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UTILIZATION OF RESIDUAL HEAT FROM THE DISTILLATION IN THE ETHANOL PRODUCTION PROCESS TO GENERATE ELECTRICITY THROUGH AN ORGANIC RANKINE CYCLE (ORC)

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Abstract. *The need to decrease the dependence of fossil fuels has raised the interest in exploring other renewable energy sources, specially ethanol from sugarcane in Brazil. Inside the ethanol production process, there is a step called distillation, which separates ethanol into water, in the so-called distillation towers, where there is a need for heat (process steam) in the so-called reboilers and the extraction of heat (cold utilities) in the condensers. The heat to be withdrawn in the condensers may be serving as the heat source for Organic Rankine (ORC) cycles. Thus, the main objective of this work is the study of the thermodynamic properties of the application of organic fluids in an ORC for the utilization of residual heat from the distillation system in the sugarcane ethanol production process, as well as the gain of power inserted to the power generation in a traditional Rankine Cycle. The simulations were done in the Engineering Equation Solver software (EES), using an isentropic fluid (R227ea), and the results showed an increase of produced electricity in the ethanol production process, being able to take advantage of a residual heat.*

Keywords: *Organic Rankine Cycle, Residual Heat, Ethanol Production Process.*

1. INTRODUCTION

The need to decrease the dependence of fossil fuels has raised the interest in exploring other renewable energy sources. Brazil stands out in the global scene due to its large production of ethanol from sugarcane. In 2014, Brazil was the largest producer and exporter of this fuel (Vieira et al., 2007), reaching 30 billion liters of ethanol in 2016 (Portal Brasil, 2017). Figure 1 shows a simplified diagram of the ethanol production process from sugarcane.

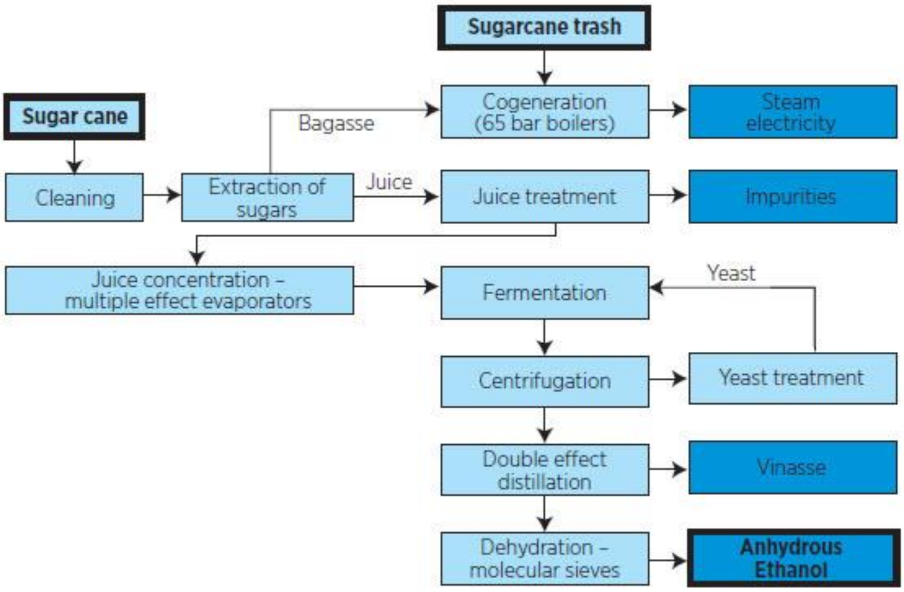

Figure 1. Ethanol Production Process (Cleanleap, 2017).

The ethanol production process begins with the juice extraction system, where the sugarcane bagasse and juice are separated. Bagasse serves as fuel for the cogeneration system. The juice undergoes a treatment and is concentrated before going to the fermentation system. In the fermentation step, the sucrose present in the juice is converted into ethanol. The product resulting from the fermentation is called wine and has an ethanol concentration between 7 and 10% ethanol and the rest water and other residual components. The distillation system separates ethanol into water, in the so-called distillation towers, where there is a need for heat (process steam) in the so-called reboilers and the extraction of heat (cold utilities) in the condensers. The heat to be withdrawn in the condensers may be serving as the heat source for Organic Rankine (ORC) cycles.

