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Comparison of the Pumping Powers with various Coolants of fusion K-DEMO Blanket

Il-Woong Park[1], Yeon-Gun Lee[1], Min-Young Park[1], Eung Soo Kim[1]*
Goon Cherl Park[1,2]
[1]*Seoul National Univ., Daehak-dong, Gwanak-gu, Seoul, Korea*
[2]*KEPO International Nuclear Graduate School, Seosaeng-myeon, Ulju-gun, Ulsan, Korea*
Corresponding author: kes7741@snu.ac.kr

1. Introduction

As part of a Department of National Fusion Research Institute (NFRI) Project, Seoul National University (SNU) is calculating pumping power of blanket system using various coolants. The main goal of this preliminary study is to estimate minimum coolant pumping powers for blanket heat removal and to compare them for evaluating thermal-hydraulic performances. In this study, the calculations were conducted based on a plate-type blanket design, which was newly proposed by NFRI. This study is basically consisted of three steps. First, candidates of coolant are selected. Second, calculating conditions are determined. Last, the pumping powers of various coolants are calculated and compared. The details are described below.

2. Selection of Coolant Candidates for K-DEMO Blanket

According to the literatures, there are conceptually various coolant materials available for the fusion blanket. They include water, gases (helium, CO_2, Ar, etc), molten salts (Flibe, Flinak, etc), and liquid metals (Sodium, Lead, etc) [1]. Of them, some coolants were first screened out because of the following reasons:

- Molten salt has a low melting point and corrosion problem.
- Liquid metal has a MHD, corrosion (lead, lead-bismuth) and Chemical stability (sodium) problems.
- Air has low cooling capability and neutron reaction (nitrogen), chemical stability (oxygen) problem.
- Argon has low cooling capability.
- Steam has a corrosion problem.

From the screening process, the four coolants have been finally selected as potential candidates. They include water, supercritical water, helium, and carbon dioxide as listed in Table I. Table I summarizes the general requirement of heat transport coolant in the first column, and compares the candidate coolants. According to this table, the liquid coolants (water, super-critical water) are superior to the gaseous coolants (helium, CO_2) in heat transfer performance, but inferior to them in safety. Heat transfer performance of supercritical CO_2 is estimated to be in the middle of liquid and gaseous coolants without safety issues.

Table I: Comparison Candidates of K-DEMO coolant

	water	**Super critical water**	**Helium**	**CO_2**
Heat performance	High	Very High	Low	Low
Safety	Low	Very Low	High	High
Corrosion	Mid	High	Low	Low
Fouling	High	High	Low	Low
Leakage	Low	Mid	High	Mid
Neutron absorption	Mid	Mid	Very Low	Very Low
Chemical reaction	High	High	Low	Low
Mechanical stress	Mid	High	Mid	Mid
Thermal stress	Low	Low	High	High
Electronic convert system	Indirect Rankine	Direct Rankine, Indirect Rankine	Direct Brayton Indirect, Brayton Indirect, Rankine	Direct Brayton, Indirect Brayton, Indirect Rankine
Experience	Mid	Low	Mid	High
Cost	Low	Low	High	Low

3. Condition of K-DEMO blanket

Condition of K-DEMO blanket is affected by temperature window of structure material and geometry of blanket. Table II summarizes the presumed conditions of K-DEMO blanket used in this study.

Table II: Presumed condition of K-DEMO blanket

Element	Condition
Total Heat Generation (Q)	2000 (MW_{th})
Channel Width (W)	0.004(m)
Heat Transfer Surface Area (S)	14451(m^2)
Allowable Heat Flux (q)	166.1(kW/m^2) (Assuming PF = 1.2)
Total Flow Area (A)	2.89(m^2)
Cooling Length (L)	10(m)

3.1 Temperature window of structure material

Table III summarizes the temperature and pressure conditions for different candidate coolants. Temperature window of use of RAFM steels is 350-550℃. So, coolant inlet and outlet condition considered 350℃ and 550℃.[2] But pressurized water hard to satisfy both temperature window and water critical point. So, pressurized water inlet temperature was adjusted to 300℃ in this study. The pressure conditions were presumed from pressurized water reactor (PWR), fire plant, and high temperature gas-cooled reactor (HTGR).

