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A comparative thermodynamic analysis of ORC and Kalina cycles for waste heat recovery: A case study for CGAM cogeneration system

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ABSTRACT

A thermodynamic modeling and optimization is carried out to compare the advantages and disadvantages of organic Rankine cycle (ORC) and Kalina cycle (KC) as a bottoming cycle for waste heat recovery from CGAM cogeneration system. Thermodynamic models for combined CGAM/ORC and CGAM/KC systems are performed and the effects of some decision variables on the energy and exergy efficiency and turbine size parameter of the combined systems are investigated. Solving simulation equations and optimization process have been done using direct search method by EES software. It is observed that at the optimum pressure ratio of air compressor, produced power of bottoming cycles has minimum values. Also, evaporator pressure optimizes the performance of cycle, but this optimum pressure level in ORC (11 bar) is much lower than that of Kalina (46 bar). In addition, ORC's simpler configuration, higher net produced power and superheated turbine outlet flow, which leads to a reliable performance for turbine, are other advantages of ORC. Kalina turbine size parameter is lower than that of the ORC which is a positive aspect of Kalina cycle. However, by a comprehensive comparison between Kalina and ORC, it is concluded that the ORC has significant privileges for waste heat recovery in this case.

1. Introduction

General population growth with economic development is leading to increasing energy consumption [1]. Multi-generation systems such as combined heat and power generation (CHP) are attractive. Among the cogeneration systems, gas turbine cogeneration is a well-known system which uses the hot gases leaving the gas turbine for producing saturated steam as a by-product [2–4]. One of the well-known proposed cogeneration systems, is CGAM (which was named after the first initials of the participating researchers including C. Frangopoulos, G. Tsatsaronis, A Valero and M. von Spakovsky) [3–8], which is a cogeneration plant producing 30 MW power and 14 kg/s of saturated steam. CGAM consists of a high temperature gas turbine and an air preheater to use a part of thermal energy of the hot gases leaving the gas turbine as well as a heat recovery steam generator in which the saturated steam is produced [5]. Global warming, splitting of the ozone layer and other environmental problems lead to the energy policy consideration. In addition, increasing the electricity price up to a rate of 12% annually motivates the use of waste heat and renewable

Abbreviations: AC, Air compressor; AB, Absorber; AP, Air preheater; AWT, Ammonia water turbine; CC, Combustion chamber; COND, Condenser; Eva, Evaporator; GT, Gas turbine; G, Genarator; HRSG, Heat recovery steam generator; ORCT, Organic Rankine cycle turbine; P, Pump; REG, Regenerator; SEP, Separator; V, Valve

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Nomenclature

$\dot{E}_i$	Exergy rate [kW]
$\dot{E}_D$	Exergy destruction rate [kW]
$\dot{E}_F$	Fuel exergy rate [kW]
$\dot{E}_{in}$	Entrance Exergy rate [kW]
$\dot{E}_P$	Product Exergy rate [kW]
e_i	Specific thermo mechanical flow exergy at state i [kJ/kmol]
e_{ch}	Specific chemical exergy [kJ/kmol]
e_{ph}	Specific physical exergy [kJ/kmol]
h	Specific enthalpy [kJ/kmol]
LHV	Lower heating value [kJ/kmol]
$\dot{n}$	Molar rate [kmol/s]
P_i	Pressure at state i [bar]
$\dot{Q}$	Heat transfer rate [kW]
r_p	Pressure ratio [Dimensionless]
$\bar{R}$	Universal gas constant [kJ/kmol K]
s	Specific entropy [kJ/kmol K]
T_i	Temperature at state i [K]
$\dot{W}$	Produced or consumed power by components [kW]

Greek letters

ε	Exergy efficiency [%]
$\eta_{C,isen}$	Isentropic efficiency of compressor [%]
$\eta_{T,isen}$	Isentropic efficiency of turbine [%]
$\eta_{P,isen}$	Isentropic efficiency of pump [%]
η	Energy efficiency [%]

Subscripts

0	Reference environment state
D	Destruction
env	Environmental
F	Fuel
in	Input
i	State point
k	k'th component
l	Loss
out	Outlet
P	Product
q	Heat transfer
w	Power

sources for power generation [9,10]. Possible solutions may be the use of organic Rankine cycle (ORC), Kalina cycle (KC) and other types of the low grade heat sources to power generations in order to utilize the waste heat as an energy source for power generation, desalination, cooling and other possible purposes which are more cost-effective than using the fossil fuel [11–14].

