Generating the Electricity from Fluegas Produced by Boiler through a ORC Thermodynamic Cycle (Organic Rankine Cycle) By Using a Shaft Tightness in Turbo-Expander

Omid Rowshanaie, Saari Bin Mustapha, and Hooman Rowshanaie

Abstract**—**In recent years, an increase in fossil fuel prices and imposing strict laws and regulations by environmental organizations have resulted in an increasing interest on the parts of researchers in oil industry to implement various projects to eliminate pollutants emitted by fluegas in order to achieved the desired standards. Today, different processes including heaters, furnaces, and boilers are used by different industries resulting in the production of a large volume of fluegas. The energy and heat wasted by these gases can be recovered even in low temperatures in order to be used in various processes such as preheating refinery fluid flows or generating electricity. ORC (Organic Rankine Cycle) is a thermodynamic cycles used for generating electricity in the majority of plants and also in this article; furthermore, its function is similar to Karno cycle. In a ORC thermodynamic cycle, superhot vapor of fluegas is first produced by a boiler and then it is sent to a evaporator then sent to a turbo-expander to produce electricity. Finally, the remaining vapor is condensed by an air cooler and it is sent back to the ORC thermodynamic cylce. ORC thermodynamic cycles are usually based on vapor working fluid fluids such as NOVEC7000, R123, R134a, and R245fa (1,1,1,3,3-pentafluoropropane), (employed in the present article) as the working fluid of ORC thermodynamic cycle.

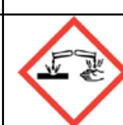
Keywords**—** fluegas, ORC thermodynamic cycle, evaporator, turbo-expander, air cooler.

I. Introduction

NOWADAYS the oil price is dramatically increase and this phenomenon is 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 in ORC (Organic Rankine Cycle) [1].

The most important obstacle in all ORC thermodynamic cycles is choosing the suitable working fluid. In this ORC thermodynamic cycle uses a number of working fluids such as: NOVEC7000, R123, R134a, and R245fa that some reason for choose one or two working fluids from these, are more important, the first and foremost is thermodynamic performance, another one is environmental behavior, and the last but not the least which in industrial world has a more benefit effect is system cost. For choosing the suitable and affordable working fluid should be focus on some point that in the below mention them.

TABLE I

	R245fa	NOVEC 7000	R123	R134a
Autoignition Temperature (^0C)	412	415	770	>750
Volatility Range	Low	Medium	High	Low
Boiling Point @ 1atm (^0C)	15.3	34	27.9	-26.2
Labeling Pictograms				
Hazard Statement	Contains gas under pressure; may explode if heated. Asphyxiate in high concentrations.	Contains gas under pressure. Acidity.	Acidity. Colorless. Volatile liquid with ethereal and faint sweetish odor.	Has Halogens acids and possibly carbonyl halides. Hazardous polymerization will not occur.
$\Delta h_{Vap.}$ (kj/kg) @ 100^0C	134.4	105.9	Not Available	Not Available
$\rho_{Vap.}$ (kg/m^3) @ 100^0C	73.15	53.03	Not Available	Not Available
Toxicity	Oral Inhalation Dermal	Skin Oral Inhalation Eyes Ingestion	Skin Eyes Inhalation Ingestion	Skin Eyes Inhalation Ingestion

The first and foremost is working fluid should be non-flammable, for knowing this properties would refer to the autoignition temperature, and this is non-fiction, if

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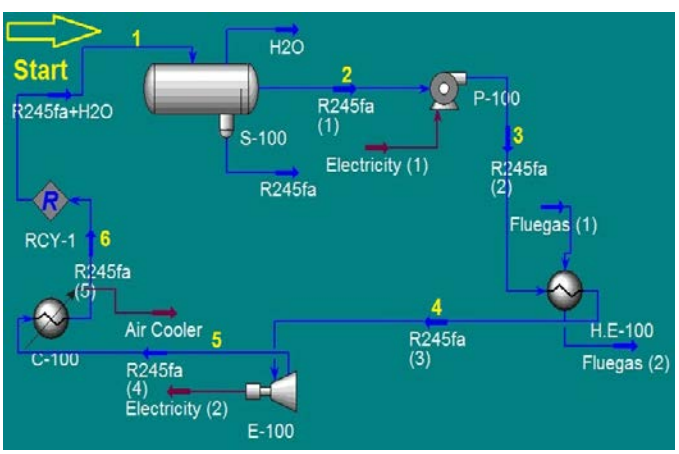
autoignition temperature of a working fluid is high, this working fluid is closed to non-flammable. Another point which causes to select a suitable working fluid for this thermodynamic cycle is volatility because when do not use turbo-expander in a hermetic and tightness container, the range of volatility of working fluid would be low for increasing the efficiency of ORC cycle. Another point is reasonable and low boiling point temperature in a normal working condition because even though boiling point temperature of working fluid is low; therefore, the evaporator need to consume lower heat energy to change the phase of working fluid from liquid to gas; although, ORC thermodynamic cycle need a little evaporator instead of big one, and the system cost is decreasing. Other points which can consider together and get the same result to select an affordable working fluid for this thermodynamic cycle are labeling pictograms, hazard statement, and toxicity of these working fluids that can see in table 1. The last but not the least point that more influence for choosing the suitable working fluid is high heat of vaporization ($\Delta h_{Vap.}$) and high density in vapor state ($\rho_{Vap.}$) in reference temperature. Because when these properties are high for working fluid, it means the ORC thermodynamic cycle need a smaller turbo-expander; furthermore, the cost of system is decreasing slightly.

