Surface Wettability Enhancement Strategies for Cast Nylon Plates in Vertical Falling Film Towers: Experimental Implications for Liquid Desiccant Cooling Systems

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Abstract - *Liquid desiccant cooling (LDC) systems have become an energy-efficient and eco-friendly substitute to traditional vapor compression air conditioning technologies, especially those with high loads in the latent component. The efficiency of the LDC systems is closely related to the efficiency of heat and mass exchange between the liquid desiccant and the process air, which is regulated by the wettability of contact surfaces. Cast nylon plates are also the material that is now being viewed as structured falling film tower packing material because of their low cost, corrosion resistance, mechanical durability, and fabrication ability. Nevertheless, the unruly character of their surface nature, which is largely hydrophobic, does not allow uniform coverage of the liquid films, thus creating dry spots, mal-distributed flows, and diminished system efficiency. This review is a critical analysis of experimental methods that have been used to improve the surface wettability of cast nylon plates in vertical falling film towers that are utilized in liquid desiccant cooling operations. Different methods of surface modification, such as mechanical texturing, chemical treatment, and others, as well as, the use of plasma activation and coating methods are discussed with references to their effects on contact angle, film stability, heat and mass transfer coefficients, and the overall cooling performance. The main experimental results of recent literature are summarized to define the trends of performance, real life challenges, and gaps in the research. The review gives useful information to the researcher and designers who are seeking to maximize the output of the falling film tower by enhancing the wettability control.*

Keywords: Liquid desiccant cooling; Vertical falling film tower; Surface wettability; Cast nylon plates

1. Introduction

Over the last twenty years, the demand of energy-saving low-emission cooling technologies in the world has grown significantly because of the high rates of urbanization, the improvement of living standards, and the inevitable apprehension of the climate change. Although the most commonly used, conventional vapor compression air-conditioning (VCAC) systems consume a lot of energy and are highly reliant on fossil fuel-produced electricity. In addition, refrigerants that are also used in VCAC systems are also major contributors of global warming and ozone depletion. In this regard, other cooling technologies that would have the ability to lower the use of electrical energy but still note thermal comfort have received significant research and industrial attention. Of these, one promising option has been liquid desiccant cooling (LDC) systems which so far have found applications where high latent cooling loads are typically present [13].

Liquid desiccant cooling systems work in the principle of dehumidification with the hygroscopic liquid solutions which may be lithium chloride, lithium bromide, calcium chloride or triethylene glycol. These solutions directly take in moisture in humid air hence decoupling the latent and sensible cooling mechanisms. The separation allows LDC systems to be more efficient and with high indoor air quality than their traditional counterparts [4,5]. LDC systems also have the potential to be recycled with low-grade thermal energy produced by renewable energy sources like solar collectors, geothermal energy, or industrial waste heat, and this makes them even more sustainable [6,7]. Nevertheless, issues of compactness in the system, heat and mass transfer, compatibility with materials and long-term stability in operation remain barriers to the extensive implementation of LDC technology.

Out of all the elements of an LDC system, the absorber in which the moisture transfer between air and the liquid desiccant takes place, is one of the primary concerns of the system performance. Vertical falling film towers are frequently used as an absorber because of their capability to offer high interfacial area between liquid and air and at the same time, the construction is fairly easy and the pressure drop is less [8,9]. In such towers, a thin desiccant film of liquid trickles downwards over structured or flat surfaces by gravity, with humid air flowing either in the same direction or the opposite. The excellent heat and mass transfer in this kind of configurations is highly reliant on the establishment of a continuous, stable, uniformly spread liquid film [10]. Any motion that interrupts the flow of the film, e.g. formation of rivulets, dry areas, etc., may greatly decrease the effective contact area, and, therefore, the rate of moisture uptake.

1.1 Liquid Desiccant Cooling Systems: The basics and importance.

In Figure1. The basic benefit of the liquid desiccant cooling is that it can independently regulate the humidity and temperature. In hot and moist environments (where latent loads are high relative to cooling demand) the traditional air-conditioning systems tend to work poorly because they must remove an excessively high amount of moisture. LDC systems overcome this limitation by completely eliminating moisture in the air stream through direct means, typically ahead of or in parallel with sensible cooling, which leads to low compressor loads and a lower power use [11,12]. Moreover, liquid desiccants allow operation without frosting problems that are usually witnessed in the solid desiccant systems.

