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Operating temperatures and flow rates during partial load operation for the modular plant design of KALIMER

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1. Introduction

A modular plant design concept is being considered for the scale-up of KALIMER. It is expected to have a considerable advantage and to reduce the investment risk over conventional plant designs [1]. To prepare the control study for the modular concept, a partial load study was made from 100% down to 25% full load conditions. The multi-modular plant has two basic requirements: maintenance of constant steam temperature and constant steam pressure to the turbines for unequal module powers. In order to evaluate the temperature effects at the partial load operating conditions, the previously developed computer code [2] was used, and the results of the calculations are presented in this paper.

2. Methods and Results

Fig.1 shows the heat balance of the KALIMER system at 100% power level for each power module. The heat transport and connected systems of the reactors mainly consist of the primary heat transport system(PHTS), intermediate heat transport system(IHTS), and steam generator system. The PHTS is a pool based system and transports the generated heat from the core to the IHX's. The heat is transferred to steam generators through the IHTS loops.

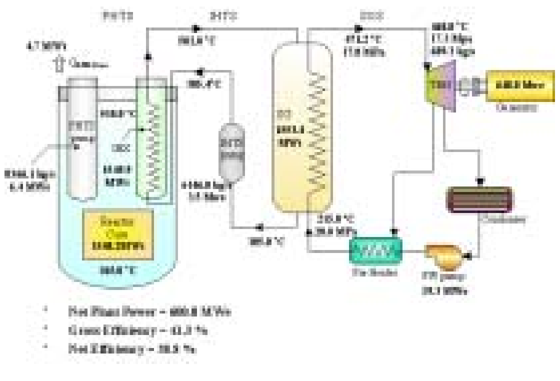

Fig. 1.Heat balance of 600 MWe KALIMER at 100% power.

In order to maintain steam temperature from the steam generator, the hot side temperature in the intermediate loop is varied and lowered for partial load operation. This also requires a similar variation in the hot side temperature of the primary system for partial load operation. Variable flow is required in both intermediate and primary systems to maintain temperature differences on the tube sheet ends of the steam generator and the IHX. During the load-following transients, the following constraints are considered in programming temperature and flow rate to make the heat transport systems operate within their design conditions in order to protect the reactor core and other components in the plant. [2]

- Core inlet temperature should be less than 420 °C for the mechanical integrity of core inlet structures.
- Primary sodium flow rate should be greater than 50% and 35% in the intermediate loop to prevent thermal stratification in the pool and pipes
- Steam temperature and pressure at turbine inlet should be constant for unequal module powers.
- Temperature differences on the tube sheet ends of the steam generator and the IHX should be maintained relatively constant
- Feed water temperature should be greater than 150 °C to prevent sodium freezing.

2.1 Mathematical Method of solving the problem

The following are five equations governing the three heat transport systems. And there are 13 unknowns in these equations in a case when the steam temperature is one of the unknowns.

$$Q = \dot{m}_p C_p (T_{p,h} - T_{p,c})$$
$$Q = \dot{m}_i C_p (T_{i,h} - T_{i,c})$$
$$Q = \dot{m}_{fw} (h(T_s, P_s) - h(P_{fw}, T_{fw}))$$
$$Q = UA_{IHX} \Delta T_{LMTD,IHX}$$
$$Q = UA_{SG} \Delta T_{LMTD,SG}$$

$$Q, T_{p,h}, T_{p,c}, T_{i,h}, T_{i,c}, T_s, P_s, T_{fw}$$
$$\Rightarrow A_{IHX},\ A_{SG},\ \dot{m}_p, \dot{m}_i, \dot{m}_{fw}\ (100\%\ condition)$$

$$A_{IHX},\ A_{SG},\ \dot{m}_p, \dot{m}_i,\ Q, T_s, P_s, T_{fw}$$
$$\Rightarrow \dot{m}_{fw}, T_{p,h}, T_{p,c}, T_{i,h}, T_{i,c}\ (part\ load\ condition)$$

For the calculation of 100% condition eight unknowns are given as design parameters, then five unknowns are derived from the above five equations. Two heat transfer area results from the derived five unknowns with other input parameters are used for the calculation of system temperatures during the part load condition.

