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ENERGY AND EXERGETIC ANALYSIS OF THE ENERGY PRODUCTION PROCESS FROM THE INCINERATION OF URBAN SOLID WASTE

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Abstract. *The production of urban solid waste is an economic, social and environmental problem. In Brazil, this problem is even more serious because the provision of 41 % of all the garbage produced goes to open-air dumps with no adequate treatment. In this context the incineration of waste can become an excellent alternative, because in addition to treating the waste generated by reducing the volume of waste by 90 %, the hot gases generated in the incineration can be used to generate electricity in Rankine cycle plants. Thus, the objective of this work is to evaluate the energetic and exergetic potential of waste incineration for energy production in Rankine cycle plants.*

Keywords: *Rankine Cycle, Energetic analysis, Exergetic analysis*

1. INTRODUCTION

The production of urban solid waste is an economic, social and environmental problem. In Brazil, this problem is even more serious because the provision of 41 % of all the garbage produced goes to open-air dumps with no adequate treatment. Although there is a 1998 law that makes this environmental crime, little effort has been made to enforce this law.

One of the reasons for this is that most of the Brazilian municipalities that are responsible for collecting and disposing of garbage are in a very precarious fiscal situation. With no money in hand for investments, the waste goes to inadequate landfills that can contaminate fountains, foul smells and pollute the soil.

In this context the incineration of waste can become an excellent alternative, because in addition to treating the waste generated by reducing the volume of waste by 90 %, the hot gases generated in the incineration can be used to generate electricity in Rankine cycle plants. Waste incineration is widely criticized for generating atmospheric pollution, but today there are emission treatment systems that can efficiently treat this type of emission.

One of the ways to make garbage incineration feasible in Brazil would be to create credit lines that could finance the commissioning of these plants. The payment of this funding could come from the revenues generated by the generation of electricity with hot gases from the incineration. This would solve the environmental, economic and social problems of disposing of garbage in Brazil. Thus, the objective of this work is to evaluate the energetic and exergetic potential of waste incineration for energy production in Rankine cycle plants.

2. MATH MODEL

The mathematical model proposed in this extended summary will use the first law of thermodynamics to perform a mass and energy balance for a rankine cycle plant utilizing hot gases from incineration. The entropy balance in the system and the exergetic analysis will be developed in the complete work due to the lack of extended abstract space.

The energy balance in the boiler, in steady state can be written:

$$0 = \dot{m}_g LHV_g + \dot{m}_v (h_p - h_b) \tag{1}$$

where $\dot{m}_g$ it is garbage mass flow (kg/s), LHV_g is low heating value of garbage (kJ/kg) , $\dot{m}_v$ is the steam mass flow (kg/s), h_p is the specific enthalpy of the liquid water that exits the pump (kJ/kg), h_b is the specific enthalpy of steam that left the boiler (kJ/kg).

The energy balance in the turbine, in steady state can be written:

$$0 = -\dot{W}_t + \dot{m}_v (h_b - h_t) \tag{2}$$

where $\dot{W}_t$ is the mechanical work of turbine (kJ/s), h_t is the specific enthalpy of steam that exits the turbine (kJ/kg).

The energy balance in steam phase of the condenser, in steady state can be written:

$$0 = \dot{Q}_{cond} + \dot{m}_v (h_t - h_c) \tag{3}$$

where $\dot{Q}_{cond}$ is the heat transfer in condenser (kJ/s), h_c is the specific enthalpy of liquid water that exits the condenser (kJ/kg).

The energy balance in the pump, in steady state can be written:

$$0 = -\dot{W}_p + \dot{m}_v (h_c - h_p) \tag{4}$$

where $\dot{W}_p$ is the mechanical power of pump (kJ/s).

The efficiency of Rankine cycle can be calculated as:

$$\eta = \frac{\dot{W}_t - \dot{W}_p}{\dot{m}_g LHV_g} \tag{5}$$

The above equations were encoded in the EES software and solved simultaneously.

The LHV_g of the urban solid waste was determined to be 2000 kJ/kg, based on data consulted in the literature (Lin et al., 2015). The production of garbage per person was done by consulting the literature and was obtained the value of 1 kg per person per day in Brazil (Kawai and Tasaki, 2015).

The exergy balance in the boiler, in steady state can be written:

$$0 = \dot{m}_g E_g + \dot{m}_v (e_{vp} - e_{vb}) - \dot{E}_{db} \tag{6}$$

where E_g is the exergy of garbage combustion (kJ/kg), e_{vp} is the specific exergy of the liquid water that exits the pump (kJ/kg), e_{vb} is the specific exergy of steam that left the boiler (kJ/kg) and $\dot{E}_{db}$ is the destroyed exergy on boiler (kJ/h).

The exergy balance in the turbine, in steady state can be written:

$$0 = -\dot{W}_t + \dot{m}_v (e_{vb} - e_{vt}) - \dot{E}_{dt} \tag{7}$$

where e_{vt} is the specific exergy of steam that exits the turbine (kJ/kg), $\dot{E}_{dt}$ is the destroyed exergy on turbine (kJ/h). Due to an ideal turbine hypothesis, the energy destroyed in this control volume is zero.

