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Thermal Sizing of a forced draft sodium-to-air heat exchanger and its operation strategy in KALIMER

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1. Introduction

The conceptual design of the sodium cooled fast reactor, KALIMER-600(Korea Advanced LIquid MEtal Reactor) [1] has been completed and an advanced concept of the Gen IV SFR, whose electric output is 1200MWe, has been developed. The overall design features of both reactor systems are very similar and they employ a pool type primary heat transport system (PHTS), a two-loop intermediate heat transport system (IHTS), a steam generator system (SGS) and a shutdown heat removal system (SHRS). In particular, the SHRS provides a highly reliable heat removal capability from the primary system in the case of an unavailability of the main heat transfer route through the water/steam system.

The SHRS comprises two diverse decay heat removal loops (PDRC and IRACS)[1], and both loops remove heat from the primary sodium pool by using sodium-to-sodium heat exchangers, and reject the heat load to the environment by using a different kind of sodium-to-air heat exchanger located on the roofs of the reactor or auxiliary buildings. Each system is able to fulfill the decay heat removal requirements, even in the case of a complete loss of one of the loops. **Fig. 1** shows the general configuration of the heat transport system of KALIMER-600.

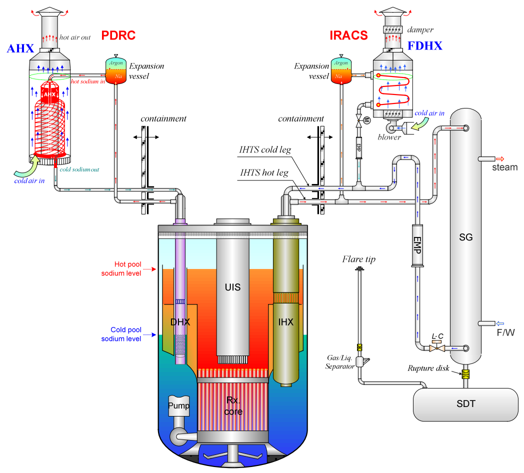

Fig. 1 Overview of the heat transport system

The PDRC (Passive Decay heat Removal Circuit) system relies exclusively on a natural convection heat transfer, *i.e.*, a natural circulation on the sodium-side and a natural draft on the air-side. In contrast, IRACS (Intermediate Reactor Auxiliary Cooling System) is normally operated in a forced flow condition, and it consists of an IHX (intermediate heat exchanger), a forced-draft sodium-to-air heat exchanger (FDHX), and sodium pipings connecting the IHXs with the FDHX via a part of the IHTS loop. Each loop is equipped with a single electro-magnetic pump (EMP) located at the IRACS cold-leg, a motor-driven air blower and isolation dampers on the air side.

This study provides the basic design procedures of the IRACS, in particular an FDHX thermal sizing, with its operation method or strategy during a scheduled reactor shutdown period.

2. Methods and Results

2.1 Determination of the IRACS design point

One of the most important steps in the IRACS design is to set up the system design point. During a scheduled plant shutdown, the system should reach the refueling mode within 24 hours after a reactor shutdown [1]. Hence the IRACS should be designed to have a controllable heat removal capacity to maintain the temperature condition of the refueling mode. For this reason, as shown in **Fig.2**, the IRACS design point has been determined by considering the system cooling rate and the decay heat level at the entry time of the refueling mode.

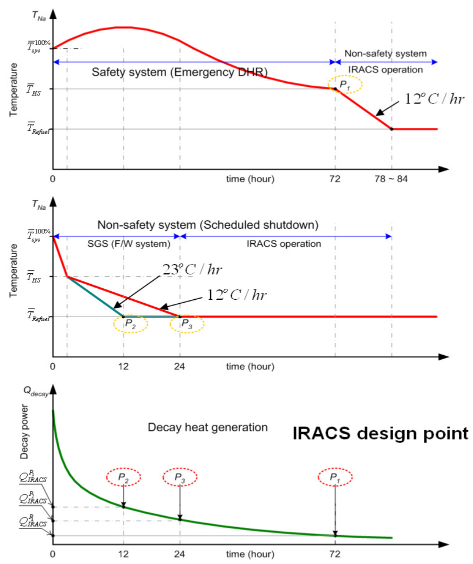

Fig. 2 Determination of the IRACS design condition

Quantitative analysis results regarding a decay heat generation provide the design capacities of the IRACS for KALIMER-600 and for the Gen IV SFR, which are 20MWt and 40MWt, respectively. Hence the design capacity per single IRACS loop for both systems becomes 10MWt each, which signifies that the required heat capacities of the FDHX are 5MWt for the KALIMER-600 and 10MWt for the Gen IV SFR [1]. By considering the operating conditions for a refueling mode, other design parameters for the FDHX thermal sizing could be set up as follows.

