Energy 96 (2016) 482–494

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Single-loop organic Rankine cycles for engine waste heat recovery using both low- and high-temperature heat sources

Young Min Kim*, Dong Gil Shin, Chang Gi Kim, Gyu Baek Cho

Department of Environmental and Energy Systems, Korea Institute of Machinery and Materials, 171 Jang-dong, Yuseong-gu, Daejeon 305-343, Republic of Korea

ARTICLE INFO

Article history:
Received 26 April 2015
Received in revised form
17 November 2015
Accepted 20 December 2015
Available online 4 February 2016

Keywords:
Organic Rankine cycle (ORC)
Engine
Waste heat recovery (WHR)
Single-loop ORC
Dual-loop ORC
Thermal efficiency

ABSTRACT

A highly efficient single-loop ORC (organic Rankine cycle) is proposed for engine WHR (waste heat recovery) from a gasoline vehicle. IC (Internal combustion) engines have two waste heat sources—exhaust gas and engine coolant—with similar quantities of energy but different temperatures. Dual-loop systems can obtain the maximum power output from engine WHR; however, the systems occupy large amounts of space and are complex, heavy, and economically unfavorable, particularly for vehicle applications. A highly efficient single-loop system can overcome such limitations. This paper compares the performances of conventional single-loop systems and proposes a novel single-loop ORC system for engine WHR from both low- and high-temperature sources. The novel single-loop system produces approximately 20% additional power from engine WHR when operating under the target engine conditions.
© 2015 Elsevier Ltd. All rights reserved.

1. Introduction

Currently, engine waste heat recovery (WHR) is attracting considerable interest as a means to improve the fuel efficiency of vehicles [1,2]. Typically, only around 30% of the energy in the fuel burned by an automobile is converted into driving power. Of the rest, 30% is wasted through exhaust gas, and another 30% is wasted through the engine coolant. To recover waste heat from HT (high-temperature) heat sources such as exhaust gas, a Rankine cycle using water as the working fluid is ideal because of its high boiling temperature; however, for LT (low-temperature) heat sources such as coolants, an organic Rankine cycle (ORC) is more suitable because it is more compact than the water–steam cycle.

In the Rankine cycle for waste heat recovery, if the temperature of a waste heat source becomes higher, the boiling temperature must be increased in order to minimize the temperature difference for heat transfer between the waste heat source and the working fluid. This achieves the maximum thermal efficiency of the cycle. Furthermore, it is very important to maximize the net output power by incorporating the utilization efficiency of the waste heat together with the thermal efficiency of the cycle. Therefore, dual-loop systems are the most suitable method for obtaining the maximum net output power from both heat sources because it is possible to optimize each cycle for each heat source with an appropriate working fluid and its optimal operating temperature and mass flow rate.

BMW [3] employed a dual-loop Rankine cycle (RC) system for passenger cars with an HT steam cycle and LT ORC. Kim et al. [4] presented the optimization of the design pressure ratio for positive displacement expanders in a dual-loop RC system with an HT steam cycle and LT ORC for vehicle engine WHR. Dolz et al. [5] studied different bottoming Rankine cycles with water–steam and/or ORC configurations in a heavy-duty diesel engine. Wang et al. [6] analyzed the characteristics of a novel system combining a dual-loop ORC in a gasoline engine using R245fa and R134a for the HT and LT cycles, respectively. Zhang et al. [7] applied the same dual-loop ORC system in a light-duty diesel engine. However, such dual-loop systems occupy a considerable amount of space and are complex [8], heavy, and economically unfavorable, particularly for vehicle applications.

This article is based on a paper entitled “Highly efficient single-loop organic Rankine cycle for engine waste heat recovery” presented at 9th Conference on Sustainable Development of Energy, Water and Environmental Systems (SDEWES) from 20th to 27th September 2014.

* Corresponding author. Tel.: +82 42 868 7377; fax: +82 42 868 7305.
E-mail addresses: ymkim@kimm.re.kr (Y.M. Kim), sdk@kimm.re.kr (D.G. Shin), cgkim@kimm.re.kr (C.G. Kim).

http://dx.doi.org/10.1016/j.energy.2015.12.092
0360-5442/© 2015 Elsevier Ltd. All rights reserved.

