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Performance analysis of double organic Rankine cycle for discontinuous low temperature waste heat recovery

Dongxiang Wang, Xiang Ling*, Hao Peng

Jiangsu Key Laboratory of Process Enhancement and New Energy Equipment Technology, School of Mechanical and Power Engineering, Nanjing University of Technology, No. 5 Xin Mo Fan Road, Nanjing 210009, PR China

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A B S T R A C T

This research proposes a double organic Rankine cycle for discontinuous waste heat recovery. The optimal operation conditions of several working fluids have been calculated by a procedure employing MATLAB and REFPROP. The influence of outlet temperature of heat source on the net power output, thermal efficiency, power consumption, mass flow rate, expander outlet temperature, cycle irreversibility and exergy efficiency at a given pinch point temperature difference (PPTD) has been analyzed. Pinch point analysis has also been employed to obtain a thermodynamic understanding of the ORC performance. Of all the working fluids investigated, some performances between each working fluid are rather similar. For a fixed low temperature heat source, the optimal operation condition should be mainly determined by the heat carrier of the heat source, and working fluids have limited influence. Lower outlet temperature of heat source does not always mean more efficient energy use. Acetone exhibits the least exergy destruction, while R245fa possesses the maximal exergy efficiency at a fixed PPTD. Wet fluids exhibit lower thermal efficiency than the others with the increasing of PPTD at a fixed outlet temperature of heat source. Dry and isentropic fluids offer attractive performance.

1. Introduction

The steel industry is one of the most energy intensive industries. Recently, there is a great increasing demand of steel along with the rapid development of industry, contributing plenty of low temperature waste heat which accounts for about 30% approximately of the whole waste heat in steel works. However, owing to lack of effective recovery methods, this part of energy, such as discontinuous flushing slag water in blast furnace iron making process, has been directly discharged. Meanwhile, the discharged waste heat gives rise to thermal pollution and therefore becomes an environmental concern. Accordingly, adoption of alternative renewable technologies that are environment friendly to convert this part of energy into more useful energy, such as shaft power or electricity, has attracted more and more attention for its potential in reducing energy consumption and alleviating environmental problems.

Utilizing conventional steam Rankine cycle (RC) to recover energy from discontinuous flushing slag water is not the best choice technologically or the most selection economically due to dissatisfactory performance [1,2]. However, the organic Rankine cycle (ORC) is a substitutive technology applicable for low temperature waste heat recovery. The ORC applies the principle of the conventional steam RC, and the main difference is the working fluid, organic fluid is used in ORC, while water is used in RC. There is no need to reach a high temperature to generate vapor for running an expander since boiling temperatures of organic working fluids are lower than steam boiling temperatures. Consequently, ORC exhibits great flexibility in utilizing of low temperature heat source. Hung et al. [3] compared the efficiencies of ORC using cryogens such as benzene, ammonia, R11, R12, R134a and R113 as working fluids, and found that for operation between two isobaric curves, isentropic fluids are most suitable for recovering low temperature waste heat. Drescher et al. [4] proposed a method to find suitable thermodynamic fluids for ORC in biomass power and heat plants, the results reveal that the family of alkybenzenes shows the highest efficiency. Saleh et al. [5] analyzed the thermodynamic performances of alkanes, fluorinated alkanes, ether and fluorinated ethers as working fluids in ORC for geothermal power plants based on the BACKONE equation of state, and found that n-butane has the highest thermal efficiency. Yamamoto et al. [6] developed a numerical simulation model of ORC and carried out experimental analysis. The results revealed that R123 gives higher turbine power than water, and the best operating conditions for R123 exist when

* Corresponding author. Tel.: +86 25 83587321; fax: +86 25 83600956.
E-mail address: xling@njut.edu.cn (X. Ling).

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