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Increasing Electricity generation By Using Organic Rankine Cycle (ORC) Through the Fluegas of Boilers as a Heat Source

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Abstract— **At the moment generating a large-scale electricity power from power plants especially thermodynamic cycles such as Organic Rankine Cycle (ORC) is becoming a controversial obstacle in related studies. In present ORC thermodynamic cycle, R245fa, NOVEC700, and R141b as refrigerant working fluids sent to a Heat Exchanger then sent to an Expander to produce electricity. Finally, the remaining working fluids are condensed by a Cooler and it is sent back to the ORC thermodynamic cycle. Current study is conducted and analyzed the net power output of Expander, the maximal net power output of ORC, the value of heat transfer between Fluegas to each working fluids at Heat Exchanger, the total heat transfer capacity $(UA)_{total}$, and compare between the optimum pressure of working fluids at inlet of Expander and temperature of working fluids at inlet of Expander, which R141b has a highest amount compare with R245fa, and NOVEC7000. Whereas, with increasing the optimum pressure of working fluids at inlet of Expander, the temperature of working fluids at inlet of Expander is increasing slightly, because the optimum pressure of working fluids at inlet of Expander has a more effect on amount of electricity generated by Expander and as a result on the net power output of ORC.**

Keywords— Organic Rankine Cycle (ORC); Working fluid; R245fa; NOVEC7000; R141b; Fluegas

I. Introduction

Nowadays the oil price is dramatically increasing and this phenomenon due to the all economic obstacle in all over the world especially China, India, and Iran, On the other hand, the governments try to apply the greenhouse gases that produce from boilers such as Fluegas to increase the efficiency of fossils fuels and decrease the negative aspects of these kinds of gases such as worldwide disaster as same as global warming and also air pollution; in addition, the grade of temperature of these type of gas is a little bit high, therefore we can use this type of gases as heat source in some thermodynamic effective cycles [1–3]. For achieving these objectives, can be proposed and conducted various thermodynamic cycles such as the Organic Rankine Cycle, Supercritical Rankine Cycle, Kalina Cycle, Goswami Cycle, Trilateral Flash Cycle, and Transcritical Rankine Cycle which driven by a number of refrigerant working fluids and they simulate and carried out for conversion of low-grade heat sources in to electricity [4]. The most and famous examples of these effective thermodynamic cycles are: TRC (Transcritical Rankine Cycle), Kalina cycle, and ORC (Organic Rankine Cycle) have been proposed to convert low temperature thermal energy into power [5]. The ORC thermodynamic cycle is capable to convert low-grade waste heat source to electric power. The focus of recent researches has been on solar energy, biomass energy, geothermal resources, power plant waste heat, and Fluegas of boilers [6-9]. The lower and medium temperature of heat source of ORC (<300^{0}C) can cause to higher thermal efficiencies, reliability and flexibility as well as simpler control and lower maintenance costs for more economical and effective [10-14]. The Organic Rankine Cycle (ORC) applies the principle of the Steam Rankine Cycle, but uses organic working fluids with low boiling points to recover heat from lower temperature heat sources instead of water as a working fluid. ORC thermodynamic cycle has a number of advantages such as; its simple structure, the availability of its components, the easiness of its application to local small-scale power generation systems, and driven by low-grade heat sources which has a temperature lower than 370 ^{0}C and below this temperature called low-grade temperature in industry [15-19].

Selecting the best and suitable working fluid for ORC thermodynamic cycle with considering the normal operating condition has more important to achieve the best efficiency and more economical electric generation of ORC. In 2012 Chen et al. conducted a supercritical ORC which one time driven by R134a/R32 as a zeotropic mixture refrigerant working fluid and for second time driven by R134 as a refrigerant working fluid, their result showed this fact that the cycle efficiency was increased by 10–30% with R134a/R32 compared to a cycle with R134a[20]. In 2012 Hun Kang et al. investigated an ORC system by using R245fa as a working fluid and also they using a radial turbine coupled with a high-speed generator was design for thermodynamic properties of working fluid which using in this study. Then they founded the maximum average cycle, turbine efficiencies, and electric power to 5.22%, 78.7%, and 32.7 KW, respectively [21]. In 2012 Chao et al. simulated and analyzed a subcritical ORC thermodynamic cycle and compare between R114, R245fa, R123, R601a, n-pentane, R141b, and R113 as working fluids, for selecting the best candidate for ORC thermodynamic cycle according to the maximum net power output, suitable working pressure, total heat transfer capacity, expander SP (size parameter), and calculate the OET (optimal evaporation temperature) by Numerical simulation methods [22]. In 2012 Wang et al. designed and analysis an ORC thermodynamic cycle with using R123 and R245fa as working fluids, and driven by a typical Kiln furnace waste exhaust gas as a low-grade heat source, and also used HRVG (Heat Recovery Vapor Generator) as a evaporator and produce superheated vapor of working fluid. They revealed that, using optimum inlet pressure of turbine can cause to maximum net power electricity as an output. On the other hand, they concluded that, with increasing the inlet temperature of turbine can leads to decrease the electricity power as an output [23]. In 2013 Omid et al. simulated, conducted, and analyzed the Organic Rankine Cycle (ORC) by using the HYSYS simulation software, that ORC cycle working by R246fa as a representative of HFC refrigerant fluids and NOVEC7000 as a representative of HFE refrigerant fluids as working fluids and Fluegas of boiler as a heat source of Heat Exchanger, their result revealed that the comparison of net power generated by Expander between these two valuable refrigerant working fluids with generating large-scale electric energy for using in industrials, petrochemicals, and refineries as a foremost objective function [24]. In 2014 Qiang et al. considered the effects of the increasing in condensation temperature of the zeotropic mixture which consist of butane/pentane (R600/R601), butane/isopentane (R600/R601a), isobutane/pentane (R600a/R601) and isobutane/isopentane (R600a/R601a) were selected as the working fluids for the geothermal heat source of ORC and octane/decane, nonane/decane and octamethyltrisiloxane/decamethyl tetrasiloxane (MDM/MD2M) selected as working fluids for the cogenerated ORC that driven by the biomass energy, on the ORC thermodynamic performance. Their result revealed that, the highest net power output appears at the higher mole fraction of the more volatile working fluids; furthermore, higher increasing in condensation temperature can cause to large thermal loss to the heat sink and Exergy destruction in the condenser [25]. In 2014, Baomin et al. by using the Transcritical Rankine Cycle (TRC) try to make a comparison between a number of working fluids such as pure CO_2 and zeotropic mixtures composed of CO_2 that mixed with R32, R1270, R161, R1234yf, R134a, R152a, and R1234ze by according to Irreversibility and Exergy of component of TRC thermodynamic cycle to produce higher electric energy [26].

