EXERGOECONOMIC ANALYSIS OF A HYBRID SYSTEM OF WASTE INCINERATION AND ABSORPTION REFRIGERATION

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ABSTRACT

The current global scenario presents a significant increase in energy demand for HVAC-R (Heating, Ventilation, Air Conditioning and Refrigeration) systems. Considering also that Brazil has the sixth most expensive energy in the world and that there is currently a greater scarcity of natural resources for energy generation, it is necessary to seek viable alternatives with lower energy consumption to the currently most used models, without any quality loss. On the other hand, absorption refrigeration and waste incineration systems can be lines of studies and research to be considered, considering that it is possible to reduce electrical energy consumption and also the environmental impacts that the usual compression refrigeration systems provide. In this context, one of the segments of Thermal Systems Engineering studied is the exergoeconomic analysis that comprises the concepts of Heat Transfer, Fluid Mechanics and Thermodynamics, based on the Second Law of Thermodynamics and which uses the notions of optimization and economic analysis. Therefore, this work aims to perform an exergoeconomic analysis of a hybrid system of waste incineration and absorption refrigeration, with the specific objective of developing an exergoeconomic model for the hybrid system. Absorption incinerator-refrigerator. This is an exploratory bibliographic research using an absorption refrigerator from the Center for Research and Development of Self-Sustainable Energy (NPDEAS) of the Federal University of Paraná, in which a model was made with a macroscopic approach of the mass and heat transfer phenomena of a absorption refrigeration cycle, applying the principles of conservation of mass and energy in steady state for each component of the cycle, that is, each component will be considered as a single control volume. It is expected that it will be possible to predict the behavior of the absorption refrigeration system and that it will be possible to develop a scientific analysis tool to design, control and optimize absorption refrigeration systems, using waste incineration. The highest exergy destroyed was verified in the desorber with about 0.9461 kW and through the exergoeconomic analysis of the incinerator, it was found that the cost rate associated with the product of the incineration gases was $ 39,926.31 per year.

Keywords: refrigeration, systems by absorption, exergoeconomic analysis, waste incineration.

INTRODUCTION

The current global scenario presents a significant increase in energy demand for HVAC-R systems, consisting of Heating, Ventilation, Air Conditioning and Refrigeration operations. (Souza, 2020). Specifically in relation to Brazil, according to the Ministry of Mines and Energy (MME) of the Brazilian Federal Government (2018), the industry consumed approximately 37.5% of total electricity, followed by the residential sectors (25.4%). and commercial (17.8%), of which about 38.5% of the total consumption of electricity was destined for HVAC-R systems (Martinez, 2020).

Considering also that Brazil has the sixth most expensive energy in the world and that there is currently a greater scarcity of natural resources for energy generation, it is necessary to seek viable alternatives with lower energy consumption to the currently most used models, without that there is any loss of quality. This is because traditional vapor compression refrigeration systems have a significant predominance over other systems. In contrast to this, absorption refrigeration systems can be lines of studies and research to be considered, considering that it is possible to reduce the consumption of electric energy and also the environmental impacts that the usual refrigeration systems provide (Revista do frio, 2018; Souza, 2020).

The Center for Research and Development of Self-Sustainable Energy (NPDEAS) of the Federal University of Paraná (UFPR) has absorption refrigeration prototypes, as shown in Fig. 1, and it is necessary to deepen the study in those that take advantage of a heat source that would be neglected, the namely: the incineration of urban solid waste.

Figure 1. Ammonia-water absorption refrigerator prototypes developed by NPDEAS. Available from: Souza (2020).

Still in the NPDEAS, there is a parallel treatment proposal for the gases from this incineration mentioned by the prototypes, which is shown in Fig. 2.

Finally, in agreement with Bejan, Tsatsaronis and Moran (1996), Moran and Shapiro (1998) and Balestieri (2001), one of the segments of Thermal Systems Engineering studied is the exergoeconomic analysis that comprises concepts of heat transfer, fluid mechanics and Thermodynamics, based on the Second Law of Thermodynamics. and that uses the notions of optimization and economic analysis. This definition of exergoeconomic analysis can be applied in the context of the hybrid system of waste incineration and absorption refrigeration within the scope of UFPR's NPDEAS, seeking technical and commercial feasibility of the prototypes.

