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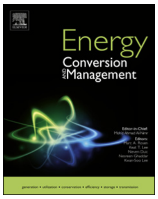

Thermoeconomic multi-objective optimization of an organic Rankine cycle (ORC) adapted to an existing solid waste power plant

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ABSTRACT

In this paper, thermodynamic and thermoeconomic analyses, and also optimization of an organic Rankine cycle (ORC) were performed. The system was adapted to an existing solid waste power plant with a 5.66 MW installed power capacity in order to produce additional power from the exhaust gas. The actual operating data of the plant were utilized during all stages of the analyses. The originality of this paper is based on the analysis of the possibility of the energy conversion of an exhaust gas with a temperature of 566 °C into the electricity by utilizing an ORC system in the concept of waste-to-energy. Four different working fluids: toluene, octamethyltrisiloxane (MDM), octamethyl cyclotetrasiloxane (D4) and n-decane were considered and analyzed for the current system. This is also another novelty of this study due to lack of such a study, in the open literature, that deals with an ORC utilized for a typical municipal solid waste power plant. According to the thermoeconomic analyses, toluene was found to be the optimum working fluid with the maximum power output of 584.6 kW and the exergy efficiency of 15.69%. The optimization of the cycle was performed by using the non-dominated sorting genetic algorithm method (NSGA-II) in MATLAB software environment. The optimization results were compared and the deviations of the net power output and the total cost rate were evaluated as −5.89%, −3.51 \$/h for toluene; 0.96%, −3.60 \$/h for MDM; 8.45%, −2.04 \$/h for D4 and 2.00%, −5.54 \$/h for n-decane, respectively.

1. Introduction

The organic Rankine cycle (ORC) is a proper and proven process for conversion of low and medium temperature heat to electricity. In addition, electricity production from the high temperature heat source is also possible and important for ORC systems. Therefore, ORC technology has a huge economical potential and this potential can help to supply a remarkable portion of energy requirement. Furthermore, ORC is a popular energy recovery technology due to its small-scale feature from geothermal energy, solar energy and biomass energy [1]. Hence, there are many studies in ORC research field to evaluate effective parameters on its performance. Energy and exergy analyses of a waste heat driven ORC were performed by Kaşka [2] considering the performance of the cycle and the pinch point sites by means of the actual data. In most studies, energetic and exergetic efficiencies of typical ORC systems with a variety of organic fluids were examined [3–6]. In this research field, another important parameter which affects the performance of a system is estimated as outlet temperature of heat source. Many ORC systems based on heat source temperature domain for thermal efficiency, exergy destruction rate and mass flow rate were investigated by Li [7]. A thermo-economic methodology was performed by Desai and Bandyopadhyay [8] in order to compare organic and steam Rankine cycles. Some researchers focused on selection of proper and more effective working fluids [9–12].

Various genetic algorithm methods can be used in order to improve performance of ORC by maximizing net power output or exergy efficiency and by minimizing total cost rate or heat exchanger area per unit net power output (APR) or levelized energy cost (LEC). Feng et al. [13] performed an optimization study on ORC system by using exergy efficiency and APR as objective functions. The exergy efficiency was increased to 8.1% and the APR was decreased to 15.89% by using NSGA-II optimization method on the basic ORC system. In another study of Feng et al. [14], three different working fluids were used to compare NSGA-II optimization results on ORC system by selecting the exergy efficiency and LEC as objective functions. It is found that the exergy efficiency and LEC of working fluids can be improved around 0.5% and 0.1%, respectively. Wang et al. [15] carried out a NSGA-II optimization study on ORC system with R134a as working fluid by selecting the exergy efficiency and the overall capital cost as objective

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Nomenclature

A	heat transfer area, m^2
$\dot{C}$	cost rate, \$/h
c	cost per exergy unit, \$/GJ
c_f	unit exergy cost of fuel, \$/GJ
c_p	unit exergy cost of fuel, \$/GJ
$\dot{D}$	cost rate of exergy destruction, \$/h
$\dot{E}x$	exergy rate, kW
f	exergoeconomic factor
h	specific enthalpy, kJ/kg
i	interest rate
$\dot{m}$	mass flow rate, kg/s
n	total life time
N	annual operation time
P	pressure, bar
PR_{ORC}	pressure ratio of ORC
$\dot{Q}$	heat addition, kW
r	relative cost difference
s	specific entropy, kJ/kg·K
T	temperature, °C
U	heat transfer coefficient, $W/m^2 \cdot K$
$\dot{W}$	work flow rate-power, kW
$\dot{Z}$	capital cost rate, \$/h