II. METHOD AND MATERALS

A. Simulation of ORC Thermodynamic Cycle

For starting the simulation of ORC thermodynamic cycle by HYSYS should be use the initial data that show in Table I. As shown in this table the working fluids are in the normal working condition and also in liquid phase should be start the simulation for ORC.

TABLE I. Initial data which needed to simulate of ORC in HYSYS

Initial Parameter	**Value**
Mass Flow Rate, $\dot{m}_{ORC}$/ Kg/h	15×10^6 – 30×10^6
Phase Fraction of Working Fluid (Inlet of Separator, Outlet of Pump, Outlet of Cooler)	0
Phase Fraction of Working Fluid (Outlet of Heat Exchanger, Inlet and Outlet of Fluegas, Outlet of Expander)	1
Initial Mole Fraction of Working Fluid	0.9
Initial Mole Fraction of H_2O	0.1
Mole Fraction of Fluegas (H_2O, CO_2, N_2, O_2)	0.19, 0.09, 0.7, 0.02
Initial Temperature (Inlet of Separator), T_i/ ^0C	5
Temperature (Inlet of Fluegas), $T_{Fluegas\ in}$ /^0C	200
Temperature (Outlet of Fluegas), $T_{Fluegas\ out}$/^0C	80
Initial Pressure(Inlet of Separator), P_i/ KPa	101.3
Pressure (Outlet of Pump), $P_{outlet\ of\ pump}$ /KPa	250
Pressure(Outlet of Heat Exchanger), $P_{outlet\ of\ H.E}$ /KPa	200
Pressure (Outlet of Expander), $P_{inlet\ of\ Ex}$ /KPa	180
Pressure (Outlet of Cooler), $P_{outlet\ of\ Cooler}$/KPa	101.3

The process of this ORC thermodynamic cycle which will be design and simulate in present study is very marvelous and interest. The schematic of ORC process which output of HYSYS simulation software has shown in Fig. 1 for R245fa, NOVEC7000, and R141b as working fluids.

As can be seen from Fig. 1 first of all, In present ORC thermodynamic cycle, which simulated by HYSYS software, working fluids stream are not completely pure and has small amount of mole fraction of H_2O (90% working fluid and 10% H_2O). For purification or if better say, for increasing the mole fraction of working fluids and decreasing the mole fraction of H_2O, first of all the working fluids in liquid, normal, and steady state working condition, it means 5 ^{0}C as an initial temperature, 101.3 KPa as an initial pressure, and in 15×10^6 - 30×10^6 Kg/h as range of mass flow rate at liquid phase (phase fraction = 0) transfer to a separator (S-100). Working fluids stream at Separator which has the temperature, pressure, and Entropy differences constant; therefore, the working fluids stream at separator is Isothermal, Isobaric, and Isentropic. After completing the purification process of these working fluids in separator, working fluids enter to the Heat Stream Pump (P-100) for adjust the fluid flow and increasing the pressure of working fluids to 250KPa, as a result; the stream of each working fluid at Pump is Isentropic. Then, working fluids enter to the tube and shell Heat Exchanger (H.E-100) for changing their phase from liquid to gas (it means the mole fraction of each working fluid should be change from 0 to 1) because after this equipment, the working fluids should be enter to the Expander (E-100) as a feed for producing the Electricity. This tube and shell Heat Exchanger (H.E-100) for changing the phase of these working fluids from liquid to gas need a heat source which named Fluegas of Boilers. Fluegas has 160 - 240 ^{0}C range of temperature. Hence, Fluegas with 0.19 H_2O, 0.09 CO_2, 0.7 N_2, and 0.02 O_2 as mole fraction of composition of Fluegas and with 160 – 240 ^{0}C as inlet temperature and 40 – 120 ^{0}C as outlet temperature using as an heat source at current shell and tube Heat Exchanger (H.E-100). But as a control temperature of inlet stream of Fluegas, set to 200 ^{0}C and as a control temperature of outlet stream of Fluegas, set to 80 ^{0}C. In present tube and shell Heat Exchanger the temperature of each working fluid is increasing but the pressure of each working fluids is reducing to 200 KPa. After exit these working fluids from this heat exchanger (H.E-100), working fluids in gas phase enter to the Expander (E-100) where working fluids causes to rotate the seal shaft and producing the Electricity energy. Each working fluids stream at Expander same as Pump is Isentropic. Also the temperature of working fluids at Expander is decreasing slightly, furthermore; the pressure of working fluids at Expander is decreasing to 180 KPa. After exit these working fluids from Expander, for recovery of these working fluids, and coming back them to the present ORC thermodynamic cycle, it means changing the phase of this working fluids from gas to liquid and use again in ORC thermodynamic cycle should be enter to the Cooler (C-100) which working by cool drops water with cool air. In this equipment the temperature and pressure of each working fluid are come back to the pressure and temperature at the first section of ORC system. So with changing the phase of these working fluids of this ORC thermodynamic cycle, working fluids can come back to this thermodynamic cycle and using again for producing electricity. The last but not the least equipment in present ORC thermodynamic cycle is Recycle (RCY-1). This exclusive equipment is using for a number of most important reasons, which consist of: close the ORC thermodynamic cycle without any error in each equipment, adjust the working fluid stream from laminar flow to turbulent flow, set the initial temperature of each working fluids stream at the first section of ORC it means at the inlet of separator to near of their boiling point temperature for increasing the efficiency of Heat Exchanger, and doing very well the duty of Separator it means the dewatering from working fluid stream at the first section of ORC system and if better to say, increasing the mole fraction of each working fluids from 0.9 to 0.9998 and decreasing the mole fraction of water containing of each working fluids from 0.1 to 0.0002. As an important result, if any disturbance of function of this instrument occurs, especially the dewatering of Separator that due to add a Recycle at the end of ORC thermodynamic cycle, it means the simulation of present ORC thermodynamic cycle is uncorrected and the working fluid which driven current ORC is not suitable for this simulation of current ORC thermodynamic cycle.

