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Comparison of various Brayton cycles for a Sodium-cooled Fast Reactor

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1. Introduction

A gradual increase of the world energy demand and the concern about the global climate change encourages the nuclear energy development. The nuclear energy is considered as one of the most realistic energy sources for both reducing the carbon dioxide emission and attaining sufficient and stable electricity supply for economy development. As a part of the nuclear energy development, many countries around the world are focusing on the next generation reactor development. One of the next generation reactors that is seriously being considered is the Sodium-cooled Fast Reactor (SFR). However, current SFR design faces the difficulty in public acceptance due to the potential threat from sodium-water reaction (SWR) when the current conventional steam Rankine cycle is utilized as a power conversion system for SFR. To substitute the violent sodium-water reaction with milder or no reaction, several Brayton cycle concepts including the S-CO_2 cycle, helium cycle and nitrogen cycle are considered by many research organizations. This paper discusses these Brayton cycles'performance for SFR application compared to the current steam Rankine cycle.

2. Brayton cycle design

The current researches on Brayton cycle for SFR are carried out by various research institutes. Table 1 shows various Brayton cycle designs for the SFR application.

A supercritical CO_2 (S-CO_2) Brayton cycle is designed by various research institutes because of the relatively high efficiency under mild turbine inlet temperature range (450-750^{o}C) which includes SFR operating condition [1, 2]. In this study, the reference reactor is . The recompressing cycle suggested by Feher is considered as the most efficient layout for the S-CO_2 cycle[3].

Helium Brayton cycle, however was mainly studied for the high temperature operation (>700^{o}C) such as high temperature gas-cooled reactor application until the heating and cooling interstage layout was suggested by S. A. Wright et.al [4]. The reheating and intercooling processes are typical process to improve the cycle efficiency. The idea is to utilize sodium which is an incompressible fluid for heat carrier for reheating stages so that the pumping work is minimized while the power cycle efficiency is maximized. In this study, 2T4C (2 turbines and 4 compressors) layout is analyzed because the efficiency increase from 2T4C to 3T6C layout is less than 2% but the number of components increase 50% more.

Nitrogen Brayton cycle is considered by CEA for the SFR application [5]. The major benefit of nitrogen cycle is that the existing air turbine technology can be directly applied. However, the control logic of closed Brayton cycle is completely different from the open cycle and therefore the critical technology for control has to be developed still.

KAIST-CCD which is designed by KAIST research team is used to assess the performance of aforementioned Brayton cycles and the algorithm of the code is showed in Fig. 1. Fig. 2 shows the efficiencies of Brayton cycles for various turbine inlet temperature. The turbomachinery efficiency and recuperator effectiveness are referred from the previous design studies [1, 4, 5]. The conventional steam Rankine cycle efficiency is referred from the previous research [6].

As shown in Fig. 2, S-CO_2 cycle shows the highest efficiency compared to other Brayton cycles and steam Rankine cycle from the even in the mild turbine inlet temperature range.

Table I. Brayton cycle designs

reference reactor	KALIMER	ABR	ASTRID
research institute	KAERI	SNL	CEA
fluid	CO_2	helium	nitrogen
layout	recompressing	2T4C	simple recuperated intercooling
turbine efficiency (%)	93.4	95	93
MC efficiency (%)	89.1	90.5	89
RC efficiency (%)	87.5	-	88
HTR effectiveness (%)	91.7	95	95.1
LTR effectiveness (%)	94.6	-	-

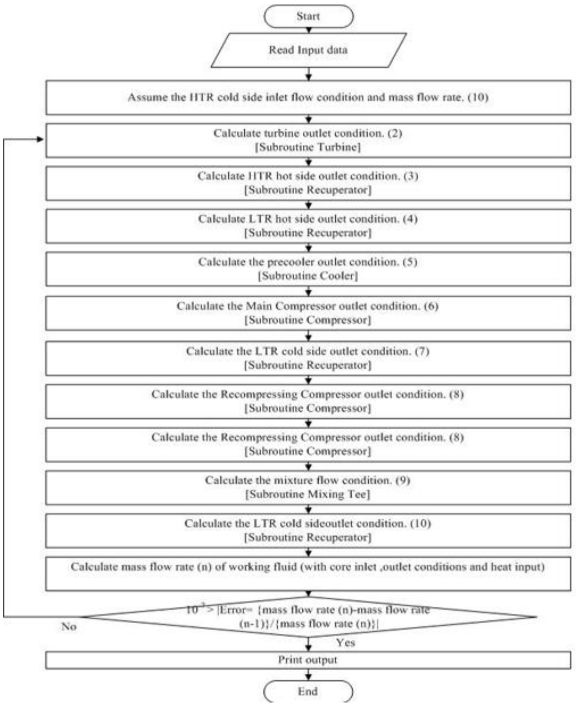

Fig. 1 KAIST-CCD algorithm

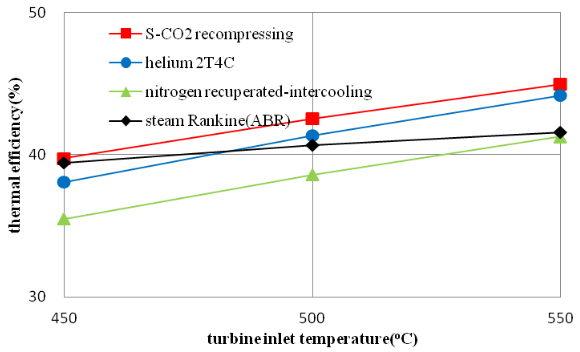

Fig. 2 Brayton cycle efficiency comparison

3. Heat Exchanger design

The size of Brayton cycle can be estimated from the total heat exchanger volume because the portion of the heat exchanger volume is over 70% in the whole power conversion system. Most of studies related to the S-CO_2 cycle adopted Printed Circuit Heat Exchanger (PCHE) which is compact with a wide operating range [7].

KAIST research team developed an in-house code, KAIST-HXD to design a PCHE for various purposes. The total volume including recuperators and coolers is compared in Fig. 3. The size of S-CO_2 cycle is relatively small than the other Brayton cycles.

4. Summary and further work

To increase the public acceptance of SFR by substituting sodium-water reaction with milder sodium-gas reaction, alternatives for power conversion system for SFR are briefly discussed. The thermal efficiency and heat exchanger size of Brayton cycles are compared among selected cycles and the S-CO_2 cycle shows the highest efficiency with smallest volume. The other factors including the turbomachinery design and sodium-CO_2 reaction will be considered in the future.

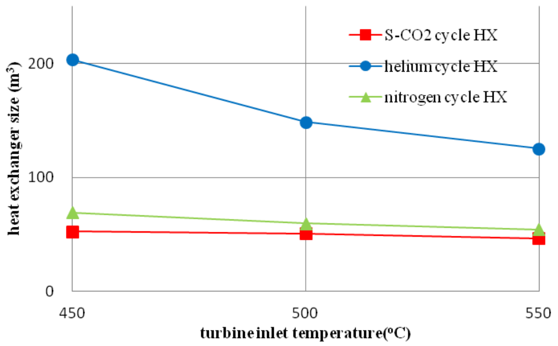

Fig. 3 The size of Brayton cycle heat exchangers

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