All in all, after considering all these properties which show in table 1, the best choice for working fluid which using in this ORC thermodynamic cycle is R245fa [2].

II. Material And Methods

A. ORC Process

The process of this ORC thermodynamic cycle which show in Fig. 1 is very marvelous and interest.



Picture. 1 Scheme of ORC

In this ORC thermodynamic cycle, liquid R245fa as a working fluid is not completely pure and has 0.1 mole fraction H_2O. For purification or if better say, for increasing the mole fraction of R245fa and decreasing the mole fraction of H_2O, first of all the working fluid with 30*106 kg/h mass flow rate, 14.69 0C temperature, and 101.3 KPa pressure transfer to a

separator (S-100). After completing the purification process of working fluid in separator, and decreasing the mole fraction of R245fa and H_2O to 0.9998 and 0.0002 respectively, R245fa enter to the electrical pump (P-100) with 1651.86 hp for adjust the fluid flow and increasing the pressure, then R245fa enter to the heat exchanger (H.E-100) for changing the phase from liquid to gas because after this equipment, the working fluid should be enter to the expander (E-100) as a feed for producing the electricity. This heat exchanger (H.E-100) for changing the phase of working fluid from liquid to gas, need a heat source which named fluegas. Fluegas has 180-220 0C temperature, but in Hysys simulation software because this software cannot accept the temperature range for fluegas. Unwillingly and reluctantly using the average of this temperature range it means 200 0C, 10980 KPa pressure and 67340 m3/h volume flow rate for inlet and after exit the fluegas from heat exchanger (H.E-100), the temperature and pressure decrease to 80 0C and 253.6 KPa respectively. After exit the R245fa from this heat exchanger (H.E-100) the temperature is increasing, and pressure is decreasing. Then R245fa in gas phase enter to the expander (E-100) which working fluid causes to rotate the seal shaft and producing the electricity energy at about 6408 KW under best working condition and state. After exit the R245fa from expander, for recovery of R245fa, it means changing the phase of this working fluid from gas to liquid and can use again in ORC thermodynamic cycle should enter to cooler (C-100) which working by cool drops water with cool air. So with changing the phase of R245fa as a working fluid of this ORC thermodynamic cycle, R245fa can come back to this thermodynamic cycle and using again for producing electricity.

In this ORC thermodynamic cycle with adding a modification can increase the efficiency of ORC thermodynamic cycle at about 10% more than last state. The most important modification for this ORC thermodynamic cycle is using a turbo-expander which enclosed in to a hermetic and tightness container. Because all the turbo-expander do not hermetic and tightness, and always has leakage of working fluid. In this case shaft tightness of turbo-expander versus shaft seal has two important differents: the first and foremost different is pressure different at about 780 KPa and the second important different is rotational speed at about 3550 rpm different from shaft seal.

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 evaporator (E-100), because if add a preheater before evaporator (E-100), the negative pressure drop occur at next equipment; in other word, in evaporator the pressure is decreasing dramatically, and cannot use two evaporator (first one as a preheater and second one as a phase changer) together in this ORC thermodynamic cycle.

The following equation developed by Ali Bourji et.al [3]

which can estimate the amount of electricity generated by a simple ORC thermodynamic cycle:

$$P=Q_{fg}[AT_{fg}T_a+BT_a+CT_{fg}+D]$$

P : amount of electricity energy [kw]
Q_{fg} : volume flow rate of fluegas [m^3/h]
T_{fg} : temperature of inlet fluegas [^{0}C]
T_a : ambient temperature(=21) [^{0}C]
A : -0.00411 [without dimension]
B : 0.775 [without dimension]
C : 1.122 [without dimension]
D : -211.63 [without dimension]

This equation has application to 177-260 0C, and defining an area which a working fluid is becoming this area to a super critical area. The temperature and pressure range of this super critical area is lower than critical point of working fluid.

III. Conclusion

In a nutshell, statistical estimation of other researches reveal this fact that add or remove and increase or decrease some equipment or parameters can cause to increase the performance and efficiency of ORC thermodynamic cycles. In other word, with increasing the usage of exhaust heat the efficiency and the outlet of net power of ORC thermodynamic cycle are increasing as well as possible. The most important thing that impact on net power and efficiency is selecting a sufficient working condition for ORC thermodynamic cycle .If want to have the appropriate efficiency and net power output in ORC thermodynamic cycles, the temperature of industrial process as the exhaust heat should not more than 370 0C; furthermore, more than this temperature can cause heat pollution in environment and increasing the global warming. All in all, the organic rankine cycle (ORC) has a number of advantages such as: great flexibility, high safety, and low maintenance [4].