The most important point for adding a preheater as a modification in this ORC thermodynamic cycle is that cannot add a preheater such as: an extra Heat Exchanger or a Heater, before the tube and shell Heat Exchanger (H.E-100), because if add a preheater before this tube and shell Heat Exchanger (H.E-100), the pressure of working fluid stream is more decreasing and negative pressure drop occur at next equipment (Expander); in other word, in Heat Exchanger the pressure is decreasing dramatically, and cannot use two Heat Exchanger (first one as a preheater and second one as a phase changer) together in this ORC thermodynamic cycle.

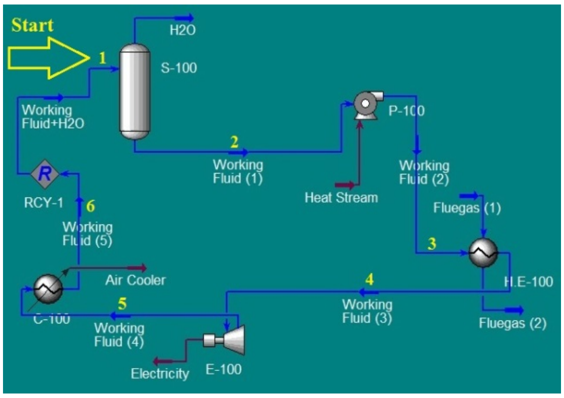

Fig. 1. Schematic of ORC Process Which Driven By R245fa, NOVEC7000, and R141b as Working Fluid

Table II (a, b, &c) summarize a number of important initial parameters of R245fa, NOVEC7000, and R141b as working fluids that gathering for helping this study in simulation of present ORC thermodynamic cycle and easy to analysis the thermodynamic and thermal parameters which will be investigate and discuss in continue of this study.

TABLE II (a). Initial parameters of R245fa, NOVEC7000, and R141b as working fluids that more important for simulation, calculation, and analysis of present ORC system

Alt. Name of Working Fluids	Chemical Formula	Group Name	Ingredient Name	MW (Kg/mole)	$T_{b.p}$ (^{0}C)	$P_{I.L}$ (Kg/m^3)
R245fa	$CHF_2CH_2CF_3$	HFC	1,1,1,3,3-Pentafluoropropane	134.1	15	1339
NOVEC7000	$C_3F_7OCH_3$	HFE	1-Methoxyheptafluoropropane	200	34	1400
R141b	$C_2H_3Cl_2F$	HCFC	1,1-Dichloro-1-fluoroethane	116.9	32.05	1227

(b)

Alt. Name of Working Fluids	T_c (^{0}C)	P_c (KPa)	V_c (m^3)	Freezing Point (^{0}C)	Autoignition Temperature (^{0}C)	ODP	GWP	Solubility in Water (@25^{0}C)
R245fa	154	3640	36.16	<103	412	0.08	0.03	7.18 gr/l
NOVEC7000	165	2480	56.87	-122.5	417	0.0	370	60 ppmw
R141b	204.1	4250	41.05	-103.5	420	0.11	0.09	0.509%

(c)

Alt. Name of Working Fluids	Appearance	$\Delta h_{vap.}$ (kj/kg) @ 100^{0}C	$\rho_{vap.}$ (kg/m^3) @ 100^{0}C	Toxicity
R245fa	Colorless liquid	134.4	73.15	Oral Inhalation Dermal
NOVEC7000	Clear, colorless liquid	105.9	53.03	Skin Oral Inhalation Eyes
R141b	Clear, transparent, colorless liquid	123.6	86.47	Skin Eyes

III. THE THEORETICAL FORMULA OF ORC

A. The Maximal Net Power Output Of ORC ($\dot{W}_{net}$)

These experiments were carried out to find out the maximal net power output of ORC which includes the power consumed by the pump, the power generated by the Cooler, and main objective of present ORC, it means the net power output of Expander. The maximal net power output of ORC can be drive and calculate by equation below:

$$\dot{W}_{net} = \dot{W}_{Ex} + \dot{W}_{Cooler} - \dot{W}_{Pump} \qquad (1)$$

Where $\dot{W}_{net}$ is the maximal net power output of ORC. $\dot{W}_{Ex}$, $\dot{W}_{Cooler}$, and $\dot{W}_{Pump}$ are the net power output of Expander, the power generated by the Cooler, and the power consumed by the Pump.

