A STUDY ON ORGANIC RANKINE CYCLES WORKING WITH R 245 fa AND R 236 fa

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Abstract: In this paper is analysed the Organic Rankine Cycle working with two enveronmentaly friendly refrigerants: R 245 fa and R 236 fa (both of them from the HFC family).

Having in view that the choice of the proper refrigerant is an important issue, are exposed the properties of R 245 fa and R 236 fa.

Using the exergy analysis is possible to asses the thermodynamic efficiency of a process. That's why are calculated exergy losses for the both situations. It is seen that R 236 fa presents higher values for the exergy losses.

Keywords: Organic Rankine Cycle, refrigerant, exergy.

1. INTRODUCTION

Fossil fuels are the most commonly used means of energy in the modern world. Although important reserves of fossil fuel still exists, the major increase in fossil fuel consumption since the 19th century has lead to a severe depletion of these reserves. On the other hand, although they are a natural substance, fossil fuel consumption leads to a severe increase in air, water and land pollution. In order to create energy, the fuel is burned, resulting chemical compounds into the air.

Carbon dioxide, sulphur and nitrogen oxides are three of the mostly met products of burning fossil fuels. These lead to atmospheric damage to the ozone layer and also contribute to acid rain. In urban centres, the use of fossil fuel causes the smog which gives breathing problems to people that inhale it.

Additionally, the fuel transportation from the reserves around the world might end with environmentally devastating oil spills.

Above mentioned negative implications of fossil fuel consumption led to several scientific actions that search alternative energy sources able to replace

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traditional fossil fuel uses. As a consequence, solar, wind, hydroelectric and geothermal power seem to be potential substitutes of fossil fuel applications.

Organic Rankine Cycles (ORC_s) can different working fluids in order to exploit low grade heat sources to produce useful work. The ORC process works like a Clausius–Rankine steam power plant but uses an organic working fluid instead of water. The working fluid is heated to boiling and the expanding vapour is used to drive a turbine. This turbine can be used to drive a generator to convert the work into electricity. The working fluid vapour is then condensed back into a liquid.

Figure 1 shows the configuration of the basic ORC for converting waste heat into useful electric power and its process in a T–s diagram.

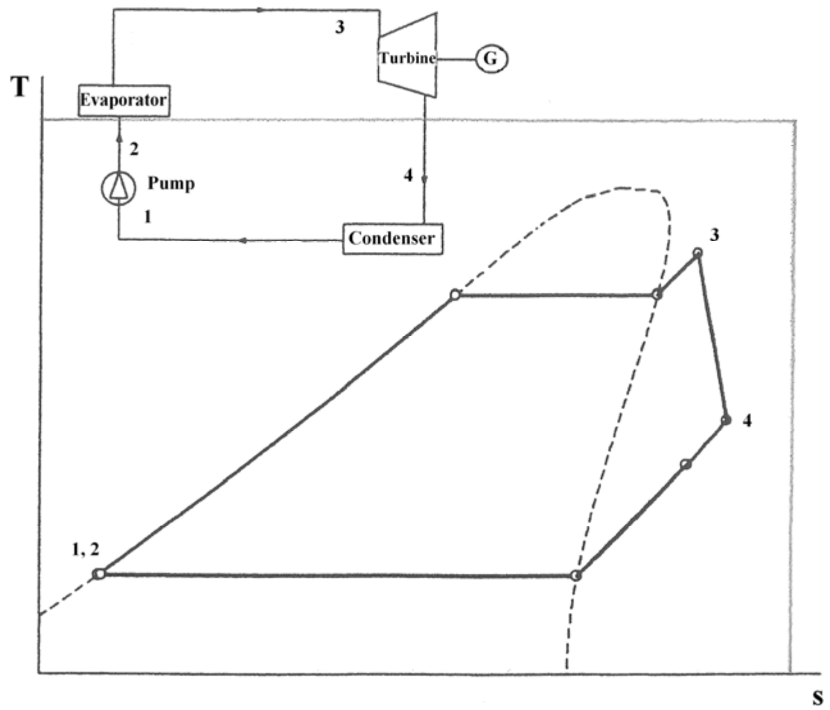

Fig. 1. Schematic basic ORC and the T–s diagram

2. ABOUT THE WORKING FLUIDS

One of the main challenges of ORC process is the choice of the appropriate working fluid.

