ENERGY AND EXERGETIC EVALUATION OF THERMODYNAMIC SYSTEMS APPLIED TO WATER HEATING AT LOW TEMPERATURES

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Abstract:

The changes in human needs in the 21st century are increasingly dependent on different energy sources. This work aims to compare the energetic and exergetic efficiency of a shower heated by electric resistance and a solar heater. The method employed is based on the first and second principles of thermodynamics. We found that, under conditions at low heating temperature, the shower has better exergetic efficiency due to solar heating when compared to electrical energy since the destroyed exergy is lesser in the solar heater. Energy efficiency, which is a quantitative aspect, is greater in electrical resistance, as presents better performing energy compared to solar energy. Therefore, heating at low temperatures, the solar heater is recommended, from the thermodynamic perspective.

Keywords: Efficiency; Exergetic analysis; Shower; Electric Resistance; Solar Heater.

AVALIAÇÃO ENERGÉTICA E EXERGÉTICA DE SISTEMAS TERMODINÂMICOS APLICADOS AO AQUECIMENTO DE ÁGUA A BAIXAS TEMPERATURAS

Resumo: Diante das transformações das necessidades humanas no século XXI cada vez mais dependente das diversas fontes energéticas, esse trabalho tem como objetivo realizar uma comparação na eficiência energética e exergética de um chuveiro aquecido por resistência elétrica e aquecedor solar. O método empregado é fundamentado pelo primeiro e segundo princípio da termodinâmica. E verificou-se que, sob condições de baixa temperatura de aquecimento, o chuveiro possui melhor eficiência exergética por aquecimento solar, em comparação a energia elétrica, pois a exergia destruída é menor no aquecedor solar. Já a eficiência energética, aspecto quantitativo, é maior na resistência elétrica, pois é uma energia de melhor desempenho, em relação a solar. Portanto para a utilização fim, aquecimento a baixas temperaturas, é recomendado o aquecedor solar, a partir da perspectiva termodinâmica.

Palavras-chave: Eficiência; Energia; Exergia; Resistência elétrica; Aquecedor solar.

1. INTRODUCTION

Electricity consumption in Brazil is based on an energy matrix mostly composed of hydropower plants. Brazilian government data from 2019 show that around 64% of the country's electric energy advances in hydropower plants, followed by thermoelectric plants (in 23%) and the remaining 13% are distributed in nuclear and renewable energy - mainly solar and wind [1]. Energy sources must be chosen according to their application to reduce losses. Thus, Deckmann and Pomilio [2] approach their work with electricity quality (QEE) that is transported in Brazil, suggesting modeling in the exergetic sphere for electricity distribution systems. This shows that the quality of energy is not only linked to its end use, but also to its transport.

Martins Júnior, Lopes Júnior and Silva Júnior [3] approach in his work solar energy as an excellent source of renewable energy that has higher energy and exergetic quality in its use. However, a contribution from solar energy in 2016 generated an energy capacity of around 21 MW, which represents a negligible share in the Brazilian energy matrix. The authors point out that there is a large potential field for the use of solar energy, highlighting the Northeast, which has an area of 1,558,000 km², with excellent levels of average irradiation and little interannual variability in most locations.

The growing concern with environmental issues and sustainable development, shows that is necessary to track the measures for decision making of energy sources evaluated by their quality, which can be achieved, based on the analysis of exergy [4]. In this sense, the term exergy expresses the energy capacity to carry out work, enables the quality analysis of different energy sources, taking into account its final application, with this it is possible to identify which alternatives, how best to use for different contexts of use [5].

Thus, the study of exergy was highlighted in the scientific community, governments and society [6] due to the possible changes that its analysis can promote to the environment from assertive decision-making for the development of energy supply strategies, mainly in the current scenario due to the increasing release of greenhouse gases (GHG) into the atmosphere and the related increase in the average temperature of the Earth's surface observed in recent decades [7].

