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QUALITATIVE REVIEW OF THERMOECONOMIC ANALYZES IN SOLAR REFRIGERATION SYSTEMS APPLIED TO ABSORPTION CHILLERS

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Abstract.

The implementation of solar refrigeration in absorption chillers has been a topic widely researched in the scientific community in view of the search for compatibility of the thermal comfort standards required in the current century with the need to search for the consumption of sustainable energy sources in refrigeration equipment. Based on this scenario, this work aimed to conduct a qualitative literature review of thermoeconomic analyzes in solar cooling systems applied to absorption chillers. As a result, a volume of research was obtained in three basic categories: energy and exergetic analyzes in low capacity chillers, effect of the climate on the thermoeconomic performance of absorption systems by solar refrigeration and the implementation of cogeneration systems using solar energy as one of the sources.

Keywords: Chillers, Solar cooling, Absorption Cycle, Thermoeconomics.

1. INTRODUCTION

In the 21st century, there is a great search for the use of refrigeration systems that aim to reduce the emission of greenhouse gases and are also suitable for sustainable energy consumption. There is a strong economic motivation and a need to investigate current technologies, in order to determine the appropriate systems from the cooling needs, from the potential of solar thermal energy worldwide (Nkwetta and Sandercock, 2016).

Solar cooling also provides a subject of great interest to the scientific community due to the coincidence of peak cooling demand and the availability of solar radiation. Although solar cooling can be implemented using photovoltaic plates and solar collectors, there are several studies comparing showing a greater advantage in using solar collector systems, due to the fact that the high costs of batteries in photovoltaic systems, do not alter a thermoeconomic profitability in the short and medium term (Sarbu and Sebarchievici, 2015; Otanicar, Taylor and Phelan, 2012).

Several studies have demonstrated the use of absorption chillers as one of the most technically adaptable equipment for the implementation of solar cooling. However, there are currently a number of barriers in the development of solar cooling technology on the market: high costs for absorption chillers, as well as a lack of standardization, market familiarity and compatibility with the construction project. Due to this difficulty, several projects are emerging in the development of small-scale and economical solar absorption refrigeration systems, with efficient heat dissipation from the ambient air, being able to use renewable heat sources and, therefore, have a minimum consumption of electricity. (Anand, Gupta e Tyagi, 2015).

Due to the aforementioned barriers, there is a scientific effort, in the last decade, of several researchers who are promoting new options of projects in the use of absorption systems with the use of solar collectors, energy systems and cooling modes, seeking overcome this initial state-of-the-art stage in solar cooling systems. Because of this, according to the author, technical analyzes (of thermodynamic nature) associated with the economic return of using these types of equipment are still extremely necessary in view of the increasing need for renewable energy sources (Leonzio, 2017).

From this scenario, this work has the general objective of conducting a qualitative literature review of thermoeconomic analyzes in solar cooling systems applied to absorption chillers.

2. METHODOLOGY

Figure 1 shows the methodological flow implemented in the qualitative review.

In step 1 (problem formulation), a literature search was carried out to evaluate thermoeconomically absorption cycles triggered by solar cooling.

In step 2, two databases were selected: Science Direct and Research Gate. These databases were chosen in order to be considered, in the scientific community, important repositories of works published in the most important magazines in the world.

In step 3, descriptors were selected to enable the main works related to the formulation of the problem of this research to be identified. As the repositories selected in step 2 supported, in their advanced search, only the use of a number of 5 Booleans (AND, OR IF, etc.), a set of descriptors was structured that used a maximum of 5 terms. The following array of descriptors were used: “(absorption Chiller OR absorption cycle) AND (solar cooling) AND (thermoeconomic OR exergetic) AND analysis”.

In step 4, after applying the descriptors, 57 articles were found. From that amount found, the first decision was made regarding the year of publication. As a research decision, we sought to analyze files that had a year of publication greater than 2014. After this screening, 16 articles were discarded, leaving only 39 papers.

