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Combined two stage desalination and cooling plant

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HIGHLIGHTS

- Improved yield in desalination
- Two outputs from a single source of energy
- High overall energy utilization factor
- Use of solar thermal energy in place of conventional sources
- Modified version of humidification and dehumidification (HDH) cycle

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ABSTRACT

Two or more than two outputs from a single source result an overall high energy utilization factor (EUF) compared to the single output system. In this work, two stage humidification and dehumidification (HDH) desalination system has been extended with cooling system integration. Solar flat plate collector and concentrating collector are selected respectively for HDH desalination and single effect vapor absorption refrigeration (VAR) plant. The cooling after desalination increases the yield of distillation compared to without its integration. The sequence of operations in the combined plant is first stage air preheatinghumidification–dehumidification, second stage air preheating–humidification–dehumidification and final cooling of air with chilled water. The work is aimed on thermodynamic study for maximization of EUF for cycle and plant. The role of humidifier efficiency, its effectiveness, hot water temperature and chilled water temperature (by varying VAR evaporator temperature) has been studied on integrated performance. The resulted distilled water is 670 LPH with 75 kW cooling at unit volume of air (1 m^3/s). The cycle EUF and plant EUF are 0.58 and 0.33 respectively.

1. Introduction

The integrated energy system offers multiple benefits to the society and it is a short cut method to meet the scarcity of power and energy in the country. It also avoids the dependence on electricity for day to day needs. Multi benefits (two in this case) can be obtained from a single source of energy which improves the overall energy utilization factor (EUF) of integrated energy system.

Solar desalination with a humidification–dehumidification process has proven to be an efficient method of utilizing solar energy for obtaining fresh water from saline water [1]. Orfi et al. [2] conducted an experiment on desalination system and showed that the optimum water to air mass ratio ranges from 1.6 to 2.2. Yamali and Solmus [3] also experimented on humidification and dehumidification (HDH) process and concluded that the productivity of fresh water remains approximately the same when the air mass flow rate is increased. Hou et al. [4] developed a concept of compression of humidified air, cooling by sea water and expansion in a turbine for desalination and air conditioning. They resulted that the COP of the proposed refrigeration system rests mainly on efficiency of compressor and turbine. El-Agouz [5] focused on experimental study on HDH with heating of compressed air and water using electric heater. Farsad and Behzadmehr [6] developed mass and energy balance equations for humidifier, condenser and other components in HDH cycle.

In a typical commercial building, a large portion of electricity is usually consumed in air conditioning to control indoor-air temperature and humidity [7]. Researchers developed many ideas and concepts for the integration of energy systems in the area of cogeneration and trigeneration. Tamm and Goswami [8] developed a combined power and cooling system at a USA university. Wang et al. [9] proposed a combined power and refrigeration cycle which combines the Rankine cycle and the absorption refrigeration cycle. Srinivas and Reddy [10] invented a new cooling cogeneration cycle by coupling vapor power cycle and vapor absorption refrigeration cycle. Srinivas et al. [11] performed a parametric evaluation for a biomass based cogeneration plant with a triple pressure heat recovery system. Srinivas and Vignesh [12] developed

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a cooling system from the waste heat and used for compressed air cooling to boost the power output.

The literature survey shows that the desalination plants are not combined with cooling systems. Cooling finds the needs in domestic, industrial and plant level of applications. The combined HDH desalination and cooling plant result two added advantages of increased water yield and additional cooling benefit. Therefore the current proposed work is focused on the performance levels of combined plant under variable operation conditions. It is planned to carry out the studies for the optimization of parameters involved to get better yields. A study on humidifier efficiency, humidifier effectiveness, hot water inlet temperature, and cooling plant temperature has been carried out for the integrated plant.

2. Methodology

Fig. 1 shows the component's assembly and material flow details for the proposed two stage desalination and cooling plant. The nodal state properties are tabulated in Table 1 for the material flow diagram shown in Fig. 1. This study is only a thermodynamic analysis and from the results obtained an experimental setup will be developed. A blower located at the inlet of desalination plant, forces the atmospheric air into the humidifier via an air preheater (2–3). The temperature of air in air preheater is increased with the use of hot water (18) supplied by solar water heater (SWH). The fills in the first humidifier are wetted by the hot water spray (20) from the SWH. Because the hot water temperature is more than the air inlet temperature (3), heating and humidification results in the humidifier. The water temperature will decrease (21) by latent heat loss to air. The air picks the moisture that can be adopted (4) depending on heat and mass transfer conditions. After heating and humidification, the humid air is cooled in air cooled dehumidifier (4–5) for the first stage desalination. The condensed distilled water is collected in a transparent water receiver or container (6) having an analyzer at the top. The processes in the first stage desalination are repeated in the second stage desalination. For centralized air conditioning, the air from the last stage humidifier needs cooling by the chilled water. But complete cooling by chilled water from the exit of second humidifier (9) to low temperature (11) needs more amount of chilled water which increases the capacity of cooling plant. So, the humid air is cooled and dehumidified in two stages. First, the humid air can be cooled in a conventional heat exchanger (9–10) with air or circulating cooling water and in the second by the chilled water (10–11). Thus the distilled water is generated in two stages (6 and 12) and the total (15) is collected and taped in a second container. The rest of the cooled air is used for centralized air conditioning (13–14). The chilled water (27) is generated in a vapor absorption refrigeration (VAR) system using solar energy. VAR chillers are used for the final stage dehumidification of air (10–11).