Therefore, the general objective of this work is to perform an exergoeconomic analysis of a hybrid waste incineration system existing in the Mechanical Engineering laboratory of UFPR. In order to achieve the general objective, the following specific objectives were defined: Develop an exergoeconomic model for the absorption incinerator-refrigerator hybrid system starting with the incinerator, calculate the exergies destroyed by the components of the absorption refrigeration cycle to seek further optimization opportunities and calculate the cost rate associated with the incinerator product, to be replicated in the future for all components of the system.

MATHEMATICAL MODEL

The approach adopted to establish the model was to perceive the absorption refrigeration system under a macroscopic view of the heat and mass transfer phenomena, in steady state and disregarding the pressure losses in the heat exchanger lines due to friction. Therefore, the elements were defined individually as just a control volume and having their respective properties uniform in their domain. The Engineering Equation Solver (EES) software will be applied to solve the equations and obtain the necessary thermodynamic properties. (Herold, Radermacher, Klein, 2016; Martinez, 2018; Martinho, 2013).

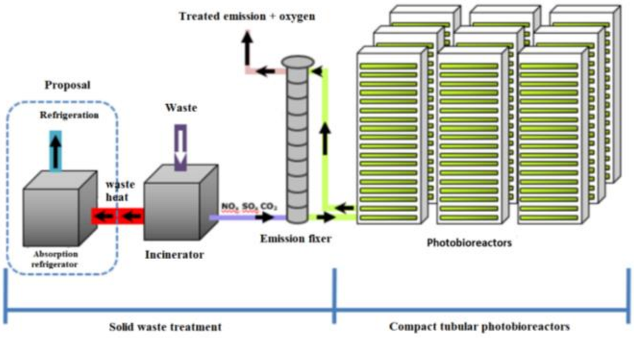

Figure 2. Application of the absorption prototype in NPDEAS. Adapted from: Souza (2020).

In summary, the physical problem of this project is composed by the macroscopic analysis of the elements that compose the single-stage absorption refrigeration system: a condenser, two expansion valves, an evaporator, an absorber, a pump and a desorber / rectifier and a garbage incinerator connected to the desorber. The input and output exergy flows will be studied and the laws of conservation of mass and energy will be used in the control volume as a whole. The Fig. 3 presents the absorption refrigeration system applied for the mathematical modeling.

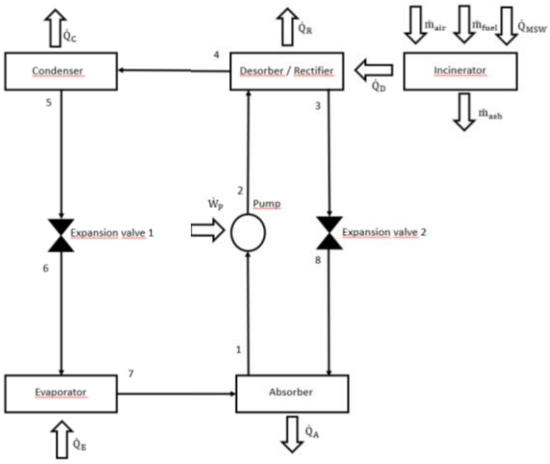

Figure 3. Absorption cooling system applied for mathematical modeling. Adapted from: Souza (2020).

A mass flow balance of inlet and outlet of the mixture in the pump was performed, being the working fluids ammonia and water, in this case for the Eq. (1) and Eq. (2).

$$\dot{m}_1 = \dot{m}_2 \quad (1)$$

$$x_1 = x_2 \quad (2)$$

$\dot{m}_1$ corresponds to the mass flow rate of the mixture entering the pump, $\dot{m}_2$ corresponds to the mass flow rate of the mixture at the pump, x_1 corresponds to the proportion of ammonia before the pump and x_2 corresponds to the proportion of ammonia after the pump.

The Equation (3). shows how to determine pump specific work.

$$w = \frac{v_1(P_2 - P_1)}{\eta_B} \quad (3)$$

w corresponds to the specific pump work, v_1 corresponds to point 1 specific volume, P_1 corresponds to the pressure at point 1, P_2 corresponds to the pressure at point 2 and η_B corresponds to the pump efficiency.

The Equation (4) shows how to calculate the enthalpy of point 2.

$$h_2 = h_1 + w \quad (4)$$

h_1 corresponds to the specific enthalpy of point 1 and h_2 corresponds to the specific enthalpy of point 2.

