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Investigation of three Organic Fluids Effects on Exergy Analysis of a Combined Cycle: Organic Rankine Cycle / Vapor Compression Refrigeration

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ABSTRACT

In this study, the energy and exergy analysis of a combined cycle was carried out. This cycle consists of an organic Rankine cycle and a vapor compression refrigeration cycle for producing the cooling effect. Three organic fluids were used as working fluids: the first is isentropic (R123), the second is wet (R134a) and the last is dry (R600). The parametric analysis allowed us to characterize the combined system and to study the effect of some parameters that were used to estimate the thermal and exergy efficiency of the studied system. The comparative study of the combined cycle performance working with organic fluids showed that the isentropic fluid gives the highest value of both thermal end exergy efficiency 51.2% and 25.1%, respectively. The results showed that the operating parameters have a significant impact on the performance of the combined system. On the other hand, the results of the exergy destruction distribution showed also that the exergy is strongly destroyed in the condenser followed by the ORC Evaporator.

1. Introduction

Currently, a continuous increase in energy consumption is observed. According to the international energy outlook [1], world energy consumption increases by 28% between 2015 and 2040. For this reason, new highly efficient systems have been discovered to compensate the lack of energy especially those integrate several energy units. Combined systems are then the best solution for supplying vapor compression refrigeration systems by exploiting the mechanical energy provided by the Organic Rankine System (ORC). As an example of the thermal power plants, gas turbine plant uses fossil fuels as a primary energy input to generate electricity, where exhaust combustion gases are used to conduct other thermal cycles including, absorption refrigeration cycles, desalination cycle and heating units, Rankine steam and organic Rankine cycles. Braimakis *et*

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al., [2] state that current technologies aim at producing electricity from low grade heat, this electricity can be usually derived from different forms of energy including geothermal energy as Heberle *et al*., [3], Liu *et al*., [4] and Bu *et al*., [5] did in their study, Drescher *et al*., [6] and Taljan *et al*., [7] worked on biomass fuels but sun *et al*., [8] worked on industrial waste streams. Rayegan *et al*., [9] and Shaaban *et al*., [10] have chosen the solar energy to derive electricity from. Organic Rankine cycle (ORC) is one example of these technologies. There has been great interest in the integration of multi-energy production units; many energy and environmental problems can be solved through the use of low-temperature heat sources like solar energy, biomass and residual heat recovery. Many studies on cooling technologies operating at low temperatures are attracting the attention of many researchers around the world like the work of Bu *et al*., [5] and Salah [11]. One important study conducted by Touaibi *et al*., [12]. They realized an energy and exergy analysis of single effect water Lithium bromide absorption cooling system. This system is powered by a field of solar thermal collectors with the cooling capacity of 10 kW. They performed an evaluation of the exergy destruction at the level of each component constituting the system.

Several researchers have also studied the choice of working fluids and the ORC's performance. A study conducted by Hung *et al*., [13] on the organic Rankine cycle; Organic fluids were used as working fluids to convert low-grade energy. The researcher identifies Suitable working fluids which yield high system efficiencies. The performance of different working fluids which operate specific regions was also discussed in the study of Wang *et al*., [14]. Thermal efficiencies and exergy destruction rates of the working fluids were studied in a suitable region which is designated by the evaporation pressure and condensation temperature for an engine heat recovery application were evaluated. Moreover, Liu *et al*., [4] performed a thermodynamic analysis of the organic Rankine cycle. They used different hydrocarbon working fluids including butane (R600), isobutane (R600a), pentane (R601) and isopentane (R601a). These fluids are driven by geothermal hot water of 100°C to 150°C. An organic Rankine vapor compression cycle was used for air conditioning and the thermodynamic model which was developed by Bu *et al*., [5] where six working fluids were selected and then compared to each other to identify suitable working fluids. A thermodynamic modeling and optimization of the energy system was realized by Ahmadi *et al*., [15], a micro gas turbine, an absorption cooling and an organic Rankine cycle have been studied; This cycle is used for the production of power such as heating, cooling and hydrogen. A thermodynamic modeling and economic analysis of a micro co-generation system was presented in the study of Karellas et al. [16]; the system is capable of combining heat and power production and refrigeration based on the joint operation of the Organic Rankine Cycle (ORC) and a Vapor Compression refrigeration cycle (VCR). An integrated solar combined cycle; steam with organic Rankine cycle was analyzed by Shaaban [10]; the aim behind was to increase the net output power and reduce the specific fuel consumption. Saleh were studied the working fluids for low-temperature organic Rankine cycles and the performance of ORC-VCR system activated by low-grade thermal energy [11]. The effects of different working parameters on the system performance were examined. Lizarte *et al*., [17] presented a new design of a refrigeration system which consists of a combined organic Rankine cycle and cascade refrigeration system. The latter is used for low-evaporation-temperature applications. The working fluids which were used are natural refrigerants. To estimate the exergy efficiency and the overall system coefficient of performance, a parametric study has been performed.