The ORC is a well-known plant, and it verified to be a valuable system to convert the sensible heat to mechanical power during the years. The KC is in competition with the ORC, specifically for the case of waste heat recovery [15]. Both the ORC and KC are potential alternatives for generating power from low temperature heat sources efficiently. Although the simple configuration of ORC can be accounted as its advantage due to its simplicity, reliability, and flexibility, the KC may have better performance from the second law perspective [16].

Many researches have been carried out for waste heat recovery by ORC. The working fluid of ORC has an important role in these cycles performance; therefore, some of the surveys focus on selection of best working fluid to gain the desired thermodynamic conditions [17–21]. Some other surveys have been performed on different configurations and comparing them with each other.

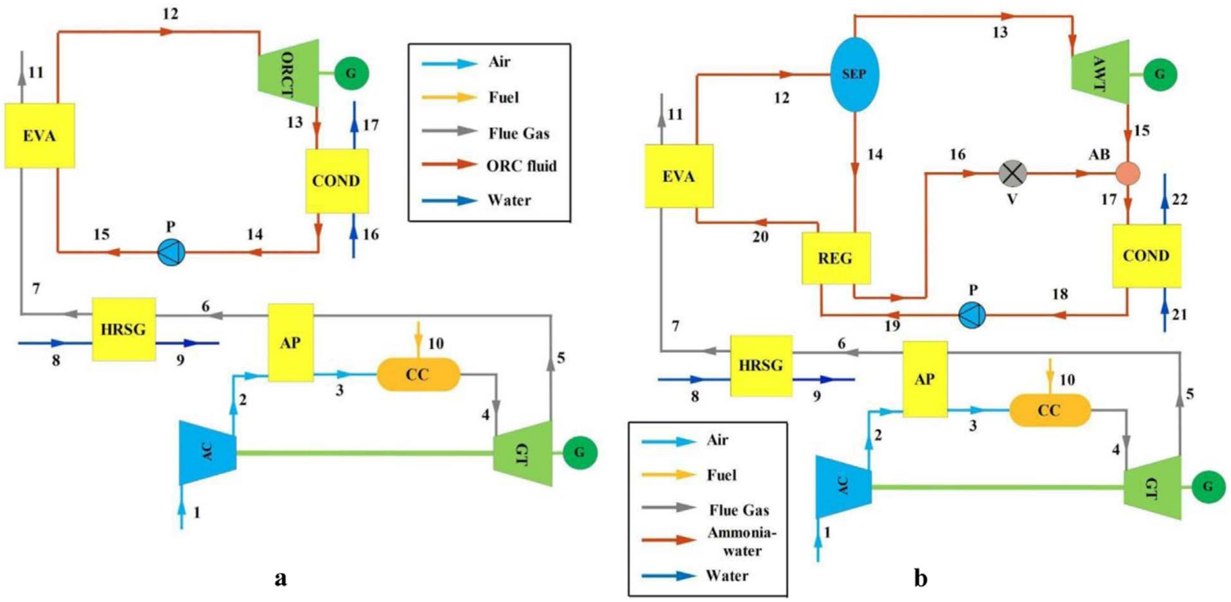

Fig. 1. Schematic diagram of the combined cysles. (a) CGAM/ORC (b) CGAM/KC (AC: Air compressor, AB: Absorber, AP: Air preheater, AWT: Ammonia water turbine, CC: Combustion chamber, COND: Condenser, Eva: Evaporator, GT: Gas turbine, G: Genarator, HRSG: Heat recovery steam generator, ORCT: Organic Rankine cycle turbine, P: Pump, REG: Regenerator, SEP: Separator, V: Valve).