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OPTIMIZATION AND EXERGETIC ANALYSIS OF A REGENERATIVE CYCLE USING BIOGAS COMBINED WITH HYDROGEN AS FUEL

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Abstract. *Recently, a great expectation of large investments in renewable energy is noticeable in Brazil, it is aiming the dependency on hydroelectric plants reduce due to rain shortages. It is important to think in alternative ways of obtaining energy through residue and recycling. The residue, also known as trash, mainly the organic type, which still represents a disposal problem to its sources offers great energy power and should be used efficiently. The biogas, for instance, can be obtained in sanitary landfills or bio digesting units. Biogas is already studied in many countries and universities, it provides alternatives which, in the future, can replace non-renewable energy. In this study, optimization and exergetic analysis of a regenerative cycle using biogas combined with hydrogen as fuel are performed. To do so, mathematical modeling of the cycle is performed based on a thermodynamic model where mass, energy, entropy and exergy balances are considered. Also, the mathematical modeling of the combustion relative to the process is performed combining the methane (as biogas) and hydrogen. This latter fuel element will be inserted to increase the power supply in an aquatubular boiler.*

Keywords: *thermodynamic modeling, optimization, exergetic analysis, regenerative cycle, biogas and hydrogen.*

1. INTRODUCTION

Energy generation can be produced by thermoelectric plants using biogas with hydrogen as fuel to feed the boilers. Biogas is obtained from sanitary landfills and bio digesters due to organic matter decomposition and hydrogen from the fuel cell. This study was performed to demonstrate how much the combined organic residues can be useful in energy generation.

2. COMPUTATIONAL PROCEDURE

Figure 1 shows, only at the knowledge discretion, a simplified thermodynamic model with energy mass balance of a regenerative cycle.

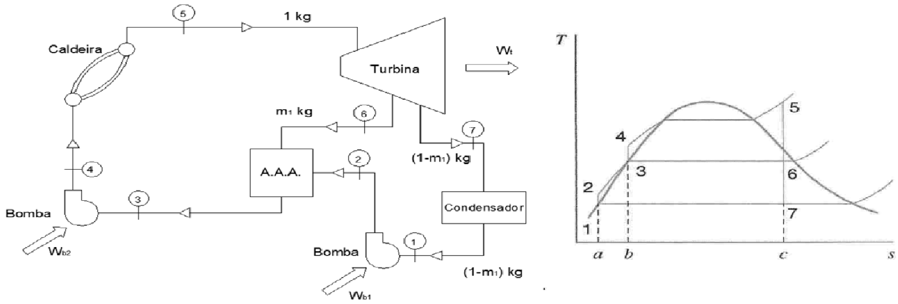

Figure 1. Schematic drawing and T-s diagram of regenerative cycle.
Source: Sonntag; Borgnakke (2006) Adapted.

2.1 Boiler

The boiler mathematical model (Figure. 1 – part 4 and 5) was developed based on mass-energy balances applied to this component. The balances regarding permanent regime are presented on equation (1) and equation (2).

$$\dot{m}_4 = \dot{m}_5 \quad (1)$$

$$\dot{Q}_H = \dot{m}_4 (h_5 - h_4) \quad (2)$$

2.2 Turbine

The turbine is presented on Figure 1, part 5,6,7. The balances of mass and energy applied to the turbine, considering the cycle in *permanent regime*, presented on equation (4) and equation (5).

$$\dot{m}_5 = \dot{m}_6 + \dot{m}_7 \quad (4)$$

$$\dot{W}_{turbina} = \dot{m}_5 h_5 - \dot{m}_6 h_6 - \dot{m}_7 h_7 \quad (5)$$

Considering a theoretical turbine, in a first approach no heat exchange with the environment was considered (adiabatic turbine), applying the second law of Thermodynamics to this component as presented on equation (6).

$$s_5 = s_6 = s_7 \quad (6)$$

2.3 Low pressure pump

Low pressure pump is presented in figure 1, part 1-2. The mass and energy balances applied to the low-pressure pump, considering the cycle under permanent regime, as presented on equation (7) and equation (8).

