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Performance improvement of two-stage serial organic Rankine cycle (TSORC) integrated with absorption refrigeration (AR) for geothermal power generation

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ABSTRACT

Compared with ORC, the two-stage serial organic Rankine cycle (TSORC) can improve the temperature matching between the heat source and the working fluid. However, the power output of the low-pressure stage is relatively low. In this paper, the TSORC is integrated with the absorption refrigeration (AR), with the residual heat of the discharge water from AR used as a supplementary heat source for the low-pressure stage. The TSORC-AR is proposed, and the objective of this paper is to enhance the comprehensive performance. Furthermore, a comprehensive formula, which includes several variables such as the net power output, the thermal conductance, the volumetric flow ratio and the size parameter of the turbine, is chosen as the objective function. The results show that the supplementary heat source largely increases the evaporating load, especially in the low-pressure stage, of the TSORC-AR but makes the evaporating temperatures lower than those of the TSORC. Compared with the TSORC, the TSORC-AR can output more net power, but with a lower thermal efficiency. Overall, the TSORC-AR can make better use of the heat source and it can be popularized in engineering applications.

1. Introduction

In recent years, with the depleting of fossil fuels, the thermal energy has attracted much attention. Among cycles, the organic Rankine cycle (ORC) is promising in thermal-to-electric conversion. Many researches have been done in order to enhance the ORC performance (Mago et al., 2008; Desai and Bandyopadhyay, 2009; Hung et al., 2010; Hung, 2001; Wang et al., 2011a), especially for the systems driven by the medium-low temperature thermal energy (Gnutek and Bryszewska-Mazurek, 2001a; Gurgenci, 1986). Furthermore, the low-temperature heat can be easily gained from solar energy because of its low energy flux and strong scattering (Ji, 2013). So the application potential of the solar energy as the heat source is huge, though the thermal efficiency of the ORC power station is only 5–10% (Kose, 2007). A great deal of studies have been taken to select better working fluids (Li et al., 2012, 2013, 2014; Roy et al., 2010; Bao and Zhao, 2013) and improve the cycle structure in order to increase the cycle performance, at the same time, multilevel utilization of energy has been drawing more attention.

The working fluid selection and system structure integrating with the cycle parametric optimization are the two basic aspects to improve the system performance. In the respect of the working fluid selection, Wang et al. (2011b) found the thermodynamic properties of R11, R141b and R113 are better than those of R245ca and R245fa, and the environmental compatibility of R245ca and R245fa are more optimal. Borsukiewicz-Gozdur and Nowak (2007) investigated the heat conversion efficiency of ORC system driven by geothermal water from 80 °C to 115 °C, and R245fa shows the maximum efficiency. Han et al. (2012) analyzed nine kinds of working fluids using the thermal efficiency and exergetic efficiency as the objective function, and they found that R245fa is pretty good.

For the improvement of the system structure of ORC, a cascade organic Rankine cycle (CORC) system using solar energy and liquefied natural gas (LNG) for thermal power generation is put forward by Li et al. (2016) and Li (2011), and they proposed a new hybrid solar electricity system based on ORC and PV cells. The results show that the net power output of the ORC is 1 kW and the heat conversion efficiency is approximately 6.8% or even higher. In order to make the best of energy, Mohammadi et al. (2017) proposed a hybrid system composed

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Nomenclature

A	area (m^2)
c_p	specific heat (kJ/(kg· °C))
f	function
g	acceleration of gravity (m/s^2)
h	specific enthalpy (kJ/kg)
H	head of delivery (m)
I	irreversible loss rate (kW)
K	heat transfer coefficient (W/(m^2 °C))
M	molar mass (kg/kmol)
m	mass flow rate (kg/s)
P	pressure (MPa)
q_0	refrigerating output (kW)
Q	heat transfer rate (kW)
s	specific entropy (kJ/(kg °C))
T	temperature (K)
T_0	ambient temperature (K)
ΔT	temperature difference (K)
t	temperature (°C)
v	specific volume (m^3/kg)
W	power (kW)

Greek symbol

η	efficiency (%)