The considered VAR plant is a single effect system having ammonia–water mixture as a working fluid (Fig. 2). The resulted separator temperature in cooling plant is approximately 115 °C. Therefore solar concentrating collectors have been selected as a source of heat for the VAR plant. An engine exhaust can also be used partially or fully for VAR operation. The cooled air at a low specific humidity enters the room (13) and its temperature will increase depending on heat gain from surroundings. The heated air at room (14) can be mixed and recycled in closed cycle or fresh air will be used in open cycle. The beam radiation will focus on a focal line in cylindrical parabolic concentrating collector or on a fixed focus point in case of Scheffler reflector to increase the temperature of heat transfer fluid (HTF) (29). The HTF is glycol–water. The Scheffler collector is a fixed focus type solar concentrator with two axis tracking used to generate HTF at 150 °C to 200 °C. The available area of each concentrator is 11 m^2 to 16 m^2. They can be assembled as per the required area and temperature for the plant. A solar flat plate collector is used to generate the hot water and stored at daily storage tank which can be used for humidification of air. The outlet condition of air depends upon the temperature of water spray in the air washer. Hence, by properly controlling the water temperature,

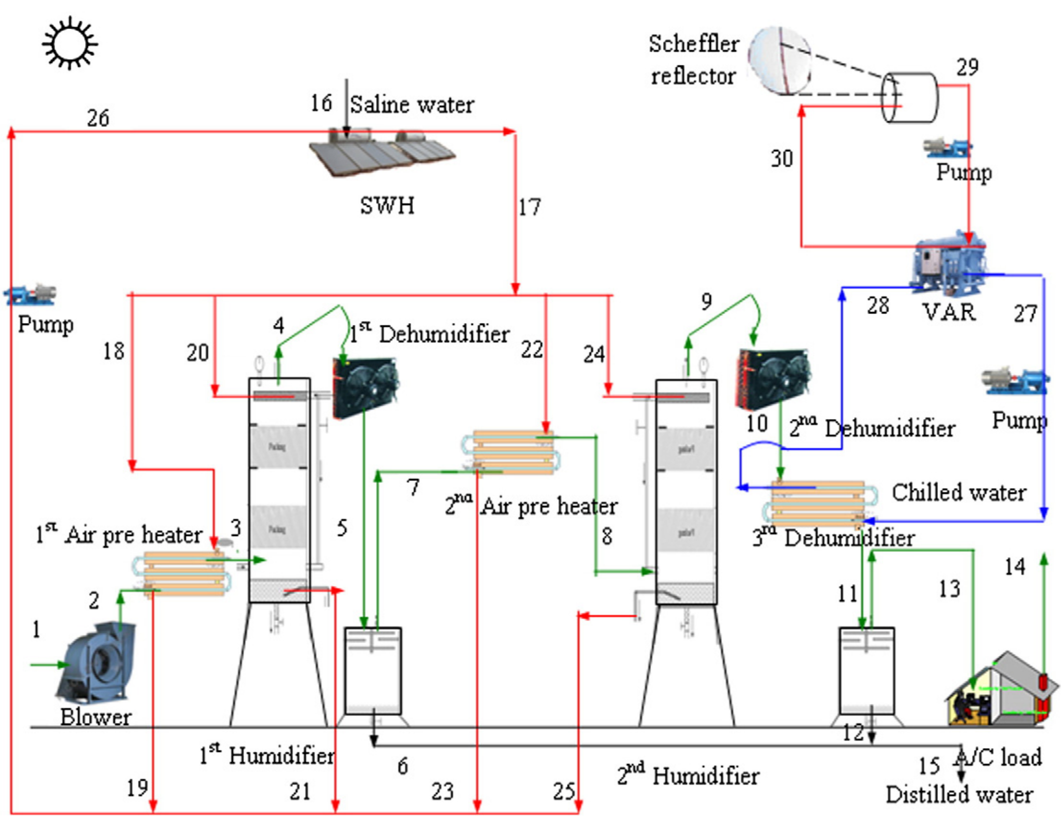

Fig. 1. Integrated plant for desalination and cooling.