Development of Supercritical CO_2 Power System for Waste Heat Application

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1. Introduction

As the global climate change becomes substantial, an effort to utilize the waste heat for the additional power generation is gaining more interests. Among various power conversion systems, supercritical CO_2 cycle is considered as one of the most promising candidates. The benefits of supercritical CO_2 cycle include: 1) high efficiency in the mild turbine inlet temperature range (450-650℃), 2) simple layout configuration and 3) small footprint incorporated with compact heat exchangers and turbomachineries. Preliminary design of supercritical CO_2 power system for waste heat application is discussed in the following section.

2. Supercritical CO_2 Cycle Design and Assessment

In this section, some characteristics of supercritical CO_2 cycle and waste heat recovery system are introduced. Several major parameters are described and the realistic performance is assessed.

2.1 History of Supercritical CO_2 Cycle Development

The supercritical CO_2 cycle has been originally introduced in 1948 by [1], Switzerland. The major advantage of supercritical cycle is to increase the turbine inlet temperature without phase change while reducing the compression work near the critical point. Among several candidates, CO_2 is considered as the cheapest and harmless material and the critical condition being close to the ambient temperature is an additional advantage of easy handling. Some designs of supercritical CO_2 cycle has been proposed by Feher, Angelino and Gokhstein [2], [3], [4]. Combs suggested a compact design concept of supercritical CO_2 system for the maritime application as well [5]. However, this innovative power system was not realized due to the absence of compact heat exchangers and high-speed motors and generators.

The supercritical CO_2 cycle was revitalized by Petr, Dostal and Moisseytsev [6], [7] and [8]. Dostal suggested this innovative power conversion system for the advanced reactor application such as high temperature gas-cooled reactor (HTGR) and sodium-cooled fast reactor (SFR). He also provided the preliminary design parameters of turbomachineries and heat exchangers.

Some small-scale supercritical CO_2 systems are investigated and analyzed as well. Sandia National Lab (SNL) and Knolls Atomic Power Lab (KAPL) manufactured hundreds kW heat source supercritical CO_2 test loops and reported the experiment data [9], [10]. Echogen is making an effort to build a commercial power module of supercritical CO_2 system mainly for the waste heat application [11].

In Korea, supercritical CO_2 cycle designs were mainly proposed for the application of sodium-cooled fast reactor, fusion reactor main power systems and high temperature fuel cell, gas turbine waste heat recovery systems. In this paper, supercritical CO_2 design mainly for the gas turbine exhaust heat utilization is investigated and analyzed depending on the operating condition and system size.

2.2 System Design

The heat source is the exhaust heat from a gas turbine, LM2500. The flue gas condition is listed in Table I.

Table I : Gas turbine flue gas condition

Power	MW	25
Flue gas temperature	℃	566
Flue gas flow rate	kg/s	70.5
Flue gas composition	%, mole fraction	N_2, 74.9 O_2, 13.7 Ar, 0.8 CO_2, 3.3 H_2O, 7.3

Simple recuperated layout is considered for the heat recovery system. Component parameters are assumed based on the manufacturing capability. The main purpose of waste heat recovery system is to maximize the usable work. The recovered heat is limited the temperature gradient of flue gas from the gas turbine.

Table II : Supercritical CO2 cycle performance

Turbine efficiency	%	80
Compressor efficiency	%	70
Waste heat exchanger effectiveness	%	80
Recuperator effectiveness	%	80
Heat exchanger pressure drop	%	1
CO_2 flow rate	kg/s	40.0
Gross power	MW	2.3

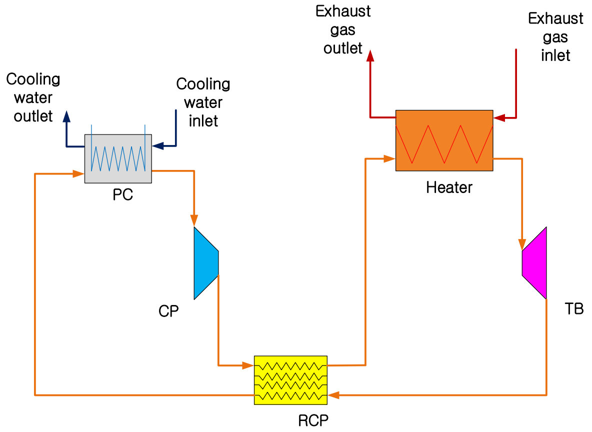

Fig. 1. Supercritical CO_2 cycle layout

Cycle layout and design parameters are shown in Table II and Fig. 1. Turbomachinery performance is conservatively assumed based on the current technology. Heat exchanger effectiveness is closely related to the heat transfer area. The heat exchanger performance is reasonably assumed to balance the economic benefits. The cooling system will be designed in the future.

3. Summary and Further work

The recuperated layout of supercritical CO2 cycle is designed and 9.2% marginal power can be potentially obtained through a heat recovery system. The corresponding component design will be performed in the future work.

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