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Optimal allocation of heat exchangers in a Supercritical carbon dioxide power cycle for waste heat recovery

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ABSTRACT

Supercritical carbon dioxide (sCO_2) power cycles have attracted attention because of their high efficiency and flexibility in various temperature heat sources including low-temperature waste heat applications. In waste heat applications, the size of the heat exchangers is an important issue because of the trade-off between performance and installation cost. For the optimal design of an sCO_2 cycle for waste heat recovery, a thermodynamic model for the basic cycle and the preheating cycle was constructed. The heat exchangers were then modeled by a finite volume analysis under the fixed total *UA* value, with the equivalent conductance representing the size of the heat exchanger. The net power and thermal efficiency of the cycle were calculated. The results of the optimization confirmed that the application of the preheater improves the performance of the basic cycle, and an optimum point of the split ratio exists. From the simulation, with an increase in the turbine inlet temperature (TIT), the thermal efficiency improves, but the net power does not always increase. Instead, a close linearity between the optimum CO_2 split ratio (ϕ) and the turbine inlet temperature was found at the maximum net power, even under different turbine inlet pressures and total *UA* values. From these results, the configuration of heat exchangers for waste heat applications can be planned appropriately to operate at the maximum net power.

1. Introduction

As climate change becomes a reality, improving facility efficiency is important for reducing CO_2 emissions in the industrial and power generation fields. The supercritical carbon dioxide (sCO_2) power cycle has been identified as one of the technologies that can enhance power generation efficiency. A typical sCO_2 power cycle is the Brayton cycle, which is famous for its simple layout and wide application to various heat sources. The high-pressure working fluid, sCO_2, enables the miniaturization of turbomachines and heat exchangers for small areas. The concept of the sCO_2 cycle was patented by Sulzer [1] in the late 1940s, and Angelino [2] presented the theoretical fundamentals in the 1960s. Feher [3] introduced a possible configuration of the working cycle and named it the Feher cycle. However, interest in this cycle declined afterward because issues of feasibility could not be solved until the 2000s.

In 2004, Dostal [4] reviewed previously presented cycles and proposed some modifications so they would be applicable to nuclear power plants. His work revived interest in the sCO_2 power cycle to revolve around fourth-generation nuclear systems, such as the sodium-cooled fast reactor [5]. Because of the possibility for its use in various heat sources and its potential to improve efficiency, the sCO_2 power cycle has recently attracted attention not only in nuclear power fields but also in renewable energy fields. Recently, Wang and He [6] conducted a thermodynamic analysis of a concentrated solar power (CSP), and Osorio et al. [7] studied the dynamic analysis of the CSP. In the geothermal field, Levy et al. [8] revealed a method to produce sCO_2 using geothermal reservoirs. Wang [9] introduced the utilization of the sCO_2 system using geothermal reservoirs from an economic perspective.

Despite a number of previous studies on sCO_2 cycles in renewable and nuclear energy applications, there have been relatively few studies on waste heat recovery applications. Chen et al. [10] utilized the sCO_2 cycle to recover the waste heat of automobiles. They showed a possible way to improve the power output once the temperature-glide matches properly with the heat source. Di Bella [11] conducted a thermodynamic simulation with the combination of a thermoelectric module and a regenerated sCO_2 Brayton cycle to recover the gas turbine waste heat from a military ship. Walnum et al. [12] investigated the

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