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Research Article

Comparative exergy and energy analyses and optimization of different configurations for a laundry purpose

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ABSTRACT

Energy usually plays a critical role in the development of a country. With the gradual decrease of available traditional fuel reserves and air pollutions problems that being followed by using them, the need to replace alternative renewable and sustainable options to decrease our dependence on fossil fuels has drawn attention. Biomass is a kind of reliable renewable energy that is used to derive combined heat and power systems known as the Organic Rankin Cycle (ORC). This paper presents of exergy analysis of three cycles which have been modeled by EES software for a laundry that needs 32 (kW) power and 2500 (kg/h) 65 (C°) hot water which hot water is our main goal in this study. In RC (gas fuel) and ORC (biomass fuel) power which is produced provides part of electricity needed in the laundry but for Boiler Proving Hot Water (BPHW) the whole electricity needed is bought from the grid. R245fa is a friendly environmentally organic fluid that is used in ORC as a working fluid. The result of this analysis shows for the same conditions the most exergy destruction occurs in the boiler and the least in the pump in three cycles. It also shows the most efficiency of second law respectively is belongs to RC, ORC, BPHW with 0.21%, 0.16%, 9% total efficiency respectively. Moreover, by utilizing EES software and genetic algorithm all of the configurations have been optimized and compared.

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INTRODUCTION

Todays is accepted that among the greenhouse gases CO_2 is the most effective greenhouse gas that followed by using fossil fuels. And CO2 has caused several damages such as global warming over recent years. Energy management and renewable energy have now been increased in any corner of the world via various motivations and legislations Combined Heat and Power (CHP) systems are a viable option which also can mitigate the environment pollutions, and can enhance performance [1,2]. Electricity is a necessity for our modern lifestyle, but currently there is

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no accessibility for around 1.5 billion people worldwide to electricity and up to a billion more have access to electricity that comes from unreliable networks [3]. There is still a huge demand for electricity generation and old fashion steam turbine generators driven by burning fossil fuels. It is widely believed that so many major environmental problems such as air pollution, increasing temperature of our planet, ozone layer depletion and acid rains have caused by the growing consumption of fossil fuels. Accordingly, renewable energy resources, such as solar, geothermal and biomass energies are used in distributed power production in a small-scale platform [4 and 6]. In recent years, the tendency of scholars and industries was generally attracted to saturated ORC cycles.

Biomass-fired Organic Rankin Cycles (ORCs) can be a good choice for sustainable, reliable and friendly environmentally energy sources in micro-scale CHP applications [10]. Some of the advantages that are presented by ORC systems compared with conventional power generation systems are economically efficient, performance enhancement, and high reliability [11, 12]. The ORC represents a reliable response to a power production problem. The ORC systems ensure high efficiencies for low-temperature heat in comparison with other methods [12 and 13].

Working fluid in ORCs is the most effective factor inefficiency of these cycles, the use of an organic fluid with lower boiling point make ORC system advantageous over conventional Rankin cycles. Hence, the selection of the working fluid has to consider as a pivotal key for the maximization of the ORC overall efficiency [14-19].

These days unlike convention systems that produce power and heating separately, the combined heat and power (CHP) systems make heat and power simultaneously and effectively especially in small scales while it is capable of saving energy [20-23]. Although the Rankine cycle is thermodynamically less efficient than the idealized Carnot cycle, the Rankin cycle is feasible. As we mentioned an ORC system works with organic fluids at low temperatures and does not need a superheating process while the water steam Rankin cycle requires superheating to avoid erosion of the turbine blade, [24]. Because of less capital and maintenance costs and with considering to use of non-eroding, non-corrosive and low temperature working fluid. An ORC turbine is more appropriate and efficient than a steam-driven turbine [25, 26]. Therefore, the ORC is much more suitable than conventional steam turbines for small plants from a limited kW to some hundreds of kW power and heating. In fact, a remarkable difference between RC and ORC is the temperature of heat available to align the demand, which is significantly lower in the case of ORC [27-28].

Today, in developed countries, there is a comprehensive view of energy management and saving, economy and Environment [29]. So that optimization and energy management is considered as a new energy source. One of the methods to optimize energy consumption is applying ORC systems for the utilization of low-temperature energy resources such as, geothermal, solar, biomass and waste heat recovery gas turbines and diesel engines and industrial chimneys. ORC systems are the modified model of the Rankine cycle for use of low-temperature heat source. This cycle consists of a thermal oil circulation orbit which passes heat from heating source to working fluid, the heat source can be flue gas of a gas turbine, microturbines, fuel cells or internal combustion engine [30, 31]. This cycle is closed and without any solid and liquid contaminants, that do not produce greenhouse gases. In addition to environmental benefits, the ORC system has small dimensions and the cost of the equipment is also justified [32]. Jamali et al. [33] performed energy, exergy and exergoeconomic analyses on multi-generation energy system. They also conducted multi-criteria optimization to maximize the exergy efficiency and minimize the cost. The parametric study they carried out revealed the effect of several parameters on performance of the system. In another study, Bademlioglu et al. [34] developed a geothermal-based cycle including an ORC system. They compared R123, R152a, R245fa and R600a, which R152a had maximum exergy efficiency. They also applied pinch point analysis to enhance the performance of the cycle. Ghasemi et.al [35] evaluated a Solar-fueled CCHP dealination system based on exergy, and energy aspects. Their system had potential to produce 802.5 kW electricity, 10391 kW heating load, 5658kW cooling loa and 9.328 $kg.s^{-1}$ drinking water. Moreover, that systems energy and exergy efficiencies were 61% and 7% respectively. Shikalgar and Saoali [36] analyzed common refrigeration systems and tried to introduce innovative design by using hot wall air cooled and specific shells in it. The results illustrated that by employing this method the COP is improved by 18-20%. Bademliglu et.al [34] assisted an common ORC cycle that used geothermal energy in it. They utilized different working fluids to compare their results. Final finding showed that, the exergy performance of the mentioned system was improved for geothermal energy resource unit flow rate. Moreover, their determined exergy efficiency and the results showed that R123 has been the best working fluid, while R152a has been the worst working fluid.

