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Verification of the thermal-hydraulic performance analysis code for a steam generator in SFR with experiments

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1. Introduction

In a SFR (Sodium-cooled Fast Reactor), the possibility of a water-steam leak into the sodium and a violent sodium-water reaction (SWR) is indispensable. To resolve the increase of construction costs for the safety of a reactor system due to a safety system, a new concept of a steam generator system should be developed. Recently, the concept of a double tube bundle steam generator (DTBSG) was proposed [1]. DTBSG removes the possibility of a SWR by a double installation of heat transfer tube bundles in a SG. The thermal-hydraulic performance analysis code was developed [2]. To verify the analysis code of the DTBSG and confirm the viability of the concept, an experimental research has been carried out. As a first step, the experiments of the heat transfer phenomena in a single helical tube bundle have been performed. The performance characteristics of the heat exchanger were verified with experimental data in various flow conditions.

2. Analysis condition

2.1 Experimental conditions

The conditions for the experiments are established to confirm the feasibility and heat transfer performance [3]. In general helical coil heat exchanger, heat transfer coefficient models have been proposed by several researchers [4]. To confirm the feasibility of the models and to improve the models to apply them to the present DTBSG concept, experimental conditions are setup. In view of the NTU, experimental range is selected as a steep change of the heat transfer rate, Q and determined to realize it easily in the apparatus

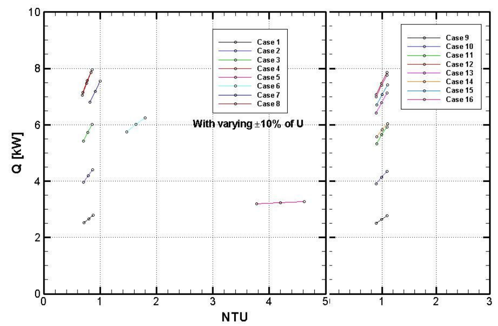


Fig. 1 NTU-Q diagram of the experiments

With a varying ±10% of the NTU, the heat transfer rate changes steeply in most of the conditions as shown in Fig. 1. There are two kinds of conditions for the experiments. Experiments for hot water vs. cold liquid metal and hot liquid metal vs. cold water conditions are performed. Wood Metal (Pb-Sn-Cd-Bi) is used as a medium liquid metal and the properties are measured [5]. The hot fluid inlet temperature is 150°C and the cold side inlet temperature is 111°C. The mass flow rate of the water is varied 0.031~0.084 [kg/s] and the mass flow rate of the wood metal is changed from 0.52 to 2.89 [kg/s].

2.2 Analysis code

ISGA (Integrated Steam Generator Analyzer) computer code was developed to analyze the thermal-hydraulic performance of three types of proposed DTBSGs. In the one-dimensional analysis, homogeneous two-phase model was used for the water/steam side. Feasibility of the DTBSG was shown by comparing it with an analytical solution of heat exchangers [2]. For a single helical tube bundle, same physical models are applied to the heat transfer between the wood metal and the water.

3. Calculation and validation

3.1 Analysis and validation

For the 19 cases, calculations are carried out. In a reference case of hot wood metal and cold water, temperature of the shell side is compared to the experimental data of 3 different circumferential angles and of identical axial normalized locations as depicted in Fig. 2. Only a 3% error is reported in the reference case.

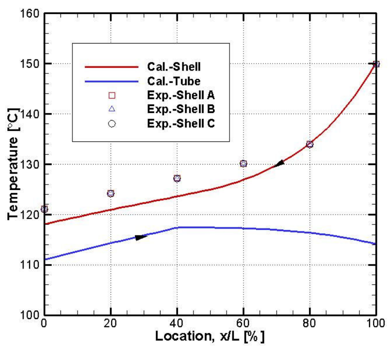
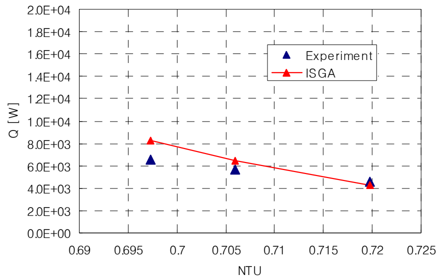


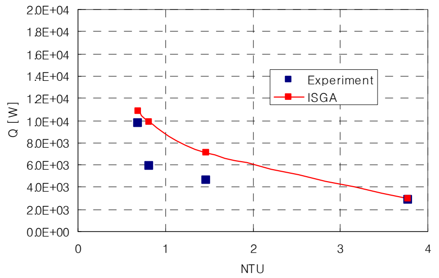
Fig. 2 Temperature distribution in steam generator

From the view point of the NTU, the heat transfer rates of the steam generator are calculated and compared to the experimental data. When the mass flow rate of the hot side and cold side is increased, the heat transfer rate is increased in the same order. Generally, the heat transfer rate is proportional to an inverse NTU.

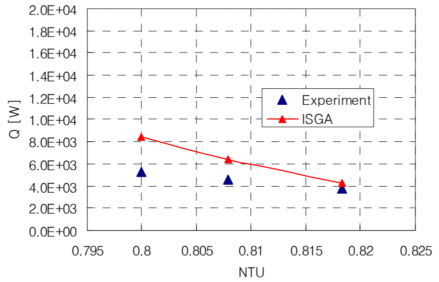
This phenomenon is mainly due to the different inlet pressures of the fluid and the differences in the ratio of the hot and cold mass flows multiplied by the heat capacities (mCp) in a series of experiments. However, the calculations and experiments show a good agreement in various conditions.



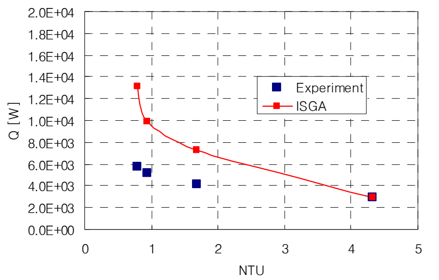
(a) case 1



(b) case 2



(c) case 3



(d) case 4

Fig. 3 NTU vs. heat transfer rate diagram

Errors between the calculations and experiments are distributed from 0.04% to 144%. When the heat capacity is changed ±10% the heat transfer rate is varied ±8%. The uncertainty in the property measurements is one of the significant factors which affect the calculations. And the ratio of mCp is also one of the important factors for the heat transfer rate. In Fig. 4, the effects of the ratio are depicted well.

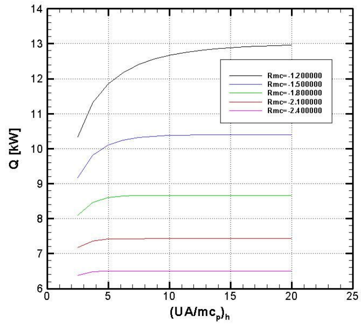


Fig. 4 Effect of the mCp ratio

And the more, the multidimensional effect of a flowfield can cause a discrepancy between an analysis and an experiment. To evaluate the multidimensional effect, a multidimensional analysis should be performed.

4. Conclusion

Experiments for the heat transfer phenomena in a single helical tube bundle have been performed. The analysis methodology for the performance characteristics of the helical tube heat exchanger were verified with experimental data in various flow conditions. The uncertainties of the property and the operation conditions affect the results. Studies on the effects and the refinement of the heat transfer models should be performed in the future. As a second step, an experimental study on the performance of the heat transfer in a double tube bundle heat exchanger will be carried out to verify the design code and to confirm the viability of the concept.

Acknowledgment

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