Table III: Condition of K-DEMO blanket (temperature, pressure)

	Water	Super Critial Water	Helium	CO_2
Pressure	15MPa	25MPa	8MPa	8MPa
Inlet Temperature	300	400	300	300
Outlet Temperature	332.5	550	550	550

3.2 Plate type blanket

This study used plate type blanket design for analysis, which was proposed by NFRI. Plate type blanket is designed to cool the whole blanket module at once each inner blanket and outer blanket. The number of cooling panel is 10 for each side and the width of cooling panel is 4mm. Based on the geometrical dimensions, heat transfer surface area, total flow area and heat flux were calculated by the following equations.

$$S = 2\pi R_o L n_o + 2\pi R_i L n_i \quad (1)$$

$$A = 2\pi R_o W n_o + 2\pi R_i W n_i \quad (2)$$

$$q = 1.2 \times Q / S \quad (3)$$

3. Calculating Pumping Power

Pumping power was calculated by a thermodynamic analysis tool. This study assumed the pump efficiency of 75%. Fig. 1 shows the pumping power calculated according to the total heat generation. In case of helium coolant with 2000MWth heat generation, pumping power to total heat generation reaches up to 22%, which is too large for practical use

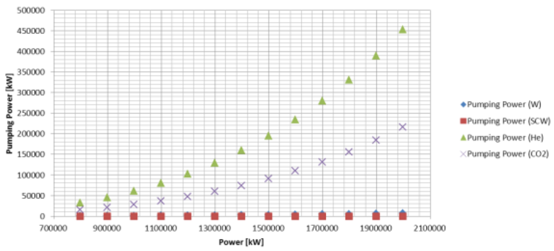

Fig. 1. Pumping power with total heat generation

Fig.2 shows the pumping power calculated for various operating pressures. In case of operating pressure of helium coolant is 18 MPa, pumping power to total heat generation is reduced to 4%. However, leakage problems might arise at this high pressure. Further studies are needed.

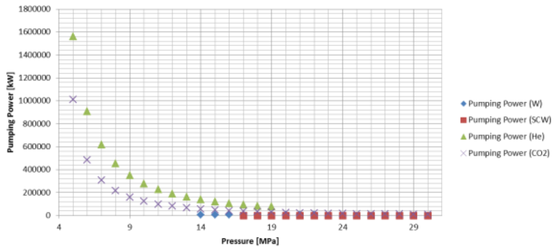

Fig. 2. Pumping power with operating pressure.

Fig. 3 shows the pumping power calculated for various channel width. In case of 0.01m channel with of helium coolant, pumping power to total power is reduced to 13%.

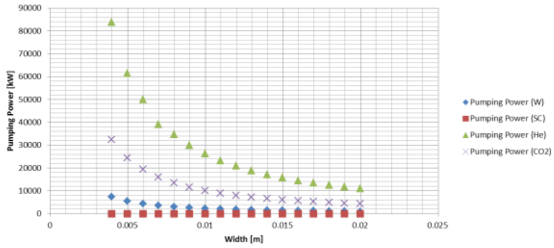

Fig. 3. Pumping power with channel width.

According to the estimation, pumping power to total power using helium coolant is 1 % in case of high pressure (18MPa) and wide channel width (0.01m) conditions. Therefore, those two parameters can be effective for reducing pumping power in case of gaseous coolants. However, increasing pressure and widening channel would cause some other engineering issues such as leakage and limiting plate volume.

4. Conclusions

This study estimated pumping powers for candidate coolants of K-DEMO blanket. According to the results, pumping capabilities of water and supercritical water are found to be better than helium and carbon dioxide. However, it seems possible for helium and carbon dioxide to be able to achieve acceptably low pumping powers if the conditions (pressure, channel width) are well adjusted. Additionally carbon dioxide was found to have better performance than helium because of its high density.

REFERENCES

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