A large number of existing studies in the literature have only examined the energy analysis of combined cycle. Therefore, it should be noted that little attention has been given to the selection of appropriate functional fluids. However, the novelty of this study is the energy and exergy analysis of the combined cycle (ORC-VCR) using three organic fluids R123, R134 and R600 which is the main goal of this study. A second objective is to study the effect of operating temperatures, especially the evaporation temperature and condensation temperature on the energy and exergy efficiency of the studied system. Another objective is to determine the distribution of destroyed exergy in the studied system.

2. Methodology

The proposed combined system configuration and operating description are presented in this section. The mathematical equations for the performance analysis are also presented.

2.1 System Description

The scheme of combined system is shown in Figure 1, which consists of two subsystems: the organic Rankine cycle (ORC), identified as 1-2-3-1 and the vapour compression refrigeration cycle (VCR) identified as 5-6-3-7-5. This system uses the same working fluid for both subsystems; the global system will be called combined system ORC-VCR. The condensation of the two cycles is carried out under the same pressure in a common condenser [5].

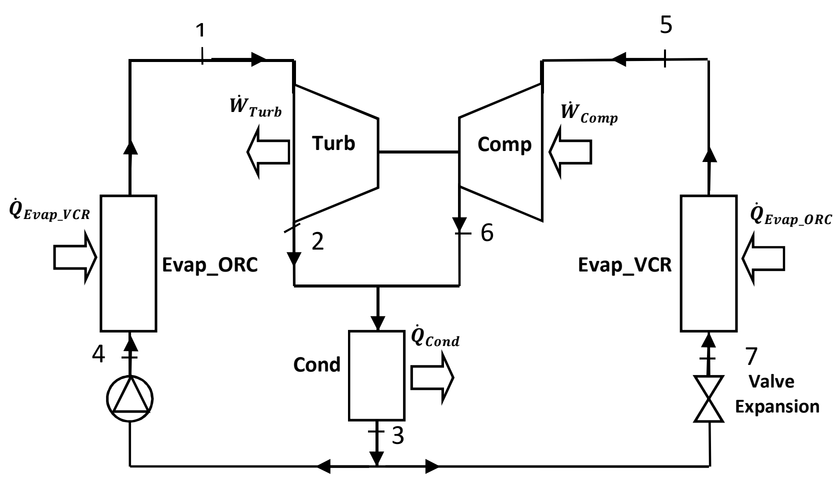


Fig. 1. Scheme of combined system ORC-VCR

2.1.1 Organic Rankine cycle (ORC)

This subsystem consists of a pump, an ORC Evaporator, a Turbine, and condenser (Figure 1). In the ORC evaporator, the working fluid is initially heated and then vaporized at ORC evaporation temperature T_{Evap_ORC} by means of the heat absorbed from the heat source $\dot{Q}_{Evap\_ORC}$. Then the steam generated at high pressure enters the expander, whose enthalpy is converted into power $\dot{W}_{Turb}$. Then, the fluid enters the condenser, where it condenser at condensation temperature T_{Cond} due to the rejection of $\dot{Q}_{Cond}$ to the external medium, which is at temperature T_0. Next, the working fluid enters the pump, which moves the fluid to the ORC Evaporator to complete the cycle [17]. The net mechanical power provided by the ORC cycle is used to drive the compressor of the VCR cycle.

2.1.2 Vapour compression refrigeration cycle (VCR)

This second subsystem consists of a compressor, a condenser, Expansion valves, and VCR Evaporator (Figure 1). In the VCR Evaporator, the working fluid absorbs the cooling load $\dot{Q}_{Evap\_VCR}$ from the cooling space at the VCR evaporation temperature T_{Evap_VCR}. Then, the working fluid is compressed in the compressor, and in the condenser, the working fluid rejects $\dot{Q}_{Cond}$ at T_{Cond} to the condensing medium which is T_0. Finally, it expands in the Expansion valve.

2.2 Mathematical Modeling

The calculations will be performed based on the following assumptions were taken into account performing the energy and exergy analysis of the combined system.

- ✓ Mass and energy flow through the plant is in steady state.
- ✓ Changes in kinetic and potential forms of energy are negligibly.
- ✓ Heat losses and pressure drops in the piping are negligible.
- ✓ The thermodynamic equations are derived for the major thermodynamic devices by treating them as control volumes.
- ✓ The expansion valve process is at constant enthalpy.

