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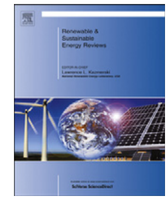

Survey of hybrid liquid desiccant air conditioning systems

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ABSTRACT

This paper reviews and surveys the available hybrid liquid-desiccant air-conditioning system technologies. These technologies are proposed as alternative to the traditional vapor-compression systems because of its advantages in removing air latent load, environment-friendly feature, ability to remove pollutants from the processed air, and ability to reduce electrical energy consumption. This paper first introduces the traditional air-conditioning system: vapor compression, vapor absorption, and evaporative cooling. In addition, the principles of liquid desiccants and liquid-desiccant dehumidification systems and the hybrid liquid-desiccant classifications are discussed. Next, combination of the liquid-desiccant systems with vapor compression, vapor absorption, and direct and indirect evaporative cooling units are outlined. Finally, conclusions and some important suggestions are presented based on the collected information.

Contents

1. Introduction

The two most common types of refrigeration systems are vapor-compression and vapor-absorption systems. In the vapor-compression system, an external source of shaft power is required to run the compressor. The vapor-compression cycle is the most widely used refrigeration cycle. In this cycle, vapor is compressed and condensed into liquid. The pressure is lowered to allow fluid to evaporate at low pressure. This refrigeration cycle requires additional external work for its operation. The processes that constitute the cycle are as follows: adiabatic compression, isothermal rejection of heat, adiabatic expansion, and isothermal addition of heat.

In recent years, many refrigeration vapor-compression systems have been introduced and developed to increase the efficiency of power distribution and to utilize industrial waste heat and renewable clean energy. Zubair et al. [1] applied the automatic hot-gas bypass technique to reduce the capacity of refrigeration and air-conditioning systems when operating at

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partial load. Zubair [2] demonstrated the advantages of add-on sub-cooler systems to improve the performance of refrigeration and air-conditioning systems. Chen and Jianlin [3] obtained better performance of a new refrigeration cycle for binary non-azeotropic mixed (R22/R134a). The performance of the new mixture in this new cycle was close to that obtained with R22. The mixed coefficient of performance (COP) of the system can be improved within the range from 8% to 9% of the conventional refrigeration cycle. Wang et al. [4] performed a thermodynamic and economic analysis of a novel compressed-air energy-storage refrigeration system; the system was a combination of a gas refrigeration cycle and a vapor-compression refrigeration cycle. Liu et al. [5] performed a thermodynamic analysis of the actual air cycle refrigeration. The results of their study showed that the pressure ratio, working temperature, and isentropic efficiency of the rotors were effective in the actual cycle performance. Toublanc and Clausse [6] proposed a novel Carnot-type cycle to achieve high performance for trans-critical and sub-critical applications. The COP of the cycle was higher by 4–70% than the conventional cycle.

The vapor-absorption systems are similar to the vapor-compression systems except for the pressure employed at each stage [7]. The absorption systems use heat energy to produce refrigeration; water is used as refrigerant, and lithium bromide is generally used as the absorber of the refrigerant [8]. Ammonia water and water lithium bromide are often used in absorption refrigeration systems, whereas ammonia water is used in condensers [9]. The required heat source temperature for this system is approximately 300 °F. Commercially, two types of absorption systems are available: the single and the double effect. The main purpose in increasing the effect cycle is to increase the system performance at high heat source [10].

Evaporative cooling is one alternative to mechanical vapor compression for air-conditioning applications. Evaporative cooling system requires only a quarter of the electric power than the mechanical vapor-compression uses for air conditioning [11]. Low energy- consuming devices were used in [12–15] for various industrial, agricultural, and residential cooling and air-conditioning applications to reduce greenhouse-gas emissions. As reported in [16], only sensible load can be handled by an evaporative cooling system, and the conventional evaporative cooling system is suitable for dry and temperate climates.

The two common types of evaporative cooling system are the direct and indirect systems [17,18], where the effectiveness of the direct evaporative cooling system is approximately 70–95% in terms of temperature. The direct evaporative cooling system adds moisture to the cooled air, whereas the indirect evaporative cooling system provides only sensible cooling to the processed air with no moisture added. Therefore, the indirect evaporative system is more attractive than the direct evaporative system. However, its cooling effectiveness is generally low, which is approximately from 40% to 60% [19].