2.2 Results

In order to generate the reference data as a starting point for the part load operation logic design, constant steam temperature(468°C), constant primary flow(100%) and constant intermediate flow(100%) conditions were given as inputs. Tentatively, the recirculation operation mode began at 25% power level.

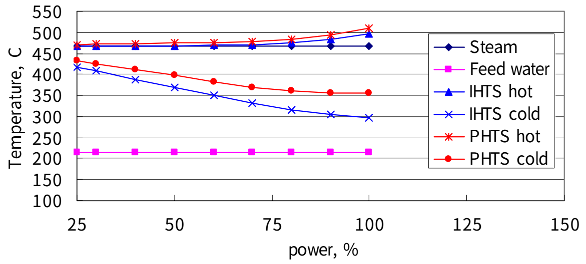

Fig. 2. Temperatures vs. plant load in a reference condition

Fig.2 shows temperatures vs. plant load in a reference condition. It can be seen that the core inlet temperature at 25% power level reach 432°C. The temperature difference on the cold side between the primary flow and the intermediate flow is about 14°C at 25% power level. Therefore it is necessary to decrease primary flow to reduce this temperature. However there is another limitation in reducing the flow rate because of the possibility of thermal stratification in the primary system due to low flow rate. The temperature difference between the feed water and the cold side of the intermediate flow reaches 197°C at 25% power level. This means the temperature of feed water should be increased at lower partial load to maintain a constant temperature difference

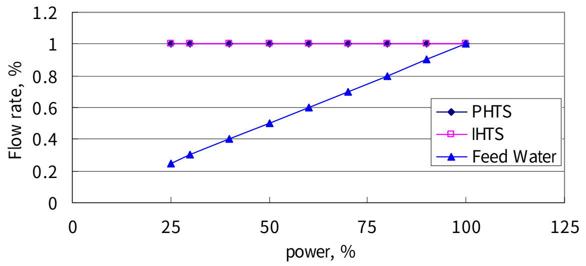

Fig. 3. Flow rates vs. plant load in a reference condition

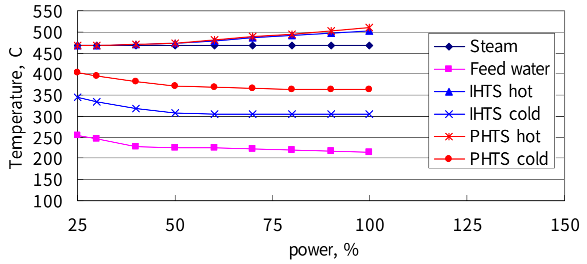

Fig. 4. Temperatures vs. plant load in constant steam temperature condition

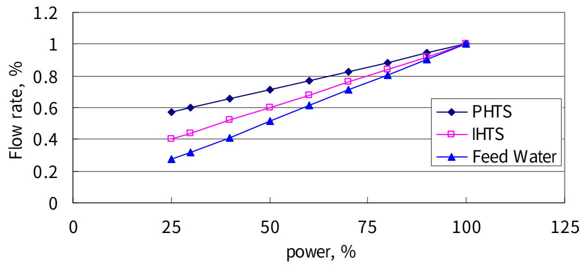

Fig. 5. Flow rates vs. plant load in constant steam temperature condition

Fig.4 and Fig.5 show temperatures and flow rates vs. plant load in constant steam condition. The primary and intermediate flow rates vary linearly from 57%, and 40% respectively at 25% power level to the rated condition. The feed water temperature is increased to 255°C at 25% power level.

3. Conclusions

Maintenance of constant steam temperature and constant steam pressure to the turbines is needed to control the reactor power level of a multi-modular plant. In the case of constant steam temperature, lower primary flow and higher feed water temperature are needed at lower partial load.

REFERENCES

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[2] Eui-Kwang Kim, Seong-O Kim, Partial load study for KALIMER in once-through mode of a superheated steam generator, Proceedings of the Korean Nuclear Society Autumn Meeting, 2009.