Subscripts and abbreviations

0	dead state
a	actual
APR	heat exchanger area per unit net power output
CEPCI	chemical engineering plant cost index
CON	condenser
CRF	capital recovery factor
crit	critical point
D	destruction
dec	decomposition
EMO	evolutionary multi-objective optimization
EVAP	evaporator
exh	exhaust
GMSWPP	Gaziantep Municipal Solid Waste Power Plant
ORC	organic Rankine cycle
OT	ORC turbine
k	component
LEC	levelized energy cost
LMTD	logarithmic mean temperature difference
NSGA-II	non-dominated sorting genetic algorithm
PEC	purchased equipment cost
PUMP	ORC pump
s	isentropic
SPECO	specific exergy costing
tot	total
wat	water
wf	working fluid

Greek symbols

ΔT	temperature difference
	exergy efficiency
εf_{HE}	effectiveness
η_{ORC}	energy efficiency
η_{PUMP}	ORC pump isentropic efficiency
η_{OT}	ORC turbine isentropic efficiency
ϕ	maintenance factor
ψ	specific flow exergy, kJ/kg

functions. The optimum range of the exergy efficiency and the overall capital cost were given in the study and the best solutions were found to be 13.8% and 1.29x10^6 USD, respectively. NSGA-II method is used in order to perform the maximum improvement potential for base system in another study carried out by Boyaghchi and Safari [16]. It was resulted that the total exergy destruction rate and the total exergy destruction cost rate could be decreased to 3.27 and 4.9 times, respectively and the total investment cost rate could be improved by 17.4% regarding to the base point by performing the optimization method. Considering the existing studies on ORC systems in the open literature, the importance of the optimization can be well understood in terms of improving the performance of the system.

As mentioned above, the applications of ORC systems are commonly

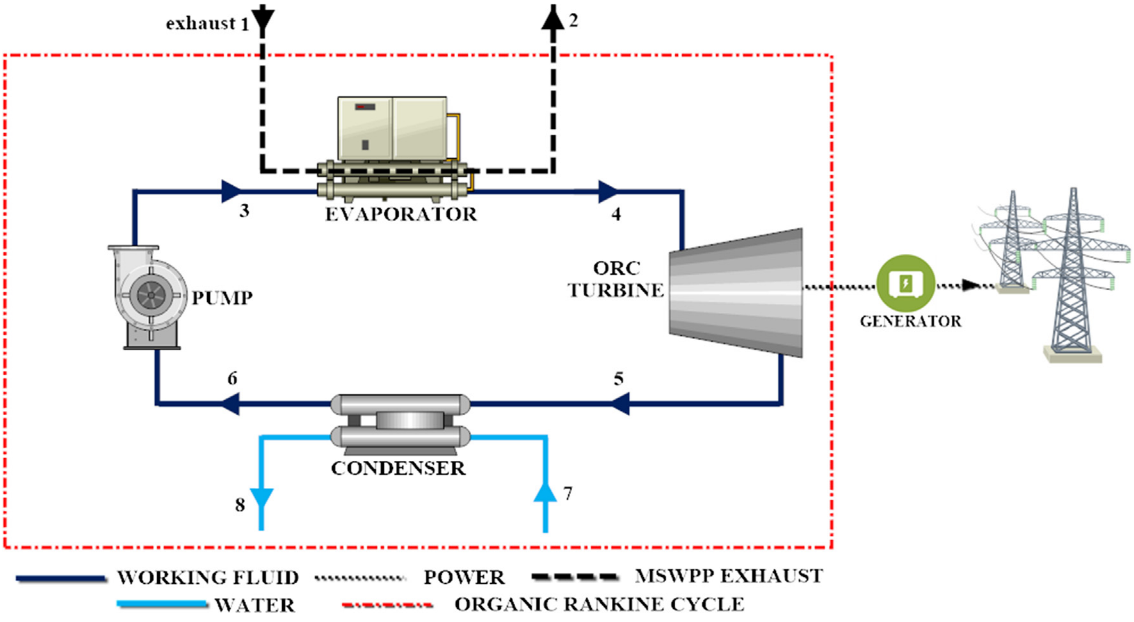

Fig. 1. Schematic diagram of the adapted ORC system.