ABSTRACT

Vapor Compression Systems (VCS) are the most common air conditioning technology. However, the VCS process is energy inefficient due to overcooling and reheating. Liquid Desiccant air conditioning (LDAC) is a potentially more energy-efficient air conditioning technology. LDAC removes vapor in the air using the liquid desiccant's high-water affinity and controls temperature using an additional cooling device. Additionally, LDAC typically requires heating to regenerate the diluted Liquid Desiccant (LD) for repeated use after absorbing moisture.

Earlier types of the LDAC systems operated at a relative high concentration and temperature during the dehumidification process, resulting in an increased heat source temperatures required for regeneration, which substantially diminished the energy efficiency advantages of LDAC systems. In the past two decades, researchers have explored a new LDAC system configuration that integrates an LDAC system with a heat pump (HP). The HP can deliver sensible cooling to lower the LD operating temperature and cool the process air. Simultaneously, it provides heating at the condenser side to facilitate the regeneration process. Subsequently, membrane-based dehumidifiers were introduced to separate the LD and airflow using a membrane that permits the passage of water vapor. This approach prevents direct contact, which otherwise would result in LD droplet carryover, addressing concerns related to health and the corrosion of air ducts. An internally cooled membrane-based dehumidifier with enhanced performance garners significant attention, as it essentially functions as a three-stream heat exchanger that facilitates both heat and mass transfer processes. Because of the intricate characteristics of the three-stream heat and mass exchanger, the finite difference models used to analyze the internally cooled membrane dehumidifier is highly detailed and comprehensive. These models are well-suited for assisting in the device's design but is not suitable for system-level simulations. The lack of simple models for internally cooled membrane-based dehumidifiers limits the evaluation of energy performance at the system level. The limitation becomes particularly pronounced when a HP is integrated, as the model hinders our comprehension of the interactions between the HP and LDAC under the transient operating conditions.

The thesis research aims to bridge the gaps related to system configuration design, limitations of existing dehumidifier models, and the analysis and assessment of transient system level performance. A model of the internally cooled membrane-based dehumidifier, based on

artificial neural networks, was created using data generated through the utilization of a published and detailed finite element dehumidifier model. The resulting model was validated by testing it with out-of-sample data and comparing its results with the validated finite difference model. An LDAC system setup using the internally cooled dehumidifier was established in Modelica using the artificial neural network model created. Furthermore, models of a VCS and an LDAC based on adiabatic dehumidifier were also developed to facilitate performance comparison. The different systems underwent simulation for an entire cooling season spanning from May to September. The internally cooled dehumidifier-based system exhibited superior energy performance, achieving seasonal energy performance levels up to 104% and 34% higher than the VCS and adiabatic dehumidifier systems, respectively. The improved performance in comparison to the VCS is due to the higher temperature operation of the HP. The improvement in comparison to the adiabatic dehumidifier system is due to the improved capacity of the internally cooled dehumidifier to deal with the absorption heat released during dehumidification. Depending on the geographical location, the internally cooled dehumidifier system displayed enhanced performance in the applications characterized by moderate sensible cooling, while its efficiency was relatively lower in arid and hot regions. Additionally, the results demonstrated that the adiabatic system performed similarly to the internally cooled dehumidifier system in locations with high sensible and latent cooling loads.

This work introduces a pioneering data-driven model for internally cooled membrane liquid desiccant dehumidifiers, representing a significant advancement in the field. The model's computational efficiency and accuracy address the challenges posed by sophisticated and computationally expensive physical models, providing a valuable tool for simulating such devices. The creation of the simple ANN-based dehumidifier model opens the possibility for simulation of internally cooled devices as part of dehumidification systems, whereas as of today its study has been mostly limited to single devices simulations. In the study, a model-based comparison of system performance between an HP-coupled internally cooled dehumidifier-liquid desiccant air conditioning system and HP-coupled adiabatic LDAC, as well as Vapor Compression Systems, elucidates the optimal operational configuration and rationale. Furthermore, a climate sensitivity analysis of system simulations guides researchers toward focusing on the development of HP-coupled internally cooled/heated liquid desiccant systems, particularly in climates that offer the greatest potential for energy savings compared to commonly used vapor compression systems.

This comprehensive exploration enhances our understanding and paves the way for more efficient and effective developments in liquid desiccant-based dehumidification technologies.