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Preliminary Evaluation of Operational Performance with Two Reactor Design Options for NHDD Application

Chang Hyun KIM, Seung Wook LEE, Hong Sik LIM, and Won Jae LEE
Korea Atomic Energy Research Institute, 150, Dukjin-Dong, Yusung-Gu, Teajeon, Korea, 305-353
changkim@kaeri.re.kr, nuclist@kaeri.re.kr, hslim@kaeri.re.kr, wjlee@kaeri.re.kr

1. Introduction

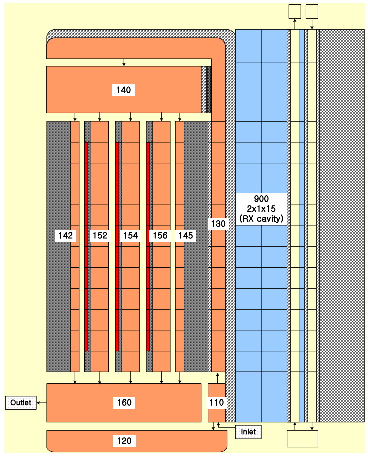
The hydrogen production system coupled with a very high temperature gas-cooled reactor (VHTR) is considered as one of the most promising application to allow new processes of massive hydrogen production. Korea Atomic Energy Research Institute (KAERI) is considering a pebble bed modular reactor (PBR) and a prismatic modular reactor (PMR) as the candidates for the reactor type of nuclear hydrogen development and demonstration (NHDD) system. The reactors are being considered to be operated at the temperature higher than 950°C with the reduced system pressure as low as possible because the operating pressure of the hydrogen production system is expected to be not as high as that of the primary system. In this study, therefore, a preliminary evaluation of operating performance is performed with two reactor design options for NHDD application.

2. Reactor System Modeling

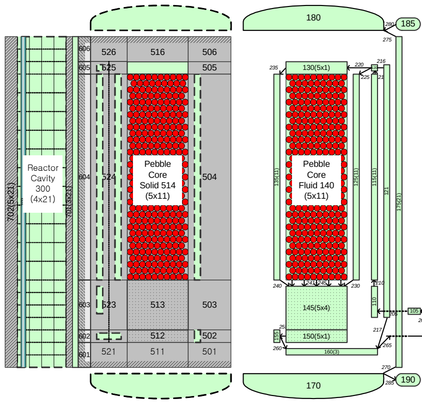
The conceptual design of PBR and PMR are based on 400MWth PBMR and 600MWth GT-MHR, respectively [1]. The reactor inlet and outlet temperatures of both types of reactors are 490°C and 950°C with the operating pressure of 7.0MPa as a base operating condition. Intermediate loop is being considered with an intermediate heat exchanger (IHX) and a helium coolant circulator. The secondary part of the IHX and the hydrogen production system layout are currently optional.

In the present study, MARS-GCR [2] and GAMMA [3] codes are used to evaluate the operational performance of PMR and PBR, respectively. The nodalization of each type of reactor is shown in Fig. 1. Both types of reactor system model include the core, the reactor vessel, and the reactor cavity with the reactor cavity cooling system (RCCS). The core barrel conditioning system (CBCS) is also modeled for the PBR system. The evaluation of the operational performance of each type of reactors is performed for the candidate operating conditions (reactor outlet temperature = 950°C, reactor inlet temperature = 400, 490, 540, and 590°C, system pressure = 4.0 and 7.0 MPa).

The IHX is modeled and the required circulator works are calculated for PMR operating conditions assuming its efficiency of 0.75. The IHX is designed as a shell-and-tube type heat exchanger with an inner diameter of 5.0*mm* and a thickness of 1*mm*. Log-mean-temperature difference is designed as 38.8°C. The required heat transfer areas and the compressor works are calculated in the above mentioned operating conditions.



(a) MARS-GCR Modeling for PMR



(b) GAMMA modeling for PBR

Fig.1 Nodalization of PMR and PBR.

3. Results and Discussions

(a) *Peak fuel and RPV temperatures*

The peak fuel and peak reactor vessel temperatures with the inlet temperature and the operating pressure are shown in Fig.2. The peak fuel temperature decreases as the inlet temperature increases. The increase of inlet temperature causes the increases of the mass flowrate and the velocity of coolant which mean the enhancement of heat transfer in core. The peak fuel temperature of PBR is higher than that of PMR due to the much higher power peaking in the PBR. However, it might be reduced by the optimized power distribution through the detailed core design. In PMR the peak reactor pressure vessel (RPV) temperature is directly proportional to the inlet temperature. The peak RPV temperature of PBR is much lower than that of PMR due to CBCS. The adoption of the conventional reactor vessel instead of 9Cr-1Mo vessel could be considered due to its cheaper manufacturing cost. Therefore, the use of the conventional RPV is worth while to be considered by the adoption of riser internal flow paths through the outer reflector and CBCS in the PMR such as PBR design.