Thus, concerns about sustainability should motivate analyzes to be made not only in relation to energy efficiency, but also of the quality of the energy supplied, which consists of the study of exergetic efficiency [5]. The analyzes on energy efficiency are based on the first principle of thermodynamics, which deals with energy conservation. The evaluation based only on the first principle, makes it possible to quantify the energy involved, however it does not allow this energy to be qualified, nor the intrinsic inefficiencies to be evidenced, due to irreversibilities. In this way, it is necessary to analyze from the second principle of thermodynamics, which makes it possible to qualify the various forms of energy involved, and in addition, it allows to verify the spontaneity of the processes and indicates the maximum useful work possible to be carried out, this can serve as a comparative parameter between the ideal and the real. Therefore, exergetic analysis allows to quantify, qualify, identify the most impacting irreversibilities in the processes, comparing the real yield with the ideal [8].

The performance is directly related to the destruction of exergy, which consist in the quantification of the irreversibility of the system, revealing the distance that it is from an ideal condition. In energy transformation processes, as the transformation occurs, more irreversibilities are generated, thereby reducing the capacity to perform work [9]. Thus, the evaluation of exergetic efficiency considers the quality of the energy taking into account its final application, seeking the least degradation of the energy.

In this sense, this work seeks to demonstrate the importance of exergetic energy analysis as a decision-making factor in the choice of energy sources, considering its end use. For this, a hypothetical case of a shower for hot baths was used. The study was based on the concepts presented by Kotas [10] and articles published in different databases [4, 5, 7, 8, 11, 12].

2. METHODOLOGY

The mathematical modeling of this study was supported by Kotas [10]. Defining the exergy as a stream of matter, which can be divided into distinct components. In the absence of nuclear effects, magnetism, electricity and surface tension, it is mathematically written according to equation 1:

$$\dot{E} = \dot{E}_k + \dot{E}_p + \dot{E}_{ph} + \dot{E}_0 \tag{1}$$

On what:

$\dot{E}_k$: kinetic exergy;

$\dot{E}_p$: potential exergy;

$\dot{E}_{ph}$: physical exergy;

$\dot{E}_0$: chemical exergy.

To generalize the calculations, it is common to work with specific properties, which consists of the ratio between the property and its mass. The specific exergy, ε = E / m, can be represented according to equation 2:

$$\varepsilon = \varepsilon_k + \varepsilon_p + \varepsilon_{ph} + \varepsilon_0 \tag{2}$$

In the present study, the portion corresponding to kinetic, potential and chemical exergy is negligible. And the equation can be simplified as shown in equation 3:

$$\varepsilon_{ph} = \Delta h - T_0 \Delta s \tag{3}$$

On what:

Δh: variation of the specific enthalpy;

T_0: reference temperature;

Δs: variation of specific entropy.

The exergetic efficiency can be calculated using the formula in equation 4:

$$\varepsilon = \dot{m}\frac{(e_{in} - e_{out})}{\dot{w}} \tag{4}$$

On what:

$\dot{m}$: mass flow;

e: specific exergy;

$\dot{w}$: power.

Initially, a search was carried out in different databases for the construction of theoretical knowledge, and in addition, data related to the systems under study was sought. With the necessary information in place, an evaluation was made of the energy and exergetic efficiency of the water heating process from its different energy sources, one consisting of the traditional way, via electric energy, and the other from solar heating.

The analysis of energy efficiency was based on the first principle of thermodynamics (equation 5):

$$\eta = \frac{q\rho c_p(T_2 - T_1)}{\dot{w}} \qquad (5)$$

On what:

q: volumetric flow;

ρ: specific mass;

c_p: specific heat;

T_1: inlet temperature;

T_2: outlet temperature;

$\dot{w}$: power.

In addition to calculating the energy efficiency for electric showers and the solar heater, their exergetic efficiency was evaluated. This efficiency is presented in equation 6, which basically consists of the ratio between useful work and available work.

$$\eta = \frac{W_{useful}}{W_{avaliable}} \qquad (6)$$

W_{useful}: useful work that has really been tapped;

$W_{avaliable}$: available work that has been provided to the system.