2.1. About R 245 fa

The refrigerant R 245 fa is selected due its good thermal transfer and control properties as well as its acceptability based on environmental concerns. R 245 fa is non ozone depleting, has a low warming potential and is non flammable. Ozone Depletion Potential for R 245 fa (HFC 245 fa) is zero and its Global Warming Potential (100–yr time horizon) is 950.

The properties of R 245 fa are given in Table 1.

Table 1. **Properties of the green refrigerant R 245 fa**

Molecular weight, [kg/mol]	134
Boiling point, [^oC]	58,8
Freezing point, [^oC]	< –160
Critical temperature, [^oC]	256,9
Critical pressure, [MPa]	3,64
Purity, [%]	$\geq$ 99,8
Moisture, [ppm]	$\leq$ 20
Acidity, [ppm]	$\leq$ 0,1
Vapour residue, [ppm]	$\leq$ 100
Appearance	colourless
Odour	No strange stench

R 245 fa can be used in a broad range of new air conditioning and refrigeration equipment, as well as to retrofit existing equipment currently using CFC and HCFC refrigerants. It can be used to replace CFC 11, CFC 113, CFC 114, HCFC 123 and HCFC 141 b in new and existing non–mechanical and secondary cooling systems, very low temperature refrigeration and industrial process air cooling and refrigeration.

2.2. About R 236 fa

Hexafluoropropane 236 fa is a HFC used as fire retardant, refrigerant, spraying agent, foamer and heat carrier. Its properties are given in below. His Ozone Depletion Potential is zero.

Table 2. **Properties of the green refrigerant R 236 fa**

Molecular weight, [kg/mol]	152,04
Boiling point, [^oC]	–1,4
Freezing point, [^oC]	–93,6
Critical temperature, [^oC]	124,9
Critical pressure, [MPa]	3,20
Purity, [%]	$\geq$ 99,5
Moisture, [ppm]	$\leq$ 10
Acidity, [ppm]	$\leq$ 3
Residue of evaporation, [ppm]	$\leq$ 100
Appearance	without suspension or precipitate
Odour	no smell

3. CONCEPT OF EXERGY ANALYSIS

In the past, the evaluation of the energy efficiency of a process was made based on the first law of thermodynamics. The quality of energy in a process can be assessed by the second law of thermodynamics, law related directly to exergy.

The exergy of a process stream at given temperature and pressure (T and p) is defined as the maximum amount of work output which can be obtained as the stream is changed reversibly from the given state to the state of equilibrium with the environment at T_0 and p_0 and is given by:

The exergy of the air stream in given by:

$$Ex = H - T_0 S \tag{1}$$

As the exergy of a stream is a direct function of its enthalpy and entropy, both of them being functions of state, exergy itself is a function of state. In this way, the exergy value of a given stream can be calculated from the stream proprieties as composition, temperature and pressure. When a system passes from state 1 to 2, the exergy change of the system is written as:

$$Ex_{12} = Ex_2 - Ex_1 = \Delta H_{12} - T_0 \Delta S_{12} \tag{2}$$

Or for a streaming fluid, the specific exergy is:

$$e = h - h_0 - T_0 \left(s - s_0 \right) \tag{3}$$

Using that

$$dh = c_p dt \tag{4}$$

And

$$p = p_0 = const ,$$

the entropy is calculated with:

$$ds = \frac{dh - vdp}{T} = \frac{dh}{T} = c_p \frac{dT}{T} \tag{5}$$

So:

$$e = \int_{T_0}^{T} \left(dh + T_0 ds \right) = \int_{T_0}^{T} \left(c_p + \frac{T_0}{T} \right) dt = c_p \left[T - T_0 - T_0 \ln \left(\frac{T}{T_0} \right) \right] \tag{6}$$

All natural processes are irreversible reason why they lead to the degradation of energy. Whenever energy is transformed or transferred, its potential for producing useful work or energy is reduced forever.