2.2.1 Modeling and energy analysis

In this subsection, the energy analysis of the system under consideration is presented. The first principle of thermodynamics is written as follows.

$$\sum \dot{Q} + \sum \dot{W} = \sum \dot{m}_{in} h_{in} - \sum \dot{m}_{out} h_{out} \tag{1}$$

For thermodynamic modeling, the combined system considered here is divided into three main parts: Organic Rankine Cycle, Vapor compression cycle and common part. The energy analysis expressions for all components in the combined system are shown in Table 1.

Table 1
Expressions for the energy Analysis of the combined system

Component	Power
	Organic Rankine Cycle (ORC)
Turbine	$\dot{W}_{Turb} = \dot{m}_{ORC}\,(h_1 - h_2)$; $\eta_{is\_Turb} = \frac{\dot{W}_{Turb}}{\dot{W}_{Turb,is}}$
Pump	$\dot{W}_{Pump} = \dot{m}_{ORC}\,(h_4 - h_3)$; $\eta_{is\_Pump} = \frac{\dot{W}_{Comp,is}}{\dot{W}_{Pump}}$
ORC Evaporator	$\dot{Q}_{Evap\_ORC} = \dot{m}_{ORC}(h_1 - h_4)$
	Vapor Compression Refrigeration (VCR)
Compressor	$\dot{W}_{Comp} = \dot{m}_{VCR}(h_6 - h_5)$; $\eta_{is\_Comp} = \frac{\dot{W}_{Comp,is}}{\dot{W}_{Comp}}$
Expansion valve	$h_3 = h_7$
VCR Evaporator	$\dot{Q}_{Evap\_VCR} = \dot{m}_{VCR}\,(h_5 - h_7)$
	Common part
Condenser	$\dot{Q}_{Cond} = \dot{m}_{ORC}(h_2 - h_3) + \dot{m}_{VCR}(h_6 - h_3)$

2.2.2 Modeling and exergy analysis

Exergy destruction is an important parameter in exergy analysis. It is defined as the potential work lost due to irreversibility. The exergy destruction rate of a control volume at a steady state is defined as [12,18]:

$$\dot{E}x_D = \sum_J \left(1 - \frac{T_0}{T_J}\right) \dot{Q}_J - \dot{W}_{cv} + \sum_i \dot{m}_{in} Ex\_in - \sum_i \dot{m}_{out} Ex\_out \tag{2}$$

Where $\dot{Q}$ is the heat transfer rate from or to the system in kW; $\dot{W}$ the mechanical power supplied by or to the system in kW ; $T_0$is the ambient temperature in °C ; T_J is the component temperature in K. The exergy of each fluid is given by the equation [19]:

$$Ex = (h - h_0) - T_0(s - s_0) \tag{3}$$

Where, T_0 and s_0 correspond to the reference condition of 1.013 bar and 25°C.

For Exergy analysis modeling, the combined system considered here is also divided into three main parts: Organic Rankine Cycle, Vapor compression cycle and common part. The exergy analysis expressions for all components in the combined system are shown in Table 2.

