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Studying effect of heating plant parameters on performances of a geothermal-fuelled series cogeneration plant based on Organic Rankine Cycle

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ABSTRACT

The present work aims to analyze the performance characteristics of the series Combined Heat and Power (CHP) system based on Organic Rankine Cycle (ORC) under influence of the heating plant parameters without considering the chemistry of the geothermal water considered as heat source. For evaluation, energetic and exergetic criteria along with the heat transfer capacities have been determined, and also the working fluid R134a has been used. The results showed that increasing the heat demand or the return temperature and only the high supply temperatures lead to destruct the net power generated by the ORC–CHP system. While, influence of the last parameters on the total exergy efficiency and losses is different; whereas raising the heat demands optimizes these exergetic indicators, variation of the supply temperature leads to an optimum for these performances. Since increasing the return temperature has purely negative impacts on all exergetic and energetic criteria, the latter can be improved by reducing this temperature with attention to the heat transfer capacities. Thus, reduction of the return temperature about 5 °C lowers the exhausted stream losses by app. 25% and enhances the power generation by app. 52% and the total exergy efficiency by 9%.

1. Introduction

Improving the exploitation of the alternative energies, such as the geothermal energy, gains always in importance due to the high conventional energy prices along with the environmental considerations [1]. The geothermal energy can be utilized, according to the type of these resources and the related costs, by power plant, heating plant or by the both at the same time in the Combined Heat and Power (CHP) plant which is the subject of our study [2]. Moreover, employing efficient technologies as power plants for converting the low-temperature heat of such resources to electricity in CHP plants contributes significantly to improving such investments. For these purposes, Organic Rankine Cycle (ORC) is the most mature and simplest technology compared with the others such as Goswami cycle, Kalina cycle, Maloney and Robertson cycle [3]. Utilization of the geothermal energy throughout stand-alone ORC plant for the sole power production has been extensively studied by several researchers for optimization or analysis purposes within scope of their assumptions. Saleh et al. [4] recommended low critical temperature fluid (n-butane) for geothermal water temperature (100 °C). Desideri and Bidini [5] found that ORC is more efficient than the other conventional technologies for utilizing the geothermal energy. Hettiarachchi et al. [6] concluded that the ammonia cycle is advisable in ORC. Fiaschi et al. [7] investigated possibility of using an absorption heat transformer to enhance low-enthalpy geothermal water temperature for producing electricity throughout ORC power plant. Heberle et al. [8] found that the non-isothermal phase change of the zeotropic mixtures (R227ea/R245fa) improves the efficiency. Masheiti et al. [9] indicated that R245fa is economically recommended. Paloso et al. [10] stated that coupling vapor absorption chiller to the ORC will generate greater power output. Gau et al. [11] offered the R245fa, R134a, R142b, R600a and R236fa as suitable fluids in ORC, respectively. Shengjun et al. [12] proved that the optimum operation parameters and working fluids are not the same for different indicators. Vetter et al. [13] summarized that the power output can be increased with supercritical cycles and suitable working fluid. Zyhowski et al. [14] investigated and concluded that R245fa is appropriate for use in ORC. Gozdur and Nowak [15] found that the cycle efficiency is not a sufficient criterion for assessment of the ORC.

Regarding the ORC–CHP systems energized by geothermal water, few activities and researches have been conducted for different assumptions and evaluations. Heberle and Brüggemann [16] compared series and parallel circuits with ORC and an

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Nomenclature

Acronyms

CHP	Combined Heat and Power
ORC	Organic Rankine Cycle

Symbols

T	temperature (°C)
$\dot{W}$	mechanical power (kW)
$\dot{m}$	mass flow rate (kg/s)
$\dot{Q}$	heat flux (kW)
q	specific heat (kJ/kg)
$\dot{E}$	energy flux (kW)
$\dot{I}$	irreversibility flow rate (kW)
$\dot{E}x$	exergy flow rate (kW)
h	specific enthalpy (kJ/kg)
s	specific entropy (kJ/(kg K))
t	time (s)
A	area (m^2)
k	total heat transfer coefficient (W/(m^2 K))
C_p	isobaric, specific heat capacity (kJ/(kg K))
P	pressure (bar)
P	power output per unit mass flow rate of hot source (kJ/kg)