Some thermodynamic considerations regarding LDC systems are that the coupled heat and mass transfer processes taking place on the airliquid interface govern the performance of LDC systems. Water vapor absorption of the desiccant is exothermic in nature and it increases desiccant temperature and decreases the absorption capacity of the desiccant unless heat is efficiently eliminated. The design of the absorber should therefore not only be such that it has high mass transfer rate but also good heat dissipation [13]. Such configurations, in particular falling film, are highly desirable in this respect, since the thin liquid film allows rapid removal of heat and reduces diffusion resistance. Nonetheless, it can still pose a significant design challenge insofar as reaching and sustaining an ideal film thickness and distribution is concerned.

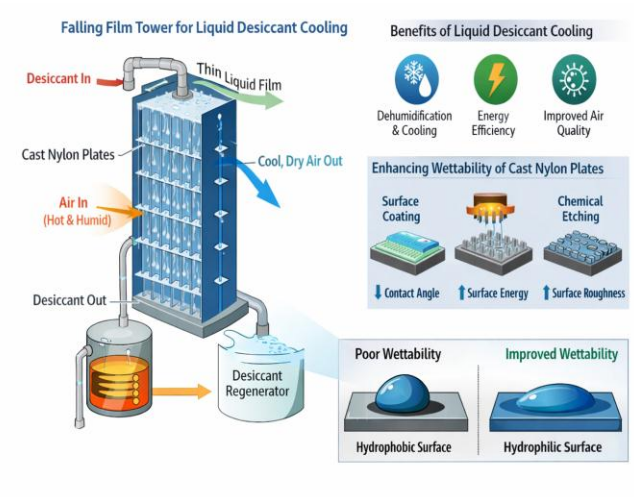

Figure 1: Liquid Desiccant Cooling Systems

1.2 Vertical Falling Film Towers and Surface Wettability Role.

Figure2 has Surface wettability as a parameter that determines the liquid film behavior in falling film towers. Wettability is defined as a property of a liquid to be able to spread over the surface of a solid, which is usually measured as the static contact angle. When the contact angle is low, the wettability of the surface is good, and uniform film spreading is achieved and, conversely, when the contact angle is high, the surface will be partially wetted and produce rivulets as well as flow instabilities [14]. Bad wettability may cause channeling of the liquid desiccant in vertical falling film delivery and leave large areas of surface dry and inactive to heat and mass transfer.

A number of studies have also proven that there is improved wettability of the surface resulting in thinner and more stable liquid film, increased inter interface area and a greater heat and mass transfer coefficient [15,16]. This effect of wettability is even greater with low liquid flow rates, which are commonly desired with LDC systems to reduce pumping energy and solution carryover. In this case, hydrophobic surfaces are highly susceptible to the film breakup, which drastically impairs the performance of the absorber. This has led to surface engineering solutions to enhance wettability ranks among the research topics in the falling film technology.