- Inlet sodium temperature of the FDHX: 217°C
- FDHX intake air temperature: 40 °C
- Maximum air flowrate: 75 m^3/sec

2.2 Thermal sizing of the FDHX

The FDHX for the active loops consists of a four pass serpentine tube bundle arrangement with a tube slope of 9°, and the shell-side air flow is assumed as a cross flow across the tube bank. The tube bank consists of 108 parallel and finned tubes attached to an upper inlet and a lower outlet header. The headers and tube bundle are mounted in a support structure which provides support for the tubes whilst allowing for a thermal expansion. A separate expansion vessel is situated above the heat exchanger and represents the highest point of the heat removal loop.

Table 1. FDHX design data

Parameter	unit	Nominal value
Number of tubes per FDHX	ea	108
Tube arrangement	-	4 passes serpentine tubes with [P_L = 2.04] & [P_T = 1.91]
FDHX sodium tube ID	m	0.028
FDHX sodium tube OD	m	0.032
FDHX sodium tube thickness	mm	2.0
Finned length of each tube	m	11.59
Fin height	mm	15.7
Fin thickness	mm	1.5
Inclined tube angle	degree	9.0
Number of Fins per unit length	ea/m	153

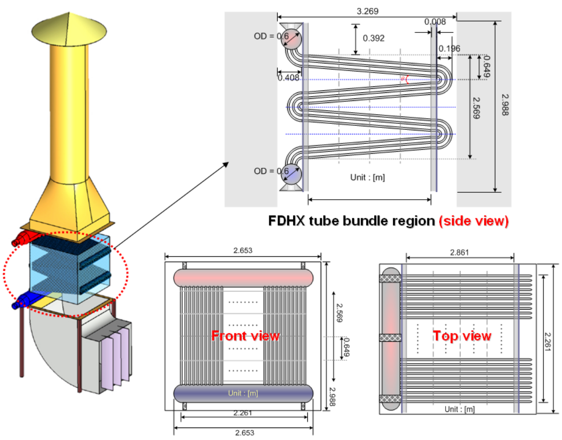

Fig.3 FDHX shape and bundle arrangement

A thermal sizing code for designing the FDHX was developed by using physical models regarding the mass conservations, one-dimensional energy balances, and pressure losses, *etc.* for the tube- and shell-sides' heat transfer medium. Proper heat transfer correlations for each heat transfer medium were also used to obtain the overall heat transfer coefficients composed of sodium-side [2] and air-side [3] heat transfer coefficients. The pressure loss terms for each flow medium were calculated for each control volume comprising of the accelerational, frictional, and gravitational pressure drops. Annular type fins were used to enhance the heat transfer rate from an FDHX tube surface by increasing the effective heat transfer surface area, and the fin effect was well reflected in the thermal sizing procedure. Based on the design conditions defined at the IRACS design point, the FDHX design parameters were reasonably well obtained as shown in **Table 1** and its schematic drawing with a bundle arrangement is shown in **Fig.3**.

2.3 Operation strategy of the IRACS and FDHX

During a standby condition of the IRACS loops, the dampers in the FDHX air path are completely closed and the air blowers are off, but a minimum sodium flow is maintained to prevent an unexpected sodium freezing or flow reversal inside the IRACS sodium pipings.

During a scheduled shutdown operation, the IRACS operation is initiated by the operator at the refueling mode, and the IRACS cold-leg set point temperature in this mode is allowed to fall to 140°C. This temperature is controlled by an adequate damper throttling of the FDHX air path or by a speed control of the air blower, if necessary. A special sodium freezing protection of the FDHX is activated if the sodium exit temperature in individual tubes falls below 125°C. This protection is based on multiple temperature measurements at selected positions with an automatic damper closure.

3. Conclusions

The IRACS was designed to have a controllable heat removal capacity to maintain the temperature condition of the refueling mode, and its design points for KALIMER-600 and Gen IV SFR were determined by considering the system cooling rate and the decay heat level at the entry time of the refueling mode. The results of the thermal sizing for the FDHX at the IRACS design point were described in this study, and its operation strategy during a standby and a scheduled shutdown operation were briefly introduced as well.

ACKNOWLEDGEMENT

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REFERENCES

[1] Dohee HAHN, *et al.*,"KALIMER-600 Conceptual Design Report,"KAERI/TR-3381/2007, Korea Atomic Energy Research Institute (2007)

[2] Lubarsky, B. and Kaufman, S. J., *Report NACA-1270*, Lewus Flight Company, Inc. (1954)

[3] Zhukauskas, A. *et al.*, "Heat Transfer in Tube Banks in a Cross flow of Fluid", *Thermophysics, the Academy of Sciences of the Lithuanian SSR*, the Institute of Physical and Technical Problems of Energetics, Mint-is, Vilnyus, pp. 1 – 190. (1968).