That is why in order to accomplish a certain exergy output, a real process always requires a higher exergy input. The difference is the exergy lost due to irreversibility.

$$Ex_{loss} = Ex_{in} - Ex_{out} = Ex_{irr} \tag{7}$$

The exergy loss gives the measure of the thermodynamic efficiency of the process. The lower the exergy loss, the higher the thermodynamic efficiency of the process and the lower the energy required. The maximum thermodynamic efficiency is set by the reversible process, where the exergy loss is zero.

Having in view that the heat source (HS) is not cooled down to the temperature T_0, the rest of exergy after the heat exchanger that is not further used is also seen as losses:

$$Ex_{loss} = m_{HS}\left(e_{2HS} - e_{0HS}\right) - m_{ORC}\left[h_2 - h_0 - T_0\left(s_2 - s_0\right)\right] \tag{8}$$

$$Ex_{loss} = m_{HS}\, c_p\left[T_{2HS} - T_0 - T_0 \ln\left(\frac{T_{2HS}}{T_0}\right)\right] + m_{ORC}\left[h_2 - h_1 - T_0\left(s_2 - s_1\right)\right] \tag{9}$$

4. DISCUSSION OF RESULTS

In this study was considered that the feed pump efficiency was of 0.85 and the turbine efficiency was of 0.80. The condensation temperature was of 20^0C. The exhaust steam after the turbine was >0.90 in order to avoid droplet erosion.

In was considered a constant superheating of 2K for live vapour temperatures <0.965 T_{cr}.

In table 3 is presented the comparison of exergy losses versus the live vapour temperature for the two selected working fluids: R 245 fa and R 236 fa. The temperature of the heat source is 210^0C.

Table 3. **Exergy losses versus live vapour temperature**

Live vapour temperature [^{0}C]	**Exergy losses [kW]**	
	R 245 fa	R 236 fa
50	10417	12000
62,5	9583	10000
75	8000	8333
87,5	6800	7083
100	5200	6000
112,5	4400	5000
125	3600	4000
137,5	2800	3333
150	2400	2500

It is known that the gain in efficiency is directly connected with the reduction of the exergy losses. Exergy analysis reveals the irreversibility and shows the possibilities where improvements in efficiency could be made.

It is seen that exergy losses decrease with the increment of live vapour temperature for the both refrigerants. A better efficiency is obtained when using R 245 fa.

5. CONCLUSIONS

In this paper was analysed a simple Organic Rankine Cycle working with two green refrigerants: R 245 fa and R 236 fa.

The present paper investigated the exergy losses for the two mentioned working fluids depending on live vapour temperature, in order to see low values of exergy losses corresponding to high values of thermodynamic efficiency.

For a heat source temperature of 210 °C, it was found that low values of exergy losses are given by high values of live vapour temperature.

The best choice is revealed to be the working fluid R 245 fa.

REFERENCES

[1]. Yari, M., *A comparative study on the performance of the Organic Rankine Cycles*, Proceedings of ECOS, Cracow, Poland, 105–113, 2008.

[2]. Mago, P.J. et al., *Performance analysis of different working fluids for use in Organic Rankine Cycles*, Proceedings ImechE Vol. 221, Part A: Journal of Power and Energy, 2207; 221: 255–264.

[3]. Saleh, B. et al., *Working fluids for low temperature Organic Rankine Cycles*, Energy 2007; 32: 1210–1221.

[4]. Schuster, A. et al., *Innovative applications of Organic Rankine Cycle*, Proceedings of ECOS, Crete, Greece, 2006.