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Modeling of a liquid desiccant dehumidification system for close type greenhouse cultivation

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ABSTRACT

Solar energy, heat exchange with the ambient & plants and vapor balance are the key variables for modeling the greenhouse. However, due to solar energy, crops continuously produce water vapors through evapotranspiration, which continuously need to be dehumidified to maintain the relative humidity in the required range. Therefore, modeling and simulation of dehumidification system seems to be indispensable, as it will help to investigate the workability and operating performance of the greenhouse. Hence, this work models and simulates the various components of liquid desiccant based dehumidification system for greenhouse cultivation. Each component of an entire stand-alone dehumidification system, namely reference greenhouse, dehumidification & regeneration reactors and solar collector are thoroughly modeled in MATLAB Simulink environment. The overall system can be effectively utilized to analyze the working performance for greenhouse cultivation. The obtained results indicate that proposed modeling is effective in showing the moisture removal, which crops generate inside the greenhouse. Besides, the developed system is very unique, as most of the previous desiccant system are designed for domestic and commercial buildings. It is envisaged that this work is very useful for the researchers and energy professionals to develop efficient integrated systems for stand-alone buildings.

1. Introduction

A greenhouse (also called a glass-house) is designed to provide a suitable environment for growing crops throughout the year. It improves growing conditions of crops and protects them from heavy rains, high winds and excessive temperature variations in winter and summer [1–5]. The greenhouse per unit area yield is higher than the yield for crops grown in the open field, as the internal climate is adjusted and controlled according to the needs and demands of particular crops. There are many advantages of greenhouse horticulture to those of open field cultivation. However, it requires high capital for setting up infrastructure (building, heating and cooling system) and high operating cost due to the massive consumption of energy [6], which is used to maintain a proper micro climate inside the greenhouse.

For the proper growth of plants, the relative humidity in a greenhouse should be maintained between 50 and 80% [7]. However, due to evapotranspiration, crops continuously produce water vapors [8,9], which continuously need to be removed to maintain the relative humidity in the required range. Cooling and desiccant based dehumidification are two different and major ways of dehumidifying the air [10]. Among the two techniques, desiccant based dehumidification is usually preferred in following conditions: (1) when the dehumidification (latent) load is higher or equal to 30% of total load of cooling, (2) when industrial low quality heat is available at low prices for regeneration of desiccant, (3) places, where tight control over relative humidity is required such as hospitals and museums and (4) places, where moisture content cause problems, such as bacteria in hostels, fogging in the arena etc. [11,12].

Generally, desiccants based dehumidification are categorized into solid or liquid forms and according to desiccant structure and properties, these are further subcategorized into five classifications: (1) Liquid spray-tower, (2) Solid packed tower, (3) Rotating horizontal bed, (4) multiple vertical bed and (5) Rotating

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Nomenclature

Cp	Specific heat at constant pressure [J/Kg °C]
G	The solar irradiation [W/m^2]
RH_o	Relative humidity outside of the reference greenhouse [−]
RH_{in}	Relative humidity inside of the reference greenhouse [−]
T	Temperature [K]
T_o	Outside temperature of the reference greenhouse [°C]
T_l	Temperature of liquid desiccant [K]
T_{in}	Inside Temperature of the reference greenhouse [°C]
U	Heat transfer coefficient [W/(m^{2}K)]
W	Humidity ratio of air [KgV/Kg dry air]
W_o-GHR	Moisture content of air at outlet of the dehumidification reactor [Kg H_2O/Kg dry air]
W_o-GH	Moisture content of air at Inlet of the dehumidification reactor [Kg H_2O/Kg dry air]
X	Dimensionless distance [−]
x	Distance along packed bed, m. also, mole fraction of water in liquid desiccant [m]
Y	Moisture content in liquid desiccant, dry base [Kg H_2O/Kgs]