With 39 selected works, stage 5 was obtained, where all the titles and curricula were read. The purpose of reading the titles and abstracts to map, previously, if the articles addressed an energetic and exergetic analysis. This is because an energetic and exergetic analysis works as an information input for studies of thermoeconomic analysis in thermodynamic processes. With this study, only 29 articles remained (10 articles were discarded because they were not found in relation to energy and exergetic analysis).

In step 6, the 29 articles were read in full. The objective, in this complete reading, was to identify whether the absorption cycle, analyzed in the article, had a thermoeconomic analysis integrated with a solar energy system. It was found that 7 articles did not address solar cooling, in a bias of thermoeconomic analysis, leaving, at the end, 22 articles. It was these 22 articles that a qualitative review was made (step 7).

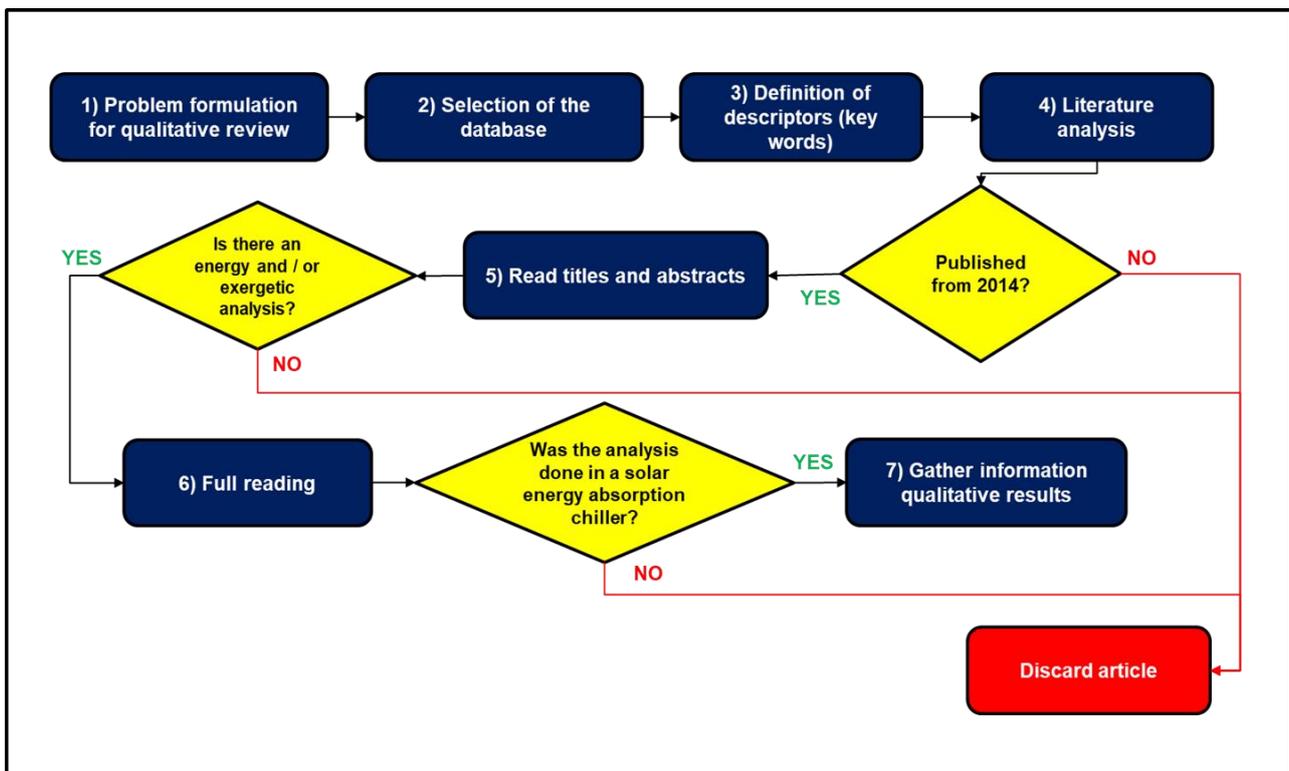


Figure 1. Methodological flow of qualitative review

3. RESULTS AND DISCUSSION

Several studies in the recent literature have shown energetic and exergetic analyzes of absorption chillers driven by solar cooling systems.

