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Simulation and parametric study of a 5-ton solar absorption cooling system in Tehran

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ABSTRACT

In this work, first, a transient simulation of a 5-ton capacity solar absorption cooling apparatus, installed and operating at NRI (Niroo Research Institute) in Tehran, is carried out utilizing the TRNSYS software. All the components (solar collectors, storage tank, auxiliary boiler, absorption chiller, cooling tower, air handling unit, heat exchanger and pumps) are modeled in the software. Then, the results of weather data, solar loop performance, absorption chiller performance, and the annular results of the system are presented and discussed. After that, a parametric analysis of the cycle is carried out. To this aim, the effects of various parameters on the performance of the solar absorption refrigeration cycle are evaluated and their optima are reported. The parameters affecting the absorption chiller parameters include collector area, storage tank capacity, the temperature set point for switching to the auxiliary boiler, and mass flow rate of the solar system. In the present research, the effects of the aforementioned parameters on the performance (solar fraction) of the solar absorption cooling system are investigated, the results are reported, and the optimum configuration is introduced. The results indicate that the performance of the setup is capable of 28% enhancement. The optimum values are collector area of 55 m^2, storage tank volume of 1 m^2, temperature set point of the auxiliary boiler of 77 °C, the solar collector mass flow rate of 1000 kg/h, and the collector slope of 33 °.

1. Introduction

The availability of new energy resources for the developing countries is prominent to their economic development, as recent studies have revealed that there is a close positive relation between the level of development and energy consumption of a country [1]. Energy resources can be categorized into renewables and non-renewables. Fossil fuels are non-renewables which now provide for the majority of the energy demand. Fossil fuel resources will be totally consumed by the next century, inflicting considerable environmental damages including pollution and global warming. Consequently, policies are laid down to tackle these issues by introducing viable alternative renewable energy technologies [2,3]. Tackling cooling peak loads in hot seasons, a major power industry issue, is discussed in this article with the application of solar energy, as a major sustainable energy resource. In the conditions that hot climate simultaneously imposes peak power demands and lower power plant efficiencies, the utilization of solar absorption chiller is a wise way out. Considering the fact that 40% of the total energy consumption occurs in buildings [4], and the high insolation of Iran, the present work discusses the simulation, parametric study, and performance enhancement of a solar-driven absorption cooling system in Tehran's climatic conditions.

Following comes a literature review for the field of solar absorption cooling systems. In 1985, Muneer [5] simulated and modeled solar chillers in order to investigate the coefficient of performance (COP), chilled water temperature and the performance of systems with various collectors. The significance of collector type selection for supplying the proper hot water temperature to the generator was studied by Li [6] in 2000. A practical solar cooling work is the SARANTIS cosmetics factory in Greece, 2003 [7]. The project comprises 2700 m^2 of flat plate collectors and two absorption chiller units of 700 kW total capacity, which can provide for 40% of the cooling demand of the factory. Bozorgmehri and Lari [8], in a techno-economic analysis, evaluated solar absorption chillers for the Iranian market of 2003. In 2006, Soltani et al. [9] experimentally studied the steps of converting a conventional absorption chiller into a solar absorption chiller. The risk of crystallization in high ambient temperature is a drawback for the absorption cooling devices.

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In 2009, Kim and Infante Ferreira [10] theoretically studied the COP of an apparatus which works with low-temperature hot water from solar collectors and circulates dilute LiBr solutions which inhere lower crystallization risks in hot and arid climates. Their proposed system maintained acceptable performance under 50 °C ambient temperature. In 2011, Praene et al. [11] studied a solar cooling system of 30 kW capacity with auxiliary heating equipment, used for heating a classroom. In their setup, 90 m^2 of flat plate collectors worked to provide 125 kWh energy for the chiller consumption. The cooler kept the classroom temperature under 25 °C between 8 a.m. and 5 p.m. In 2011, Arabi and Dehghani [12] studied the influence of various loads on the absorption chiller cycle efficiency. In 2012, Javaherdeh et al. [13] published an article on the subject of thermo-economic analysis and optimization of a lithium bromide solar driven absorption chiller. They found that increasing the hot water storage tank capacity decreased the energy consumption of the auxiliary heater, which compensated for the lack of temperature prior to the chiller generator inlet. Consequently, the fuel consumption in the auxiliary heater fell down, especially in the late hours of the day, which cut the cooling cost. However, with further increasing the storage tank capacity, the rise in the capital cost of the tank outweighs the cut in the fuel costs, and thus the overall cooling cost rises.