In this paper, the main objective was to compare three different configurations to select one for laundry applications. In these three configurations fossil fuels and renewable energy sources were exploited. A comprehensive parametric study is performed for each configuration to report the effect of different decision variables on the performance of the system. Furthermore, genetic algorithm optimization was applied for each configuration in which exergy efficiency is selected as objective function.

METODOLOGY

In this study three-cycle have been modeled and analyze in order to select the best one environmentally and

Table 1. Input data for modeling

Component	Unit	Efficiency
ORC pump	-	0.75
OR pump	-	0.45
BPWH pump	-	0.45
ORC turbine	-	0.72
OR turbine	-	0.75
Boilers	-	0.88
Electric generators	-	0.92
Supply water input temperature	°C	20
Supply water output temperature	°C	65
Supply water mass flow rate	Kg/h	2500

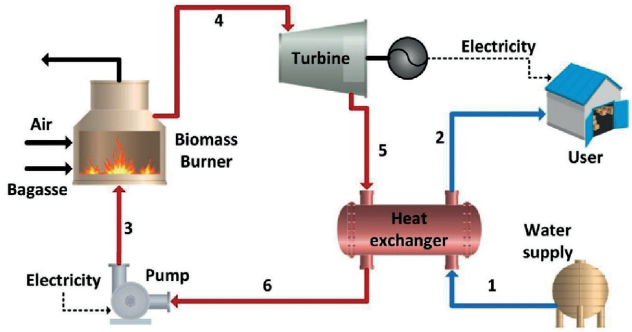

Figure 1. The ORC power system.

economically. These cycles are supposed to be used in laundry to provide 2500 (kg/h) 65 Co hot water so The main outputs of the proposed cycles are hot water. two cycles, RC and ORC moreover hot water produce electricity which provides part of the electricity demand of the laundry but in WTC the needed electricity is bought from the grid completely. The following assumptions have been considered for thermodynamic modeling:

- Hot output gas is considered ideal
- All processes are steady-state
- Heat loss and leakage in the pipes is neglected
- Turbines, pumps, heat exchangers are adiabatic

Three different configurations are expressed as follows:
1. The organic Rankine cycle with bagasse (ORC)
2. The Rankine cycle with gas fuel (RC)
3. Boiler Providing hot water (BPHW)

Input data for modeling has been presented in Table 1.

The Orc Power System

As it is shown in figure 1, the Organic Rankine Cycle (ORC) consists generally of a pump, an evaporator, a turbine, and a condenser. The illustrated energy system is developed to meet the requirements of laundry which are power and heat. A biomass burner heats the R245fa using bagasse as biomass fuel in a closed cycle which produces mechanical work by the turbine. An electric generator converts the mechanical energy to electricity that can be used in the laundry. Then, the organic fluid releases the heat in the condenser to the supply water that is needed in the laundry. The R245fa then pumped to the boiler to close the cycle.

Mass, energy, and exergy balance equations which have been evaluated in the ORC cycle has been presented below. The following equation represents the power produced by the turbine:

$$\dot{W}_t = \frac{\dot{W}_{st}}{\eta t} \tag{1}$$

Where W_{st} is the isentropic work of turbine and η_t is turbine efficiency. And for the heat exchanger the energy balance yields following equation:

$$\dot{m}_s(h_5 - h_6) = \dot{m}_s C_{pw}(T_2 - T_2) \tag{2}$$

Where m_s the flow rate of steam and w_s is the flow rate of supply ware. The thermal power transferred to the working fluid in the bagasse burner is:

$$\dot{Q}_f = \dot{m}_f LHV \tag{3}$$

Where the LHV of Bagasse is considered 17.7 Mj/kg. And energy and exergy equations for bagasse burner can be written as follows [36, 37]:

$$\begin{aligned}&[0.268C + 0.239H_2 + 0.099O_2 + 0.394H_2O + Ash] +\\&[1.075N_2 + 0.289O_2 + 0.013Ar] \rightarrow [0.268CO_2 + 0.633H_2O\\&\quad + 1.075N_2 + 0.013Ar]\end{aligned} \tag{4}$$

$$\dot{E}_{BB} = \eta_{BB} \times (\dot{m}_{bag} LHV_{Bag} - \dot{m}_{bag} h_{comb,product}) \tag{5}$$

Exergy balance for the turbine can be expressed as:

$$\dot{m}_s x_{f4} = \dot{W}_t + \dot{m}_s x_{f5} + \dot{X}_{des,t} \tag{6}$$

And exergy balance for the heat exchanger can be written as:

$$\dot{m}_s x_{f5} + \dot{m}_w x_{f1} = \dot{m}_s x_{f6} + \dot{m}_w x_{f2} + \dot{X}_{des,hx} \tag{7}$$

For the pump, the exergy balance is as follows:

$$\dot{m}_s x_{f6} + \dot{W}_p = \dot{m}_s x_{f3} + \dot{X}_{des,p} \tag{8}$$

For the bagasse burner:

$$\dot{m}_f LHV + \dot{m}_s x_{f3} + \dot{m}_s x_{f4} + \dot{X}_{des,b} \tag{9}$$

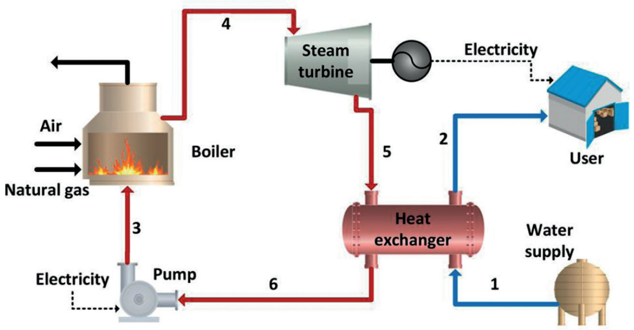

Figure 2. The RC system.

