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Energy recovery from a vapour compression refrigeration system using humidification dehumidification desalination

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ABSTRACT

Energy consumption of a process can be reduced by properly utilizing the large amount of waste heat liberated into atmosphere. The aim of this research is to improve the coefficient of performance (COP) of a vapour compression refrigeration system, by recovering waste heat from the condenser and the evaporator using humidification dehumidification desalination process. To recover the heat, air from the blower is passed through a humidifier chamber in which water is sprayed over the gunny bag placed in the air passage. The humid air circulated around the condenser coil which sub-cools the refrigerant and it also absorbs the heat from the condenser, producing hot humid air. The hot humid air is then passed over another heat exchanger (dehumidifier coil) which heats the refrigerant coming out from the evaporator so the quality of the vapour improves. At the same time, condensation occurs in the hot humid air along the surface of evaporator coil and the distilled water is collected. Refrigerator system is tested with insert like twisted tape and cone type turbulators in the dehumidifier passage to augment the performance. These modifications improved the COP of the refrigeration system up to 7.6 with a distillate water output of 0.4 l/m^2 h.

1. Introduction

Since there is a huge demand for electrical energy production and distribution, the available energy must be utilized efficiently. In India, nearly 42% of the electric energy in every house is utilized for operating refrigeration systems and Heating Ventilation and Air Conditioning (HVAC) systems [1]. These HVAC system liberate an enormous amount of heat to the atmosphere as waste. Recovery of this waste heat could improve significantly the efficiency of the HVAC systems along with a reduction of their environmental impact. Lokapure and Joshi [2] designed and fabricated a heat exchanger, which recovers the waste heat liberated in the air conditioning system, increasing the coefficient of performance (COP) of the system by 13%. Sapali et al. [3] tested a shell and coil type heat exchanger to recover the waste heat from the condenser of a bulk milk coolers and this heat was used to warm the water. The result showed that about 35% of latent heat was recovered and the COP of the system increased from 3 to 4.8. Salma [4] coupled the water heater with the condenser of a domestic refrigerator and found that heat liberated from the condenser could heat the water up to 60 °C, with a COP increase from 3 to 7. Ramyashree et al. [5] recovered the heat from the condenser unit of a windows air conditioner for water heating and showed that the COP of the system increased by 6% and reduced the thermal pollution.

Earlier some researchers analyzed the effect of integrating the air conditioning with desalination system. Hawlader et al. [6] experimentally analyzed the solar assisted heat pump desalination and concluded that the system can be efficiently introduced for the small scale desalination with hot water supply. Gao et al. [7] examined a HDH desalination system integrated with a vapour compression heat pump. The desalination unit utilizes the waste heat from the condenser and the evaporator of the heat pump for the desalination process and achieved the distillate output of 60 kg/day. An experimental research in an integrative air conditioning unit and desalination is (Yuan et al. [8]) reported that the integration of unit augments the overall system performance. Halima et al. [9] studied a solar still which integrated with a compression heat pump and found 75% higher water output than the conventional solar still. Transient and economical analysis has been conducted on an integrated air conditioner HDH desalination system powered by Fouda et al. [10] and recommended that the proposed system is more efficient in hot and humid climatic conditions. Diaby et al. [11] coupled an air gap membrane distillation with an air conditioner and stated that this system can reduce the energy consumption