Table 2
Expressions for the exergy model of the combined system

Component	Exergy	Exergy Destruction rate	Exergy Efficiency
		Organic Rankine Cycle (ORC)	
Turbine	$\dot{E}x_{Turb} = \dot{m}_{ORC}[h_1 - h_2 - T_0(S_1 - S_2)]$	$\dot{E}x_{D\_Turb} = T_0\dot{m}_{ORC}(S_2 - S_1)$	$\eta_{Ex\_Turb} = \frac{\dot{W}_{Turb}}{\dot{E}x_{\_Turb}}$
Pump	$\dot{E}x_{Pump} = \dot{m}_{ORC}[h_3 - h_4 - T_0(S_4 - S_3)]$	$\dot{E}x_{D\_Pump} = T_0\dot{m}_{ORC}(S_4 - S_3)$	$\eta_{Ex\_Pump} = \frac{\dot{E}x_{Pump}}{\dot{W}_{Pump}}$
ORC Evaporator	$\dot{E}x_{Evap\_ORC} = \dot{m}_{ORC}[h_1 - h_4 - T_0(S_1 - S_4)]$	$\dot{E}x_{D\_Evap\_ORC} = T_0\dot{m}_{ORC}(S_1 - S_4) - T_0\frac{\dot{Q}_{Evap\_ORC}}{T_{Evap\_ORC}}$	$\eta_{Ex_{Evap_{ORC}}} = 1 - \frac{\dot{E}x_{D\_Evap\_ORC}}{\dot{E}x_{Evap\_ORC}}$
		Vapor Compression Refrigeration (VCR)	
Compressor	$\dot{E}x_{Comp} = \dot{m}_{VCR}[h_6 - h_5 - T_0(S_6 - S_5)]$	$\dot{E}x_{D\_Com} = T_0\dot{m}_{ORC}(S_6 - S_5)$	$\eta_{Ex\_Comp} = 1 - \frac{\dot{E}x_{Comp}}{\dot{W}_{Comp}}$
Expansion valve	$\dot{E}x_{Exp\,Valve} = \dot{W}_{Exp\,Valve}$	$\dot{E}x_{D\_Exp\,Valve} = T_0\dot{m}_{VCR}(S_3 - S_7)$	$\eta_{Ex\_Exp\,Valve} = 1 - \frac{\dot{E}x_{Exp\,Valve}}{\dot{W}_{Exp\,Valve}}$
VCR Evaporator	$\boldsymbol{\dot{E}x_{Evap\_VCR} = \dot{m}_{VCR}[h_5 - h_7 - T_0(S_5 - S_7)]}$	$\dot{E}x_{D\_Evap\_VCR} = T_0\dot{m}_{VCR}(S_5 - S_7) - T_0\frac{\dot{Q}_{Evap\_VCR}}{T_{Evap\_VCR}}$	$\eta_{Ex\_Evap\_VCR} = 1 - \frac{\dot{E}x_{D\_Evap\_VCR}}{\dot{E}x_{Evap\_VCR}}$
		Common part	
Condenser	$\dot{E}x_{Cond} = \dot{m}_{ORC}[h_2 - h_3 - T_0(S_2 - S_3)] + \dot{m}_{VCR}[h_6 - h_3 - T_0(S_6 - S_3)]$	$\dot{E}x_{D\_Cond} = T_0\dot{m}_{ORC}(S_3 - S_2) + T_0\dot{m}_{VCR}(S_3 - S_6) + T_0\frac{\dot{Q}_{Cond}}{T_{Cond}}$	$\eta_{Ex\_Cond} = 1 - \frac{\dot{E}x_{D\_Cond}}{\dot{E}x_{Cond}}$

2.3 Performances of Combined System ORC-VCR
2.3.1 ORC Thermal efficiency

The thermal efficiency of organic Rankine cycle is defined as:

$$\eta_{Th\_ORC} = \frac{\dot{W}_{net}}{\dot{Q}_{Evap\_ORC}} \tag{4}$$

$$\dot{W}_{net} = \dot{W}_{Turb} - \dot{W}_{Pump} \quad (5)$$

2.3.2 VCR Coefficient of performance

The actual COP of the vapor compression refrigeration is defined as follows:

$$COP_{VCR} = \frac{\dot{Q}_{Evap\_VCR}}{\dot{W}_{Comp}} \quad (6)$$

2.3.3 Thermal efficiency of combined system

The thermal efficiency of combined system is defined as follows:

$$\eta_{th\_Sys} = \frac{\dot{Q}_{Evap\_VCR}}{\dot{Q}_{Evap\_ORC} + \dot{W}_{Pump}} \quad (7)$$

2.3.4 Coefficient of performance of combined system

The coefficient of performance of combined system ORC-VCC is defined as follows:

$$COP_{Sys} = \eta_{Th\_ORC}.COP_{VCR} \quad (8)$$

2.3.5 Exergy Efficiency

The overall exergy efficiency of the cycle has been evaluated as the ratio between the useful exergetic production and the exergy input of the system.

$$\eta_{Ex\_Sys} = \frac{\dot{E}x_{Evap\_VCR}}{\dot{E}_{x\_Evap\_ORC} + \dot{W}_{Pump}} \quad (9)$$

2.4 Validation of Simulation

To validate the present model, the simulation results have been compared with the available numerical data in the literature using the R600 as working fluid. The results of this study were compared with the simulation data published by Saleh, [11]. Table 3 presents the combined system performances for the same operating conditions used by Saleh [11]. According to comparison, the agreement between the two simulation results is good.

