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Solar-assisted single-double-effect absorption chiller for use in Asian tropical climates

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ABSTRACT

Solar energy is accessible throughout the year in tropical regions. The latest development of absorption chillers has demonstrated that these systems are suitable for effective use of solar energy. The utilisation of solar energy for heat-driven cooling systems has significant advantages. Without a doubt, solar energy represents a clean energy source that is available without any additional fuel cost, and that can be proportionally accessible when the cooling load increases during the middle hours of the day. This study focuses on a single-double-effect absorption chiller machine that was installed in Indonesia. The system is driven by a dual-heat source that combines gas and solar energy. This system is characterised by simulating its performance in various conditions in terms of the cooling water (28–34 °C) and the hot water (75–90 °C) inlet temperatures. The reference operating condition of this system is 239 kW of cooling capacity. The mathematical model is validated and shows a good agreement with experimental data. In the operative range considered, simulation results yield a coefficient of performance between 1.4 and 3.3, and a gas reduction ratio from 7 to 58% when compared to a double-effect absorption chiller driven by gas. Based on the simulation results, this system is expected to have a good potential for widespread use in tropical Asia regions.

1. Introduction

Solar energy is a renewable source that can solve energy problems worldwide [1]. There are several reasons for use of renewable energy sources and for directing research efforts towards energy problems. Foremost, non-renewable energy sources are limited and steeply diminishing due to the increasing energy demands. Additionally, non-renewable sources are typically associated with environmental problems. Some tropical Asian countries are geographically aligned with the equator, and their locations are thus beneficial for the abundant availability of solar energy throughout the year. Tropical Asian countries have the potential for an average daily solar radiation of approximately 4–7 kW h/m^2/day [2–7].

Single-effect absorption chillers have being extensively used since the 1960s, and in 1980s, the double-effect was developed [8]. Subsequently, multiple-effect configurations have been developed to overcome the performance limitation imposed to the single-effect type, and accordingly, have elicited higher coefficient of performance (COP) values [9]. Conventionally, absorption chillers are driven by heat from an electrical heater, gas flaring, waste heat from engines, and other sources. Since the input heat needed for the single-effect absorption cycle is not required to have a high-temperature level [10], a system was conceived for use of heat from solar energy [11].

A collector area with a large size is required to fulfill a large capacity for hot water. The required hot water capacity depends on the nominal cooling capacity of the absorption chiller. For instance, a lithium bromide-water double-stage absorption chiller machine installed in Tunisia with a 16 kW cooling capacity needed a parabolic, trough solar collector area of 39 m^2 [12]. Based on another experiment in Reunion Island, a lithium bromide-water, single-effect absorption chiller possesses a 30 kW cooling capacity, and used a double-glazed flat plate solar collector with a total area of 90 m^2 [13]. Furthermore, in Seville (Spain), a double-effect absorption chiller with a 174 kW cooling capacity featured a linear Fresnel

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solar collector with a total aperture area of 352 m^2 [14]. Even though the cooling capacity and the solar collector area cannot be directly compared, these application cases can be used as references. In general, a higher cooling capacity requires a larger solar collector area.

Absorption chillers installed on buildings that have a large cooling load and limited exposed areas, cannot use only solar energy to fulfill the total cooling load due to the lack of available solar collector areas, and due to fact that the operative performance of the solar collector is highly dependent on the availability and intensity of solar radiation. The amount of solar radiation which can be absorbed is, in turn, greatly affected by weather conditions. Due to the occasional changes of the weather conditions, this type of absorption system requires a reserve of energy that can stabilise the system operability and match the user demand continuously. Among the conventional energy sources, natural gas is more environment-friendly and relatively cheaper than other fossil fuel [11]. Therefore, natural gas is suitable to be combined with solar energy. The development of the single-double-effect absorption chiller, which uses a combination of solar energy and natural gas, is described in Refs. [15,16]. The single-double-effect absorption chiller was installed in Indonesia as a field test (Fig. 1) at the end of 2013 to assess its performance and characteristics in Asiatic tropical regions. This system was chosen because it has a large capacity and can utilise solar energy, even though the area of the solar collectors is limited. This configuration is based on the same working principle as other conventional absorption chillers. The main feature of this system is mainly a special temperature generator used as the component in the system that is directly heated by solar energy, whereby additional water vapour is desorbed and subsequently condensed in the special condenser. This system also has a different flow direction for the cooling water than usual configurations, whereby the water flows from the condensers to the absorber to maximise the utilisation of solar energy. Basically, this system was designed to maximise the use of solar energy despite the possible limitation of the solar collectors. During a partial-load operation, this system can work either as a single-effect or as a single-double–effect system. Since no previous study is available about this system in tropical Asia regions, this work is presented to analyse its performance and characteristics.