The exergy balance of the condenser, in steady state can be written:

$$0 = \dot{m}_w (e_{we} - e_{wo}) + \dot{m}_v (e_{vt} - e_{vc}) - \dot{E}_{dc} \tag{8}$$

where $\dot{m}_w$ is the refrigerant water mass flow on condenser (kg/h), e_{we} is the specific exergy of refrigerant water that enter the condenser (kJ/kg), e_{wo} is the specific exergy of refrigerant water that exits the condenser (kJ/kg), e_{vc} is the specific exergy of work water that exits the condenser (kJ/kg) and $\dot{E}_{dc}$ is the destroyed exergy on condenser (kJ/h).

$$0 = -\dot{W}_p + \dot{m}_v (e_{vc} - e_{vp}) - \dot{E}_{dp} \tag{9}$$

where $\dot{E}_{dp}$ is the destroyed exergy on pump (kJ/h). Due to an ideal pump hypothesis, the energy destroyed in this control volume is zero

The second law efficiency can be calculated as:

$$\eta_{II} = \frac{1 - \dot{E}_{dtot}}{\dot{m}_g E_g} \tag{10}$$

where $\dot{E}_{dtot}$ is the total destroyed exergy.

The E_g of the urban solid waste was determined to be 24387 kJ/kg, based on data consulted in the literature (Eboh et al., 2016).

3. RESULTS

The option for the incineration of municipal solid waste for electricity generation was evaluated in different scenarios. As can be seen in Table 1, cities with low population tend not to be economically feasible the incineration process since turbine efficiency is very small. An alternative to small towns would be the formation of cooperatives with neighboring cities that could enable large-scale incineration projects. As can be seen in cities with larger population, incineration is a viable alternative for electricity production.

Population	Waste generation (kg/h)	Power generation(kw)	Efficiency	Pressure on boiler (kPa)	Steam boiler exit temperature (°C)
1200	50	11,13	0,1984	900	250
12000	500	147	0,26	2000	400
120000	5000	1763	0,31	4000	400
1200000	50000	18707	0,3325	6000	500

In figure 1 is possible to observe the effect of population on efficiency and power generation.

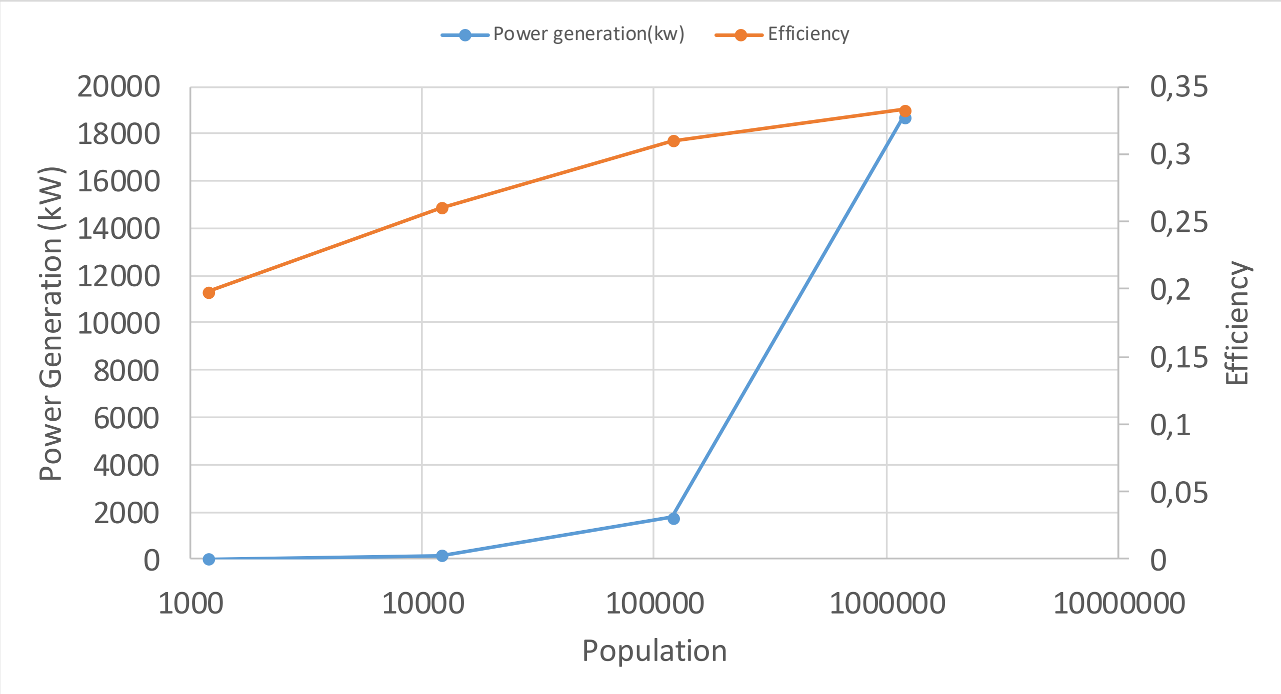

Figure 1. Effect of population on power generation and efficiency.

The total destroyed exergy of plant with 50000 kg/h of waste generation was 252192 kJ/h. This yields a second law efficiency of approximately 26 %, which is lower than first law efficiency. The next step in this work is to minimize the destroyed energy in the system by modifying design parameters such as system pressure, steam outlet temperature, turbine outlet temperature and pressure. Through this analysis it will be possible to obtain better operating conditions of the system.

4. CONCLUSIONS

The article demonstrates that large scale incinerators are the best way to generate electricity with good efficiency.

5. REFERENCES

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6. RESPONSIBILITY NOTICE