Ali Bourji et.al [3] doing similar research in this area, but different heat source temperature (fluegas temperature) which show in figure 1. They using low temperature range of fluegas for this ORC process, and the amount of electricity energy produced in their research is equal to 8815 KW under high efficiency of ORC thermodynamic cycle. But present research has a different temperature range of fluegas which show in figure 2. The amount of electricity energy produced in present research is equal to 6408 KW under high efficiency of ORC thermodynamic cycle and without any negative pressure drop in equipment.

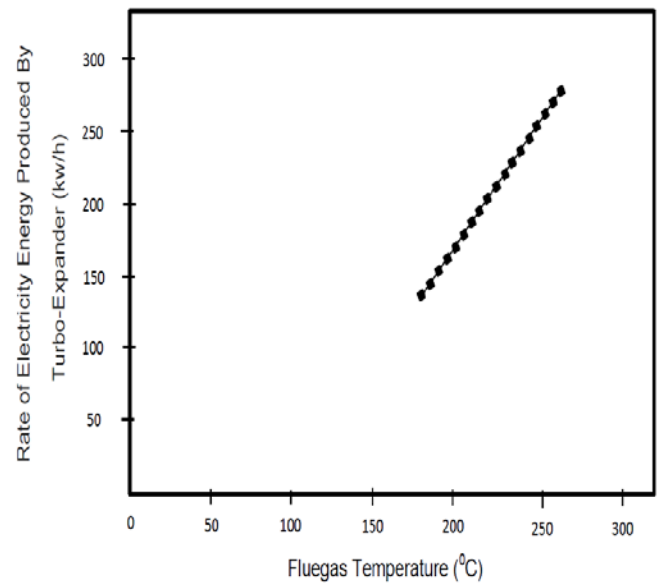


Fig. 1

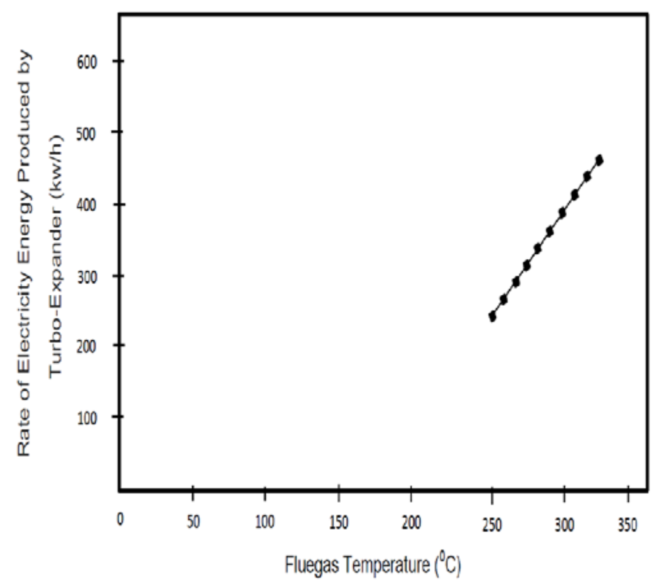


Fig. 2

After compare above figures to each other, Ali Bourji et.al [3] and present research claimed that the rate of electricity energy produced by turbo-expander of ORC thermodynamic cycle with fluegas temperature have a linear relative to each other; otherwise, with increasing the fluegas temperature, the rate of electricity energy is also increasing in both above figures.

Another result that achieve in present research is relating between mass flow rate of R245fa as a working fluid of this ORC thermodynamic cycle and electricity energy produced by turbo-expander of ORC thermodynamic cycle which show in figure 3.

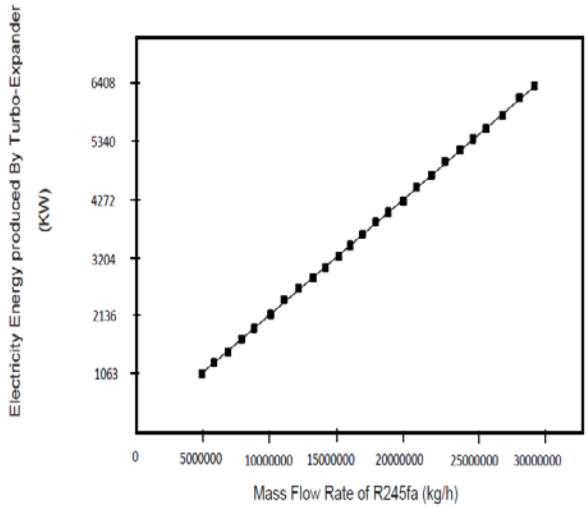


Fig. 3

In these results which show in figure 3, with increasing the mass flow rate of R245fa, the electricity energy produced by turbo-expander is also increasing. Because when the mass flow rate of R245fa is increasing, it means the potential energy of R245fa for rotating the seal shaft of turbo-expander is increasing, and as a result, the amount of electricity energy is increasing.

At the end, if refinery employers using ORC process which simulated in present research, they can become the refineries to independent from electricity energy producing, and decreasing the cost of refineries for buying the required electricity energy of refinery equipment from electricity power plants.

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