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Research Paper

Natural induced flow due to concentration gradient in a liquid desiccant air dehumidifier

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HIGHLIGHTS

- The natural induced flow due to change of concentration in a loop is investigated.
- The natural flow originates from heat sink toward the heat source.
- The unique features of the system explained.
- The natural closed loop acts as an air dehumidifier.
- The near zero energy liquid desiccant dehumidifier is presented.

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ABSTRACT

Natural heat and mass transfer can be achieved simultaneously in a stratified medium. In this study, the natural induced flow due to change of concentration of a desiccant liquid in a closed circulation loop is experimentally investigated. The proposed novel system is a liquid desiccant dehumidifier which consists of two modules: the absorber and the generator, in which no parasitic pump energy is required. The experimental system consists of a closed loop equipped with hollow fiber membranes across which water vapor can be passed. The circulating fluid, lithium chloride, is used as the water vapor absorber while the cooling/heating fluid of the loop is cold/hot water. The preliminary results of the system operations are presented and explained which show that the system can be a promising air dehumidifier device in air conditioning systems.

1. Introduction

An economical method on heat transfer between two thermal sources is to use NCLs (natural circulation loops) system which offers advantages such as independence from an external power source, simple design and silent operation. More specifically, the distinctive advantage of NCLs device is dependency of fluid flow in the loop to stratification of density. The density gradient, in all cases, was caused by the temperature difference between hot and cold thermal sources. The flow of HTF (heat transfer fluid) in conventional applications such as thermo siphon solar water heater [1], turbine blade cooling [2], and geothermal energy [3] or in such modern applications as nuclear power generation [4], electronic chip cooling [5], chemical processes [6], refrigeration [7], and ship propulsion [8] are naturally caused by density gradient in NCLs.

Many studies have been devoted to the characterization of the fluid flow in NCLs. Vijayan et al. [9–11] extensively studied the NCLs in different configurations and studied the fluid flow features both experimentally and analytically. They investigated the stability behavior of NCLs and derived a stability map for rectangular loops. By introducing some dimensionless parameters, they found that the loop orientation with both heater and cooler standing vertically yielded the most stable flow whereas the least stable flow obtained with horizontal configurations. In another study, Vijayan et al. [12,13] introduced nanoparticles into the fluid and studied the characteristics of the NCLs. In a number of studies, Misale and coworkers studied the NCLs features and the stabilizing effects of varying heat sink temperatures [14], loop inside diameters [15], and local pressure drops [16]. In all of the above investigations, the flowing fluid serves as the heat transfer medium and its motion is caused by heat transfer as the sole driving force.

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Nomenclature

C	concentration
h	enthalpy (kJ/kg)
$\dot{m}$	mass flow rate (kg/s)
P	pressure (kPa)
$\dot{Q}$	rate of heat transfer (W)
R	gas constant (kJ/kg K)
T	temperature (°C)
$\dot{V}$	volume flow rate
Greek symbols	
ε_m	mass transfer effectiveness
η_m	mass transfer efficiency
η_{II}	2nd law efficiency
ω	specific humidity
Abbreviations	
abs	absorber
ave	average
cum	cumulative
del	difference
down	lower horizontal branch
gen	generator
HR	humidity ratio
RH	relative humidity
sol	liquid desiccant solution
up	upper horizontal branch
Subscripts	
0	dead state condition
1	flow inlet
2	flow outlet
a	air
abs	absorber
cum	cumulative
db	dry bulb
gen	generator
in	inlet fluid flow
m	mass
wb	wet bulb
out	outlet fluid flow
v	water vapor

The present study investigates the natural fluid flow induced by concentration difference and explores its distinctive features. In this new approach, not only the thermal energy exchanges between source and sink but also there are mass transfer between source and sink in the NCL. In this system, the working flow is a desiccant liquid and the mass transfer fluid is water vapor. The proposed system can be mainly utilized in liquid desiccant dehumidifier systems.

In air conditioning systems, the moisture content of the air must be efficiently controlled. For example, air conditioning in hot humid climates is accomplished by both cooling and dehumidifying. Dehumidification is commonly achieved by cooling the air down to the dew point temperature in order to extract its vapor in liquid form, which often leads to excessive power consumption and drops air temperatures far below the desired levels. A better way to dehumidify air, however, is to maintain air in contact with an either liquid or a solid desiccant material. Examples of solid desiccants include silica gel, active alumina, active carbon, and zeolite while for liquid type ethylene glycol, certain hydrated salts such as lithium chloride [17–21] and calcium chloride [23,24,17] can be listed.

Lithium chloride is capable of absorbing moisture from the air in a system called 'absorber' due to its low equilibrium vapor pressure. Absorption of water vapor from the air is accompanied by heat generation mostly due to the phase change involved. Obviously, the lithium chloride solution after saturation with water vapor should be regenerated in the 'generator' unit by a hot and dry air stream. The best dehumidifying results are achieved by alternate heating and cooling of the liquid desiccant in the generator and absorber units, respectively [24]. The types of contact commonly used between air and the liquid desiccant range from the conventional ones, such as packed bed or falling film [17,25,22], spray chamber [26–31], coiled spray chamber [31], and bubble type absorption [32] to the newer membrane contactor types [33–36]. The three former types, which make a direct contact between air and the desiccant, prevent the risk of liquid entrainment to indoor spaces, which cause corrosion due to the corrosive nature of the desiccant. However, there is no direct contiguity between the air and desiccant streams in membrane contactor types in which water vapor is transferred through membrane pores. The mass transfer in these types occurs across a semi-permeable and hydrophobic surface and mass flow rate depends on the magnitude of the contact area. In other words, surface density plays a determinant role.

In the aforementioned contact types, the liquid desiccant needs to reciprocate between the absorber and the generator modules and the liquid transmission is usually accomplished mechanically. Due to the corrosive nature of hydrated salt solutions, the pump should be made of anti-corrosive materials, which raises costs. In addition, the pump power inlet makes another drawback of such systems, i.e. parasitic energy consumption [37].

In the present experimental work, the HFM (hollow fiber membrane) is used, which is amongst the highest densely packed membrane contactors [38]. The HFM is cylindrical in shape with diameter of millimeters to form a pack of HFM tubes. Investigations in the field of HFM include numerical [38] and analytical [39] studies. In the proposed system here, the natural induced flow in the NCL is achieved using the combined natural mass and heat transfers. The system operates as an air dehumidifier and consists of two modules: absorber and generator. The liquid desiccant of lithium chloride serves as the heat and mass transfer medium which absorbs water vapor in the absorber and exudes in the generator. The paper is organized as giving system setup in Section 2 and explaining experimental procedure in Section 3. Results and discussions of the novel NCL system is provided in Section 4 and conclusions are drawn in Section 5. The application of the proposed system as a new air dehumidification device is also illustrated.

2. System setup

The experimental setup is schematically shown in Fig. 1. The system is a closed loop made up of two main modules, i.e. absorber and generator, in which heat/mass transfer takes place between the fluid streams. Heat transfer mainly takes place between the water stream in the shell part and the desiccant liquid in the inner tube part of the heat/mass exchanger. In the generator module, hot