Table 3
Validation of the model with the results of the Saleh [11]

Parameters; $\dot{m}_{ORC} = 1$ kg/s $T_{Evap\_ORC} = 80$ °C; $T_{Cond} = 40$ °C; $T_{Evap\_VCR} = 5$ °C; $\eta_{is\_Comp} = \eta_{is_{Pump}} = 75$ %, $\eta_{is\_Turb} = 80$ %		
	Saleh Work (2016)	Present work
η_{Th_ORC}	0.0776	0.0789
COP_{VCR}	5.12	5.12
η_{th_Sys}	0.48	0.49
COP_{Sys}	0.39	0.40

3. Results

The different results presented in this work are obtained by solving the equations of the developed model. Three organic fluids are used as working fluids; R123, R134a and R600 to study the effect of various parameters on the performance of the combined system taking into account the operating temperatures. Particularly, the ORC evaporator temperature ranged from 70°C to 95°C and VCR Evaporator temperature ranged from -20°C to 10°C. Also to study the exergy destruction distribution in the system; the thermo-physical and thermodynamic properties of working fluids are determined by the REFPROP Computer software developed by Lemmon [20]. These properties are shown in Table 4.

Table 4
Properties of studied working fluids

	T_{Crit} (°C)	P_{Crit} (bar)	ODP	GWP
R134a	100.6	40.56	0	1300
R123	185	37.9	0.02	93
R600	152	37.9	0	3

3.1 Performances of Combined System ORC-VCR

By taking into account the following input data: $T_{Evap\_ORC} = 80$ °C; $T_{Cond} = 40$ °C; $T_{Evap\_VCR} = 5$ °C; $\eta_{is\_Turb} = \eta_{is\_Comp} = \eta_{is_{Pump}} = 85$ %, the performances of the combined system can be seen in Table 5.

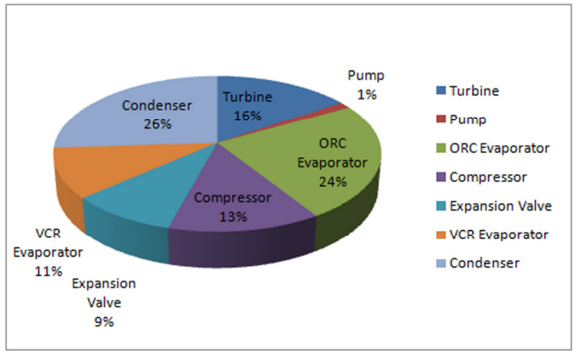
Table 5
Performances of the combined system ORC-VCR according to the studied working fluids

	R123				R134a				R600			
	$\dot{m}_{VCR} = 0.6705$ kg/s				$\dot{m}_{VCR} = 0.572$ kg/s				$\dot{m}_{VCR} = 0.6716$ kg/s			
Component	$\dot{W}_J/\dot{Q}_J$ (kW)	$\dot{E}_{xD}$ (kW)	η_{Ex} (%)	$\dot{E}_x$ (kW)	$\dot{W}_J/\dot{Q}_J$ (kW)	$\dot{E}_{xD}$ (kW)	η_{Ex} (%)	$\dot{E}_x$ (kW)	$\dot{W}_J/\dot{Q}_J$ (kW)	$\dot{E}_{xD}$ (kW)	η_{Ex} (%)	$\dot{E}_x$ (kW)
Turbine	16.16	2.65	85.9	18.81	14.93	2.53	85.5	17.46	34.86	5.72	86.86	40.13
Pump	0.27	0.23	14.81	0.04	1.66	1.58	4.75	0.079	1.14	1.07	5.78	0.066
ORC Evaporator	186.48	4.18	84.54	27.05	170.83	3.93	84.00	24.67	398.98	8.8	84.79	57.86
Compressor	16.16	2.29	85.76	13.86	14.93	2.38	86.00	12.84	34.86	5.68	83.67	29.17
Expansion Valve	0	1.61	0	01.61	0	0	0	2.53	0	4.70	0	4.7
VCR Evaporator	95.63	1.79	73.90	6.86	82.99	1.71	71.50	6.00	202.35	3.78	74.14	14.62
Condenser	282.38	4.49	67.00	13.65	255.48	3.61	69.63	11.89	602.46	8.92	70.76	30.03

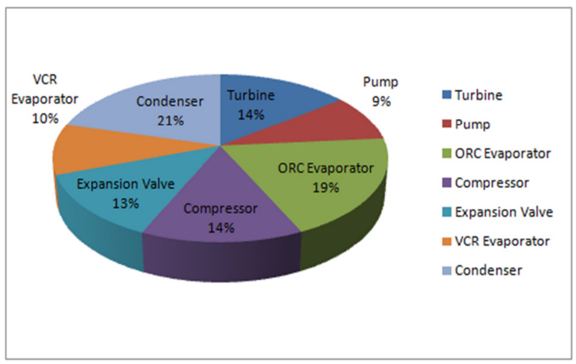
	R123	R134a	R600
$\dot{W}_{net}$ (kW)	15.89	13.27	33.72
η_{Th_ORC} (%)	8.52	7.77	8.45
COP (-)	5.92	5.55	5.80
COP_{Sys}	0.5043	0.4312	0.4901
η_{Th_Sys} (%)	51.20	48.11	50.57
$\eta_{Ex,sys}$ (%)	25.10	22.78	24.67

