Experimental and numerical investigation of mechanisms governing the performance of electrodialysis for liquid desiccant regeneration

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BEng & MSc

This thesis is presented as part of the requirements for the conferral of the degree:

Doctor of Philosophy (Engineering)

The University of Wollongong

Faculty of Engineering and Information Sciences

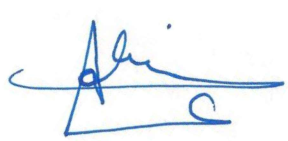
Sustainable Buildings Research Centre

October 2017

This research has been conducted with the support of an Australian Government Research Training Program Scholarship.

Declaration

I, *Ali Hussein Jabbar Al-Jubainawi*, declare that this thesis submitted in partial fulfilment of the requirements for the conferral of the for the award of *Doctor of Philosophy, at the Sustainable Buildings Research Centre, Faculty of Engineering and Information Sciences*, from the *University of Wollongong*, is wholly my own work unless otherwise referenced or acknowledged. This document has not been submitted for qualifications at any other academic institution.



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October, 2017

Abstract

Due to increasing concern about energy demand growth and its environmental impact, together with the need to improve indoor thermal comfort and building energy performance, significant effort has been made to develop innovative technologies to promote building energy efficiency while sustaining the built environment. Of these technologies, liquid desiccant air conditioning (LDAC) is a promising solution to control humidity in buildings whilst simultaneously reducing energy consumption. The regeneration of liquid desiccant is a critical step in a LDAC system because the water captured during dehumidification has to be removed from the system. Electrodialysis (ED) as one of the membrane-based regeneration techniques has recently been considered as a technical option to regenerate liquid desiccants. A key distinction between the use of ED for water treatment and for liquid desiccant regeneration is the solution concentration. Issues such as the impact of ion-exchange membranes (IEMs) on the regeneration of high concentration solutions, the factors governing the mass transfer mechanisms, and the influence of solution temperature on ED regeneration have not yet been studied. This thesis aims to fill some knowledge gaps in the use of ED for liquid desiccant regeneration by evaluating the performance of ED regeneration with different IEM pairs, examining the mass transfer mechanisms governing ED regeneration, and investigating how the temperature of the regenerated solution and the difference in temperature between spent and regenerated solutions affects the performance of ED.

The regeneration performance and energy consumption of ED with three different IEMs (i.e. CMV-AMV, CSO-ASV and CMO-DSV) for LiCl regeneration were first examined based on a lab-scale ED experimental system. The experiments were designed and analysed using the Taguchi and Analysis of Variance (ANOVA) methods. Although the regeneration performances of the CMV-AMV and CSO-ASV pairs were almost the same, the CMV-AMV pair consumed much less energy than the CSO-ASV pair. Despite the fact that the CMO-DSV pair consumed less energy than the others, the regeneration performance of the CMO-DSV membrane pair was negatively affected by the increasing difference in osmotic pressure. The CMV-AMV membrane pair was therefore considered to be the best option of the three IEMs used for LiCl regeneration.

The factors governing the mass transfer mechanisms of the CMV-AMV membrane pairs were then examined in detail. These experiments revealed that water flux due to osmosis was significant whereas salt flux due to the difference in concentration between the regenerated and spent solutions was insignificant. The average water flux from the

spent solution to the regenerated solution due to the electro-osmosis phenomenon decreased from 0.292 to 0.161 g/s m^2 when the initial concentration of the solutions in the spent and regenerated tanks increased from 18 to 30% (wt/wt) respectively, with the same current of 12 A and the same solution flow rate of 100 L/h. A numerical study was then carried out using COMSOL Multiphysics and based on the Nernst-Plank equation to simulate phenomena such as concentration polarisation, boundary layer distribution, and limiting current density. The results showed that the concentration polarisation and the boundary layer along the ED membranes increased significantly during regeneration, and the impact of the boundary layer and concentration polarisation on the CEM was greater than on the AEM.

The influence that the temperature of the regenerated solution and the difference in temperature between the regenerated and spent solutions had on the performance of ED for liquid desiccant regeneration was also evaluated experimentally. The results revealed that better regeneration performance and lower energy consumption can be achieved when the temperature of the solution at the inlet of regenerated channels is higher, and the difference in temperature between the inlets of the regenerated and spent channels is also greater. Moreover, the regeneration performance of the ED stack improved by 19% while the energy consumption decreased by 19.3% when the temperature of the regenerated solution at the ED inlet increased from 20 to 30 ^oC, the difference in temperature between the spent and regenerated solutions at the ED inlet increased from 5 ^oC to 15 ^oC, and when the initial concentration of the regenerated solution was 29% (wt/wt), the initial difference in concentration between the regenerated and spent solutions was 0% (wt/wt), the solution flow rate was 60 L/h and the current was 12 A.

A mathematical model was developed to predict the performance of ED by considering how the influence of the solution temperature at the inlet of ED channels affected regeneration performance. The results showed that the energy consumed by the ED stack decreased from 133.4 to 122 and 112.2 W, and the regeneration performance increased from 0.022 to 0.025 and 0.028% (wt/wt) when the difference in temperatures between the spent and regenerated solutions at the ED inlet increased from 5 to 10 and 15 ^oC, while the other parameters remained unchanged. The main findings from this thesis showed that ED is promising for regenerating liquid desiccant when the factors governing the regeneration are properly considered. The results of this study could help to facilitate the development of liquid desiccant air conditioning system integrated with an ED regeneration process.

Acknowledgments

I would like to express my gratitude and appreciation to Dr. Zhenjun Ma and Prof. Long D. Nghiem for their supervision and guidance during my PhD study. I would also like to thank Prof Paul Cooper for his advice.

I would like to express my gratitude to Mr Craig McLauchlan and Mr John Barron for their technical support in my experimental work.

I would also like to thank the Higher Committee for Educational Development (HCED) in Iraq for the PhD sponsorship support.

My appreciation also goes to all my colleagues at the Sustainable Buildings Research Centre for their constant support in accomplishing my research and thesis writing.

I would like to thank all my friends I met in Wollongong for their constant love and support. They made my PhD time in Wollongong happy, colourful and memorable.

Lastly, I appreciate and will always be grateful to my parents, my brothers and my sister. Thank you so much for your endless love, tolerance and patience no matter what situation I am in.