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ORIGINAL ARTICLE

Parametric and working fluid analysis of a combined organic Rankine-vapor compression refrigeration system activated by low-grade thermal energy

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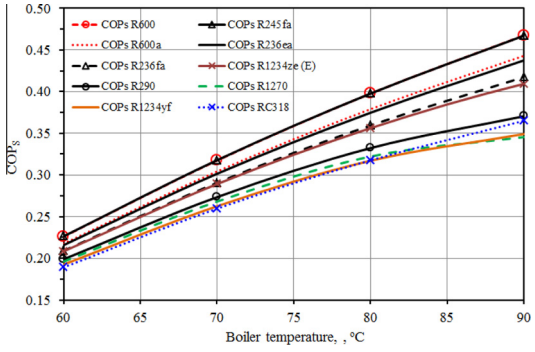
GRAPHICAL ABSTRACT



The effect of boiler temperature on the COP_S for different candidates in the basic ORC-VCR system.

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Nomenclature

Latin letters

ALT	atmospheric lifetime, years
CFCs	chlorofluorocarbons
COP	coefficient of performance
CMR	compressor compression ratio
EPR	expander expansion ratio
GWP	global warming potential
h	enthalpy, kJ/kg
HCFCs	hydrochlorofluorocarbons
HCs	hydrocarbons
HFCs	Hydrofluorocarbons
HFOs	hydrofluoroolefins
LFL	lower flammability limit, % by volume in air
M	molecular mass, kg/kmol
$\dot{m}$	mass flow rate, kg/s
NBP	normal boiling point, °C
ODP	ozone depletion potential
ORC	organic Rankine cycle
P	pressure, kPa
T	temperature, °C
v	specific volume, (m^3/kg)
VCR	vapor compression refrigeration
$\dot{Q}$	rate of heat transfer, kW
$\dot{W}$	power, kW

Greek letter

η	efficiency

Subscripts

b	boiler
c	compressor
e	evaporator
exp	expander
net	net
s	system
sat	saturated pressure
total	total
P	pump
x	quality
1, 2, 3 ...	respective state points in the system

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ABSTRACT

The potential use of many common hydrofluorocarbons and hydrocarbons as well as new hydrofluoroolefins, i.e. R1234yf and R1234ze(E) working fluids for a combined organic Rankine cycle and vapor compression refrigeration (ORC-VCR) system activated by low-grade thermal energy is evaluated. The basic ORC operates between 80 and 40 °C typical for low-grade thermal energy power plants while the basic VCR cycle operates between 5 and 40 °C. The system performance is characterized by the overall system coefficient of performance (COP_S) and the total mass flow rate of the working fluid for each kW cooling capacity ($\dot{m}_{total}$). The effects of different working parameters such as the evaporator, condenser, and boiler temperatures on the system performance are examined. The results illustrate that the maximum COP_S values are attained using the highest boiling candidates with overhanging T-s diagram, i.e. R245fa and R600, while R600 has the lowest $\dot{m}_{total}$ under the considered operating conditions. Among the proposed candidates, R600 is the best candidate for the ORC-VCR system from the perspectives of environmental issues and system performance. Nevertheless, its flammability should attract enough attention. The maximum COP_S using R600 is found to reach up to 0.718 at a condenser temperature of 30 °C and the basic values for the remaining parameters.

Introduction

Nowadays, there are numerous attempts in the utilization of renewable energies such as geothermal heat, wind energy, and solar energy as clean energy sources for electricity production or cooling processes. Also, waste heat can be considered as renewable and clean energy, since it is free energy and there is no direct carbon emission. Waste heat can be rejected at a wide range of temperatures depending on the industrial processes [1].

An ejector refrigeration system and an absorption refrigeration system can be activated by thermal energy source with a temperature range from 100 to 200 °C. They have several advantages such as simple structure, reliability, low investment cost, slight maintenance, long lifetime, and low running cost [2,3]. Nevertheless, they are not appropriate for thermal sources less than 90 °C and are also not appropriate for work-