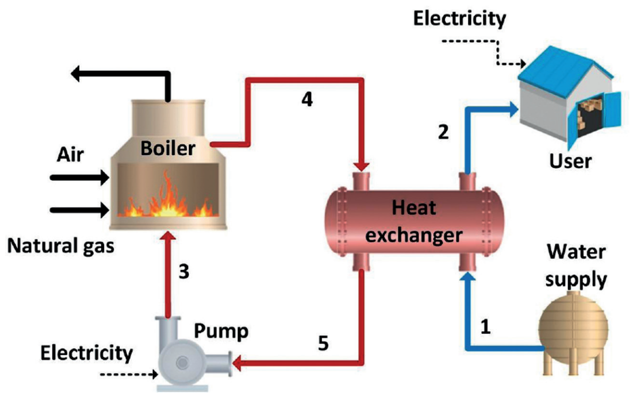

Figure 3. The BPHW system.

Where, x_i and X_{des} is the exergy and exergy destruction for each element, respectively.

The Rankine Cycle (Rc)

As can be seen in figure 2 the process and also equations in this cycle areas the same as ORC that we explained before, one of the differences between these two cycles is their working fluids. Steam is the working fluid in RC while in ORCs the working fluid is an Organic fluid in which R245fa is used in the ORC that presented in this study. Moreover, the fuel of the RC system is considered to be natural gas.

Boiler Providing Hot Water (BPHW)

BPHW system consists of a pump, a boiler and a heat exchanger as illustrated in figure 3. The pump supplies the subcooled water to the boiler where the water is heated and vaporized (state 3). The high-pressure vapor flows into the heat exchanger (state 4) and the temperature of supply water increased from 20 up to 65°C and left the heat exchanger (state 2). The vapor after transferring its heat to supply water, changes to saturated water and is pumped back to the evaporator (state 5) and the cycle is completed.

Mass and energy balance equations have been presented as follow:

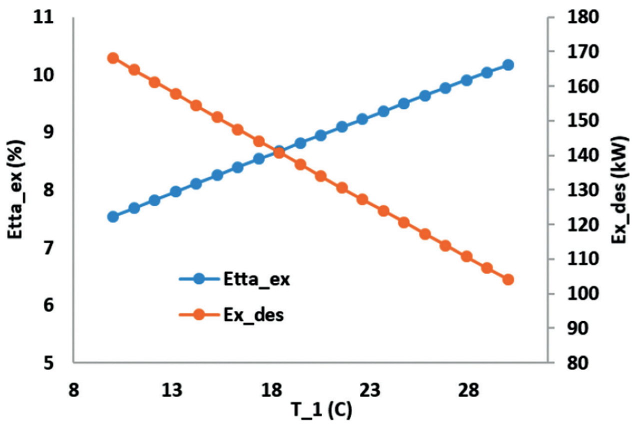

Figure 4. impact of the temperature variation of inlet water in the heat exchanger.

Energy balance for the heat exchanger:

$$\dot{m}_s h_4 + \dot{Q}_{hx} + \dot{m}_s h_5 \tag{10}$$

For the pump, actual work transfer to pump expressed as follows:

$$\dot{W}_p = \frac{\dot{W}_{sp}}{\eta_p} \tag{11}$$

Where, W_{sp} is the isentropic work of pump, and η_p is the efficiency of the pump. Exergy balance for heat exchanger:

$$\dot{m}_s x_{f5} + \dot{m}_w x_{f1} = \dot{m}_s x_{f6} + \dot{m}_w x_{f2} + \dot{X}_{des,hx} \tag{12}$$

And exergy balance for the pump:

$$\dot{m}_s x_{f6} + \dot{W}_p = \dot{m}_s x_{f3} + \dot{X}_{des,p} \tag{13}$$

Exergy balance for the boiler can be expressed as:

$$\dot{m}_f LHV + \dot{m}_s x_{f3} = \dot{m}_s x_{f4} + \dot{X}_{des,b} \tag{14}$$

SENSITIVITY ANALYSIS FOR PROPOSED SYSTEMS

Sensitivity Analysis For Bwhp System

The figure 4 illustrates impact of the temperature variation of inlet water in heat exchanger at range of 10°C to 30°C on exergy efficiency and exergy destruction. As it can be seen in mentioned figure, by increasing the temperature, the exergy efficiency is improved from 7% to 10%, while, exergy destruction rate is decreased from 170 kW to 100 kW.

Figure 5 shows the effect of the alteration of outlet temperature on exergy efficiency and exergy destruction. In the range of 50°C to 70°C, both thermal efficiency and exergy destruction of the whole system have been increased. On the other hand, even though exergy destruction has been increased, the reason for increasing exergy efficiency is improving in the exergy of products. In fact, improving in exergy of the product has overcome the increasing of exergy destruction.

Impacts of the temperature of stream 4 on the exergy efficiency and overall exergy destruction have been illustrated in figure 6. As it is clear, with the increasing mentioned temperature from 350°C to 550°C, both target functions consist of overall exergy destruction and exergy efficiency did not change significantly. The reason for mentioned phenomenon is the independent relation between those parameters.

With changes in the pressure of stream 4, the results of the effects of this parameter on exergy efficiency and total exergy destruction have been shown in figure 7. As it is vivid, the pressure varying from 6000 to 10,000 kPa has a similar effect on the temperature of stream 4 on the exergy efficiency and total exergy destruction, and these two parameters are approximately independent of the pressure of stream 4. The results of the sensitivity analysis in this system show that the effects of the inlet and outlet temperature of the heat exchanger on exergy efficiency and total exergy destruction are greater.

Sensitivity Analysis Of Rankine System

In this system, firstly, the behavior of exergy efficiency and total exergy destruction with changes in the inlet temperature of the heat exchanger has been shown in figure 8. By increasing inlet temperature at the system required water, the exergy efficiency is improved. On the other hand, the amount of overall exergy destruction in the mentioned system by inlet temperature changes of the heat exchanger is decreased from 170 kW to 110 kW.