When heat sources with low temperatures (< 200 ° C) are available, the ORC can be used to produce energy by operating with organic working fluids, different from traditional water steam. One of the major challenges in designing an ORC is the proper choice of working fluid for the operation. This design decision has a great influence on the performance of thermal systems.

The main objective of this work is the study of the thermodynamic properties of the application of different organic fluids in an ORC for the utilization of residual heat from the distillation system in the sugarcane ethanol production process, as well as the gain of power inserted to the power generation in a traditional Rankine Cycle.

2. COMPUTATIONAL PROCEDURE

2.1 Thermodynamic analysis of the Organic Rankine Cycle through EES software

The equations used in the modelling were obtained by the adoption of simplifying hypotheses in Eq. (1), Eq. (2) and Eq. (3), which represent the mass balance, energy balance and entropy balance respectively (Çengel and Boles, 2013).

$$\frac{dm_{CV}}{dt} = \sum \dot{m}_{in} - \sum \dot{m}_{out} \tag{1}$$

$$\frac{dE_{CV}}{dt} = \dot{Q}_{CV} - \dot{W}_{CV} + \sum \dot{m}_{in}\left(h + \frac{V^2}{2} + gz\right)_{in} - \sum \dot{m}_{out}\left(h + \frac{V^2}{2} + gz\right)_{out} \tag{2}$$

$$\frac{dS_{CV}}{dt} = \sum \dot{m}_{in} s_{in} - \sum \dot{m}_{out} s_{out} + \sum \frac{\dot{Q}_k}{T_k} + \dot{S}_{gen} \tag{3}$$

For the calculation of thermal efficiency of the cycle, the Eq. (4) was used, which represents a measure of performance.

$$\eta = \frac{\text{Net power output}}{\text{Heat input}} \tag{4}$$

Fluids were simulated in the basic ORC layout presented in Fig. 2, using the EES software, because it already has the thermodynamic properties of the various organic fluids to be studied. It was adopted as hypotheses that all processes occur in steady state, without variations of kinetic and potential energy, with heat transfer processes at constant pressure, with no load losses and reversible. The isentropic efficiency of the pump was considered as 0.85, and 0.90 for the turbine.