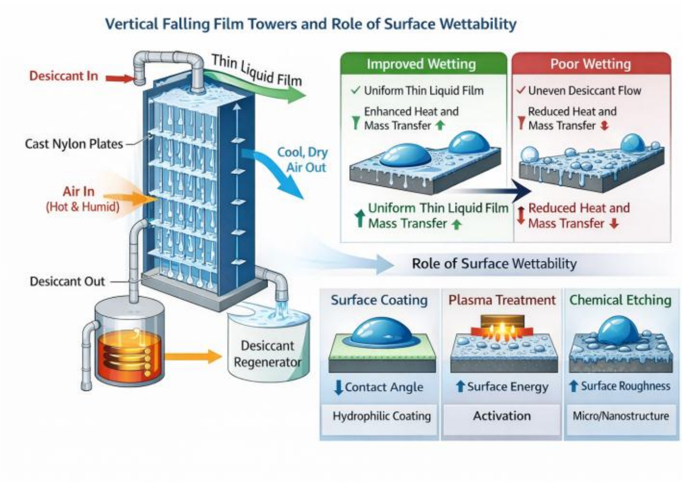

Figure 2: Vertical Falling Film Towers and Role of Surface Wettability

1.3 Packing and Contact Materials Nylon Plates Cast.

The choice of materials used to construct falling film tower surfaces is controlled by various factors that can be categorized as corrosion resistance, mechanical strength, manufacturability, cost, and compatibility with the textile used as a desiccant of the liquid. Aluminum alloys and stainless steel are also good thermal conductors that are affected by corrosion problems when subjected to concentrated desiccant solutions, especially the chlorides and bromides [17]. Glass and ceramic materials are very good in chemical resistance but are fragile and very costly hence their usability in large system is limited.

Polymeric materials and particularly engineering plastics including cast nylon, polypropylene, and polyvinyl chloride have become the interesting alternatives because of their low density, good resistance to corrosion, and simplicity to fabricate [18]. Cast nylon, specifically, is good in terms of mechanical properties, dimensional stability and long service life even in wet operating conditions. These are the benefits that cast nylon plates can be utilized as structured packing or flat contact surfaces in the vertical falling film towers. The fact that cast nylon, however, is highly hydrophobic on its inherent surface, thus giving it a relatively low contact angles with aqueous desiccant solutions [19], is a huge deficiency to this material. It is a natural hydrophobicity that suppresses the spread of natural films and requires external intervention to increase surface wettability.

1.4 The review requires a need to be wetted and the extent of its scope.

Numerous improvement measures of enhancing the wettability of cast nylon surfaces have been investigated in experimental works. Among the most frequently explored methods are mechanical surface texturing, chemical etching, plasma and corona treatments and hydrophilic coatings [2022]. The ways to achieve this are through altering surface chemistry, increasing surface energy or creating micro- and nano-scale roughness which facilitates capillary-mediated spreading. Although major advancements have been made in the reduction of the contact angle and control of the uniformity of the films, it has been revealed that the efficacy and stability of these treatments are quite inconsistent and depend on the operating conditions and the desiccant chemistry.

However, in spite of the increasing number of experimental data, the current literature is usually disjointed due to a lack of a comprehensive comparison of studies that concentrate on a particular treatment or operating conditions. Also, the long-term stability, scalability and economics of wettability enhancement methods in cast nylon plates are not adequately taken care of. Thus, such a review is timely and needed, which actively evaluates experimental wettability improvement solutions to cast nylon surfaces in vertical falling film towers. The review summarizes the literature available to present important findings, gaps in the research, and offer suggestions to further streamline and build the high-performance liquid desiccant cooling systems.

2. Methodology

This is a review that is premised on an extensive examination of experimental literature published in peer reviewed material, conference papers and dissertations writing on liquid desiccant cooling, falling film towers and the enhancement of surfaces of polymers. The criteria used to select them were: (i) the use of cast nylon or related polymeric materials in falling film configurations, (ii) experimental assessment of wettability parameters including contact angle, film thickness, or spreading behavior, and (iii) applicability to performance in heat and mass transfer in LDC systems. The studies were divided based on the kind of wettability enhancement method. Observed improvements were compared to key performance indicators, experimental setups and identified dominant trends and limitations.

3. Conclusion

The wettability on the surface is the determining factor in the application of vertical falling film towers in liquid desiccant cooling systems. Cast nylon plates are appealing in terms of mechanical and chemical benefits but they need intentional surface accessibility to enable consistent and steady flow of liquids in a film. This review indicates that experimental wettability improvement methods including mechanical texturing, chemical treatments, plasma activation and hydrophilic coating can play a major role in decreasing contact angle and enhancing the continuity of the film through cast nylon surfaces. Increased wettability has been shown to result in an increase in the heat and mass transfer coefficients, increase in the rate of moisture removal and increased stability of the absorber operation. Nevertheless, it has issues as far as long term durability, scalability of treatment, and compatibility with aggressive desiccant solutions are concerned. Further studies are needed on hybrid surface modification methods, long term performance testing and techno economic testing to enable the practical application of the wettability enhanced cast nylon plates in the liquid desiccant cooling systems used in commercial applications.

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