In 2013, Chamanpara [14] simulated and optimized single-effect solar absorption lithium bromide chillers for a residential building in Shiraz, Iran. In this study, the effects of condenser, absorber, and generator inlet water temperatures on the COP, Carnot COP, and exergy efficiency were studied. The results revealed that increasing the condenser and absorber temperatures decreased the COP and exergy efficiency. Also, increasing the generator temperature increased the COP, while the exergy efficiency increased firstly then decreased. In 2014, Chaiyat and Kiatsisiroat investigated the performance enhancement occurred due to the addition of a heat pump between the condenser and evaporator of a LiBr/H_2O absorption cycle [15]. In 2015, Sun et al. [16] studied a solar absorption cooling/heating system which used an auxiliary heater, when the solar irradiation did not suffice. In this experimental work, 1020 m^2 of evacuated tube solar collectors were used in order to provide the cooling/heating requirements of a 10,000 m^2 building. According to the work, the application of the aforementioned solar absorption device annually saved up to 49.7% of the energy consumption, in comparison with the conventional absorption chiller system. Solar hot water supply can be used for other applications. For instance, in a transient simulation study, Lima et al. [17] suggested the use of solar collectors and storage tank for supplying the hot water demand of a hospital laundry. They optimized the collector area, tilt angle, water flow rate, and the size of the storage tank. They also studied the economic payback of the system and defined the case as profitable.

In 2016, a comparison of LiCl/H_2O and LiBr/H_2O as working fluids of absorption cycles was carried out, and the novel LiCl/H_2O pair was revealed to require about 8% lower collector area which means the higher exergetic efficiency of this pair [18]. In the same year, Bellos et al. [19] compared different collector types for application in solar-driven absorption cooling in Greece. Among flat plate, evacuated tube, compound parabolic trough, and trough collectors, the evacuated tube collector was the most profitable one, while the trough collector was the exergetic optimum one with too high capital cost. This fact was also supported by Tashtoush et al. [20] in 2015, where they found the performance of the evacuated tube type better than the flat plate type, when working in a solar ejector cooling system. Experimental and simulation studies have been carried out in [21] on a double-effect absorption cooling cycle equipped with a flat-plate evacuated solar collector which proved to be relatively profitable and efficient.

In 2016, Shirazi et al. [22] studied a solar absorption system in three different control modes and indicated the optimum control mode. According to their results, a configuration of series auxiliary heaters performed better than a parallel one; moreover, circulating a variable mass flow rate (with a constant temperature goal) led to better performance of the solar section. In an innovative approach, Herrera et al. [23] suggested a predictive control approach for a producer-consumer micro-network with a solar hot water storage, as its producer, and an absorption chiller as one of its consumers. The control system worked modularly, consisting of one controller for the producer, and one for each consumer. These controllers worked in conjunction to result in an optimized control signal for the renewable energy production module. In another study [24], the parametric study, feasibility assessment, and optimization of solar assisted absorption air conditioning system were investigated. The researchers found the best performing configuration among different optimized absorption cooling options, based on an energetic, economic and environmental multi-objective analysis of transient simulation results. The same group found that substantial subsidies are essential for a solar assisted single-effect LiBr-H_2O absorption cooling system to achieve economic feasibility [25].

A case study of dual heat source, single-effect absorption chiller installed in Indonesia showed the high potential of these systems for widespread application in the tropical zone [26]. In 2016, Cai et al. [27] experimentally investigated the COP, refrigeration capacity and the lowest evaporation temperature of a single effect, air cooled, ammonia/salt absorption cooling cycle for different salts in the solution. In the same year, Ochoa et al. [28] investigated the dynamic behavior of an absorption chiller subject to sever power and thermal load disturbances. Their simulation results showed good compliance with the experimental data. Rashidi et al. [29] proposed a combination of the Kalina cycle and an absorption chiller to work as a cogeneration cycle, in a configuration that the Kalina subsystem discharged heat to the chiller desorber. In 2017, Shirazi et al. [30] used a transient simulation in order to assess the feasibility of single, double, and triple effect absorption chillers in combination with a variety of solar collectors. Their results revealed that a double-effect absorption cycle coupled with a field of evacuated flat plate collectors presented the best trade-off between the energy efficiency and costs, for a wide climatic range. In the same year, Bellos et al. [31] analyzed a single effect solar driven absorption chiller from the exergetic and economic aspects, each in a separate stage, in order to find the most suitable collector area and storage tank volume that yields the shortest payback period.

Besides those mentioned, in 2017, Agrouaz et al. [32] have carried out simulations and a parametric study on the effects of some important factors on the solar fraction and COP of a residential air conditioning cycle for the climatic conditions of Moroccan cities. They could put forward a technical configuration guideline for designers, taking into account collector slope, collector area, storage tank size, evaporator, and generator mass flow rate. Similarly, Ochoa et al. [33] investigated the effect of varying heat transfer coefficient of lithium bromide solution as a function of pressure, temperature, and concentrations, on the precision of predicting temperature profiles in a single effect chiller. Also, some effort has been centered on performance enhancement of absorption cooling. Agyenim [34], for instance, proved that phase change material (PCM) can help dealing with the peak cooling loads, storing the excess diurnal solar energy for later use in absorption chillers. In another approach, Muye et al. [35] proposed a novel power-cooling absorption cycle which was capable of providing for both cooling and power demands of a household. The device used a scroll expander as the power generator. A comprehensive,