$$\dot{m}_1 = \dot{m}_2 \quad (7)$$

$$\dot{W}_{bomba;baixa} = \dot{m}_1 (h_1 - h_2) \quad (8)$$

Considering a theoretical pump, no heat exchange with the environment (adiabatic turbine), the second law of thermodynamics is applied to this component as presented on equation 9.

$$s_1 = s_2 \quad (9)$$

2.4 High pressure pump

The high-pressure pump is presented in figure 1, part 3-4. The mass and energy balances are applied to this component considering the cycle under permanent regime, as presented in equation (10) and equation (11).

$$\dot{m}_3 = \dot{m}_4 \tag{10}$$

$$\dot{W}_{bomba;alta} = \dot{m}_3 (h_3 - h_4) \tag{11}$$

Considering a theoretical pump, no heat exchange with the environment (adiabatic turbine), the second law of thermodynamics is applied to this component as presented on equation (12).

$$s_1 = s_2 \tag{12}$$

2.5 Effective work produced in the regenerative cycle and its efficiency

The effective work produced in the regenerative cycle is obtained from the total work produced in the cycle minus the work performed by the pumps as shown in equation (13).

$$\dot{W}_{líquido} = \dot{W}_{turbina} - \dot{W}_{bomba;alta} - \dot{W}_{bomba;baixa} \tag{13}$$

The regenerative cycle efficiency is obtained from the second thermodynamics law and can be calculated by the equation (14).

$$\eta_{teórico} = \frac{\dot{W}_{líquido}}{\dot{Q}_H} \tag{14}$$

Some real operation can be implemented to the regenerative cycle. The efficiency of the 1st law or equipment efficiency for the low-pressure pump and for the low-pressure pump (Figure 1, part 1-2 and part 3-4) is calculated according to equation (15) and equation (16).

$$\eta_{bomba;baixa} = \frac{h_{2s} - h_1}{h_{2,real} - h_1} \tag{15}$$

$$\eta_{bomba;alta} = \frac{h_{4s} - h_3}{h_{4,real} - h_3} \tag{16}$$

The 2nd Law efficiency or equipment efficiency for the low-pressure pump (Figure 1, part 5-6-7) is calculated according to equation (17).

$$\eta_{turbina} = \frac{h_5 - m_1 h_6 - (1 - m_1) h_7}{h_5 - m_1 h_{6s} - (1 - m_1) h_{7s}} \tag{17}$$

The 2nd law efficiency or equipment efficiency for the low-pressure pump (Figure 1, part 4-5) is calculated according to equation (18).

$$\eta_{caldeira} = \frac{\dot{Q}_{H;utilizado}}{\dot{Q}_{H;entregue}} \tag{18}$$

3. RESULTS AND DISCUSSION

Preliminary results were obtained from a simplified computational simulation performed in Matlab software. In this simulation only the biogas was considered as fuel. The heat input in the boiler (real efficiency, 30% to 50% - Figure 2) was provided from biogas combustion (pci < 26167,5 kJ/kg). From these results were observed that the boiler must work in high pressures, once the heat power of biogas is significantly high, generating superheated steam in the boiler output. With such parameter, this boiler can be categorized as A, according to NR 13 (boilers and pressure vessels), category A applies to equipment with pressures higher than 1960 kPa. The effective work produced in the cycle and the total work produced in the turbine are presented on figure 3. This figure shows that the work performed in the cycle depends on the boiler efficiency, which influences directly on the superheated steam production, on the graphic as stable low between 40-50%. An interesting observation on figure 4 is the influence of the lower pressure of the turbine output, where the fluid proceeds to the condenser (figure 1). The lower the pressure P7, the greater is the work performed by the turbine. When P7 is linked to the pump work, the pressure increment makes the necessary pump operation work decrease.