2. Principle of liquid desiccants

The dehumidifier and regenerator are the main components of a liquid-desiccant dehumidification system. The most common technology today for the dehumidifier and regenerator is the packed bed. However, packed beds must work under high desiccant-flow rates to achieve good dehumidification without internal cooling [20]. The main role of the desiccant is to attract water vapor from air; thus, it can be classified as both solid and liquid desiccant. Several types of solid materials can hold off water vapor, e.g., silica, polymers, zeolites, alumina, hydratable salts, and mixtures. Other available liquid desiccants are calcium chloride, lithium chloride, lithium bromide, tri-ethylene glycol, and a mixture of 50% calcium chloride and 50% lithium chloride. These liquid desiccants have common general properties, but their requirements cannot be fully addressed by any single desiccant. These requirements include low vapor pressure, low crystallization point, high density, low viscosity, low regeneration temperature, and low cost. Several works have been done to investigate the characteristics of a single and the mixture of two liquid desiccants.

Liquid desiccants can be regenerated at low temperature, from approximately 50–80 °C [21]. Thus, the regeneration process could be driven by heat sources with a relatively low temperature of approximately 70 °C, such as solar energy, waste heat, and geothermal power. Hassan and Salah [22] proposed a desiccant with a mixture of 50% weight of water calcium chloride and 20% calcium nitrate. They studied the physical properties of the mixture, such as viscosity, vapor pressure, density, and heat, and the mass transfer process. The results of their study showed a significant increase in vapor pressure of approximately 14.7, 20.6, 34.4, and 47.3 mm Hg at 30, 40, 50, and 60 °C, respectively. Xiu-Wei Li et al. [23] proposed a novel method that mixed lithium calcium chloride and lithium chloride. The experimental results showed that the dehumidification effect of the mixture was 20% more than the lithium chloride solution alone.

3. Principle of liquid-desiccant dehumidification and regeneration process

Air is dehumidified when it comes in contact with strong liquid or solid desiccants; subsequently, to provide sensible cooling to the dehumidified air, traditional vapor compression, vapor absorption, and direct or indirect evaporative cooler units are used, and the dehumidified air is sent to the conditioned space. When the solution is weakened by absorption of moisture, it is sent directly to the regeneration process to release the moisture using external heat resources. This process is called "reactivating" the desiccant [24].

The simplest liquid-desiccant system configuration, shown in Fig. 1, consists of a conditioner, regenerator, a heat exchanger to heat the solution, and another heat exchanger to cool the solution. The solution attracts moisture from the air in the conditioner, which weakens the solution. The weak solution is sent through the heat exchanger for heating and then sprayed into the regenerator. In the regenerator, the air carries away the water vapor from the solution. After this process, the solution is sent to the conditioner across the heat exchanger for cooling.

Liquid-desiccant dehumidification often requires two desiccant air-contact devices: absorbers and regenerators. A liquid-desiccant absorber/regenerator system has three configurations: packed tower, spry chamber, and spry coil arrangement [25]. Models for heat and mass transfer in the packed configuration

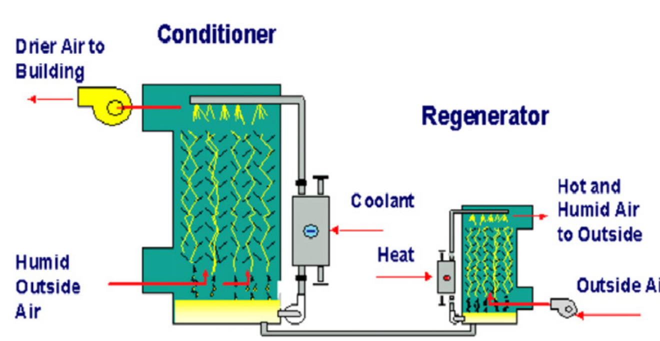

Fig. 1. Liquid desiccant system.