Preliminary study on heat balance of 100MWe sodium-cooled fast reactor

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1. Introduction

Based on world nuclear association[1], growth in the world's population and economy will result in a substantial increase in energy demand over the coming years. The increment of clean energy source to fulfill the increased energy demand is strongly required to relieve climate change. With this situation, investment for the renewable energy sources like solar and wind power are increased, however, its intermittency and large space requirement are one of the main issues that need to be solved. Nuclear reactor system can be one of options to be able to make up those issues.

Various small sized, long fuel cycle reactor systems are under development by many countries. It can not only be operated without refueling during long term but also contribute to solve the problems related to spent fuels. EM^2 is a compact gas-cooled fast reactor with an ultra-long fuel cycle[2]. ARC-100 is a small modular type sodium-cooled reactor with a 20 year refueling cycle[3]. TerraPower is also developing a small sodium-cooled fast reactor combined with a molten salt energy storage system[4]. The SALUS(Small, Advanced, Long-cycled and Ultimate Safe sodium-cooled fast reactor) whose design is based on PGSFR, is a 100MWe long fuel cycle sodium-cooled fast reactor system that is under consideration in KAERI.

The study for design modification has been started in KAERI. As the initial step for design review, the preliminary heat balance evaluation for SALUS was performed.

The initial design value for heat balance evaluation was decided based on various existing reference SFR including PGSFR[5,6]. In this study, those collected reference design data were introduced and preliminary estimated plant heat balance was presented.

2. Methods and Results

The DENOP(DEtermination of Normal OPerating conditions[7]) code was employed to decide the heat balance of SALUS in this study.

In order to decide the inlet and outlet core temperature, the core temperature differences with respect to core exit temperatures were presented in Fig 1. The black symbols represent the experimental, demonstration or prototype fast reactors. The red symbol represent the commercial sized reactors. The number above the respective symbols represents the value of the y-axis, the temperature difference between core inlet and outlet.

The reactor core can be classified into two based on fuel materials, one is metal fueled core and the other is oxide fueled core. The SALUS employs metal fuel as same as PGSFR. The thermal conductivity of metal fuel is an order of magnitude higher than that of oxide fuel. This reduces peak temperatures and local hot spots. Metal fuel also has a relatively low heat capacity, which limits the stored heat in the fuel, allowing the fuel to be cooled more readily[8]. However, it is known to be relatively less durable in high temperature than oxide fuel.

Therefore, the lower core exit temperature is more preferable considering long fuel cycle, which should be operated for a long period without refueling. The core inlet and exit temperature were lowered by 35℃ and 30℃, respectively, in comparison with those of PGSFR by considering the characteristic of long fuel cycle reactor.

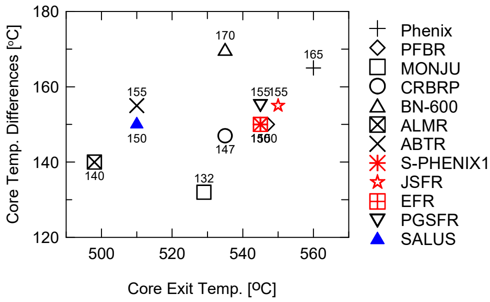

Fig. 1 Core temperature differences with respect to core exit temperature in various reactor design

The cycle efficiency of balance of plant(BOP) is one of the most important factors to affect plant's gross efficiency. Moisseytsev et al.[9] analyzed the BOP cycle efficiency with respect to core exit temperature in a superheated steam Rankine cycle(SHS), supercritical water cycle(SCW), and a S-CO2 Brayton cycle(S-CO2). The steam cycle efficiency was decided to be 41.1%, which is referred at the core exit temperature of 510℃ of the SHS curve in the reference.