A study of the economic evaluation was developed, in the basis of the energetic and exergetic analysis, on the implementation of a solar cooling system, which activates a Chiller by absorption of LiBr-H₂O, in Athens (Greece). When analyzing different areas of solar capture from a solar collector of vacuum tubes and different thermal storage tanks, the authors found, as a great thermoeconomic solution, a set of solar collectors with an area of 450m² and a tank with a volume of 14m³, returning the investment made in a total of 15 years (Bellos et al., 2017).

A case study developed an exergetic analysis of a simple effect absorption system, powered by solar cooling, in southeastern Spain. Using a flat plate solar collector, the exergetic analysis made it possible to conclude that the heat supply temperatures in the generator, in the range of 70 ° C to 80 ° C, allowed better COP values. The author also highlights the use of thermal reservoirs as a primary factor for the correct delivery of this ideal temperature range (Rosiek, 2019).

There was also a proposal for an energetic and exergetic analysis of an ammonia and water absorption cycle. The authors included, in the analysis, the evaluation of the exergy destroyed in the solar collector (which in the research was of the parabolic type). They found a COP worth 0.444. In contrast, exergetic efficiency was equal to 0.026. In addition, the solar collector was the device that most promoted the destruction of exergy (Petela and Szlek, 2019).

Franchini et al. (2015) carried out the modeling, design, and construction of a micro-scale LiBr-H₂O absorption chiller, with a capacity of 5kW, demonstrating energy feasibility in its preliminary results, although, in the thermoeconomic bias, the system distances itself from compression systems steam. Said, El-Shaarawi and Siddiqui (2015) also analyzed the changes in parameters and devices of a 10 kW solar cooling absorption system, aiming at its operational optimization. The simulation results indicate a 10% increase in the conventional design COP using heat recovery from the deflegmator and an 8% increase in the conventional design COP due to the use of refrigerant storage, accumulating an 18% improvement.

The modeling, design, and construction of a micro-scale LiBr-H₂O absorption chiller, with a capacity of 5kW, was carried out, demonstrating energy feasibility in its preliminary results, although, in the thermoeconomic bias, the system distances itself from steam compression systems (Franchini et al., 2015). Said, El-Shaarawi and Siddiqui (2015) also analyzed the changes in parameters and devices of a 10 kW solar cooling absorption system, aiming at its operational optimization. The simulation results indicate a 10% increase in the conventional design COP using heat recovery from the deflegmator and an 8% increase in the conventional design COP due to the use of refrigerant storage, accumulating an 18% improvement.

A thermoeconomic analysis of a solar cooling system by absorption was carried out using different types of solar collectors (flat plate, vacuum tube and parabolic). The system aimed to meet a thermal load demand of 10 kW. The results explained in the research pointed to a better efficiency of the system from the use of a vacuum tube solar collector, being the most viable economic solution with a cost of approximately 7.2 k € for a collection area of 24 m² (Asadi et al., 2018).

A research approached an energetic and exergetic study of an absorption refrigeration system, using LiBr-H₂O, evaluating the influence of the various types of solar collectors available on the market. The performance parameters evaluated were the performance coefficient, exergy efficiency, destruction of exergy and potential for improvement. The study concluded that vacuum tube solar collectors showed better efficiency in heat gain, compared to flat plate collectors with single and double glass. The authors also found that the greatest destruction of exergy is in the solar collector (Kerme et al., 2017).

An analysis was made of the application of an absorption Chiller assisted by solar energy, with a capacity of 5 tons of refrigeration (TR), using the TRNSYS® software. The authors performed a parameterization of the main devices of the system, varying the thermal or power exchange capacity, seeking to find out how much the optimum combination of each device could attribute to the system's performance improvement. As a conclusion, the research showed that the correct setup can show an improvement of up to 28% in the improvement of exergetic efficiency (Sokhansefat et al., 2017).

An analytical study of an Absorption Chillers with LiBr-H₂O, powered by solar energy, was carried out in a residential application. The authors made an analysis considering that the small Chiller was air-cooled, and obtained as a result equipment that had a COP around 0.61, meeting the thermal demand of the residence in almost 70% (Chen, Dai and Wang, 2017).