Symbols

η	Efficiency of solar collector
η_{op}	Optical efficiency of the solar collector

Subscripts

a	Air
am	Ambient
col	Solar collector circuit
l	Liquid desiccant
LDs	Liquid desiccant solution
m	Solar collector medium
opt	Optical
LDS	liquid desiccant system
v	Vapor
w	Water

Honeycomb [13]. Adsorption and Absorption are the two process, which normally take place in desiccants dehumidification. The former adsorbs moisture at its surface, keeping the molecular structure of the material unaffected. However, adsorption takes place only in solid desiccant materials, such as activated aluminum, activated carbon, silica gel, zeolites and etc. [14]. Whereas, in later process, the desiccant materials absorb water vapors from the air, lowering the vapor pressure in the air. However, it is worth mentioning that it can take place both in liquid and solids.

Liquid desiccant system (LDS) is usually preferred over solid, as it works more efficiently with low temperature regeneration (reactivation). Besides this, it is more effective in killing bacteria, viruses and has potential to remove biological contamination from the air [15]. LDS relatively has a higher water absorption capacity than solid, and it also acquires less space than multiple batch solid system. Another advantage of this desiccant involves the single regenerator reactor that can be used for multi conditioned air inlets [10,16–19].

Capitalizing the above advantages, various works related to LDS have been carried out to examine the workability and performance of dehumidification system. For instance, a study is carried out in Ref. [20], which shows that LDS can be effectively utilized under low grad heat in hot and humid regions. In Ref. [21], it was concluded that LDS is more economical in producing fresh water and cooling down the building in the humid climate. A similar desiccant system was also investigated [22] for a packing area in pharmaceutical factor. It was found that considerable energy could be saved if solar energy is utilized. In another work [23], authors concluded that liquid desiccant is shown to be potential candidate for conditional technology, specifically for buildings in humid areas. While authors in Ref. [24] claimed that if LDS along with thermal storage is utilized, potential saving could be achieved for commercials building such as hotels, retails and offices. An important conclusion is also reported in Ref. [25], where authors concluded that LDS incurs less environmental burden, compared to conventional cooling system for building.

It should be noted that all the aforementioned LDS works [20–25] are only limited to building applications and to the best of authors knowledge, no liquid desiccant based dehumidification system have yet been reported for greenhouse cultivation. Since greenhouse has been extensively used for multiplying crop productivity throughout the year, the study to how these dehumidification system work for greenhouse cultivation is very crucial. Therefore, modeling and simulation of these system seems to be enviable to investigate the workability and operating performance for the application of greenhouse cultivation.

Hence, this work models and simulates the thermal behavior of various components of liquid desiccant based dehumidification system for greenhouse cultivation. Energy model of each component is comprehensively modeled using MATLAB tools and thereafter integrated to make a complete stand-alone dehumidification system. The proposed modeling is comprised of four steps; first step models the thermal behavior of reference greenhouse to quantify the relative humidity and temperature using the HAMBase tool of MATLAB. While to estimate the rate of vapor generation due to solar energy, FAO Penman Monteith equation is modeled using the Simulink features of MATLAB. Subsequently, both the models have been integrated to investigate the state of relative humidity in the reference greenhouse. In the second step, an energy-mass balance model of a dehumidification and regeneration reactors have been developed to analyze their working performance. Third step involves the mathematical model of a solar collector, which is used for regenerating the desiccants. In the final step, all the developed components in previous steps have been integrated to create the complete desiccant dehumidification system. The overall dehumidification system can be effectively utilized to analyze the workability and thermal performance for greenhouse cultivation.

It is worth mentioning that the developed system is capable of removing moisture generated by crops inside the greenhouse, which shows the effectiveness of the proposed model. On top of that, the modeled desiccant system is very unique, as it is developed specifically for greenhouse cultivation, which minimizes the consumption of conventional energy through the utilization of solar energy. This is quite different from the previous modeling works, where majority of the desiccant system are modeled for domestic and commercial buildings. It is envisaged that this work is very useful for the researchers and energy professionals, who intend to develop efficient integrated systems for stand-alone buildings by utilizing solar energy and industrial low quality energy.