The COP of this system is calculated as the cooling capacity divided by the natural gas consumption. Therefore, the use of solar energy is always beneficial for the system operability. It will be demonstrated by the analysis that follows that the single-double-effect absorption chiller is a suitable system for areas that are characterised by a high amount of available solar energy. Therefore, this system is mostly appropriate when used in the tropical regions, and the investment cost required is expected to be recovered in a short payback period. The purpose of this study is to characterise the performance of the single-double-effect absorption chiller with variations in the cooling water inlet temperatures and the hot water inlet temperature from solar energy using simulations. This analysis will provide the basis for future optimisation efforts of the system and improve its control methodology. Correspondingly, the elicited results confirm that solar energy can be fully utilised in a single-double-effect absorption chiller in tropical climates.

2. Solar thermal cooling system

The solar thermal cooling system using the single-double-effect absorption chiller (Fig. 2) supplies chilled water to the mechanical research centre (MRC) building. The building includes laboratories, meeting rooms, and lecturer rooms. The official active hours of the building are between 8:00 until 16:00. Evacuated tube solar collectors, located on the roof top of the MRC building, are used to absorb solar energy. The total aperture area of the solar collectors is 181.04 m^2, 62 modules evacuator tubular collectors were installed, which combined two modules in series as one unit that consisted of 32 tubes, and they were divided into eight parallel rows with each tube in a single module being connected to a manifold. A hot water storage tank with a volume of 1000 L is used to maintain the temperature of the hot water stable for driving the absorption

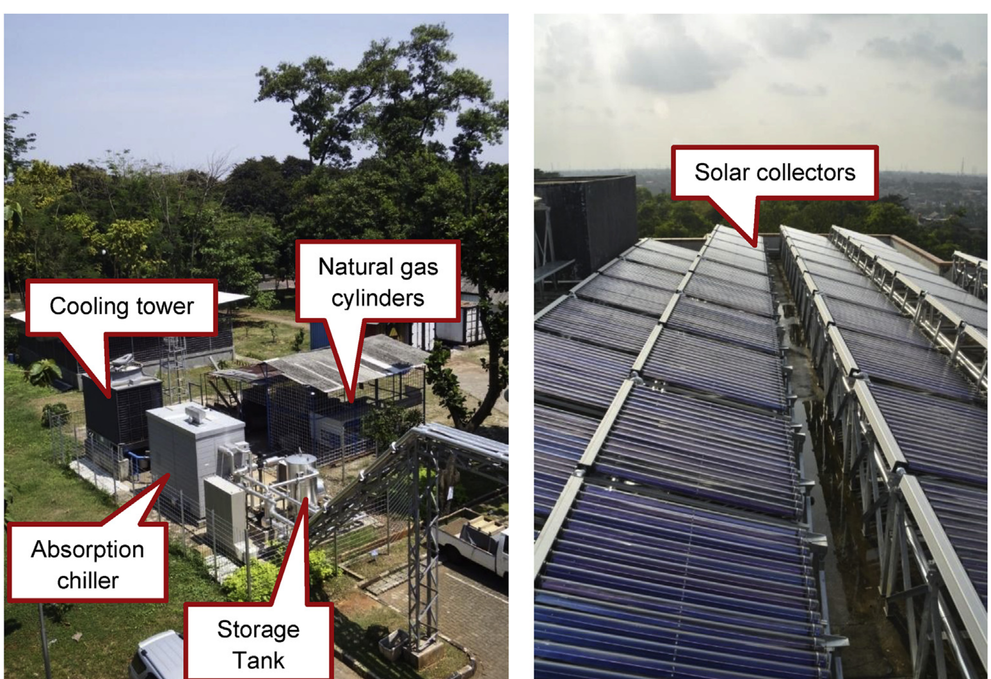

Fig. 1. Field test machine in Indonesia (Universitas Indonesia).