B. Heat Transfer between Fluegas to Working Fluid ($\dot{Q}_{H.E}$)

One of the most important thermodynamic and heat transfer parameter that some of researchers focus and consider to this parameter, is the value of heat transfer between Fluegas to each working fluids separately. This parameter can be determine the thermal efficiency of ORC systems, size of Heat Exchanger, and also can become Heat Exchanger and whole of ORC thermodynamic cycle to economical and low cost thermodynamic cycle. The heat addition from the Fluegas as heat source of present ORC system [$\dot{Q}_{H.E}$] to each working fluid can be expressed as:

$$\dot{Q}_{H.E} = \frac{dh_{H.E}}{dt} = \dot{m}_{ORC}(h_{outlet\ of\ H.E} - h_{inlet\ of\ H.E}) \qquad (2)$$

Where [$\dot{Q}_{H.E}$] is the value of heat transfer between Fluegas to working fluid. $\dot{m}_{ORC}$ is the mass flow rate of each working fluids after dewatering at Separator. $h_{outlet\ of\ H.E}$ and $h_{inlet\ of\ H.E}$ are the enthalpy at outlet and inlet of Heat Exchanger, respectively.

C. Total Heat Transfer Capacity (UA_{total})

The total heat transfer capacity $(UA)_{total}$, which have been used to evaluate the cost of heat exchangers, can approximately reflect the total heat transfer area of heat exchangers in the ORC system [27,28]. The $(UA)_{total}$ could be evaluated by the following equations:

$$(UA)_{total} = \frac{\dot{Q}_{H.E}}{\Delta T_{H.E}} + \frac{\dot{Q}_{cooler}}{\Delta T_{cooler}} \quad (3)$$

$$\dot{Q}_{H.E} = \frac{dh_{H.E}}{dt} = \dot{m}_{W.F}(h_{outlet} - h_{inlet}) \quad (4)$$

$$\dot{Q}_{cooler} = \frac{dh_{Cooler}}{dt} = \dot{m}_{W.F}(h_{inlet} - h_{outlet}) \quad (5)$$

$$\Delta T_{H.E} = T_{outlet} - T_{inlet} \quad (6)$$

$$\Delta T_{cooler} = T_{inlet} - T_{outlet} \quad (7)$$

Where $(UA)_{total}$ is the total heat transfer capacity, $\dot{Q}_{H.E}$ and $\dot{Q}_{cooler}$ are the heat rate injected and rejected, respectively, $\Delta T_{H.E}$ and ΔT_{cooler} are the maximal and minimal temperature differences at the heat exchanger and cooler, respectively.

IV. RESULT AND DISCUSSION

Fig.2 investigates the net power output of Expander of ORC thermodynamic cycle at different specific mass flow rate of different working fluids. Higher net power output of Expander means that more power could be obtained under the same condition of Fluegas as a waste heat source, highest mass flow rate of working fluids at inlet of separator, it means section 1 of ORC thermodynamic cycle which simulates, conducts, and analyzes in current study, and same pressures at the inlet of Expander that generate electricity.

The net power output of Expander is different for each working fluid which drives ORC at the same condition and same thermodynamic characteristics as shown in Fig. 2 for R245fa, NOVEC7000, and R141b as working fluids of ORC. These working fluids are dry and contain 0.9 mole fraction pure working fluids and 0.1 mole fraction water at section 1, it means at inlet of separator. The highest range of net power output of Expander is about 6766 ± 2243.034 KW to 13530 ± 2243.034 KW when R141b is adopted. The middle net power output of Expander is about 4409 ± 1462.209 KW to 8817 ± 1469.209 KW corresponding to NOVEC7000, and the lowest net power output which belong to R245fa, has a range between 3204 ± 1062.586 KW to 6408 ± 1062.586 KW. One of the foremost reason for explain different net power output of Expander at different specific mass flow rate of different working fluids is it can be deduced that the larger net power output will be produced when the critical temperature of working fluid approaches to the temperature of the waste heat source. For adopting this reason with current results which show at Fig. 2, should be refer to critical temperature of R141b, NOVEC7000, and R245fa which assign 204.1 ^{0}C, 165 ^{0}C, and 154 ^{0}C, respectively. Furthermore, the temperature of Fluegas at inlet of Heat Exchanger is 200 ^{0}C, that it means the highest, middle, and lowest amount of net power output of Expander should be belong to R141b, NOVEC7000, and R245fa. These results in terms of above reason are agreement with results of HYSYS simulation of present ORC which show at Fig. 2. Another reason but the less important is Polytropic efficiency of Expander. This thermodynamic parameter has a linear relationship with the net power output of Expander of ORC thermodynamic cycle at different specific mass flow rate of different working fluids. All in all, the best choice of working fluid in terms of net power generated by Expander is R141b. This result is similar to Chao et al. (2011) [29].