3.2.3 Exergy destruction distribution in the combined system ORC-VCR

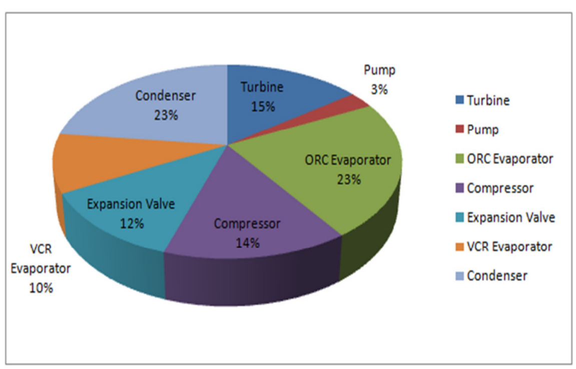
Figure 2 shows the exergy destruction distribution in the combined system for the three working fluids; R123, R134a and R600.



(a: R123)



(b: R134a)



(c: R600)

Fig. 2. Exergy destruction distribution in the system according to the studied working fluids

The obtained Results show that the largest exergy destruction is in the condenser by a percentage of (R123: 26%), (R134a: 21%) and (R600: 23%) and at the level of the ORC Evaporator with a percentage of (R123: 24%), (R134a: 19%) and (R600: 23%).

3.3 Energy and Exergy Parametric Analysis

The effects of operating temperatures will be studied, including the ORC evaporation temperature and the VCR evaporation temperature on the performances of system, in particular, the coefficient of performance, energy and exergy efficiency of the ORC-VCR system. The parametric study will be performed on three organic fluids R123, R134a and R600. To do this, certain operating parameters would be set.

3.3.1 The effect of ORC Evaporator temperature

The effects of ORC evaporation temperature on the performance of the combined system energy analysis are shown in Figs 3-5; by taking into account the three selected organic fluids will be done. Some operating parameters whose VCR evaporation temperature and the condensation temperature respectively bear these values $T_{Evap,VCR} = 5$ °C and $T_{Cond} = 40$ °C would be set. On the other hand, the ORC evaporation temperature will vary from 70°C to°C.

The results of Figure 3 show that the ORC evaporation temperature has a considerable effect on the coefficient of the combined system's performance. The coefficient performance of the combined system's performance increases considerably for the three organic fluids studied. By comparing the results obtained for the three organic fluids, it would found that the coefficient of the fluid R123 (isentropic fluid) is the highest among the others, it would be also noted that the coefficient of performance of the combined system increases from 0.4 to 0.63 with temperature ranged from 70 C° to 95°C for the ORC evaporation temperature.

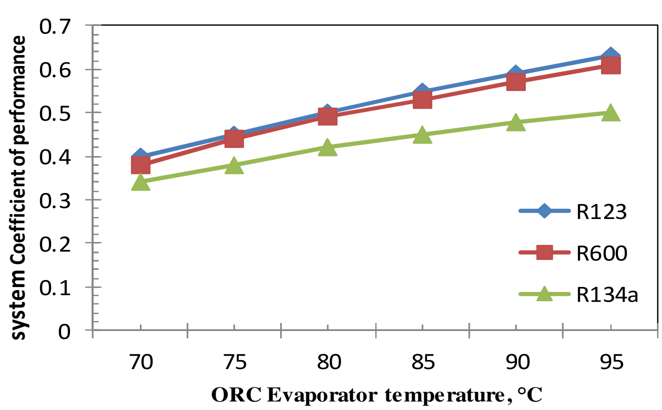


Fig. 3. The variation of the coefficient of performance of combined system with ORC Evaporator temperature according to the studied working fluids

Figure 4 shows the variation of the energy efficiency of the combined system as a function of the ORC evaporation temperature. The energy efficiency of the combined system increases considerably with the increase of temperature in which it will reach a maximum value of 65%. The organic fluid R123 offers the best performance for the combined system. According to the ORC evaporation temperature (70°C to 95°C), the thermal efficiency of the system would increase from 42% to 65%.