Thus, it is possible to determine the power in the pump through Eq. (5).

$$\dot{W}_p = \dot{m}_1(h_2 - h_1) \quad (5)$$

$\dot{W}_p$ corresponds to the pump power.

For the desorber/rectifier set, the Eq. (6) presents the determination of their respective mass flows.

$$\dot{m}_2 = \dot{m}_3 + \dot{m}_4 \quad (6)$$

$\dot{m}_3$ corresponds to the mass flow rate from the desorber / rectifier, from the generator to the absorber and

$\dot{m}_4$ corresponds to the output mass flow of the desorber / rectifier, in the direction from the rectifier to the capacitor.

The equality of Eq. (7) demonstrates the relationship of pressures at points 2 and 4, in which ammonia is expected to be in the saturated vapor state at the outlet of the rectifier.

$$P_4 = P_2 \quad (7)$$

P_4 corresponds to the pressure at the output of the rectifier.

The equality of Eq. (8) demonstrates the relationship of pressures at points 3 and 4, in which the mixture is expected to be in a saturated liquid state between the generator and the absorber, being a weak solution.

$$P_3 = P_2 \quad (8)$$

P_3 corresponds to the pressure at the generator output, towards the absorber.

The Equation (9) shows the ammonia mass balance in the generator / rectifier.

$$\dot{m}_2 x_2 = \dot{m}_3 x_3 + \dot{m}_4 x_4 \quad (9)$$

x_3 corresponds to the mass fraction of ammonia output from the generator / rectifier, from the generator to the absorber and x_4 corresponds to the mass fraction of ammonia at the output of the rectifier.

The Equation (10) demonstrates the energy balance for the generator / rectifier.

$$\dot{m}_2 h_2 - \dot{m}_3 h_3 - \dot{m}_4 h_4 + \dot{Q}_D - \dot{Q}_R = 0 \quad (10)$$

h_3 corresponds to the specific enthalpy of point 3, h_4 corresponds to the specific enthalpy of point 4, $\dot{Q}_R$ corresponds to the heat transfer provided by some heat source to the system and $\dot{Q}_D$ corresponds to heat transfer to the generator.

To determine the heat transfer from the incinerator to the generator that will be used in the thermal compressor, the Equation (11) is used, where c_{prod} corresponds to the specific heat of the products at the incinerator outlet.

$$\dot{Q}_D = \dot{m}_{prod}\, c_{prod}(T_{prod} - T_3) \quad (11)$$

After carrying out a mass and ammonia balance for what enters and leaves the condenser, we have the equality presented by Eq. (12), Eq. (13) and Eq. (14).

$$\dot{m}_4 = \dot{m}_5 \quad (12)$$

$$x_5 = x_4 \quad (13)$$

$$P_4 = P_5 \quad (14)$$

$\dot{m}_5$ corresponds to the condenser output mass flow, x_5 corresponds to the mass fraction of ammonia at the output of the condenser and P_5 corresponds to the condenser outlet pressure.

After performing the energy balance, we have Eq. (15).

$$\dot{m}_4 h_4 - \dot{m}_5 h_5 - \dot{Q}_C = 0 \quad (15)$$

h_5 corresponds to the specific enthalpy of point 5 and $\dot{Q}_C$ corresponds to the heat transfer rejected by the condenser.

The expansion valve 1 refers to the device that will lower the high pressure of the ammonia coming from the condenser to the levels of the saturation pressure of the evaporator, in the sequence. The equality of Eq. (16)

demonstrates the relationship of pressures at the outlet of the expansion device and at the outlet of the absorber.

$$P_6 = P_1 \tag{16}$$

P_6 corresponds to pressure at point 6.

After a mass and ammonia fraction balance, we have the following equalities by Eq. (17) and Eq. (18).

$$\dot{m}_5 = \dot{m}_6 \tag{17}$$

$$x_5 = x_6 \tag{18}$$

x_6 corresponds to the mass fraction of ammonia after expansion valve 1 and $\dot{m}_6$ corresponds to the mass flow rate of expansion valve 1.

The relationship in Eq. (19) shows the equality of enthalpies at the output of the condenser and after the expansion valve 1.

$$h_5 = h_6 \tag{19}$$

h_6 corresponds to the specific enthalpy of point 6.

In this component of the system, ammonia is at low pressure and can be used to absorb heat from something and consequently evaporator. For that, we have the equality of Eq. (20).

$$P_7 = P_1 \tag{20}$$

P_7 corresponds to pressure at point 7.