Nomenclature

c_p	isobaric specific heat, kJ/(kgK)
k	specific exergy, kJ/kg
E	exergy, kJ
$\dot{E}$	rate of exergy, kW
ε	energy efficiency of heat recovery
ε_{II}	exergy (second law) efficiency of heat recovery
ε_R	efficiency of recuperator
h	specific enthalpy, kJ/kg
HT	high temperature
LT	low temperature
$\dot{m}$	mass flow rate, kg/s
max	maximum
P	pressure, kPa
Q	heat, kJ
$\dot{Q}$	rate of heat, kW
RC	Rankine cycle
s	specific entropy, kJ/(kgK)
T	temperature, K
W	work, kJ
$\dot{W}$	rate of work, kW
WHR	waste heat recovery
η	isentropic efficiency
η_{th}	thermal efficiency
η_{II}	exergy (second law) efficiency

Subscripts

CW	engine coolant (cooling water)
EG	exhaust gas
E	expander
H	heater (heat source)
in	inlet
L	condenser (heat sink)
o	outlet
P	pump
R	recuperator
$R1$, $R2$	LT recuperator, HT recuperator
r	working fluid (refrigerant)
s	isentropic process
sys	system
0	dead state

Superscripts

$+$	input
$-$	output

By contrast, previous studies have found that the maximum power output of a single-loop Rankine cycle system is lower than that of a dual-loop Rankine cycle system [8] because it is difficult to fully recover and effectively utilize waste heat from both the engine's exhaust gas (HT) and engine coolant (LT). However, single-loop RC systems with water–steam or organic working fluids offer the potential for commercialization owing to their simplicity. Honda [9] employed a single-loop steam cycle and focused on the WHR of HT exhaust gas from a passenger car. Cummins [10] applied a single-loop ORC cycle using R245fa for the WHR of engine exhaust. Many single-loop RC systems for engine WHR focus on utilizing the HT waste heat source because it has a higher potential of work conversion (exergy) than the LT waste heat source [11,12]. Macian et al. [13] presented a methodology to optimize the ideal Rankine cycle for two different working fluids (water and R245fa) and different sets of heat sources in a heavy-duty diesel engine. Arunachalam et al. [14] investigated the possibilities and challenges involved in coupling multiple waste heat sources in a heavy-duty diesel engine for a single RC and the selection of a suitable working fluid. Valentino et al. [15] presented a simulation model based on an experimental study to predict the net power of a single-loop ORC for a light-duty spark-ignition engine and diesel engine. However, previous studies found that the maximum power output of a single-loop Rankine cycle system is 20%–30% lower than that of a dual-loop Rankine cycle system [16].

In this paper, the performances of several conventional single-loop ORC systems for engine WHR are compared, and their limitations to realizing maximum power are considered. And then, a novel single-loop ORC system is proposed that maximizes power by effectively utilizing waste heat from both LT and HT sources in an internal combustion (IC) engine.

2. Single-loop organic Rankine cycle systems for engine waste heat recovery

For the comparison of the performances of several conventional single-loop ORC systems for engine WHR, energy and exergy analyses of the systems are performed. In the case of the ORC for WHR, the maximum useful work from the waste heat source depends on the temperature of the heat source. Exergy analysis based on the second law of thermodynamics is very useful for evaluating the ORC system for WHR.

2.1. Systems considered in investigation

The main specifications of the targeted vehicle engine are listed in Table 1. Although the amounts of waste heat lost through the exhaust gas and engine coolant vary widely during the driving cycle, the design point was set to correspond to high-speed operation (i.e., a vehicle speed of 120 km/h), as listed in Table 2. Under these conditions, the engine produces 26.7 kW of power, and the mass flow rate of the exhaust gas is 118 kg/h. The exhaust gas temperature is 689 °C, and the corresponding amount of waste heat is 25.2 kW, assuming that the ambient temperature is 25 °C. The volumetric flow rate of the engine coolant is 40 L/min, and the temperatures of the coolant at the engine inlet and outlet are 90 and 100 °C, respectively. The waste heat lost by the engine coolant is 26.8 kW. The waste heat of the exhaust gas recovered by the heat exchanger directly connected to the exhaust port can be calculated from the temperature difference through the heat exchanger and the specific heat of the exhaust gas (c_p: 1.16 kJ/kg K). The maximum available heat of the engine coolant was assumed to be 90% (24.1 kW) of the total heat in the engine coolant in order to consider the heat loss in the coolant loop.

Table 1
Specifications of engine.

Items	Parameters
Vehicle type	Passenger car
Fuel	Gasoline
Number of cylinders	6 (V-type)
Displacement	3.3 L
Maximum power	190 kW @ 6200 rpm
Maximum torque	316.5 N·m @ 4500 rpm

Download English Version:

https://daneshyari.com/en/article/1731287

Download Persian Version:

https://daneshyari.com/article/1731287

Daneshyari.com