There is also a trend in the use of solar cooling in combined systems that involve absorption systems combined with other types of cycles. A combined absorption refrigeration cycle and an organic Rankine cycle driven by solar collectors with linear concentrators were studied. The research aimed to evaluate the feasibility of applying this combined cycle in the generation of electricity and the removal of thermal load in an academic building in an educational institution. It was found that the condenser was the device with the greatest exergetic destruction, due to the high heat dissipation (Grosu et al., 2016).

A solar energy polygeneration system was modeled, triggering a refrigeration cycle, an organic Rankine cycle and also a desalination unit, verifying the energetic and exergetic performance of this system. The study showed as a result a greater exergetic destruction also in the turbine and in the desalination unit (Kerme et al., 2020). Eisavi et al. (2018) also proposed a similar study, but with a heat exchanger (instead of the desalination unit). In this condition, the authors found that the greatest exergetic destruction occurred in the solar collectors.

Thermoeconomic evaluations were performed in refrigeration cycles in compression absorption cascades. Research has shown that in systems with low temperatures there is better thermoeconomic viability and that devices such as evaporator and heat exchanger are the ones that most influence the exergetic efficiency of these cascade systems (Cimsit, Ozturk and Kincay, 2015; Bellos, Tzivanidis and Tsifis, 2017).

An exergetic, energetic and exergo-economic analysis of a tri-generation solar cooling system was developed, which consisted of a subsystem of solar collectors, an absorption chiller and an organic Rankine cycle. Using the EES® software, it was found that the greatest destruction of exergy was in the storage tank. In addition, the turbine was found to be the highest endogenous investment cost (Montazerinejad, Ahmadi and Montazerinejad, 2019).

There are also researches that carried out energy and exergetic analysis taking into account the climate variation in the solar cooling absorption systems. A financial and energy assessment of LiBr-H₂O absorption refrigeration systems was made, with simple effect, powered by solar energy, verifying the viability of these systems in some cities in the world, based on the climatic differences of each one. Among the chosen cities, it was found that the cities of Abu Dhabi and Phoenix have the best combination of climate and minimum leveled cost of cooling, with values of 0.0575 € / kWh and 0.0590 € / kWh, respectively (Bellos and Tzivanidis, 2017). The authors, converging with Rosiek (2019), also emphasize the importance of a correct dimensioning and quality of the thermal storage tank for these adequate cooling conditions to occur.

It was verified the application of a single and double effect absorption system (system in which time it operates as a single effect and time it operates as a double effect) from the tropical climate of Asia. The authors compared this system with a gas-driven double-effect chiller and concluded that the single and double-effect chiller had a performance coefficient between 1.4 and 3.3 and a 58% reduction in gas rate with the implementation of the new system (Lubis et al., 2016).

The impact of different climate behaviors in Morocco was studied on solar cooling absorption chillers. The authors conducted the study based on data from the solar fraction. It was found that for annual average solar fraction indexes of 30%, the solar cooling chillers had a COP of 0.33. In addition, as the solar fraction in other regions reaches values around 19%, COP values can reach up to 0.12, demonstrating the equipment's thermal infeasibility (Agrouaz, et al., 2017).

In view of the above, energy and exergetic analyzes on chillers, the effect of the climate (related to climatic factors) and cogeneration systems are the most demanded themes from the scientific community in the use of chillers by solar energy.

4. CONCLUSIONS

It was possible to verify that three theoretical categories have been more approached with regard to thermoeconomic analysis in absorption chillers, powered by solar refrigeration: energetic and exergetic analysis in chillers, use of solar cooling absorption chiller in combined systems and effect of climate on the thermoeconomic performance of absorption systems by solar cooling.

As a proposal for a scientific increase for this work, a systematic analysis of the energy efficiency and exergetic coefficients of these works is suggested, seeking to conclude, with more accuracy, on the thermoeconomic viability of this equipment and its suitability for the use of sustainable energies.

5. ACKNOWLEDGEMENTS

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