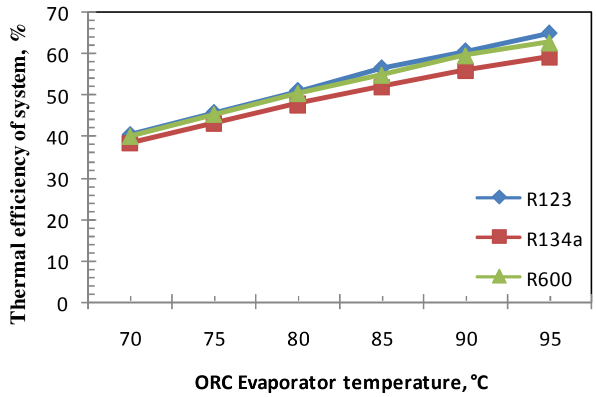


Fig. 4. The variation of the thermal efficiency of the combined system with ORC evaporator temperature according three working fluids

Therefore, the results of both Figs. 3 and 4 show that the ORC evaporation temperature has a positive effect on the performance of the combined system ORC-VCR for all the studied working fluids mainly the organic fluid R123.

Figure 5 shows the variation of the exergy efficiency of the combined system as a function of the ORC Evaporator temperature. The results show that the exergy efficiency of the combined system increases significantly with the increase of the ORC evaporation temperature in the case of the three organic fluids, but the exergy efficiency yield for the case of the fluid R123 is very high compared to the other fluids. According to the ORC evaporation temperature (70°C to 9°C), the exergy efficiency of the system would increase from 23% to 26%. The maximum value reaches a maximum value of 28 % for the temperature 95°C.

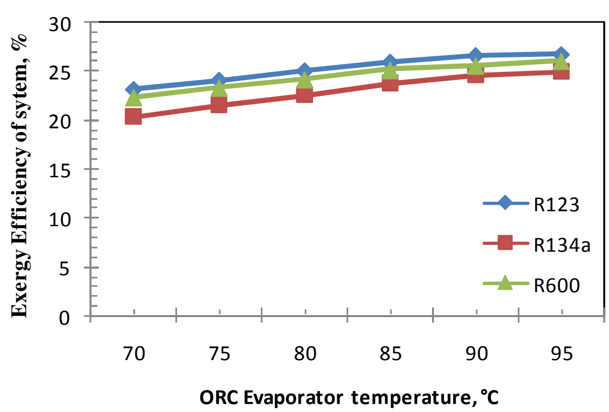


Fig. 5. The variation of the exergy efficiency of combined system with ORC Evaporator temperature according to the studied working fluids

3.3.2 The effect of VCR evaporator temperature

The results of the effect of VCR evaporation temperature on the combined system exergy analysis are shown in Figs 6-8. Some parameters are set, in particular the ORC evaporation temperature and the condensation temperature which respectively bear these values $\mathrm{T_{Evap,ORC}} = 80\ °\mathrm{C}$ and $\mathrm{T_{Cond}} = 40\ °\mathrm{C}$, while the temperature of VCR Evaporation temperature varies over a temperature range of -20°C to 10°C.

According to Figure 6, the VCR evaporation temperature has a considerable effect on the coefficient of performance of the combined system. The latter increases considerably for the three organic fluids studied. After comparing the results obtained for all studied organic fluids, it would be found the R123 (isentropic fluid) reveals the highest coefficient of performance. It will also be noted that the coefficient of performance of combined system increases from 0.23 to 0.61.

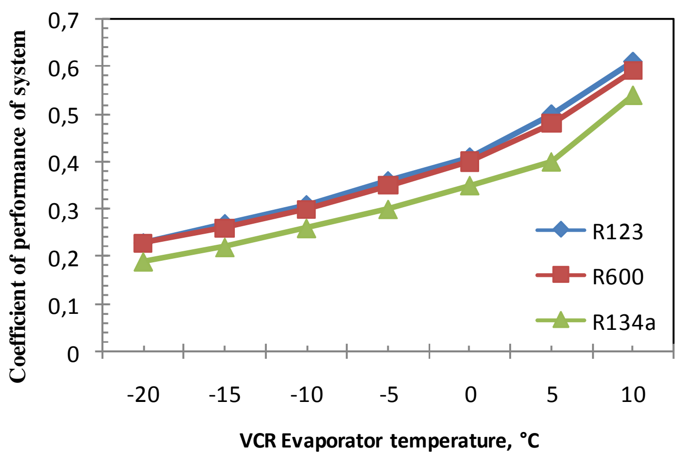


Fig. 6. The variation of the coefficient of performance of combined system with VCR Evaporator temperature according to the studied working fluids

Figure 7 shows the variation of the thermal efficiency of the combined system as a function of the VCR evaporation temperature. The results seen in this figure show that the thermal efficiency of the combined system increases significantly with temperature ranged from 20°C to 10°C and reaches a maximum value of 62%. Hence, the VCR evaporation temperature has a positive effect on the energy efficiency of the combined system for all the working fluids used mainly R123 which fulfills a high performance for the combined system. The energy efficiency of the system is increased from 23% to 62% over the VCR evaporation temperature range from -20°C to 10°C.