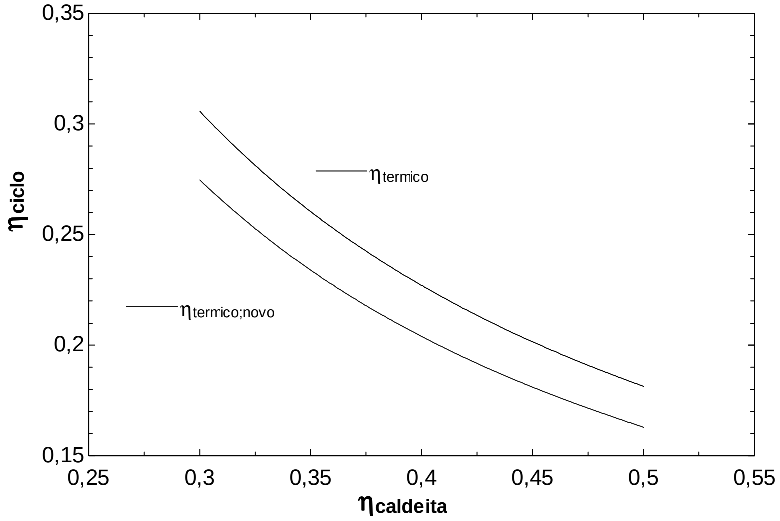

Figure 2. Ideal and real efficiencies, regenerative cycle (function of boiler efficiency).

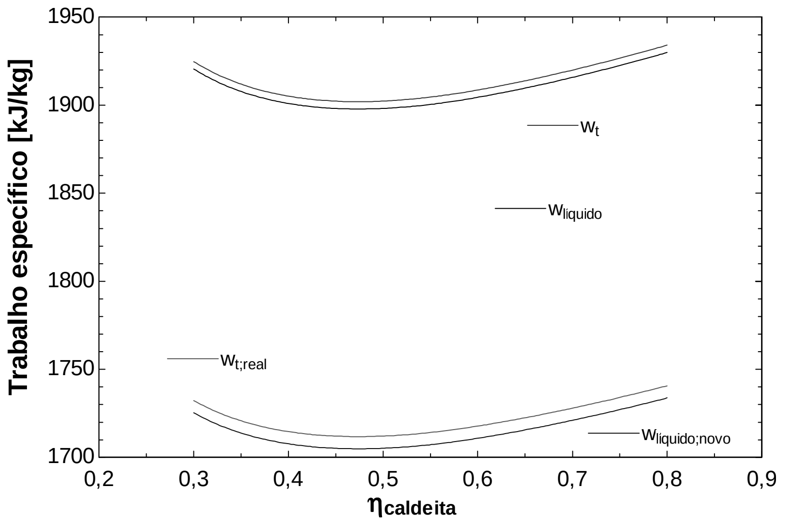

Figure 3 – Effective work produced by the cycle and turbine total work (function of boiler efficiency).

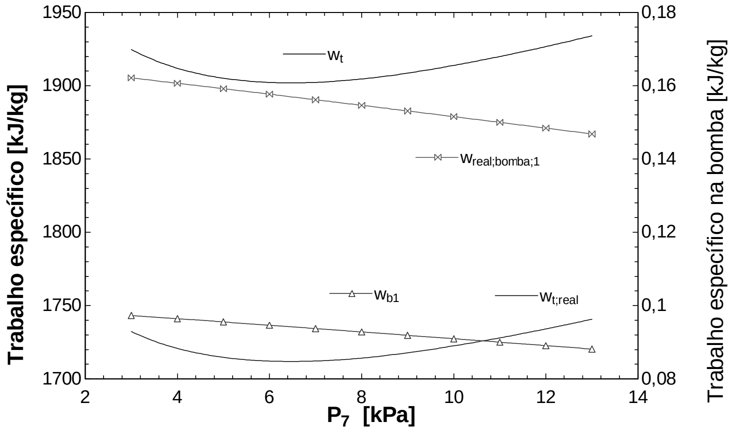

Figure 4 – Turbine and Pump work, function of lower on turbine output.

4. CONCLUSION

To obtain the preliminary results with biogas will be introduced hydrogen along with this gas in various proportions. The fuels combination aims to verify a possible improvement in the combustion process in aquatubber boilers. In order to analyze the fuels mixture potential in the cycle an exergetic analysis will be performed. The first results indicate that the biogas can be used in thermoelectric plants, especially in the lower pressure ones.

5. REFERENCES

Sonntag, Richard Edwin., and Borgnakke, Claus., 2011. *Introdução à termodinâmica para engenharia*. Rio de Janeiro 2nd edition.

BRASIL, 1978. “NR-13 Caldeiras e vasos de pressão” Ministério do Trabalho e Emprego.

6. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.