Fig. 3 indicate the maximal net power output of ORC at maximum and minimum mass flow rate of R245fa, NOVEC7000, and R141b as working fluids of present ORC system. As shown in the Fig. 3 the highest, middle, and lowest amount of the maximal net power output of ORC is belong to R141b, R245fa, and NOVEC7000 as working fluids of current ORC. The quantitate amount of maximal net power output of ORC for R141b, R245fa, and NOVEC7000 as highest, middle, and lowest amount is 1929149 ± 319912.6 KW, 1667176 ± 276566.4 KW, and 1160594 ± 195572.5 KW, respectively at maximum mass flow rate (30×10^6 Kg/h), also; The quantitate amount of maximal net power output of ORC for R141b, R245fa, and NOVEC7000 as highest, middle, and lowest amount is964575.5 ± 319912.6 KW, 833488.1 ± 276566.4 KW, 560497.3 ± 195572.5 KW, respectively at minimum mass flow rate (15×10^6 Kg/h). For describe of different net power output generated of ORC can be refer to the total Exergy of ORC at minimum and maximum mass flow rate of R141b, R245fa, and NOVEC 7000 as working fluids of ORC. In terms of the results of total Exergy of ORC, when each working fluid has a higher total Exergy of ORC, it means that working fluid has a higher maximal net power output of ORC. In other words, the highest, middle, and lowest total Exergy of ORC is allocated to R141b, R245fa, and NOVEC7000. Thereby, the highest, middle, and lowest maximal net power output of ORC is belonging to R141b, R245fa, and NOVEC7000, respectively. In terms of maximal net power output of ORC, the best choice and selection of working fluid is R141b. This result is in agreement with results of Chao et al. (2011) [30].

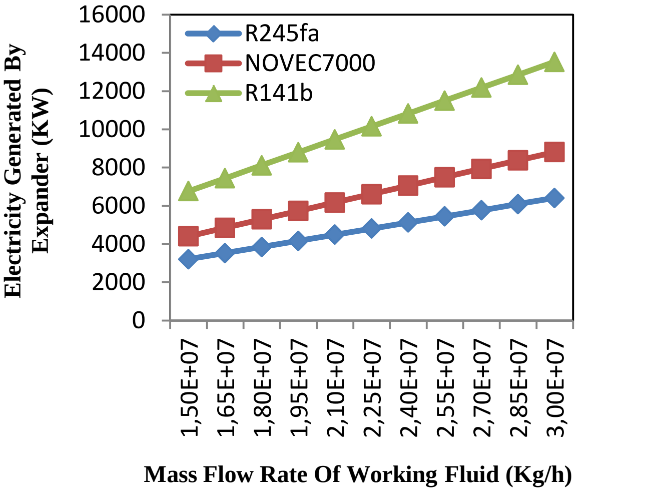

Fig. 2. The net power output of Expander of ORC thermodynamic cycle at different specific mass flow rate of different working fluids

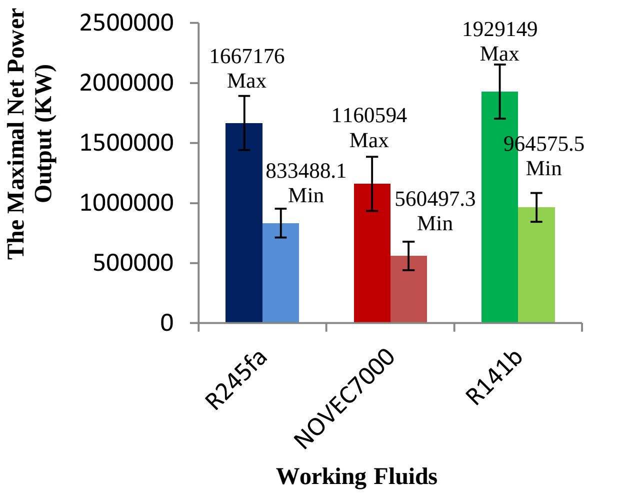

Fig. 3. The maximal net power output of ORC at maximum and minimum mass flow rate of R245fa, NOVEC7000, and R141b as working fluids of present ORC system

Fig. 4 suggests that, the value of heat transfer between Fluegas to R245fa, NOVEC 7000, and R141b as working fluids at Heat Exchanger ($\dot{Q}_{H.E}$) at different mass flow rates of each working fluid (from 15×10^6 Kg/h to 30×10^6 Kg/h). The highest, middle, and lowest amount of heat transfer between Fluegas to working fluids assign to R141b, R245fa, and NOVEC 7000, respectively. For example, at minimum mass flow rate of each working fluids the amount of heat transfer between Fluegas to working fluids for R141b, R245fa, and NOVEC 7000 in terms of highest, middle, and lowest amounts, calculate 3464951675 ± 1149194461 Kj/h, 2999951100 ± 994971222 Kj/h, and 2084919422 ± 691489567 Kj/h, respectively. At maximum mass flow rate of each working fluids the amount of heat transfer between Fluegas to working fluids for R141b, R245fa, and NOVEC 7000 in terms of highest, middle, and lowest amounts, calculate 6929903350 ± 1149194461 Kj/h, 5999902220 ± 994971222 Kj/h, and 4169838899 ± 691489567 Kj/h, respectively. The foremost reason for differences value of heat transfer between Fluegas to R245fa, NOVEC 7000, and R141b as working fluids at specific mass flow rate of these working fluids is the enthalpy deferent of each working fluid at inlet and outlet of Heat Exchanger. In sum up, the best choice between these working fluids that each one has a representative of one group of refrigerant working fluids, is the highest one it means R141b. Because of high amount of the value of heat transfer between Fluegas to each working fluid ($\dot{Q}_{H.E}$), can cause to improve and increase the amount of thermal efficiency of present ORC thermodynamic cycle. Also, the value of heat transfer between Fluegas to each working fluids ($\dot{Q}_{H.E}$), has an effect to the size of Heat Exchanger which used at present ORC. The results of P J Mago et al. (2006) [30] and Xing et al. (2013) [31], who working on similar ORC system which driven by a number of refrigerant working fluids is similar to the results which shown at Fig. 4.

