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A smart combination of a solar assisted absorption chiller and a power productive gas expansion unit for cogeneration of power and cooling

A. Arabkoohsar [a, b, *], G.B. Andresen [b]

[a] Department of Mechanical Engineering, Eindhoven University of Technology, Eindhoven, The Netherlands
[b] Department of Engineering, Aarhus University, Central Region, Aarhus, Denmark

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ABSTRACT

Solar assisted absorption chiller is one of efficient cooling production systems for large cooling capacities. The main drawback of this system is that in addition to the electricity consumption, it demands for a lot of heat in relatively high temperature range of 90–120 °C, though the solar system may provide a significant portion of this heating demand. On the other hand, in gas transmission systems, there are some expansion stations in which gas pressure is reduced considerably and this pressure drop causes temperature collapse in gas stream. Power productive gas expansion station (PPGES) is the most recent design proponed for these stations in which the unit is equipped with power generation systems. In this work, taking advantage of this temperature fall for cooling production is proposed by coupling the station with an absorption chiller. In this case, the chiller could also provide the heating demand of the expansion station. In order to evaluate the effectiveness of the proposed configuration, it is simulated for a case study in Denmark, i.e. Aarhus University (AU) hospital absorption chiller and Viborg gas station. The results show that the expansion station could provide an annual cooling production contribution of 27%. In addition, the paper presents an extensive economic assessment to prove the impact of the proposed system economically. The results show a great enhancement in the levelized cost of energy (LCOE) of the case study in case of employing the hybrid system instead of the conventional chiller.

1. Introduction

Absorption chillers are appropriate cooling production systems for large capacities. As they are heat-driven, they can greatly contribute to reduce primary energy consumption and environmental pollution if powered by renewable energies or other alternative heat production methods [1]. Many researchers have conducted various types of studies to find novel and efficient methods of deriving absorption chillers. For example, Chunling and Zengzhi [2] designed an efficient waste heat refrigeration cycle (compound absorption and vapor compression cycle) for ships. Seara et al. [3] designed a gas-to-thermal fluid heat recovery system from engine exhausts to power an absorption chiller for onboard cooling production. Wicks [4] proposed an engine driven combined compression and absorption chiller configuration for maximum fuel utilization and low temperature heat recovery. Wang and Wu [5] investigated employing an exhaust gas line and a jacket water waste heat source of a combined heat and power plant for deriving a mixed effect (combination of a single effect and double effect) absorption chiller and found it very efficient in both terms of energy and exergy performances. Shafiei and Parsa [6] presented a comparison analysis of solar absorption chillers instead of compression chillers for residential cooling to evaluate the amount of savable electricity and fossil fuels. Assilzadeh et al. [7] accomplished a simulation and optimization of a LiBr-water solar absorption cooling system with evacuated tube collectors. An experimental investigation on the performance of a dual source (gas engine waste heat and solar heat) powered absorption chiller was carried out in Ref. [8].

On the other hand, the PPGES (power productive gas expansion station) is a novel and efficient system for producing power taking advantage of the potential that gas stream offers due to its high mass flow rate and high pressure. In fact, a gas station is a gas expansion station through transmission system in which the high pressure of 40–60 bar of the gas should be reduced to a medium pressure of 15–20 bar [9]. The pressure reduction in a PPGES is

* Corresponding author. Department of Mechanical Engineering, Eindhoven University of Technology, Eindhoven, The Netherlands.
E-mail address: mani.koohsar@yahoo.com (A. Arabkoohsar).

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carried out by specially designed turbines that drive an electricity generator to produce power [10]. Clearly, passing through a turbine cause a sharp temperature drop in the gas stream. As there is the risk of generating ice cubes in the gas stream at low temperatures, which would block the stream path, the PPGESs use heaters to preheat the gas stream before the expansion [11]. Extensive information about the PPGESs can be found in Refs. [9–17]. Although expansion stations have been studied in many aspects, such as feasibility of power generation [10,11], novel methods of mass flow metering [12], renewable based heat preparation (solar or geothermal heaters) [13–17] etc., not much attention has been paid to its cooling production potential. The temperature in which gas starts freezing varies for different types of gas, depending on its compositions. However, it is usually in a range where the station outlet could be safely utilized for cooling purposes.

In this work, a clever combination of an absorption chiller and a PPGES both assisted by solar thermal systems is proposed to overcome a challenge in a cooling preparation of a new hospital located in Aarhus, Denmark. This is one of the largest hospitals of northern Europe, but many similar sized hospitals are expected to be constructed in the years to come. Fig. 1 shows an outline of the proposed system. The details will be discussed in the next section.

As the system is designed for a real case, the work will enable us to present realistic results and data. Therefore, the results of simulating the proposed system in the case study in terms of potential saving, power generation capacity etc. will be estimated in the presented work.

2. Problem description and the proposed solution

Aarhus University (AU) hospital is one of the largest hospitals in Northern Europe and despite the relatively cold Scandinavian climate, a maximum cooling demand of 3.5 MW is predicted for that. As a smart choice, a large absorption chiller is considered to be installed to provide this cooling demand. The heating demand of this absorption chiller is going to be supplied by waste incineration CHP plants that generally provide the energy demand of the local district heating network. The temperatures of the supporting and return lines of these CHP plants are 95–100 °C and 35–40 °C, respectively.