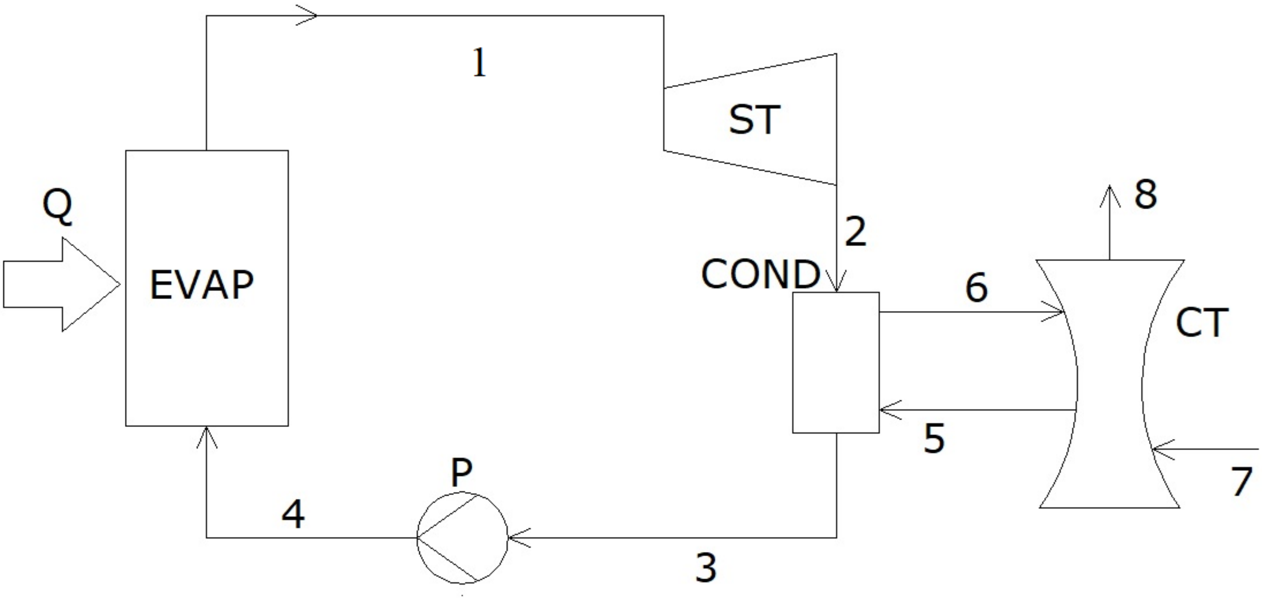

Figure 2. Basic layout of the Organic Rankine Cycle.

For modeling, it is necessary to provide some variables. The parameters used in the simulation can be seen in Table 1.

Table 1. Parameters adopted for cycle simulation (Dias et al., 2011).

Parameters	Values
Processed sugarcane	493 ton/h
Maximum temperature	68°C
Maximum pressure	1200 kPa
Heat transfer rate from the condenser of destilation system	35 MW

Table 2 summarizes the initial parameters considered and calculated for all models in each state of the Figure 2.

Table 2. Parameters used in modelling.

State	Description	Considered Parameters	Calculated Parameters
1	Evaporator outlet	T_1 = 68°C, P_1=1200 kPa	h_1, s_1
2	Turbine outlet	s_2=s_1, P_2=P_3	h_2, x_2, h_{2real}
3	Condenser outlet	T_3=35°C, x_3=0	h_3, s_3, P_3
4	Pump outlet	P_4=P_1, s_4=s_3	h_4, h_{4real}
5	Cooling water input at the condenser	T_5 = 20°C, x_5 =0	h_5, s_5
6	Cooling water outlet of the condenser	T_6 = T_5 + 20°C, x_6 = 0	h_6, s_6
7	Damp air input at cooling tower	T_7 = 20ºC, P_7 = 100 kPa, φ_7 = 0.35	P_{g7}, P_{v7}, h_{v7}, ω_7, s_{v7}, s_{air7}, vol_7
8	Damp air outlet of cooling tower	T_8 = 25ºC, P_8 = 100 kPa, φ_8 = 0.85	P_{g8}, P_{v8}, h_{v8}, ω_8, s_{v8}, s_{air8}, vol_8

3. RESULTS AND DISCUSSION

The study was made with R227ea, which is an isentropic fluid. The value of P1 (pressure at the state 1) was determined based on the evaluation of the T-s diagram, opting for values of pressure that the lines were around the temperature of the state 1 of the layout. Figure 3 shows the graph plotted for the modelled fluid.