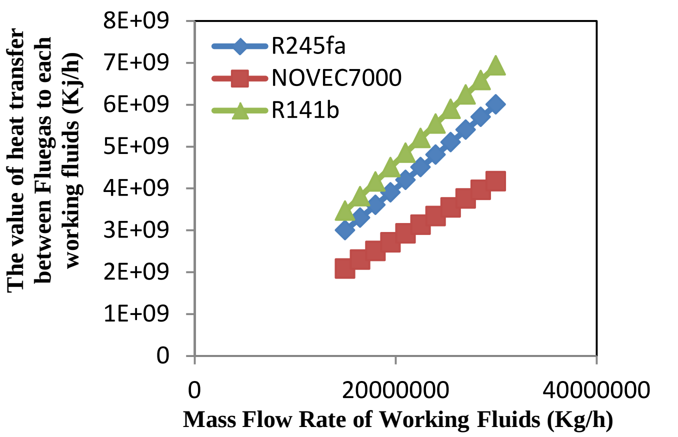

Fig. 4. The value of heat transfer between Fluegas to R245fa, NOVEC 7000, and R141b as working fluids at different mass flow rates of each working fluid

Fig. 5 and Fig. 6 illustrate the total heat transfer capacity $(UA)_{total}$ for R245fa, NOVEC7000, and R141b as working fluids at minimum mass flow rate and maximum mass flow rate of working fluids, respectively. Usually, the higher total heat transfer capacity $(UA)_{total}$ means the more cost of the heat exchanger. As shown in the Fig. 5 and Fig. 6 the total heat transfer capacity for R245fa, NOVEC7000, and R141b is 97812.10447 ± 32440.6051 KW/^{0}C, 61523.84342 ± 20405.15 KW/^{0}C, and 98647.69078 ± 32717.74 KW/^{0}C, respectively, at minimum mass flow rate of working fluids and 195624.2096 ± 32440.6051

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KW/^{0}C, 123047.6885 ± 20405.15 KW/^{0}C, and 197295.3815 ± 32717.74 KW/^{0}C, respectively, at maximum mass flow rate of working fluids. Current results claim that R141b is highest. And for NOVEC7000 is lowest, but in terms of these results the total heat transfer capacity for R245fa is middle and near to R141b. The first and foremost reason for increase and decrease the total heat transfer capacity $(UA)_{total}$ at these different working fluids is the temperature differences of heat exchanger and cooler ($\Delta T_{H.E}$ and ΔT_{cooler}). Because this thermodynamic parameter has an inverse correlation with temperature differences of heat exchanger and cooler; actually, in present ORC thermodynamic cycle, after close the cycle by Recycle instrument, the temperature of each working fluids set to near the boiling point of each working fluids for increase the efficiency and become economically of heat exchanger and also present ORC thermodynamic cycle. The second important reason that can cause more influence to change the $(UA)_{total}$ for R245fa, NOVEC7000, and R141b as working fluids is mass enthalpy of working fluids at heat exchanger and cooler ($\Delta h_{H.E}$ and Δh_{cooler}) with linear relationship. The last but not the least effective reason for go up and go down of each column of Fig. 5 and Fig. 6 is mass flow rate of working fluids before heat exchangers. Because the mass flow rate of working fluids ($\dot{m}_{W.F}$) has a linear correlation with total heat transfer capacity $(UA)_{total}$, it means with increasing the ($\dot{m}_{W.F}$) , $(UA)_{total}$ is increasing. All in all, the best choice and selection for present ORC thermodynamic cycle in terms of economic consideration, higher total net power output, and higher efficiency is NOVEC7000. Similar responses have been reported in another ORC system which simulated and analyzed by EES (Engineering Equation Solver) by Chao et al. (2012) [29].

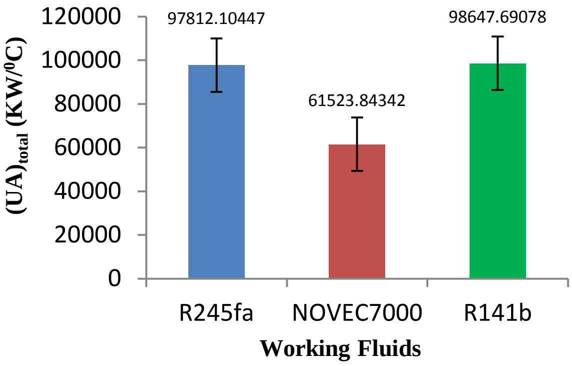

Fig. 5. The total heat transfer capacity $(UA)_{total}$ of the ORC with different working fluids at maximum mass flow rate of working fluids

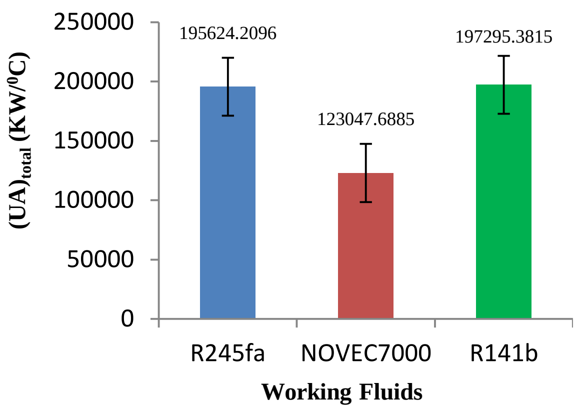

Fig. 6. The total heat transfer capacity $(UA)_{total}$ of the ORC with different working fluids at minimum mass flow rate of working fluids