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Nomenclature

Q	Refrigeration effect, kJ/kg
W	Work input, kJ/kg
H	Enthalpy, kJ/kg

Subscript

1	Compressor inlet
2	Compressor outlet
3	Condenser outlet
4	Evaporator inlet

in addition to fresh water output. A novel hybrid humidification–dehumidification and air conditioning system reported by Nada et al. [12] shows an increase in specific humidity and air mass flow rate and this, enhancing the fresh water production rate and refrigeration capacity of the integrated system. Kabeel et al. [13] evaluated a hybrid desiccant air conditioner with HDH desalinator powered by solar energy and observed an increasing distillate water productivity ranging from 3.175 kg/h to 5.011 kg/h. Elattar et al. [14] performed a parametric and economic study on the potential of a solar hybrid air conditioning and HDH desalination. The study reveals that the total operating cost increases with the increase in outdoor air temperature and outdoor humidity. Kabeel and Abdelgaied [15] experimentally evaluated a two stage indirect solar dryer coupled with HDH desalination. The experimental result showed that the distilled water production improved from 29.6 kg/day to 42.3 kg/day and also raises the gained output ratio of the proposed system. Yamili and Solmus [16] analyzed a solar HDH desalination system with a single and double pass solar air heater. By varying the air mass flow rate and temperature of air, feed water and cooling water it has been observed that the integration of double pass solar air heater increases the productivity by 8% compared to the integrating with a single pass air heater. Al-Enezi et al. [17] examined the consequence of varying the parameters such as flow rate of air, feed water and cooling water as well as temperature of air, feed water and cooling water in a HDH desalination process. Peak distillate is obtained for high feed water temperature and air flow rate and low cooling water temperature of the dehumidifier. An energy and exergy analysis was performed by Muthusamy and Srithar [18] on a humidification dehumidification desalination system integrated with multiple inserts. The presence of inserts in the humidifier and dehumidifier augmented the energy and exergy efficiency of the HDH desalination. Muthusamy and Srithar [19] reported that turbulators usage in the humidifier and dehumidifier saved 40% input power compared to the conventional HDH desalination unit. Rajaseenivasan and Srithar [20] experimented a biomass powered bubble column humidification-dehumidification desalination system with the direct and preheated air supply and found that decreasing hole diameter boosted up the specific humidity of air, reaching the peak efficiency of 96% at 1 mm hole diameter. The peak distillate output of 6.1 kg/h and 3.5 kg/h was collected with the preheated and direct air supply respectively. Rajaseenivasan et al. [21] made an experiment to improve the efficiency of the humidification-dehumidification desalination system by using a bubble column humidification dehumidification desalination system and achieved a distillate of 16.3, 20.6 and 23.9 kg/m^2 day using conventional solar air heater, solar air heater containing turbulators and dual purpose solar collector containing turbulators respectively.

In summary, vapour compression refrigeration systems are widely used for domestic and commercial applications in day to day life. So, performance improvement of the refrigeration system should be concentrated in reducing the electricity consumption. Scientific literature shows that most of the studies are carried out to improve the performance of the air conditioner by effectively utilizing the waste heat from air conditioner for the desalination process, but they leave a gap to apply the concept of waste heat recovery from vapour compression refrigeration for desalination process. HDH desalination is a kind of simple water treatment process which is suitable for low temperature

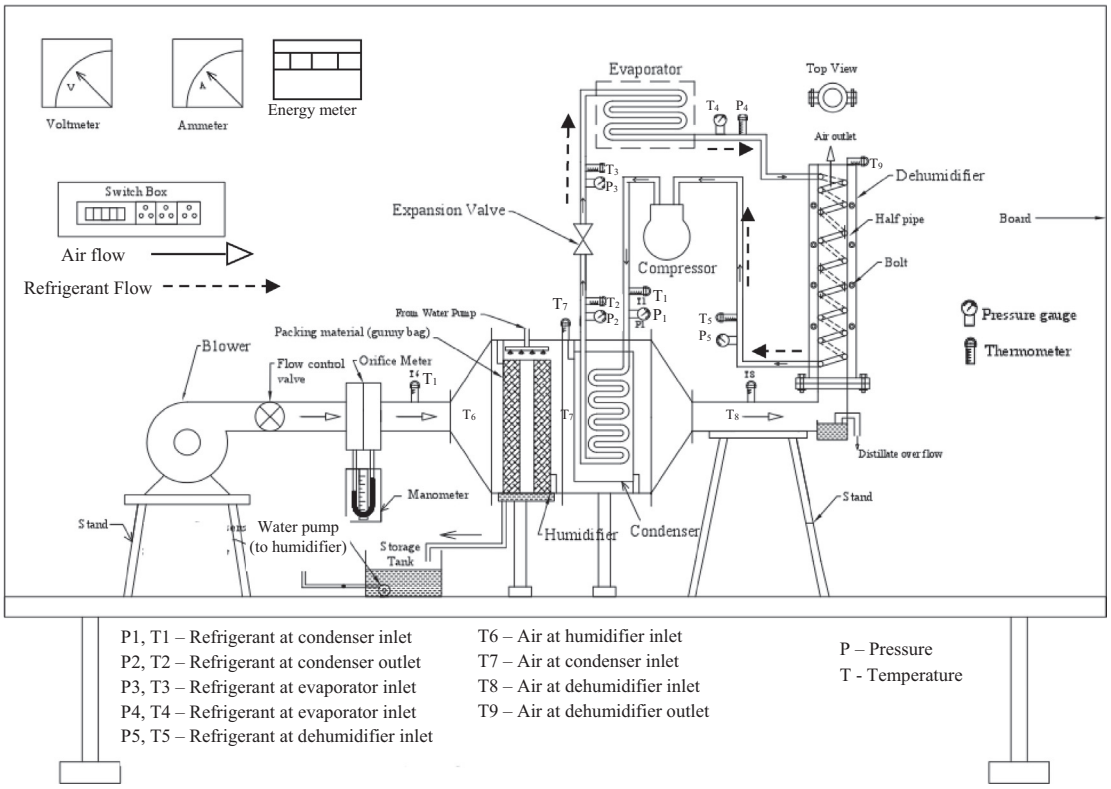

Fig. 1. Schematic diagram on experimental VCR integrated desalination system.