The problem of this outline is that in the summer, when the chiller cooling duty increases and consequently its heating demand comes up, the local district heating network is at its lowest demand time and therefore the CHP plants would normally operate at very low loads. But with the addition of the absorption chiller, the CHP plants have to work at increased loads to provide their heating demand. However, the absorption chiller outlet temperature is around 85–90 °C. Evidently, this high temperature hot water is neither appropriate for the CHP return lines nor is it usable for heating applications, as there is not enough heat demand.

In order to solve this problem, Arabkoohsar and Andresen [18] recently proposed a scheme in which the absorption chiller is assisted by a solar thermal system and the rest of its heat demand is supposed to be provided by district heating supporting line through a heat exchange loop process in an efficient manner so that the CHP systems are not required to work at higher loads. As the chiller in this system was proposed to be driven by simple evacuated tube solar collectors with a relatively low maximum temperature, a single effect LiBr-water absorption chiller was suggested to be installed. For further information about this system refer to [18].

In this work, a more efficient proposal is given for overcoming the aforementioned problem for the case study, i.e. the absorption chiller of the AU hospital. In this configuration, the chiller is again powered by a solar thermal system but after being accompanied by a PPGES in order to reduce the cooling load. Fig. 2 shows the schematic of the proposed configuration. According to the figure, the system consists of the two main parts of the solar thermal powered absorption chiller and the solar assisted PPGES. In this figure, the red arrows represent the CHP water paths, the dark and light blue arrows are water and cooling water streams, the orange lines are natural gas streams and the purple arrows are water/glycol mixture flows. The light and dark green arrows are respectively the light and heavy LiBr-water solution flows.

As there are several references for absorption chillers and expansion stations, no detailed explanation is presented about them and important notes in the operation of these systems are only going to be mentioned. Table 1 presents information about the values of important parameters in the hybrid system.

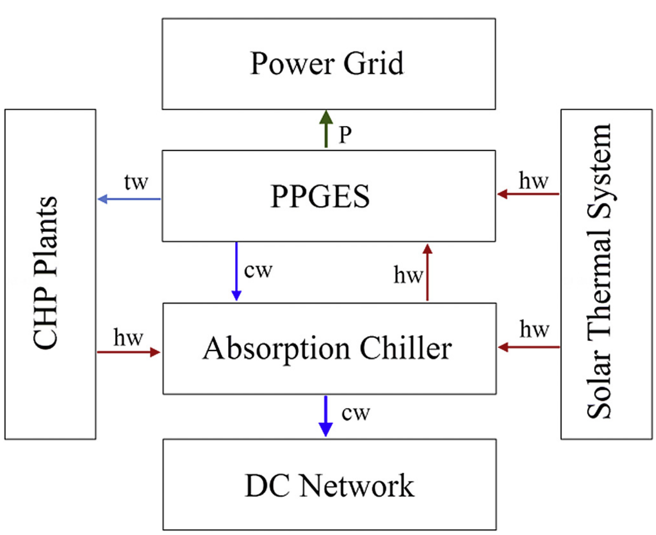

Fig. 1. The outline of the proposed combined system; hw: hot water, cw: cold water, tw: tepid water.

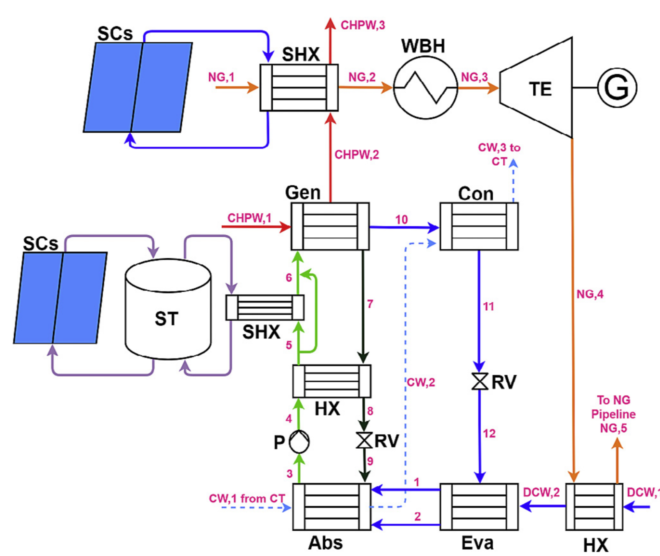

Fig. 2. The schematic diagram of the combined expansion unit and the solar assisted absorption chiller; Abs: absorber, P: pump, RV: restrictor valve, HX: heat exchanger, SHX: solar heat exchanger, ST: storage tank, SCs: solar collectors, Gen: chiller generator, Con: condenser, Eva: evaporator, WBH: water bath heater, TE: turbo-expander, G: electricity generator, CW: cold water, CT: cooling tower, DCW: district cooling water, CHPW: CHP unit water, NG: natural gas.