident condition, two-stage coolant flow prevents the leakage from channel to the atmosphere. Even if the electricity production decreases in this condition, it provides safer process and saves some time to start shutdown system.

ACKNOWLEDGMENT

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