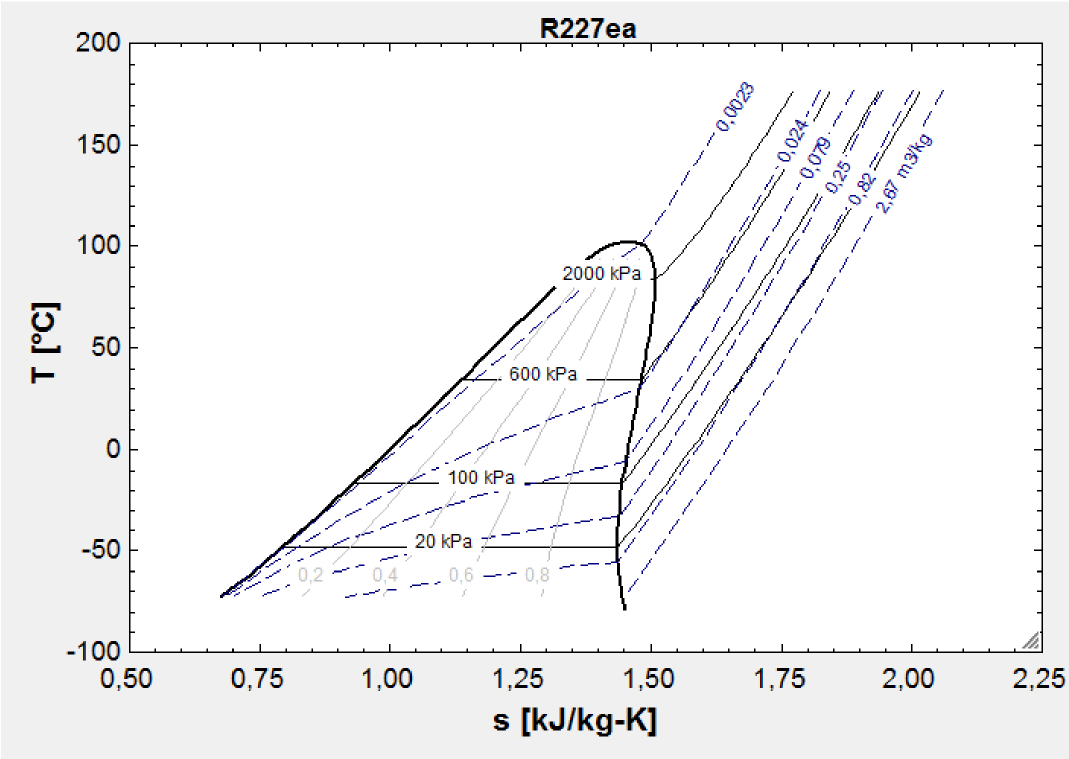

Figure 3. T-s diagram of R227ea.

At Table 3, the operation conditions of R227ea at the ORC are presented, and Table 4 contains some parameters that present the performance of this fluid in the simulation.

Table 3. Operation conditions of R227ea.

R227ea (isentropic fluid)						
State	**Description**	**Pressure [kPa]**	**Temperature [°C]**	**Enthalpy [kJ/kg]**	**Entropy [kJ/kg]**	**Quality (x)**
1	Evaporator outlet	1200	68	368.4	1.524	-
2	Turbine outlet	610.8	50.09	360.4	1.527	-
3	Condenser outlet	610.8	35	240.7	1.139	0
4	Pump outlet	1200	35.45	241.2	1.139	-

Table 4. Parameters calculated at the simulation of R227ea.

Efficiency [%]	Mass flow [kg/s]	Produced power at the turbine [kW]	Consumed power at the pump [kW]	Electricity surplus increase [%]
5.89	275.1	2202	141.7	6.67

By the analysis of the results found in table 4, one can verify a great quantity of produced power at the turbine, that leads to an electricity surplus of 6.67%, when comparing to a traditional Rankine Cycle configuration (Dias et al., 2011). This result will increase the total electricity produced, taking advantage of a residual heat that would be a loss in the process. The calculated efficiency of the cycle is adequate to the expected in a ORC.

4. CONCLUSIONS

This paper had the objective of studying the use of a residual heat from the distillation of an ethanol production process to generate more power using an Organic Rankine Cycle. At first, the parameters used to evaluate the fluid performance are efficiency, power consumed at the pump, power produced at the turbine and mass flow. Considering that, it was found good results in general using an isentropic fluid (R227ea). Other fluids could be tested in future analysis in order to compare the results.

To date, only the most basic configuration of the Organic Rankine Cycle has been revised, but modifications can be made to increase its efficiency. Such modifications can explore the characteristics of each fluid class and thus identify configurations that perform better.

5. ACKNOWLEDGEMENTS

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7. RESPONSIBILITY NOTICE

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