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Conceptual Design for BOP of the Sodium-Cooled Fast Reactor

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1. Introduction

The heavy dependence on nuclear power eventually raise the issues of an efficient utilization of uranium resources, which Korea presently imports from abroad, end of a spent fuel storage [1]. From the viewpoint that sodium-cooled fast Reactors (SFRs) have the potential of an enhanced safety by utilizing inherent safety characteristics, trans-uranics (TRU) reduction and resolving the spent fuel storage problems through a proliferation-resistant actinide recycling. SFRs are sure to be most promising nuclear power operation.

The Korea Atomic Energy Research Institute (KAERI) has been developing SFR design technologies since 1997. And nowadays, the preliminary heat balance of the demonstration SFR is calculated [2].

However, in order to verify design condition of the NSSS, it is necessary to set the heat balance and the conceptual design for BOP of the SFR as a part of the SFR design technique development business. Moreover, in order to confirm whether the heat balance can actually appropriate via the turbine characteristic, it is required to carry out the performance analysis of the turbine cycle.

For that, the main purposes of this study are; 1) to derivate the conceptual design for BOP, 2) to analyze the performance of the turbine cycle, 3) to derivate the main consideration for BOP design.

2. Preliminary Design Concept

In this section some of initial conditions used to setup the heat balance. The conceptual design includes turbine cycle configuration, condenser, pumps and feed water heaters.

2.1 Interface initial conditions of the NSSS

The steam conditions at SG outlet are 17.8MPa, 471.2℃, 689.3kg/s and at HP turbine inlet are 16.8MPa, 468 ℃. The feed water conditions at FW heater outlet are 20.8Mpa, 215℃. The thermal power generated is 1549.9MWt corresponding to an electrical power of 640 MWe. The condenser is maintained at a vacuum of 37.5 mmHg. The Gross efficiency is 41.3% [2].

2.2 Turbine cycle configuration

It is difficult to ensure the turbine characteristic data. So, we selected the turbine configuration of the SAMCHEON-PO fossil fired plant due to similar steam condition (see Table 1). The 600MWe turbine is of tandem compound design separate high pressure (HP), intermediate (IP) and low pressure (LP) cylinders. The LP turbine is of a tandem compound 4 flow type while HP and IP turbines are of single flow type(See fig. 1).

The steam conditions at HP turbine inlet are 16.8MPa, 468 ℃, 621.7kg/s. The design of the reactor gets considerably simplified with steam to steam reheat cycle. Hence, all the designers of SFRs are preferred steam to steam reheat cycle. The live steam reheater has high pressure live steam on the tube side. The steam to be reheated is on the shell side. Live steam flow is 67.5kg/s at 468 ℃ while the reheat steam flow is 577.78kg/s and reheated to 319.6 ℃. The capacity of the reheater is about 134MW and is sized such that no excessive pressure drop occurs on the reheated steam.

Table 1: Main Steam Condition

	Nuclear	Fossil	SFR
Main Steam Pressure(MPa)	6.46	25.3	17.8
Main Steam Temperature(℃)	280.5	541	471.2
Mass Flow(kg/s)	1,632.3	420.2	689.3
Net Plant Power (MWe)	1000	500	600

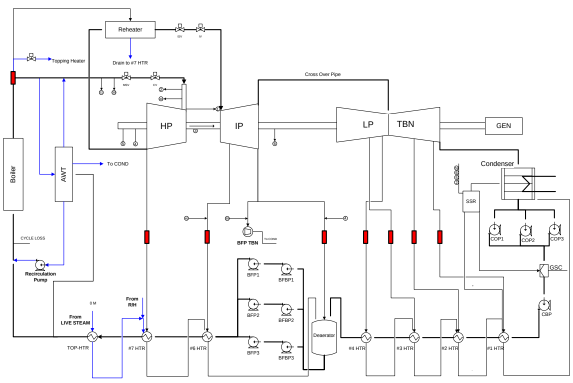

Fig. 1 SFR BOP Turbine Cycle

2.3 Condenser and Pumps

The condenser ensures the condensation of the exhaust steam from the main turbine and from the turbines driving the feed water pumps. It also absorbs the steam flow of the turbine bypass system. The condenser is of the box type construction with divided water box design which facilitates operation of one-half of the condenser while the other half is under maintenance. Condenser employs once-through sea water cooling on the tube side and is so designed that all tubes are drained automatically into the condenser water boxes.