Fig. 7 corresponding to compare between the optimum pressure of working fluids at outlet of Heat Exchanger or inlet of Expander and temperature of working fluids at outlet of Heat Exchanger or inlet of Expander. Whereas, the optimum pressure of working fluids at inlet of Expander has linear relationship with temperature of working fluids at inlet of Expander, with increasing the optimum pressure of working fluids at inlet of Expander, the temperature of working fluids at inlet of Expander is increasing slightly, because the optimum pressure of working fluids at inlet of Expander has a more effect on amount of electricity generated by Expander and as a result on the net power output of ORC. With increasing the optimum pressure of working fluids at inlet of Expander, the electricity generated by Expander and the net power output of ORC is increasing dramatically; in sum up, when the optimum pressure of working fluids before entering to the Expander it means at the inlet of Expander is increasing as homogenous, the glide of internal potential of working fluids can causes to increase the speed of Expander shaft and at the end of the day, generated more output electricity energy from Expander in terms of results which shown in Fig. 8. As shown in Fig. 7 and Fig. 8 in the same optimum homogenous pressures of working fluids at the inlet of Expander, the highest, middle, and lowest temperature of working fluids at the inlet of Expander is NOVEC7000, R141b, and R245fa, respectively. And also for Electricity generated by Expander, the highest, middle, and lowest is R141b, NOVEC7000, and R245fa, respectively. Because in present ORC thermodynamic cycle, after close the cycle by Recycle instrument, the temperature of each working fluids set to near the boiling point of each working fluids for increase the efficiency and become economically of heat exchanger and also present ORC thermodynamic cycle, hence sometimes for a number of refrigerant working fluids which have more different of thermal energy to each other, the thermal energy convert to electricity energy in Expander and this is one of important and foremost reason for differences electricity generated in Expander by R245fa, NOVEC7000, and R141b as working fluids. In sum up, the suitable choice and selection for working fluids are R141b and NOVEC7000. These results similar to reported results by Baomin et al. (2013) [32] who worked on Transcritical Rankine Cycle (TRC systems) which driven by some zeotropic mixture working fluids.

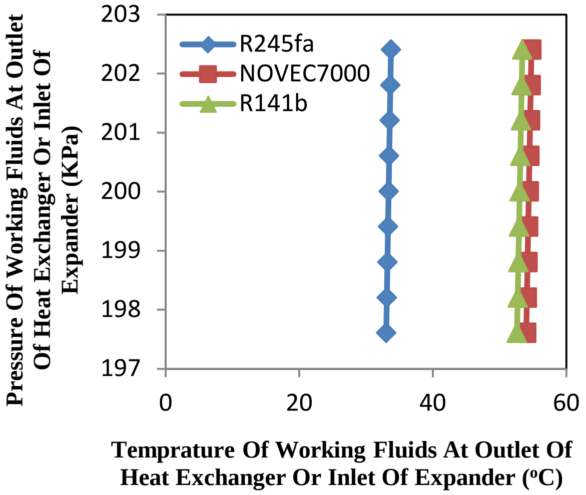

Fig. 7. The impact of optimum pressure of working fluids at inlet of Expander with temperature of working fluids at inlet of Expander

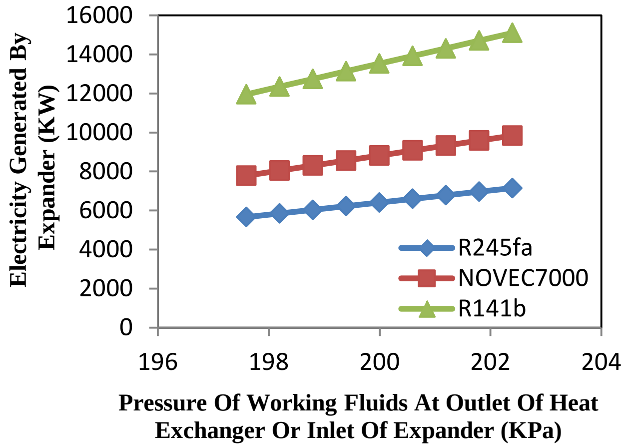

Fig. 8. The impact of optimum pressure of working fluids at inlet of Expander with electricity generated by Expander

V. CONCLUSION

In a nutshell, present ORC thermodynamic cycle was simulated and analyzed by Aspen HYSYS V7.3-aspenONE software simulation. For simulating, conducted, and analyzed current ORC system which driven by three different refrigerant working fluids that consist of: R245fa from HFC refrigerant fluids group, NOVEC 7000 from HFE refrigerant fluids group, and R141b from HCFCs group, using Fluegas of boiler as a heat source of tube and shell Heat Exchanger (H.E-100) with 19% H_2O, 9% CO_2, 70% N_2, 2% O_2 as compositions; furthermore, choosing the Peng-Robinsone fluid package as a solvent method for this ORC system. In this ORC thermodynamic cycle, working fluids are input to the Separator (S-100) at 5^0C and 101.03 KPa as a normal condition (liquid phase), then; working fluids are not completely pure and has small amount of mole fraction H2O (10% H_2O and 90% working fluid), but this is not mean the working fluids are wet because this amount of H_2O is so minimal and can be neglected and all the three working fluids are dry. Hence, for purification or if better say, for increasing the mole fraction of working fluids and decreasing the mole fraction of H2O, first of all the working fluids transfer to a separator (S-100). After completing the purification process of these working fluids in separator, and decreasing the mole fraction of H_2O, working fluids enter to the Pump (P-100) for adjust the fluid flow from turbulent to laminar and increasing the pressure of working fluids, then working fluids enter to the tube and shell Heat Exchanger (H.E-100) for changing their phase from liquid to gas because after this equipment, the working fluids should be enter to the Expander (E-100) as a feed for producing the Electricity. This tube and shell Heat Exchanger (H.E-100) for changing the phase of these working fluids from liquid to gas need a heat source which named Fluegas of boiler. Fluegas has 180-220 0C temperature. After exit these working fluids from this tube and shell Heat Exchanger (H.E-100), working fluids in gas phase enter to the Expander (E-100) where working fluids causes to rotate the seal shaft and producing the Electricity power energy. After exit these working fluids from Expander, for recovery of these working fluids, it means changing the phase of this working fluids from gas to liquid and use again in ORC thermodynamic cycle should be enter to Cooler (C-100) which working by refrigerant fluid depends on dew point of each working fluids. So with changing the phase of these working fluids of present ORC thermodynamic cycle, working fluids can come back to this thermodynamic cycle and using again for producing Electricity energy power.