Subscripts

A	evaporator
c	condenser
cw	cooling water
eva	evaporating
p	pump
g	generator
hw	heat source water
in	inlet
m	mechanical
mix	mixture
net	net
obj	objective
opt	optimal
out	outlet
pre	pre-cooling or pre-heating
pp	pinch point
s	isentropic
sub	subcooling
sup	superheating
t	turbine
th	thermal
wf	working fluid
0	environment
11, 12, 21, 22, 2, 3, 4, 5, 16, 17, 18, 26, 27, 28, a, b, c, d, e, f, g, h, i, j	state points

Acronyms

ORC	organic Rankine cycle
TSORC	two-stage serial organic Rankine cycle
TSORC-AR	TSORC integrated with absorption refrigeration
CCHP	combined cooling, heating and power
VFR	volumetric flow ratio
SP	size parameters

of a gas turbine, an ORC cycle and an absorption refrigeration cycle as a combined cooling, heating and power system for residential usage. The results show that the ORC turbine inlet temperature is the most effective parameter as it can change both net power output and energy efficiency of the system. Salgadoa et al. (2017) integrated Rankine power cycles with single- and double-effect absorption machines. Al-Mousawia et al. (2017) evaluated the potential of using integrated absorption–ORC system to generate cooling and power simultaneously. A small scale solar powered ORC has been put forward by Taccania et al. (2016) to enhance the gross electrical efficiency, and there are still a great deal of aspects that need to be optimized. Freeman et al. (2017) investigated the power generation potential of a domestic solar combined heating and power (S-CHP) system, a promotion of practical application for the ORC, in the UK. Moreover, considering the transient nature of the waste heat resource, Gnutek and Bryszewska-Mazurek (2001b) proposed a new methods to make full use of the resource. Yamamoto et al. (2001) studied the economy of a circulatory system. Papadopoulosa et al. (2012) adopted a multi-level method for ORC systems used in power and/or heat co-generation from renewable, low enthalpy sources. Astolfi et al. (2014) found that the highest efficiencies via employing fluids with a critical temperature slightly lower than the temperature of the geothermal water for most of the investigated cases. Li et al. (2015) presented a two-stage serial organic Rankine cycle (TSORC), and they found that the TSORC can enhance the system performance and reduce the system irreversible loss and is better than the ORC, but the power generation of the low-pressure stage needs to be improved. Exhaust heat of the absorption refrigeration (Joybari and Haghighat, 2016; Dixit et al., 2017; Mohammadi et al., 2017; Hajabdollahi, 2015; Boyaghchi and Heidarnejad, 2015) can be effectively used as a portion of heat source for the power generation system using ORC. Therefore, the power generation and refrigeration could be performed simultaneously in the same system.

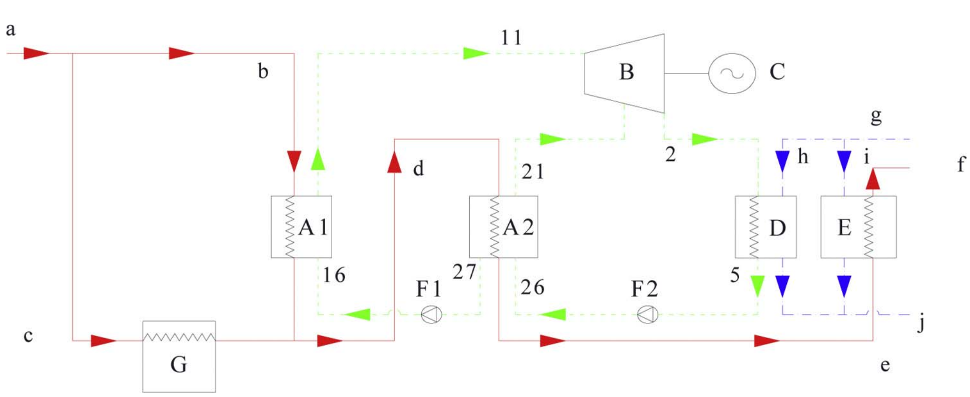

Fig. 1. Schematic diagram of the TSORC-AR. (For interpretation of the references to color in the text, the reader is referred to the web version of this article.)