Performing the mass balance and ammonia fraction, we have the equality of Eq. (21) and Eq. (22).

$$\dot{m}_6 = \dot{m}_7 \tag{21}$$

$$x_6 = x_7 \tag{22}$$

x_7 corresponds to the mass fraction of ammonia at the evaporator outlet and $\dot{m}_7$ corresponds to the evaporator outlet mass flow.

With this, it is possible to perform the energy balance in this component, presented by Eq. (23).

$$\dot{m}_6 h_6 - \dot{m}_7 h_7 + \dot{Q}_E = 0 \tag{23}$$

h_7 corresponds to the specific enthalpy of point 7 and $\dot{Q}_E$ corresponds to heat transfer to the evaporator.

The Equation (24) presents the energy balance for this respective component.

$$\dot{m}_7 h_7 + \dot{m}_8 h_8 - \dot{m}_1 h_1 - \dot{Q}_A = 0 \tag{24}$$

$\dot{m}_8$ corresponds to the absorber inlet mass flow, after expansion valve 2, h_8 corresponds to the specific enthalpy of point 8 and $\dot{Q}_A$ corresponds to the heat transfer rejected by the absorber.

The expansion valve 2 will be responsible for reducing the pressure of the solution coming from the generator, towards the absorber. For that, the equalities of Eq. (25) and Eq. (26) present the relations of pressures and enthalpies of this component.

$$P_8 = P_1 \tag{25}$$

$$h_3 = h_8 \tag{26}$$

P_8 corresponds to pressure at point 8.

After carrying out the mass and ammonia balance, we have the following relations presented by the equalities of Eq. (27) and Eq. (28).

$$\dot{m}_3 = \dot{m}_8 \tag{27}$$

$$x_3 = x_8 \tag{28}$$

x_8 corresponds to the mass fraction of ammonia at the outlet of expansion valve 2.

This component will use the energy from burning garbage and natural gas (CH_4) to supply heat to the thermal compressor, more specifically to the generator, through the hot gases as a product of the incinerator. The combination of waste and methane form the hybrid fuel of the component, having the following associated equations Eq. (29), Eq. (30), Eq. (31), Eq. (32) and Eq. (33).

$$\dot{m}_{prod} = \dot{m}_{hf} + \dot{m}_{air} - \dot{m}_{ash} \tag{29}$$

$$\dot{m}_{hf} = \dot{m}_{ch4} + \dot{m}_{msw} \tag{30}$$

$$\dot{m}_{air} = AFR\, \dot{m}_{air} \tag{31}$$

$$\dot{m}_{ash} = 0.04\, \dot{m}_{air} \tag{32}$$

$$\dot{Q}_{comb} - \dot{Q}_0 - \dot{W}_{fan} - \dot{m}_{prod} h_{prod} - \dot{m}_{ash} c_{ash} T_{prod} = 0 \tag{33}$$

$\dot{m}_{prod}$ corresponds to the mass flow of products at the incinerator outlet, $\dot{m}_{hf}$ corresponds to the mass flow rate of hybrid fuel, $\dot{m}_{air}$ corresponds to the air flow at the incinerator inlet, $\dot{m}_{ash}$ refers to the flow of ash leaving the incinerator, $\dot{m}_{ch4}$ corresponds to the mass flow rate of methane at the incinerator inlet, $\dot{m}_{msw}$ corresponds to the mass flow rate of garbage or wood at the incinerator inlet, AFR corresponds to the fuel air ratio, $\dot{Q}_{comb}$ corresponds to the heat of combustion supplied to the incinerator, $\dot{Q}_0$ refers to the heat lost from the incinerator walls.

In developing exergetic analysis, it is necessary to specify the exergy flows of the entire system. For this, Eq. (34) was used, which determines the specific flow exergy at each point in the cycle. After making the exergy balance for the considered control volumes, the main properties are obtained at the points of the cycle, such as temperature, pressure, ammonia mass fraction of the fluid and enthalpy at each point of the cycle. Thus, for the use of Eq. (34), it is still necessary to define the entropies (s_i) and the properties of the dead state (h_0, s_0) for each point of the cycle of the absorption refrigeration system. To determine the entropies of the system, the EES library will be used from the thermodynamic properties calculated at each point. As for the dead state, the properties will be defined as the following ambient conditions: T_0 = 25ºC and P_0 = 101.325 kPa. With this, the values of h_0 and s_0 are also determined.