The most important point for adding a preheater as a modification is in this ORC thermodynamic cycle cannot add a preheater such as: a Heat Exchanger or a Heater, before the tube and shell Heat Exchanger(H.E-100), because if add a preheater before it, the negative pressure drop occur at next equipment; in other word, in Heat Exchanger the pressure is decreasing dramatically, and cannot use two Heat Exchangers (first one as a preheater and second one as a phase changer) together in this ORC thermodynamic cycle.

After simulated, conducted, and analyzed of current ORC system the main conclusions are made as follows:

1. Investigate the net power output of Expander (E-100) of current ORC thermodynamic cycle at different specific mass flow rate of different working fluids. This result achieved at lowest to highest range of mass flow rate of each working fluids, it means: 15×10^{6} Kg/h- 30×10^{7} Kg/h. The highest range of net power output of Expander is about 6766 KW to 13530 when R141b is adopted. The middle net power output of Expander is about 6766 ± 2243.034 KW to 13530 ± 2243.034 KW when R141b is adopted. The middle net power output of Expander is about 4409 ± 1462.209 KW to 8817 ± 1469.209 KW corresponding to NOVEC7000, and the lowest net power output which belong to R245fa, has a range between 3204 ± 1062.586 KW to 6408 ± 1062.586 KW.
2. Consider the maximal net power output of ORC at maximum (30×10^{6} Kg/h) and minimum (15×10^{6} Kg/h) mass flow rate of R245fa, NOVEC7000, and R141b as working fluids of present ORC system. The quantitate amount of maximal net power output of ORC for R141b, R245fa, and NOVEC7000 as highest, middle, and lowest amount is 1929149 ± 319912.6 KW, 1667176 ± 276566.4 KW, and 1160594 ± 195572.5 KW, respectively at maximum mass flow rate (30×10^{6} Kg/h), also; The quantitate amount of maximal net power output of ORC for R141b, R245fa, and NOVEC7000 as highest, middle, and lowest amount is 964575.5 ± 319912.6 KW, 833488.1 ± 276566.4 KW, 560497.3 ± 195572.5 KW, respectively at minimum mass flow rate (15×10^{6} Kg/h).
3. Suggest the value of heat transfer between Fluegas to R245fa, NOVEC 7000, and R141b as working fluids at Heat Exchanger ($\dot{Q}_{H.E}$) at different mass flow rates of each working fluids (from 15×10^{6} Kg/h to 30×10^{6} Kg/h). at minimum mass flow rate of each working fluids the amount of heat transfer between Fluegas to working fluids for R141b, R245fa, and NOVEC 7000 in terms of highest, middle, and lowest amounts, calculate 3464951675 ± 1149194461 Kj/h, 2999951100 ± 994971222 Kj/h, and 2084919422 ± 691489567 Kj/h, respectively. At maximum mass flow rate of each working fluids the amount of heat transfer between Fluegas to working fluids for R141b, R245fa, and NOVEC 7000 in terms of highest, middle, and lowest amounts, calculate 6929903350 ± 1149194461 Kj/h, 5999902220 ± 994971222 Kj/h, and 4169838899 ± 691489567 Kj/h, respectively.
4. Founded that the total heat transfer capacity $(UA)_{total}$ for R245fa, NOVEC7000, and R141b as working fluids at minimum mass flow rate and maximum mass flow rate of working fluids, respectively. The total heat transfer capacity for R245fa, NOVEC7000, and R141b is 97812.10447 ± 32440.6051 KW/^{0}C, 61523.84342 ± 20405.15 KW/^{0}C, and 98647.69078 ± 32717.74 KW/^{0}C, respectively, at minimum mass flow rate of working fluids and 195624.2096 ± 32440.6051 KW/^{0}C, 123047.6885 ± 20405.15 KW/^{0}C, and 197295.3815 ± 32717.74 KW/^{0}C, respectively, at maximum mass flow rate of working fluids. Current results claim that R141b is highest. And for NOVEC7000 is lowest, but in terms of these results the total heat transfer capacity for R245fa is middle and near to R141b.
5. Corresponding to compare between the optimum pressure of working fluids at outlet of Heat Exchanger or inlet of Expander and temperature of working fluids at outlet of Heat Exchanger or inlet of Expander. Whereas, the optimum pressure of working fluids at inlet of Expander has linear relationship with temperature of working fluids at inlet of Expander, with increasing the optimum pressure of working fluids at inlet of Expander, the temperature of working fluids at inlet of Expander is increasing slightly, because the optimum pressure of working fluids at inlet of Expander has a more effect on amount of electricity generated by Expander and also the power generated by the cooler and as a result the net power output of ORC. With increasing the optimum pressure of working fluids at inlet of Expander, the electricity generated by Expander, cooler, and the net power output of ORC is increasing dramatically. In the same optimum homogenous pressures of working fluids at the inlet of Expander, the highest, middle, and lowest temperature of working fluids at the inlet of Expander is NOVEC7000, R141b, and R245fa, respectively. And also for Electricity generated by Expander, the highest, middle, and lowest is R141b, NOVEC7000, and R245fa, respectively.

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