Greek letters

Δ	difference (–)
η	efficiency (%)

Subscripts

in	inlet
out	outlet
t	turbine
p	pump
cw	cooling water
pin	pinch point
g	geothermal
s	system
ev	evaporation or evaporator
co	condensation or condenser
sup	supply
ret	return
m	mean
b	big
s	small
wf	working fluid
0	reference for dead state
1..4	cycle state point
log	logarithmic
hs	heating system
exh	exhaust
tot	total
ex	exergy
net	net
th	thermal
orc	organic rankine cycle
irr	irreversibility
gain	gained

additional heat generation based on second law analysis for selecting the working fluid. The CHP plant led to increase in the efficiency of up to 20% compared to a power generation and also the series circuit with isopentane was the most efficient. Guo et al. [17] investigated a novel cogeneration system consisting of low temperature geothermal-powered ORC, an intermediate heat exchanger and a heat pump subsystem at same time identifying a suitable working fluid. The results indicated that the optimized fluids based on each screening criteria are not the same and there exist optimum evaporation temperatures maximizing the P_{net} value and minimizing the A/P_{net}. Heberle et al. [18] presented a thermo-economic analysis of combined heat and power with several working fluids and power plant concepts. The second law efficiency and economic aspects were optimized when exploiting the heat source throughout the CHP plant. Kim et al. [19] investigated a series CHP system with regenerative ORC taking in consideration several working fluids and concluded that the optimum working fluid varies with the source temperature. Kim et al. [20] also studied a parallel cogeneration system using ORC and heat exchanger along with investigating working fluids. They confirmed that the selection of the working fluid for CHP system which assumes maximum second law efficiency is dependent on source temperature level. Li et al. [21] analyzed the series and parallel circuit geothermal systems (100–150 °C) in oilfield using ORC under consideration of various working fluids. The results showed that R601a has the highest cycle performance within the scope of that study and the series circuit with a preheater has higher efficiencies than that without. Dragan et al. [22] explained how to obtain energy into a trigenerative (power, heating and cooling) plant using the geothermal energy. Tempesti et al. [23] presented a thermo-economic analysis of a micro-Combined Heat and Power (CHP) plant operating through an ORC using the geothermal (80–100 °C) and solar energies. The results showed that R245fa allows the lowest price of electricity production and the lowest overall cost of the CHP plant. Khennich et al. [24] modeled two CHP systems with ORC and R134 a as working fluid. The both systems generated less mechanical power than the heat delivered to the heating load and a higher fraction of the heat source was used as the heating load increases.

From the brief literature review concerning the ORC–CHP plants, it can be noticed that all these researches did not discuss or conclude impacts of the different heating plant parameters on the ORC–CHP plant performances or on the geothermal energy utilization. So this paper presents a detailed study of impact of the heating plant parameters on the performance characteristics of the series Combined Heat and Power (CHP) system based on Organic Rankine Cycle (ORC) as power plant when exploiting the low-temperature geothermal energy. Thus, possible optimizations and problems of the ORC–CHP power production or heat source utilization in such investments can be preliminary assessed without considering the chemistry of the geothermal water due to imposing use of suitable materials for such applications. As working fluid in ORC, R134a will be screened being widely used in our laboratory for heat pumps and also we are now constructing an experimental ORC–CHP pattern along with heat pump on basis of this fluid. Therefore, the energetic feasibility or the technical situation of using this fluid in such applications must be accurately stated as long as selecting the working fluid, according to the references cited above, depends on the adopted assumptions, configuration and the evaluation criteria. R134a has been tested by several researchers in ORC under different assumptions either in stand-alone systems [9,11,25–32] or in CHP plants [17,20,23,24],