$$e_i = h_i - h_0 - T_0\,(s_i - s_0) \tag{34}$$

The exergy destroyed of each element of the absorption refrigeration cycle is determined by an exergy balance for each control volume, and it is possible to find the rate of exergy destroyed for each element of the cycle through Eq. (35), Eq. (36), Eq. (37), Eq. (38), Eq. (39), Eq. (40), Eq. (41), Eq. (42) and Eq. (43).

$$ED_p = \dot{m}_1 e_1 - \dot{m}_2 e_2 - \dot{W}_p \tag{35}$$

$$ED_{des/rec} = \dot{m}_2 e_2 - \dot{m}_3 e_3 - \dot{m}_4 e_4 + \dot{Q}_D\left(1-\frac{T_0}{T_s}\right) + - \dot{Q}_R\left(1-\frac{T_0}{T_4}\right) \tag{36}$$

$$ED_c = \dot{m}_4 e_4 - \dot{m}_5 e_5 - \dot{Q}_C\left(1-\frac{T_0}{T_5}\right) \tag{37}$$

$$ED_{VE1} = \dot{m}_6\,(e_5 - e_6) \tag{38}$$

$$ED_E = \dot{m}_6\,(e_6 - e_7) + \dot{Q}_E[1-\left(\frac{T_0}{T_7}\right)] \tag{39}$$

$$ED_{VE2} = \dot{m}_3\,(e_3 - e_8) \tag{40}$$

$$ED_A = \dot{m}_7 e_7 + \dot{m}_8 e_8 - \dot{m}_1 e_1 - \dot{Q}_A\left(1-\frac{T_0}{T_1}\right) \tag{41}$$

$$ED_T = ED_p + ED_{des/rec} + ED_c + ED_{VE1} + + ED_E + ED_{VE2} + ED_A \tag{42}$$

$$ED_{inc} = -\dot{W}_{fan} + E_{qinc} - E_{prod} - E_{ash} \tag{43}$$

where e_i corresponds to the specific exergy at the point i (i=1,8), T_0 corresponds to the dead state temperature, T_1 corresponds to the temperature at point i (i=1, 3, 4, 5, and 7), ED_P corresponds to exergy destroyed in the pump, $ED_{des/rec}$ corresponds to exergy destroyed in generator / rectifier, ED_C corresponds to exergy destroyed in the condenser, ED_{VE1} corresponds to exergy destroyed in expansion valve 1, ED_{VE2} corresponds to exergy destroyed in expansion valve 2, ED_E corresponds to exergy destroyed in the evaporator, ED_A corresponds to exergy destroyed in the absorber, ED_T corresponds to the total destroyed exergy of the absorption refrigeration cycle, $\dot{W}_{fan}$ corresponds to fan power, h_{prod} refers to the enthalpy of the incineration products, c_{ash} corresponds to the specific heat of ash, T_{prod} corresponds to the temperature of the products at the incinerator outlet, E_{qinc} refers to the exergy of the hybrid fuel at the inlet of the incinerator. incinerator, E_{prod} corresponds to the exergy from the products, E_{ash} corresponds to the exergy from the ash, ED_{inc} corresponds to the exergy of destroyed from the incinerator.

For the incinerator, previous exergetic analysis was associated with economic principles, which involve exergetic costs with operating, maintenance and capital investment costs, as shown in Eq. (44). This exergoeconomic analysis will be replicated for the other components of the refrigeration cycle, as these also already have the exergetic analysis performed.

$$C_{prodT}\,E_{prod} + C_{ash}\,E_{ash} = C_{fuel}\,E_{ash} + + C_{elect}\,\dot{W}_{fan} + Z_{CI} + Z_{OM} \tag{44}$$

C_{prodT} is the total cost of having the products, which in this case, the hypothesis of being equal to the cost associated with the ash (C_{ash}), C_{fuel} is the cost associated with the fuel, C_{elect} refers to the cost of electricity, Z_{CI} corresponds to the non-exercise capital investment cost of the incinerator, Z_{OM} corresponds to the cost of operating and maintaining the incinerator.