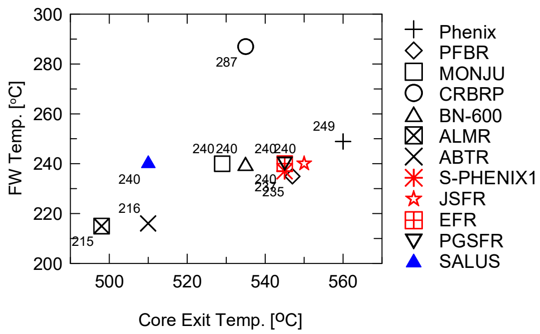

Fig. 2 Feedwater temperature in various reactor design

It is the sodium freezing issue that to be taken into accounts in feedwater temperature decision. The BOP can be exposed to various temperature conditions depending on operation modes. The relatively high feedwater temperature should be maintained to avoid sodium freezing in steam generator. The feedwater temperature of 240°C was selected, which is the same as PGSFR as shown in Fig.2.

Fig. 3 and Fig. 4 show the steam temperature and pressure condition of various reactors. In case of steam condition at BOP they should be decided based on detailed cycle analysis considering available TBN, otherwise, it is better to utilize the existing design values decided by supply vendor information. As shown in figure steam temperature increases proportional to core exit temperature. Steam pressure is also maintained at a relatively high value except few cases.

In this analysis, ABTR's steam condition was referred, whose core exit temperature is same as those of SALUS.

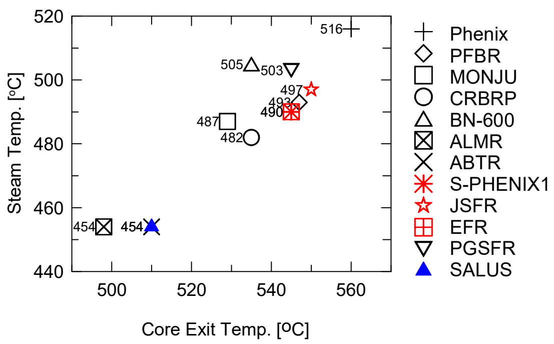

Fig. 3 Steam temperature in various reactor design

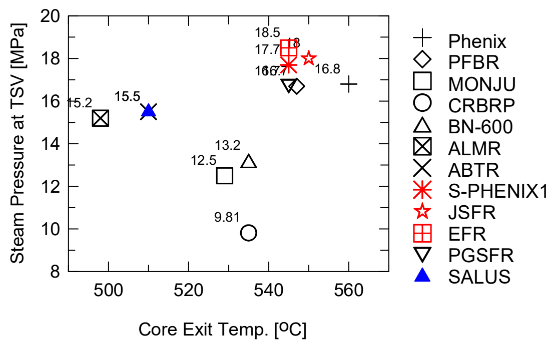

Fig. 4 Steam pressure in various reactor design

For the decision of IHTS temperature, non-dimensional temperature range is postulated from 0.2 to 0.8 and the respective temperature distribution is evaluated taking into account the following :

- Specific heat exchanger sizing parameter (UA/Q_{core})
- Flow rate requirement for IHTS
- Thermal efficiency

IHTS temperature distribution was decided to minimize the specific heat exchanger sizing parameter and to maximize thermal efficiency. The maximum flowrate shall be limited to prevent pipe erosion.

Fig. 5 shows the estimated heat balance diagram of 100MWe SALUS, having overall gross efficiency of 41.0%, and net efficiency of 37.4%.

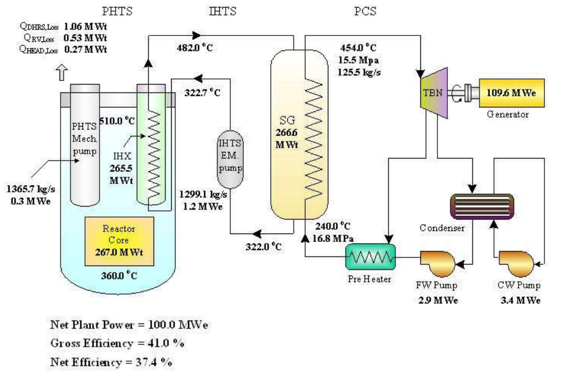

Fig. 5 Heat balance diagram of 100MWe SALUS

3. Conclusions

The major input values for DENOP code were selected by comparing the existing SFR design values in this paper. Based on those values, the preliminary heat balance for SALUS were evaluated. The finally estimated overall gross and net efficiency of the plant was 41.0% and 37.4%, respectively.

4. Acknowledgement

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