Three 50% motor driven vertical condensate pumps. The concept of using three 50% pumps for pumping arrangement has been chosen as it offers greater flexibility during part load operation compared to single pump configuration and economical as compared to multiple pump configuration.

Three 50% main feed pumps (two turbines driven and one motor driven) are provided as in the case of fossil fired stations of the same of capacity in order to minimize the changes in a well proven cycle. Turbine driven pumps are chosen as their overall efficiency is better and economical. In addition it is easier to start the feed pump using back-up steam if motor driven pump is not available.

2.4 Feed water heaters

The feed water heaters are two systems for feed water heating viz. the condensate system and feed water system. The purpose of the condensate system is to maintain the cycle flow and thermodynamic requirements by transporting the condensate collected in the condenser hot well through various stages of feed water heaters. The purpose of the feed water system is to provide adequate flow of properly heated and conditioned water to the SG.

Four full flow low pressure closed heaters(LP HTR#1, LP HTR#2, LP HTR #3, and LP HTR#4) alone is located in the neck of the condenser. These heaters have a horizontal axis and are fed by extraction steam from the LP turbine.

Feed water tank in conjunction with a deaerator heater ensures the function of deaerating the feed water to an oxygen content of less than 7 ppb. Deaerator is located at a level of 25 m in the turbine hall and is fed by extraction steam from IP cylinder exhaust. It also receives drains form the HP heaters. The deaerator pressure is 0.8MPa and temperature is 144 ℃.

High pressure heaters (IP HTR #6 and HP HTR#7) are also horizontal and are fed by HP exhaust steam and IP extraction steam respectively. The pressure drop of the turbine extraction line is set on 5%, considering HP turbine exhaust pressure and feed water temperature. In the same manner, the terminal temperature difference (TTD) is set on 2.8℃. The drain cooler approach (DCA) is set on 5.6℃ conservatively.

3. Performance Analysis for turbine cycle

From the BOP performance calculation results, it was found that the turbine internal efficiency except for HP turbine could sufficiently appropriate performance in comparison with the similar fossil fired plant (See figure 2). In case of HP turbine, the internal efficiency may lower than the fossil fired plan due to the low pressure conditions of the HP inlet (See table 1.). If we lower the turbine exhaust pressure condition to improve the HP turbine characteristic, it will be difficult to satisfy the feed water temperature condition(215℃). Moreover, it was found that feed water heater is involved the excessive design of the heating surface area, because TTD is determined the temperature difference between main feed water temperature and saturated temperature of the turbine exhaust. From the optimization design results, HP, IP and LP turbine shaft output are 34% (219MWe), 20% (125MWe), 46% (295MWe) respectively. Total heat rate is 2080 kcal/kWh. Moreover, gross cycle efficiency (41.3%) is satisfied.

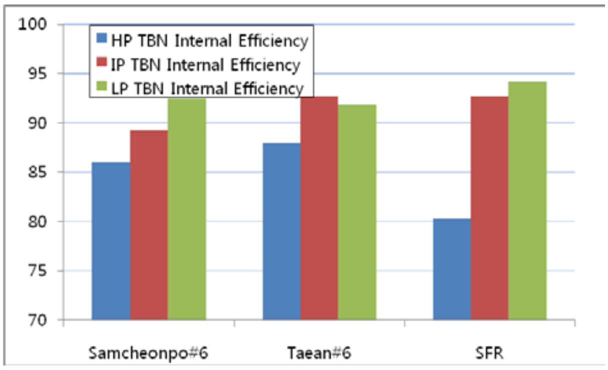

Fig. 2 Turbine Internal Efficiency

4. Conclusions

In this study, the performance analysis for the turbine cycle of SFR was carried out by using the heat balance. From the analysis results, it was found that the heat balance setup could sufficiently appropriate design. Moreover, the gross efficiency was also satisfied with the initial design condition. From this study, it was found that the main considerations need to setup the heat balance. The main considerations are: 1) to setup the turbine configuration according to SG conditions and generator power, 2) to setup the turbine exhaust pressure conditions that the performance of the TTD are satisfied main feed water temperature(215℃). The results of this study will be helpful to develop the SFR design technologies. Moreover, we have a future plan to carry out the heat balance setup on load operation

5. Acknowledgements

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