The cost of operation and maintenance is calculated using Eq. (45), where N_{op} corresponds to the number of operators, S_{1op} corresponds to the salary of 1 operator and the cost of replacement parts is added. Economic costs can be performed for 12 months to have a broad estimate.

$$Z_{OM} = N_{op} S_{1op} + Parts\ \text{replace} \tag{45}$$

RESULTS

It was necessary to define some input parameters to be able to perform the simulation, such as the pump inlet mass flow ($\dot{m}_1$), the absorber outlet pressure (P_1), the generator inlet pressure (P_2), the absorber temperature (T_1), the pump efficiency (η_B) and the mass fraction of ammonia at the output of the desorber / rectifier (x_4), according to Tab. 1.

These parameters shown in Tab. 1 were defined based on approximate observations in experiments in the NPDEAS laboratory. Although some are operating parameters and are established as intended (such as pressures and ammonia mass fractions), the future objective is to experimentally validate data such as the heat transfer provided by the incinerator to the desorber in the laboratory. Thus, more realistic values could also be obtained, for example, for the heat exchange area of the desorber, performed by the effectiveness-NTU method.

With the thermodynamic model that was implemented in the EES software, it was possible to calculate the values of mass fractions, pressures, temperatures, enthalpies, mass flows and entropies of the absorption refrigeration cycle, as shown in Tab. 2.

Table 1. Input parameters to be able to perform the simulation.

Parameters	Values
Pump inlet mass flow (kg/s)	0.01
Absorber outlet pressure (kPa)	550
Desorber inlet pressure (kPa)	1100
Absorber temperature (°C)	30
Pump efficiency	1
Mass fraction of ammonia at the output of the generator / rectifier	0.9996

Table 2. Thermodynamic properties obtained through the EES software.

Points	x_i	P_i (kPa)	T_i (°C)	h_i (kJ/kg)	$\dot{m}_i$ (kg/s)	s_i (kJ/kg K)
1	0.5925	550	30	-93.82	0.01	0.2973
2	0.5925	1100	30.05	-93.82	0.01	0.2973
3	0.3339	1100	100	234.8	0.006115	1.263
4	0.9996	1100	35.6	1313	0.003885	4.375
5	0.9996	1100	28.03	131.9	0.003885	0.4779
6	0.9996	550	6.814	131.9	0.003885	0.4886
7	0.9996	550	19.71	1309	0.003885	4.666
8	0.3339	550	80.54	234.8	0.006115	1.273

Through Tab. 2 it is possible to observe that the pressures only change in the two expansion valves and in the pump, so there is a low pressure and a high pressure. Additionally, the lowest temperature observed in the cycle is observed at point 6 and where it could be used for some refrigeration purpose, such as a cooling chamber or a chiller for water cooling. It is intended in future observations to carry out some parametric analysis varying mass flows, mass ammonia fractions and pressures, seeking an optimization for the refrigeration system.

The coefficient of performance (COP) for this system, calculated as the ratio of the heat from the evaporator to the heat from the desorber added to the pump power, was 0.4577. This value can be considered coherent in relation to the researched experimental works.

The heat transfer rates obtained by applying the initial parameters are shown in Tab.3.

Subsequently, it is intended to perform parametric analyzes varying, for example, the outlet temperatures of the absorber, outlet of the desorber, outlet of the condenser to analyze the coefficient of performance and the heat transfer rate provided from the incinerator to the desorber (as already mentioned previously). In preliminary experimental analyzes already carried out, a heat transfer capacity of about 70 kW in the desorber has been verified, but it has not yet been verified, for example, the heat transfer in the evaporator with this capacity 7 times greater in the desorber.

Table 3. Heat transfer rates of absorption refrigeration cycle components.

Component	Values (kW)
Absorber	7.46
Desorber	10
Rectifier	2.531
Condenser	4.59
Evaporator	4.574

With some of the properties presented in Tab. 2, it was possible to use Eq. (34) to calculate the point-specific exergies, as shown in Tab. 4.

Table 4. Specific exergies of the absorption refrigeration cycle points.

Points	Values (kJ/kg)
1	52.3
2	53
3	37
4	329.6
5	310.1
6	307
7	238.7
8	34.21

Exergy is energy available for use, but unlike energy, it is not conserved, so exergy is destroyed through irreversibilities. Through Tab. 4, there is a considerable difference in the values of specific exergies between points 3 and 4 (in the desorber), which already suggests attention to the destroyed exergy, as we will see later. Therefore, attention can already be focused on aspects of system operation that could provide more opportunities for economic improvements, starting with the desorber, where more relevant results could possibly be obtained.