The impact of outlet temperature of the heat exchanger on total exergy efficiency and overall exergy destruction has been figured in figure 9. with a variation of mentioned temperature between 50°C to 70°C, the exergy efficiency

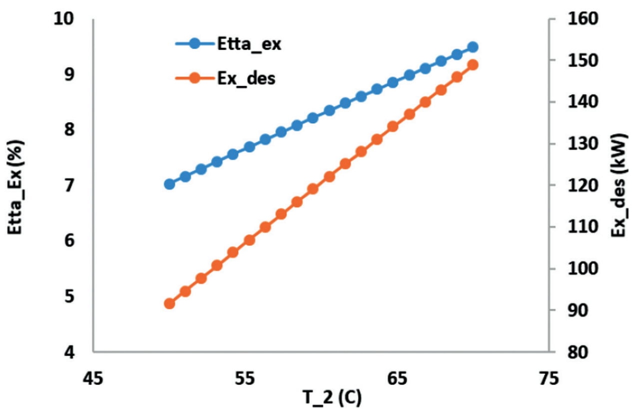

Figure 5. effect of alteration of outlet temperature on exergy efficiency and exergy destruction.

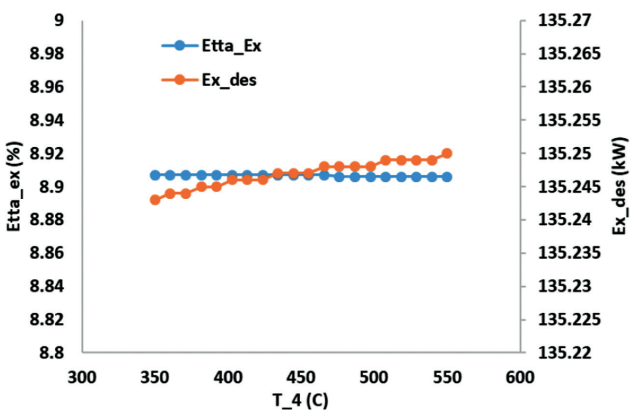

Figure 6. Impacts of the temperature of stream 4 on the exergy efficiency and overall exergy destruction.

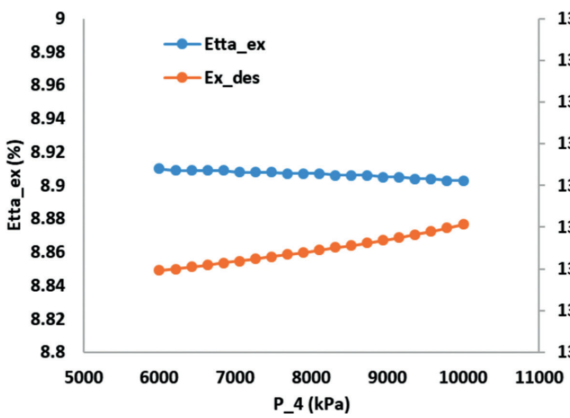

Figure 7. effects of pressure of stream on exergy efficiency and total exergy destruction.

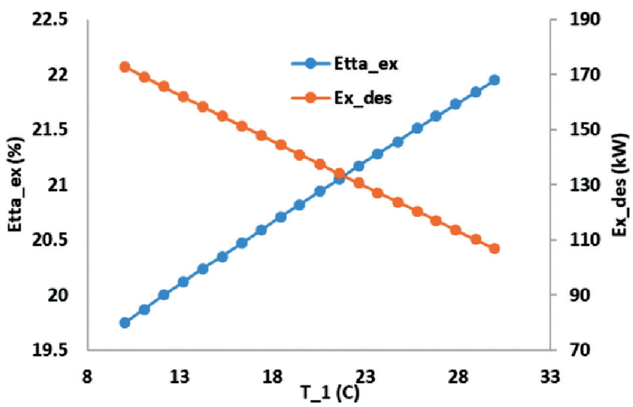

Figure 8. the behavior of exergy efficiency and total exergy destruction with changes in the inlet temperature of the heat exchanger.

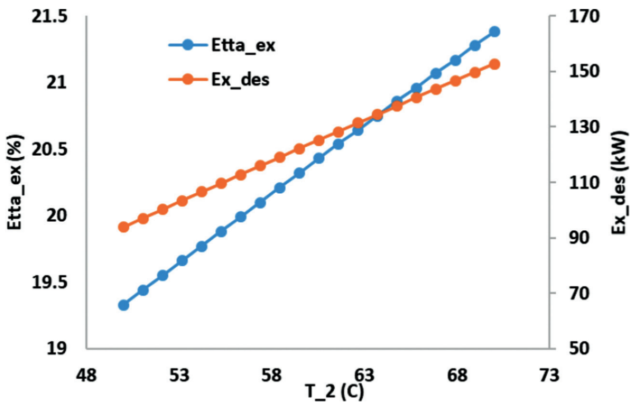

Figure 9. The impact of outlet temperature of heat exchanger on total exergy efficiency and overall exergy destruction.

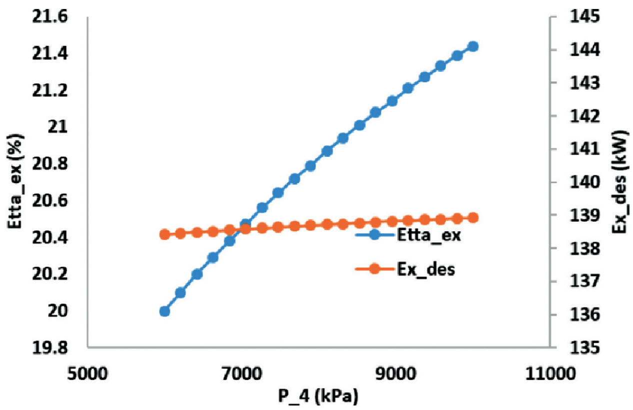

Figure 11. Changes in exergy efficiency and total exergy destruction effected by changing the turbine inlet pressure.

