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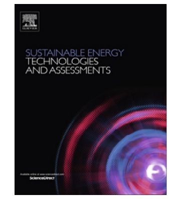

Original article

Performance estimation of mixtures in solar Organic Rankine Cycle with two mini cogeneration options for improvement purpose

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A B S T R A C T

In this paper, performance of some zeotropic mixtures has been estimated and compared with pure fluids for the use in two options of mini solar Combined Heat and Power (CHP) units based on Organic Rankine Cycle (ORC). Optimization potential and comparison of such mini systems have been mainly aimed and assessed within this analysis for predefined energy outputs. To achieve these goals, energetic and economic criteria have been identified with help of numerical simulations. The results showed that compared to pure R134a and R245fa, the mixture R409A is strongly recommendable when gaining the heat demand over ORC condenser (common ORC-CHP method), where it could reduce the production cost of the energy unit till 16.20%. For the series ORC-CHP layout, R401A becomes the relevant candidate from economic point of view, where a promotion of 4.49% could be registered with this mixture. Moreover, R401B also exhibits attractive performances in the both systems. Furthermore, comparing the two exploitation concepts demonstrated that the series one is more feasible than the common one within scope of this study. Finally, using R401A in the series unit could lead to combined optimization ranging between 16.5% and 47% versus R134a in the common method.

Introduction

Exploitation of low-temperature solar-thermal energy throughout Organic Rankine Cycle (ORC) is considered as one of the most important and latest interests relating to the solar-thermal power production. Moreover, optimization of such evolutions gains always in importance, either for the Combined Heat and Power (CHP) or single power generation option. In the both last cases, choice of the most proper working fluid for ORC at specific conditions was the main promotion strategy. Thus, many related researches were introduced in this context but at quite different propositions. For solar ORC-CHP option imposing recovery of the ORC-condenser heat for heating purposes, Yagoub et al. [1] summarized that HFE-301 is better than n-pentane for a hybrid and solar-gas driven ORC-CHP system. Facão and Oliveira [2] recommended Methanol within analyzing a micro ORC-CHP plant powered by solar energy and a natural gas boiler. Facão et al. [3,4] also simulated three solar assisted cogeneration cycles based on ORC and found that Cyclohexane has the best outcomes among the fluid screened. Baral and Kim [5] compared some working fluids and concluded that R134a and R245fa are the most appropriate ones for low- and medium-temperature solar ORC cogeneration systems, respectively. Zhang et al. [6] used supercritical carbon dioxide as a working fluid in solar ORC-CHP installation. Tempesti et al. [7,8] stated that R245fa shows the best cycle efficiency and the lowest electricity price, while R134a releases the highest heat within investigating of solar- and geothermal-powered micro CHP units. Moreover, Riffat and Zhao [9,10] used n-pentane in a novel hybrid heat pipe solar collector/ORC-CHP combination. In different way from the latter ORC-CHP concepts, Freeman et al. [11] employed R245fa to test an ORC-CHP integration consisting of evacuated solar collector, ORC and a domestic hot water cylinder supplemented by auxiliary heater. Furthermore, the authors [12] used R134a within characterizing the outputs of pure series solar ORC-CHP layout for direct utilization of the solar energy captured by flat collector.

Furthermore, many studies concerning selection of working fluid for single power production by means ORC were introduced [13–26] in framework of the fluid optimization. Wang et al. [13] recommended R245fa and R123 within scope of their propositions.

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Nomenclature

Acronyms

CHP	Combined Heat and Power
ORC	Organic Rankine Cycle
HS	Heating System
HE	Heat Exchanger
ODP	Ozone Depletion Potential
GWP	Global Warming Potential
VCC	Vapor Compression Chiller
Sc.	Scenario

Symbols

T	temperature [°C]
P	pressure [bar]
$\dot{W}$	power [kW]
$\dot{m}$	mass flow rate [kg/s]
V	volume flow rate [m^3/h]
$\dot{Q}$	heat flux [kW]
h	specific enthalpy [kJ/kg]
v	specific volume [m^3/kg]
A	area [m^2]
k	overall heat transfer coefficient [W/m^2.K]
f	ratio [–]
G	global solar irradiance [W/m^2]
a & b	heat loss coefficients [W/m^2.K] & [W/m^2.K^2]
x	dryness grade, vapor quality [–]
d	diameter [m]
D	diameter [m]
CS	channel spacing [m]
q	specific heat flux [kW/m^2]
L	length [m]
Re	Reynolds number [–]
Pr	Prandtl number [–]
Bo	boiling number [–]
$LMTD$	logarithmic mean temperature difference [°C]
MF	mass flux [kg/m^2.s]
U	flow velocity [m/s]
C	cost [€]
$PCEU$	production cost of energy unit [€/kWh]
SH	sunshine hours in the year [hour]
SL	system lifetime [year]
VFR	volume flow ratio [–]
PR	pressure ratio [–]

Greek letters

Δ	difference [–]
η	efficiency [–]
ε	hydraulic roughness grade [m]
ζ	loss coefficient due to sudden area change [–]
σ	friction factor [–]
α	heat transfer coefficient [W/m^2.K]
λ	thermal conductivity [W/m.K]
ρ	density [kg/m^3]
μ	dynamic viscosity [Pa.s]
δ	thickness [m]

Subscripts

sol	solar
c	condensation, condenser
e	evaporation, evaporator
pre	preheater
mec	mechanical
Gen	generator
ext	external
t	turbomachinery
p	pump
is	isentropic
th	thermal
tot	total
opt	optical
col	collector
sup	supply
ret	return
in	inlet
out	outlet
pp	pinch point
m	mean
0	reference for ambient
1…4	state points
fr	friction
gc	geometry change
F	fluid
max	maximal
l	liquid
tp	two phase
h	hydraulic
n	net
eq	equivalent
cr	critical
mot	motor
rej	rejection
sv	saturated vapor
sl	saturated liquid
$inter$	intermediate
$inst$	instrumentation

Quoilin et al. [14] presented Solkatherm as the most efficient fluid in small-scale solar combination of parabolic trough and ORC. Ferrara et al. [15] compared various working fluids in parabolic trough-ORC solar power plant, where Acetone showed interesting results. Zhong-he et al. [16–18] found that R245fa is an ideal fluid, while R601 was advised only for low-temperature range. Bu et al. [19] indicated that R123 is the most suitable working fluid (from overall efficiency point of view) for solar-driven ORC/VCC for ice-making. Calise et al. [20] showed that Isobutene and n-Butene offer good performance for low, medium and high solar heat; R245fa is also suitable for heat source up to 170 °C. Baral and Kim [21] summarized that R245fa is energetically and economically the best candidate for the temperature range 100–150 °C. Amin and Ani [22] found that R123 enables the highest efficiency, while R600a produces the highest work when evaluating the performance of solar thermal binary power generating system consisting of solar superheated steam cycle and ORC. Nafey and Sharaf [23] tested several working fluids in ORC with three variants of thermal solar collectors for driving a reverse osmosis unit. Toluene and Water achieved minimum collector area. Al-Sulaiman [24] found that among the combined steam-ORC cycles examined, R134a followed by the R152a combined cycle demonstrates the best exergetic performance. Tchanche et al. [25] conducted an exergetic, energetic and environmental comparison of 20 working fluids and concluded that R134a is the most suitable one for small scale solar applications with low heat source temperature (90 °C). Ashouri et al. [26] showed that benzene has the best thermodynamic performance but has the highest total cost compared to several fluids