Figure 8 shows the variation of the exergy efficiency of the combined system as a function of the VCR evaporation temperature. From the fig 7, we notice that the VCR evaporation temperature has a positive effect on the performance of the combined system for all the three working fluids used. The R123 therefore reveals a best performance for the system. The exergy efficiency of the combined system would then decrease from 26% to 22% with VCR evaporation temperature ranged from -20 °C to 10°C.

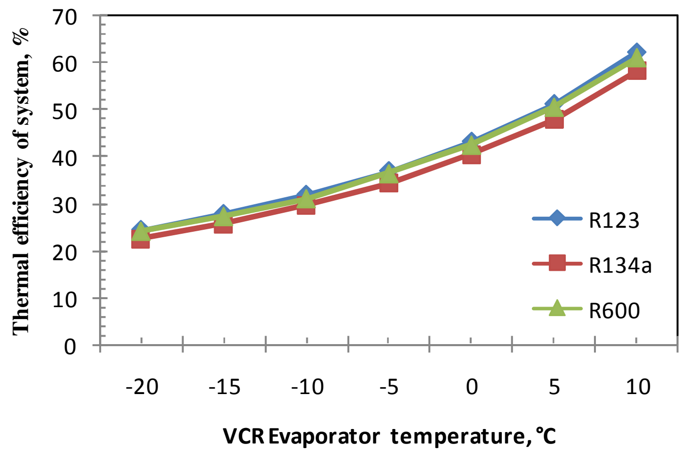


Fig. 7. The variation of the Thermal efficiency of combined system with VCR Evaporator temperature according to the studied working fluids

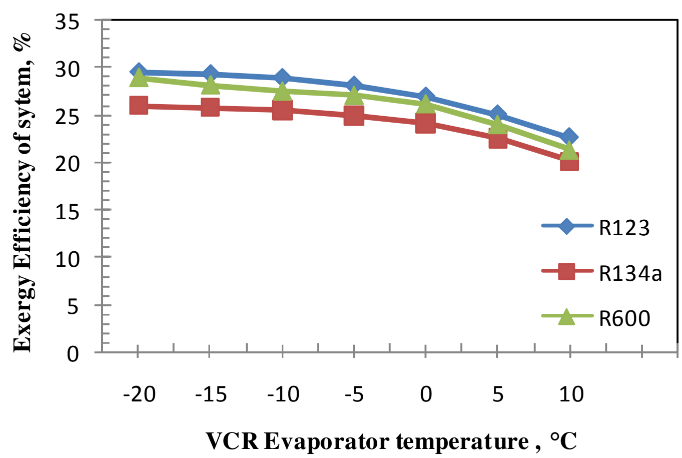


Fig. 8. The variation of the exergy efficiency of combined system ORC-VCR with VCR Evaporator temperature according to the studied working fluids

4. Conclusions

The energy and exergy analysis of a combined cycle was performed. It aims at investigating the effect of the operating parameters; ORC Evaporator temperature and VCR Evaporator temperature on the performance of the system; to improve that performance, three organic fluids were used; R134a, R600 and R123 which are wet, dry and isentropic fluids respectively. The study was realized and the following results were concluded:

1- Among the three fluids used in this study, R123 indicates the best results. The study allows us to consider it as the suitable fluid that affects greatly the combined system's performance.

2 - The distribution of exergy destruction shows that for the three studied fluids, most of the exergy is destroyed at the condenser followed by at the ORC Evaporator. For our main concern R123, it shows 26% for the condenser and 24% for the ORC Evaporator.

3 - The best performance for the combined system is offered using the R123 organic fluid:

- ✓ The coefficient of performance of the combined system is increased for both ORC and VCR evaporation temperatures. For the first, it increases from 0.42 to 0.63 at temperature ranged from 70°C to 95°C. According to the second, it increases from 0.23 to 0.62 at temperature ranged from -20°C to 10°C.
- ✓ The thermal efficiency of the system is increased for both ORC and VCR evaporation temperatures. For the first, it increases from 42% to 65% at temperature ranged from 70 °C to 95°C. According to the second, it increases from 23% to 62% at temperature ranged from -20°C to 10°C.
- ✓ The exergy efficiency of the system is increased for ORC evaporation temperatures and decreased for VCR evaporation temperatures. According to the first, it increases from 23.17 % to 26.75 % at temperature ranged from 70°C to 95°C. For the second, it decreases from 39.59 % to 26.75 % at temperature ranged from -20°C to 10°C.

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