To evaluate the amount of exergy destroyed in each component of the absorption refrigeration cycle, were used Eq. (35), Eq. (36), Eq. (37), Eq. (38), Eq. (39), Eq. (40), Eq. (41), Eq. (42) and which are shown in Tab. 5.

By Tab. 5, it can be analyzed that the focus of the destruction by the desorber is the biggest contribution with more than half of the participation in the total destroyed exergy (0.9461 kW) and a study can be carried out with the main in the reduction of the first attempt of destruction in this component. Subsequently, it is observed that the exergy destroyed in the absorber is also relevant (0.4904 kW), a component in which there is an exothermic reaction when the ammonia and water solution is mixed.

Table 5. Exergy destroyed in each component of the absorption refrigeration cycle.

Component	Values (kW)
ED_p	0.0000008344
$ED_{des/rec}$	0.9461
ED_c	0.0296
ED_A	0.4904
ED_{VE1}	0.01237
ED_{VE2}	0.017
ED_E	0.1827
ED_T	1.678

Through Eqs. (44) and Eq. (45) an analysis of the incinerator was performed, associating the exercise with the economic part, which resulted in an annual cost (C_{prodT}) of $39,926.31. Total fuel costs amounted to $18,640.23, and a greater use of waste incineration (MSW) and a lower contribution of natural gas (CH_4) will be sought to better observe the cost-effectiveness of the system. And this analysis will be replicated for the other components of the absorption refrigeration cycle. An optimization of the system has not yet been carried out, but it will be carried out in future works.

CONCLUSIONS

In this work, a mathematical model was developed and an exergetic analysis of a waste incinerator that supplies heat to the thermal compressor of an absorption refrigeration system was performed and an exergoeconomic analysis of the incinerator was performed and will be replicated for all components of the absorption system.

It was found that the largest contribution of the destroyed exergy was in the desorber with 0.9461 kW and secondly in the absorber (0.4904). A focused analysis could be carried out on how to reduce this energetic destruction of the energy available for use in the generator and then in the absorber, as possibly there would be more relevant improvements starting with these components.

In the exergoeconomic analysis of the waste incinerator, it was found that the cost rate associated with the incineration product was $39,926.31 per year and the cost rate associated with the hybrid fuel was $18,640.23, in which a optimum point of operation increase the burning of garbage (MSW) and reduction of the use of natural gas (CH_4). Additionally, the costs of each product generated by the system will be separately calculated, including the processes of cost formation and cost flows in the system.

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REFERENCES

Balestieri, J.A.P., 2001. *"Avaliação tecnológica e metodológica para o planejamento de centrais de cogeração: relatório de pesquisa de Pós-Doutorado"*. Universidade Federal de Santa Catarina, Florianópolis, Brasil.

Bejan, A.; Tsatsaronis, G.; Moran, M., 1996. *Thermal Design and Optimization*. John Wyley & Sons, New York.

Herold, K.E.; Radermacher, R.; Klein, S. A., 2016. *Absorption chillers and heat pumps*. CRC Press Taylor & Francis Group, New York.

Martinez, L.C., 2018 "*Modelagem matemática quasi-permanente e simulação de componentes de refrigeração por absorção*". Doctoral thesis, Universidade Federal do Paraná, Curitiba, Brasil.

Martinez, L.C., 2020. "*Modelagem, simulação e otimização de sistemas de compressão de vapor em regime quasi-permanente*". Doctoral thesis, Universidade Federal do Paraná, Curitiba, Brasil.

Martinho, L.C.S., 2013. "*Modelagem, simulação e otimização de refrigeradores por absorção*". Doctoral thesis, Universidade Federal do Paraná, Curitiba, Brasil.

Ministry of Mines and Energy, 2018. "*Relatório de gestão"* Modern. 21 Feb. 2022 < https://www.gov.br/mme/pt-br/acesso-a-informacao/auditorias/auditorias/2018/relatorio2018.pdf >.

Moran, M.J.; Shapiro, H.N., 1998. *Fundamentals of engineering thermodynamics*. John Wyley & Sons, New York.

Souza, G.D.G., 2020. "*Otimização exergética de sistema de refrigeração por absorção*". Master thesis, Universidade Federal do Paraná, Curitiba, Brasil.

Revista do Frio, 2018. "*Eficiência, o nome do jogo no HVAC-R*". 21 Feb. 2022 <https://revistadofrio.com.br/eficiencia-o-nome-do-jogo-no-hvac-r/>.