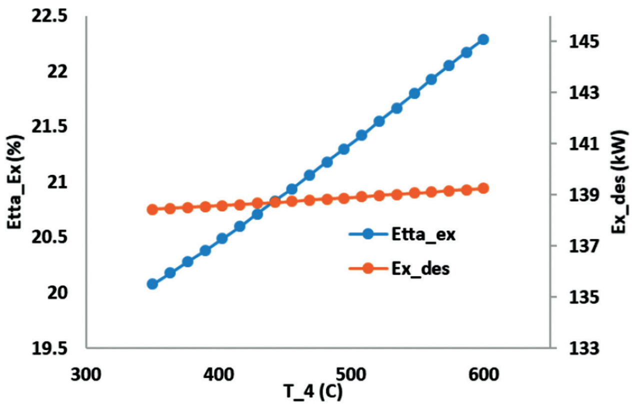

Figure 10. Behaviors of the total exergy destruction and exergy efficiency affected by changes in the inlet temperature of the turbine.

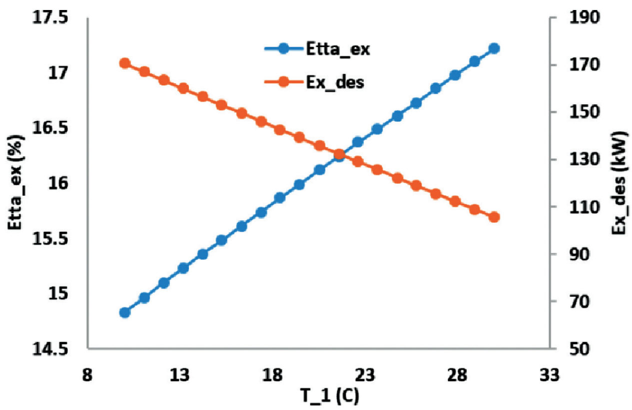

Figure 12. Effects of the inlet temperature of the heat exchanger or the temperature of stream 1 on exergy efficiency and total exergy destruction.

is increased 2% from 19% to 21%. On the other hand, the exergy destruction of the system is changed by increasing the mentioned temperature from 93 kW to 153kw. Also, in this situation, exergy destruction is increased, increasing exergy efficiency can be justified by the point that, when mentioned temperature improves, increasing of exergy of products is greater than the amount of increase in total exergy destruction. So, the final result of the mentioned circumstance is increasing in the exergy rate of products.

The input temperature of the turbine has been increased from 350°C to 600°C, and behaviors of the total exergy destruction and exergy efficiency effected by the mentioned changes have been reported in figure 10 . As can been seen, increasing in the mentioned parameter, improves exergy efficiency from 205 TO 22.3%. Moreover, increasing of that temperature, makes neglectable impacts on total exergy destruction of the system.

Changes in exergy efficiency and total exergy destruction are shown by changing the turbine inlet pressure in figure 11. As can be seen, exergy efficiency changes from 20% to 21.4% as the turbine inlet pressure increases from 6,000 to 10,000 kPa. Such as the previous figure, mentioned change has an infinitesimal impact on exergy destruction behavior of the system, also mentioned behavior is upward.

System Sensitivity Analysis

In the figure12, effects of the inlet temperature of the heat exchanger or the temperature of stream 1 on exergy efficiency and total exergy destruction have been shown. As is clear, exergy efficiency increases from 14.8% to 17.2% with an increase in temperature of stream 1. On the other hand, similar to the diagrams which examined the effects of the temperature of stream 1, total exergy destruction has been markedly reduced.

In figure 13, it can be seen the effects of heat exchanger output temperature changes on exergy efficiency and total exergy destruction. The output temperature of the heat exchanger increases the exergy efficiency of the system with increasing from 50°C to 70°C. In fact, the exergy efficiency is improved from 14.4% to 16.6%. On the other hand, the total exergy has been increased significantly, and it has been increased from 92 kW to 150 kW. As a nutshell, also the exergy destruction has been increased, due to the greater amount of increased exergy of products the exergy efficiency of the system has been increased.

In this figure 14, the effects of turbine inlet temperature on the exergy efficiency of the whole system and on the total exergy destruction have been shown. As can be seen, increasing the inlet temperature of the turbine in the range of 110 to 150°C increases the total exergy efficiency from 13.77% to 16%, although no significant changes in the exergy efficiency are observed at temperatures above 135°C. On the other hand, the total exergy destruction increases slightly with the experience of minor changes as the turbine inlet temperature changes.

Figure 14 illustrates the effects of the turbine inlet pressure on total exergy efficiency and overall exergy destruction. Unlike the previous figure, with improving the inlet pressure of the turbine in the range between 1500 to 2300 kPa, the exergy efficiency is increasing and increases from 14.9% to 16.5%, while, total exergy destruction faces with increasing in the mentioned range of pressures.

As it is shown in Figure 15, the second law of efficiency increases with rising the boiler outlet temperature for every three cycles, ORC has higher efficiency at low temperature. Hence, the ORC system is more efficient in comparison with two others for low-temperature heat sources. Heat sources such as biomass and other renewable energies, waste heat of energy-intensive industries can be a suitable source of energy as low-temperature sources, which also are environmentally benign. In this case the ORC would be more economically due to the fact that the biomass that has been used (Bagasse) is nearly free.

In Figure 16 Exergy destruction of all components (Turbine, Pump, Boiler, Heat exchanger) in each cycle has been presented, the boiler has the most exergy destruction

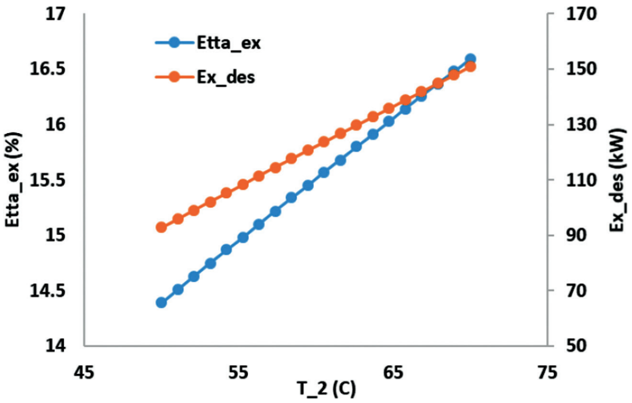

Figure 13. Effects of heat exchanger output temperature changes on exergy efficiency and total exergy destruction.

