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Solar pond powered liquid desiccant evaporative cooling

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ABSTRACT

Liquid desiccant cooling systems (LDCS) are energy efficient means of providing cooling, especially when powered by low-grade thermal sources. In this paper, the underlying principles of operation of desiccant cooling systems are examined, and the main components (dehumidifier, evaporative cooler and regenerator) of the LDCS are reviewed. The evaporative cooler can take the form of direct, indirect or semi-indirect. Relative to the direct type, the indirect type is generally less effective. Nonetheless, a certain variant of the indirect type – namely dew-point evaporative cooler – is found to be the most effective amongst all. The dehumidifier and the regenerator can be of the same type of equipment: packed tower and falling film are popular choices, especially when fitted with an internal heat exchanger. The energy requirement of the regenerator can be supplied from solar thermal collectors, of which a solar pond is an interesting option especially when a large scale or storage capability is desired.

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1. Introduction

Temperature and humidity of ambient air are two critical factors that determine comfort levels of occupants in a given space. In hot climates, it is desirable to reduce the ambient air temperature (cooling) to improve comfort levels; however in hot and humid climates (as in some Gulf countries), removal of moisture from the air (dehumidification) is almost as important as cooling [1]. Besides occupant discomfort, insufficient dehumidification can also adversely result to mould and mildew growth. ASHRAE Standard 55 [2] recommends temperature 19–28 °C and less than 65% relative humidity for comfort conditions.

Conventional air conditioning systems (for example vapour compression systems) address these issues by cooling air below its dew point such that water vapour condenses on a cooling coil, thus removing moisture from the air. The dehumidified air is then reheated to the desired temperature [3]. This process of deep cooling to dew point and reheating consequently leads to higher energy requirement. Alternatively, desiccants can be employed to use their hygroscopic properties to dehumidify the air [4,5]. Studies have reported that desiccant systems can reduce energy consumption by as much as 40% [6–8].

Desiccants are natural or synthetic substances, having a high affinity for water, capable of absorbing water vapour from their immediate vicinity. They are available in both liquid and solid states. Solid desiccants are compact and less corrosive. On the other hand, liquid desiccant offer several benefits, including, lower regeneration temperature, lower pressure drop of air across the desiccant material, suitability for dust removal by filtration, and flexibility in utilisation especially when handling large volumes of air [9–11].

In desiccant cooling cycles, the desiccant (brought into contact with air) reduces the humidity of the air by absorbing moisture from the air. Then the air temperature is reduced by conventional cooling coils or other components such as evaporative coolers [12]. However, the moisture impregnated desiccants need to be dried in a regenerator, in which the water vapour previously absorbed evaporated out from it by heating. The heat required to regenerate the desiccant can be supplied from low-temperature sources [13] such as waste heat or solar energy. Utilising solar energy for this application is particularly interesting because the greatest demand for cooling occurs during times of highest solar insolation. There are different means by which the solar thermal energy can be harnessed for this purpose; examples include conventional solar thermal collectors, solar ponds, and salt works. Besides collecting solar thermal energy, solar ponds have the inherent ability of also storing the thermal energy, and have been widely studied as such.

This paper will review the technologies used for desiccant cooling systems and solar ponds; different options will be compared and evaluated (in the preliminary sense) with regards to complexity, cost and performance, for the operating conditions prevalent the Gulf region. Also, specific technical risks and challenges will be identified and assessed for systematic appraisal. Fig. 1 shows the proposed system that combines the solar pond, the seawater bittern desiccant and the indirect/direct evaporative cooling.

2. Liquid desiccant evaporative cooling

2.1. Liquid desiccant materials

Desiccant materials play a crucial role in the development of desiccant air conditioning. The characteristics of the desiccant material being utilised impact the performance of the desiccant air conditioning systems significantly [14]. Materials for the liquid desiccants should have low vapour pressure, low viscosity and good heat transfer characteristics. The surface tension of liquid desiccant is also important as it directly influences static hold up and wetting of desiccant air contact surface [15]. Commonly used desiccants include aqueous solutions of lithium chloride, calcium chloride, lithium bromide and triethylene glycol. Other desiccants include seawater bitterns, $MgCl_2$ [16], KCOOH, glycols like triethylene glycol (TEG), diethylene glycol (DEG), MEG, propylene glycol, and mixtures of desiccants LiCl + LiBr or LiCl + $CaCl_2$ [15,17].

One key principle for selecting appropriate desiccant materials is that the desiccant materials should possess largely saturated adsorption amount and can be reactivated easily. The water absorption capacity of a desiccant solution depends on its equilibrium vapour pressure which in turn depends on its temperature and concentration. The higher the concentration and lower the temperature, the higher would be the moisture absorption capacity. But at high concentrations and low temperatures, there is an adverse possibility of crystallisation of the desiccant. Therefore, different desiccants have different optimum operating concentration levels, e.g. 55–60% for lithium bromide, 30–45% for lithium chloride, 35–45% for $CaCl_2$, $<35\%$ for $MgCl_2$, and 95–97% for TEG [18,19].

The ethylene glycols are material friendly, in that, they are not corrosive and do not crystallise during the dehumidification process. However, they are quite prone to evaporating into the air stream. Brines (especially LiCl and $CaCl_2$) are a popular choice though having the drawback of been corrosive and crystallising at concentrations higher than 40% [20]. The physical properties of some common desiccants are compared in Table 1.

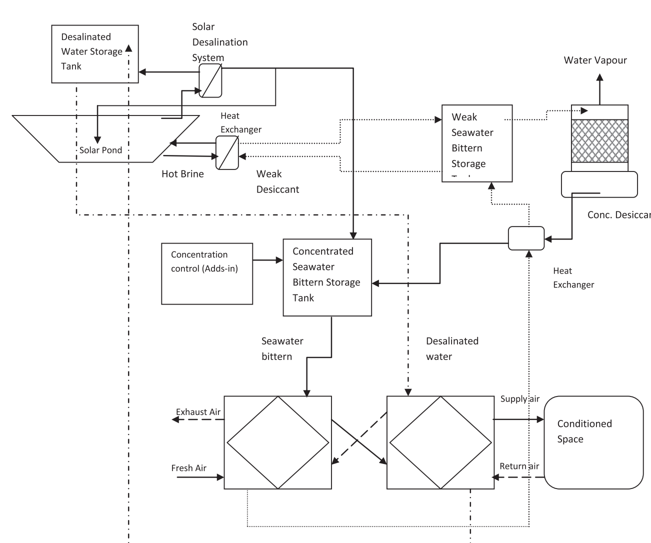

Fig. 1. Schematic of the proposed system (GORD TechnoHub).