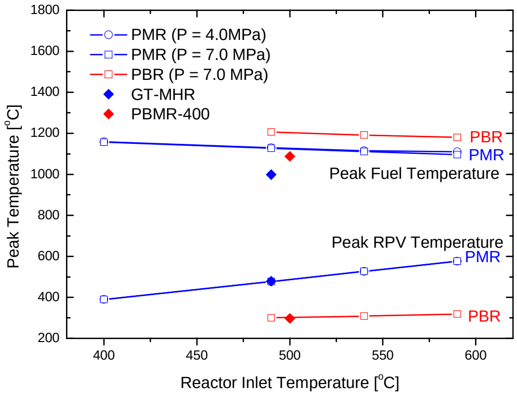


Fig.2 Peak fuel/RPV temperature.

(b) Pressure drop and Circulator Work

Lower pressure drop is preferable because the circulator work has a negative effect on the overall system efficiency. Core and vessel pressure drops are lower in PMR. Pressure drop increases with the inlet temperature due to the mass flowrate increase as shown in Fig.3. There exists the system pressure effect because the density decrease causes the velocity increase which means the increase of frictional and form pressure losses. Therefore, the higher operating pressure is preferable in terms of the pressure drop and the circulator work.

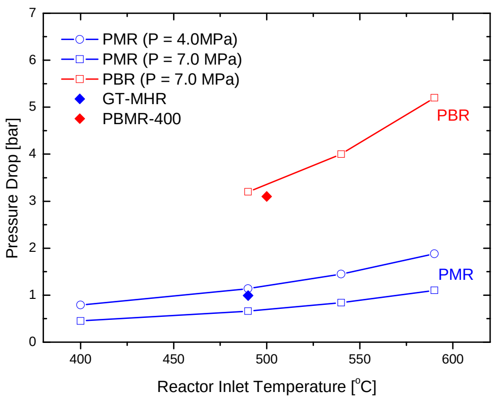


Fig.3 Pressure Drop in Reactor Vessel.

The IHX size decreases with the increase of the inlet temperature due to the increase of the mass flowrate which increases the convective heat transfer coefficient. Therefore, the elevated inlet temperature is preferable in terms of the heat transfer area of IHX. When the operating pressure is reduced, Reynolds number is also slightly reduced, which causes the decrease in the convective heat transfer coefficient.

The circulator works increases with inlet temperature. The elevated inlet temperature increases the mass flowrate which also increases the pressure drop. Therefore, the reduced inlet temperature and elevated operating pressure are preferable in terms of circulator work because the pressure drop also increases as the system pressure decreases.

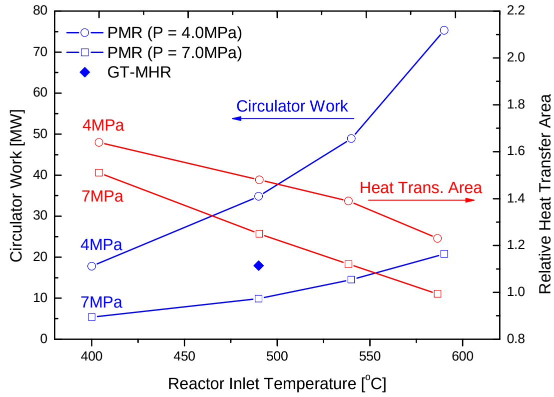


Fig.4 IHX size and circulator work.

4. Conclusions

A preliminary evaluation of operating performance is performed with two reactor design options for NHDD application. The pressure effect is negligible on the peak fuel and the peak RPV temperatures. However, the higher system pressure is preferable in terms of both of the pressure drop and the IHX size due to the decrease in the coolant density. The higher inlet temperature is preferable in terms of the peak fuel temperature. However, the elevated inlet temperature has adverse effects on the peak RPV temperatures and the pressure loss which means the larger circulator work. Therefore, the selection of the optimized reactor inlet temperature should entail a tradeoff between the heat transfer area of IHX and the circulator work.

ACKNOWLEDGEMENT

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