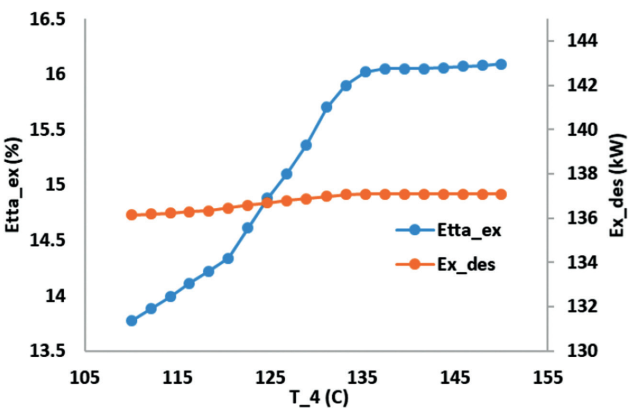

Figure 13. Effects of turbine inlet temperature on the exergy efficiency of the whole system and on the total exergy destruction.

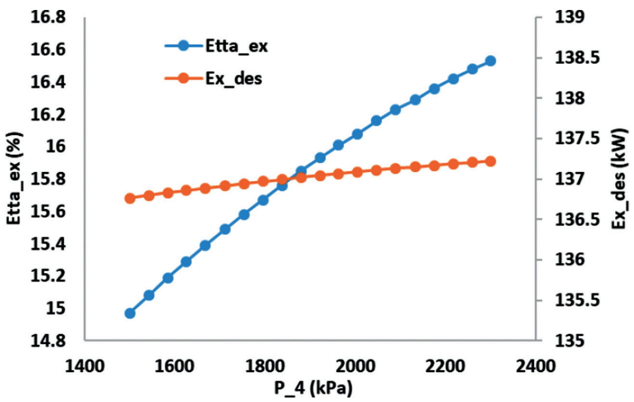

Figure 14. Effects of the turbine inlet pressure on total exergy efficiency and overall exergy destruction.

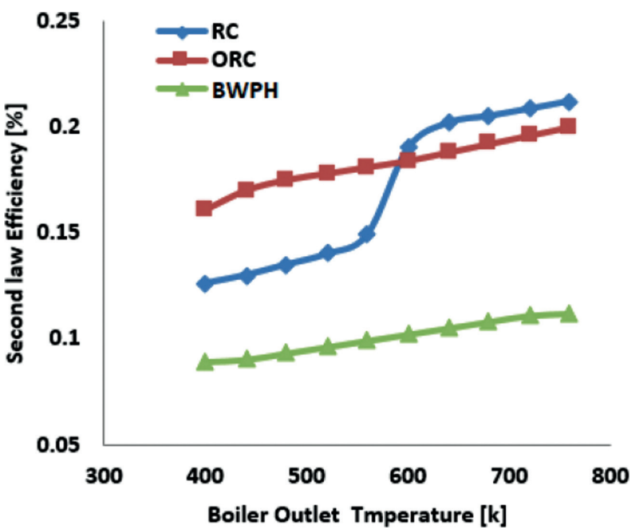

Figure 15. Second law Efficiency changes with Boiler output temperature.

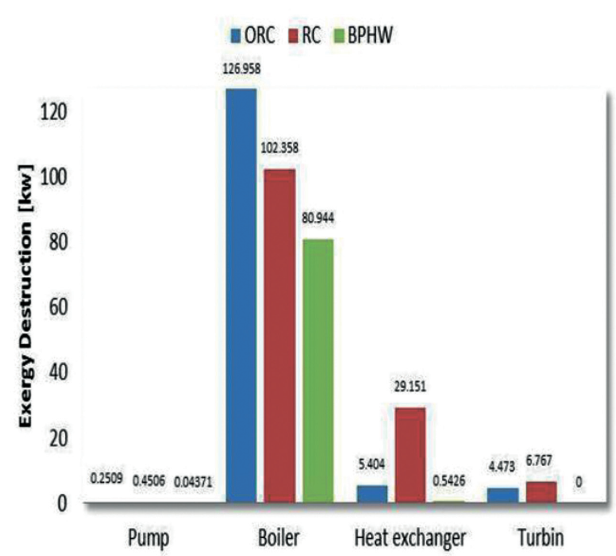

Figure 16. Exergy destruction distribution for RC, ORC and BPHW.

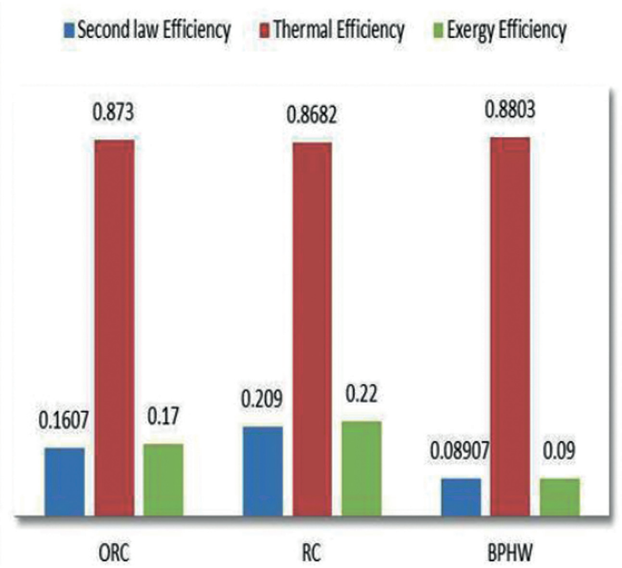

Figure 17. Second law, thermal and exergy efficiencies for each configurations.

in each case. Also, the average exergy destruction in all components is close in ORC and RC configurations.

Figure 17 reports the comparison between thermal, second law and Exergy efficiencies in each configuration. The results define that the most exergy and second law efficiencies is belonged to RC, and ORC and BPHW follows that respectively. The thermal efficiencies for all configurations are close. According to the figure, the performance of the ORC and RC configurations are close that suggesting depends on the temperature of the heat source one of them could be preferable.