It is important to note that, in order to validate the results, data were consulted in the literature referring to a 4.4 kW electric shower and a solar heater model Heliotek - MC Evolution, from Bosch.

In order to carry out the analyzes, it considered values of inlet temperature equal to 20 ° C and outlet of 40 ° C and flow rate of 0.05 L / s. The studied fluid is water, which has specific heat, and a specific mass equal to 4.2 kJ / kg.K and 1000 kg / m³, respectively. For the electric shower, the average power is 4.4 kW. For the solar heater, the specifications of the model Heliotek - MC Evolution, from Bosch [13] were used.

Applying the values presented in equation (5), an efficiency for the electric shower of 95% is obtained, in accordance with the values presented in the literature [4, 12]. And for the solar heater the efficiency obtained was 54% [13].

3. RESULTS AND DISCUSSION

In terms of exergetic efficiency, it is possible to define the yield based on the ratio between the useful work and the available work, according to equation (6), performing the calculation, it is obtained that the electric shower has a yield of approximately 7% in accordance with the results of Costa et al. [4]. And for the solar heater the exergetic efficiency was approximately 12%, also converging with the results presented in the literature [11]. It is noticed that for both sources, the exergetic efficiency is low, this is because the water is heated at low temperature (from 20 °C to 40 °C), in this range the possibility of carrying out work is very small. Table 1 summarizes the results achieved.

Table 1. Energy and exergetic performance from different sources

Energy Source	Energy efficiency (1st principle)	Exergetic efficiency (2nd principle)
Electrical Energy	95%	7%
Solar Energy	54%	12%

The results show that the process of heating water at low temperatures has low exergetic efficiency. In this sense, it is important to choose sources of energy supply compatible with the end use. Therefore, electrical energy, which has high quality, should not be used to carry out a process of low exergetic yield, this causes a high destruction of exergy. The use of a solar system is more appropriate in relation to electrical energy, which, as can be seen in Table 1, the use of solar energy instead of electrical energy, provides a 72% increase in exergetic efficiency, even though the solar system presents low efficiency, of approximately 12%, caused by the nature of the process.

From the results obtained in table 1, it can be seen that the value found with the application of the First Principle (quantity) is different from the value added with the Second Principle (quality), showing that it is necessary to evaluate energy resources both from the perspective energy efficiency as well as exergetics, so that it is possible to select integrated resource planning. With this, it takes one to adopt environmentally correct actions, one can adopt the energy efficiency indexes together with the exergetic, as parameters of decision making on energy sources according to their end use, contributing to reduce the exergetic destruction of the system and consequently influencing the mitigation of environmental impacts.

It is worth mentioning that it is necessary to carry out complementary studies to choose the system that best suits the desired objectives [14]. From an exergetic perspective, heating using solar energy is more advantageous than using electrical energy. However, it is necessary to carry out a technical-economic analysis to verify whether it is financially attractive to invest in a solar system for heating water in the place of interest.

4. CONCLUSION

The present work had as objective to make an energetic and exergetic comparison in a water heating system carried out by electric energy and solar heating. It was found that for low temperature heating systems, relatively higher exergetic efficiency is obtained using solar heating, compared to the use of electrical energy. There is less destruction of exergy. About the energy aspects, evaluated only from the perspective of the first principle of thermodynamics (energy conservation), the source of electrical energy is more efficient, which is in accordance with the literature, as electrical energy has better performance compared to solar.

Thus, for the case addressed in this work, water heating at low temperature, the solar heater proved to be more appropriate than electrical resistance, it is worth mentioning that the study considered only thermodynamic aspects, requiring a technical-economic analysis to checking the best alternative.

As a suggestion for future studies, a thermoeconomic analysis of the use of water heating systems is proposed for the two conditions discussed in this work, verifying whether the financial contribution used in a solar heating system, for example, is justified because it has a better efficiency.

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