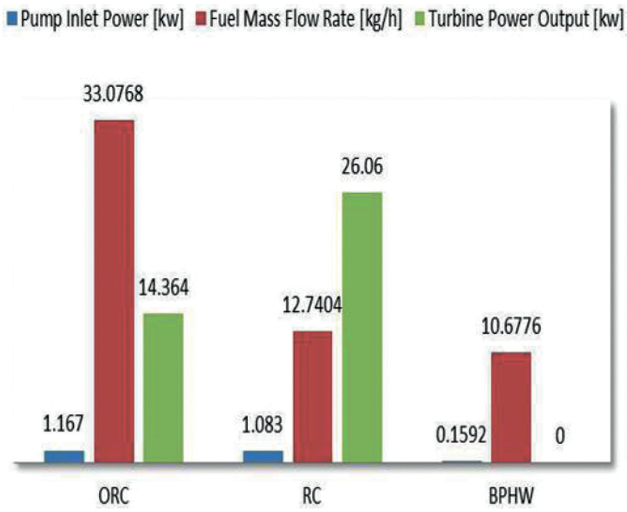

Figure 18. Pump inlet power, turbine power output power and fuel mass flow rate for all configurations.

Table 2. decision variables for the optimization for RC and BHWP systems

Case studies	From	To
T_1 (°C)	10	30
T_2 (°C)	50	70
T_4 (°C)	350	600
P_4 (kPa)	6000	10000

As it can be seen in figure 18, RC configuration has higher turbine power output and less fuel consumption than ORC configuration. This is due to the fact that the fuel of RC configuration is natural gas that has more LHV in comparison with Bagasse in ORC configuration.

OPTIMIZATION

In this section, a single-objective optimization has been conducted for each proposed system in order to maximize the exergy efficiency of the system. In the first step, for maximizing target function, independent parameters have been selected for each system. In order to mentioned optimizations in EES software, the genetic algorithm method has been utilized. The mentioned method is a technical seeking for finding the best and optimized point based on the natural selection process. The mentioned algorithm like the evolution process uses some biological techniques such as inheritance and mutation. This algorithm which has been invented by John Holand in 1967, is one of the random optimization methods that have received particular attention in the field of energy engineering and multiple generation systems. Tables 2 and 3 indicate the decision variables

Table 3. decision variables for the optimization for ORC systems

Case studies	From	To
T_1 (°C)	10	30
T_2 (°C)	50	70
T_4 (°C)	110	160
P_4 (kPa)	1500	2500

Table 4. Result of optimization for BWPH system

Parameter	Best	Base
T_1	30	20.15
T_2	70	65.15
$T_{\_4}$	600	450.2
$P_{\_4}$	6000	8188
$Eta_{\_ex}$	10.73	8.9
$Ex_{\_des}$	117.855	135.247

Table 5. Result of optimization for RC system

Parameter	Best	Base
T_1	30	20.15
T_2	70	65.15
T_4	600	450.2
P_4	10000	8188
$Eta_{\_ex}$	24.33	20.9
$Ex_{\_des}$	121.551	138.727

Table 6. Result of optimization for ORC system

Parameter	Best	Base
$T_{\_1}$	30	20.15
$T_{\_2}$	70	65.15
T_4	160	130.2
P_4	2500	2000
$Eta_{\_ex}$	18.41	16.07
$Ex_{\_des}$	119.647	137.086

for the optimization and the specified interval for them. Moreover, in tables 4 to 6, the results of the optimization of each system and the initial results are compared.

CONCLUSION

With considering to results we find out that both ORC and RC are more efficient than BP because more over the hot water, which is our main goal in this study for a laundry, power is produced in RC and ORC that can be used for providing part of electricity needed in the laundry. With a comprehensive view towards energy, economy, environment we find that in near future, with depleting fossil fuel reservoirs and getting more attention into environmental issues we have to use renewable energy sources which have low temperature, more than before, therefore use of ORC will be more efficient and justified.

- Energy efficiency for BWPH, RC, and ORC are respectively 88%, 86%, and 87%.
- Exergy efficiency for BWPH, RC, and ORC are respectively 8.9%, 20,9%, and 16%.
- Highest exergy destruction in all three configurations belongs to boiler, and in the second-place heat exchanger destroys the exergy.
- Genetic algorithm optimization increases the exergy efficiency for BWPH, RC, and ORC up to 10.73%, 24.33%, 18.41%, respectively.

NOMENCLTURE

Cp_w	specific heat at constant pressure (J/kgK)
CHP	Combined Heat and Power
EES	Engineering Equation Solver
h	Specific anthalpy(KJ/Kg)
LHV	Low Heating value (kJ/kg)
$\dot{m}$	Mass flow rate (Kg/s)
ORC	Organic Rankine Cycle
$\dot{Q}$	Thermal power (Kw)
T	Temperature (C°)
$\dot{W}$	Power (Kw)
BPHW	Boiler providing hot water
SLE	Second Law Efficiency
X	Exergy (Kw)
RC	Rankin Cycle
x	Specific exergy (kj/kg)
X_{des}	Exergy distruction (Kw)
η	Efficency

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

REFERENCES

[1] Denntice Daccacia M, Sasso M, Sibilio S, Vanoli L. Micro-Combined heat and power in residential and light commercial applications. Appl Therm Eng 2003;23:1247-1259. [CrossRef]

[2] United Nations Industrial Development Organization. Energy for a sustainable future: Contributed by the un secretary general's Advisory group on energy and climate change (AGECC). New York: United Nations Industrial Development Organization: 2010:1e44.

[3] Birol F. Energy economics: a place for energy poverty in the agenda?. Energy J 2007;28:1–6. [CrossRef]

[4] Qiu Gq, Liu H, Riffat Sb. Expanders for micro-chp systems with Organic Rankine Cycle. Appl Therm Eng 2011;31:3301–3307. [CrossRef]

[5] Karellas S, Schuster A. Supercritical fluid parameters in Organic Rankine Cycle applications. Int J Thermodyn 2008;11:101–108.

[6] Li W, Feng X, Yu LJ, Xu J. Effects of evaporating temperature and internal heat exchanger on Organic Rankine Cycle. Appl Therm Eng 2011;31:4014–4023. [CrossRef]

[7] Preißinger M, Heberle F, Brüggemann D. Thermodynamic analysis of doublestage Biomass fired organic rankine cycle for micro-cogeneration. Int J Energy Res 2012;36:944–952. [CrossRef]

[8] Qiu G, Shao Y, Li J, Liu H, Riffat SB. Experimental investigation of a biomassfired ORC-based micro-chp for domestic applications. Fuel 2012;96:374–382. [CrossRef]

[9] Drescher U, Bruggemann D. Fluid selection for the Organic Rankine Cycle (ORC) in biomass power and heat plants. Appl Therm Eng 2007;27:223–228. [CrossRef]

[10] Dai Y, Wang J, Gao L. Parametric optimization and comparative study of Organic Rankine Cycle (ORC) for low grade waste heat recovery. Energy Convers Manag 2009;50:576–582. [CrossRef]

[11] Quoilin S, Lemort V, Lebrun J. Experimental study and modeling of an organic rankine cycle using scroll expander. Appl Energy 2010;87:1260–1268. [CrossRef]

[12] Saleh B, Koglbauer G, Wendland M, Fischer J. Working fluids for low temperature Organic Rankine Cycles Energy 2007;32:1210–1221. [CrossRef]

[13] Bianchi M, De Pascale A. Bottoming cycles for electric energy generation: parametric investigation of available and innovative solutions for the exploitation of low and medium temperature heat sources. Appl Energy 2011;88:1500–1509. [CrossRef]

[14] Mikielewicz D, Mikielewicz J. A thermodynamic criterion for selection of working fluid for subcritical and supercritical domestic micro chp. Appl Therm Eng 2010;30:2357–2362. [CrossRef]

[15] Arslan O, Yetik O. Ann based optimization of supercritical orc-binary geothermal power plant: Simav case study. Appl Therm Eng 2011;31:3922–3928. [CrossRef]

[16] Schuster A, Karellas S, Aumann R. Efficiency optimization potential in supercritical Organic Rankine Cycles. Energy 2010;35:1033–1039. [CrossRef]

[17] Desai NB, Bandyopadhyay S. Process integration of organic rankine cycle. Energy 2009;34:1674–1686. [CrossRef]

[18] Rayegan R, Tao Y.X. A procedure to select working fluids for solar Organic Rankine Cycles (ORCS). Renew Energy 2010;36:659–670. [CrossRef]

[19] Quoilin S, Declaye S, Tchanche B.F, Lemort V. Thermo-economic optimization of waste heat recovery Organic Rankine Cycles. Appl Therm Eng 2011;31:2885–2893. [CrossRef]

[20] Dong L, Liu H, Riffat S. Development of small-scale and micro-scale biomass-fuelled CHP systems - a literature review. Appl Therm Eng 2009;29:2119–2126. [CrossRef]

[21] Ren H, Gao W, Ruan Y. Optimal sizing for residential chp system. Appl Therm Eng 2008;28:514–523. [CrossRef]

[22] Liu H, Shao Y, Li J. A biomass-fired micro-scale chp system with Organic Rankine Cycle (ORC) - thermodynamic modelling studies. Biomass Bioenergy 2011;35:3985–3994. [CrossRef]

[23] Moro R, Pinamonti P, Reini M. ORC technology for waste-wood to energy conversion in the furniture manufacturing industry. Therm Sci 2008;12:61–73. [CrossRef]

[24] Andersen WC, Bruno TJ. Rapid screening of fluids for chemical stability in organic Rankine cycle applications. Ind Eng Chem Res 2005;44:5560–5566. [CrossRef]

[25] Nguyen VM, Doherty PS, Riffat SB. Development of a prototype low-temperature Rankine cycle electricity generation system. Appl Therm Eng 2001;21:169–181. [CrossRef]

[26] Yagoub W, Doherty P, Riffat SB. Solar energy-gas driven micro-CHP system for an office building. Appl Therm Eng 2006;26:1604–1610. [CrossRef]

[27] Preißinger M, Heberle F, Brüggemann D. Exergetic analysis of biomass fired double-stage Organic Rankine Cycle (ORC). In Proceedings of ECOS 2012 - The 25th International Conference on Efficiency, C EOST, Optimization, Simulation and

Environmental Impact of Energy Systems June 26-29, 2012, Perugia, Italy 2012:1–11.

[28] Chen H, Goswami DY, Stefanakos EK. (2010). A review of thermodynamic cycles and working fluids for the conversion of low-grade heat. Renew Sust Energy Rev 2010;14:3059–3067. [CrossRef]

[29] Moe. Available at: www.moe.org Accesed at May 05, 2022.

[30] Hung TC. Waste heat recovery of organic Rankine cycle using dry fluids. Energy Convers Manag 2001;42;539–553. [CrossRef]

[31] Vaja I, Gambarotta A. Internal Combustion Engine (ICE) bottoming with Organic Rankine Cycles (ORCs). Energy 2010;35;1084–1093. [CrossRef]

[32] Frangopoulos CA. Exergy, Energy System Analysis and Optimization-Volume II: Thermoeconomic Analysis, Modeling, Simulation and Optimization in Energy Systems. Oxford: EOLSS Publications; 2002.

[33] Jamali D.H,Noorpoor A. Optimization of a novel solar-based multi-generation system for waste heat recovery in a cement plant. J Clean Prod 2019;240:117825. [CrossRef]

[34] Bademlioglu AH, Yamankaradeniz R, Kaynakli O. Exergy analysis of the organic rankine cycle based on the pinch point temperature difference. J Therm Eng 2019;5:157–165. [CrossRef]

[35] Heidarnejad P. Exergy based optimization of a biomass and solar fuelled CCHP hybrid seawater desalination plant. J Therm Eng 2017;3:1034–1043. [CrossRef]

[36] Shikalgar ND, Sapali SN. Energy and exergy analysis of a domestic refrigerator: approaching a sustainable refrigerator. J Therm Eng 2019;5:469–481. [CrossRef]