A Study of Silica Gel Adsorption Desalination System

By

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Abstract

Rising water scarcity due to climate change and over-exploitation of traditional water resources is of increasing concern around the World, both because of its economic implications as well as the continued habitability of long-standing communities. One solution to this issue is desalination of saline or brackish water, which has long been used in regions that have traditionally faced water shortage such as the Middle East. There are several ways in which desalination is carried out, including multi-effect desalination, multi-stage flash desalination, and membrane-based reverse osmosis (RO), which are all widely exploited commercially. The high energy demands and large 'carbon footprint' of these various current commercial technologies have spurned interest in several potential alternative technologies.

One of these alternatives is adsorption-based desalination (AD). This approach uses low-grade heat such as waste heat from a process or solar energy to generate potable water and, depending on the cycle details, cooling as well. The low-grade heat is used to form water vapour from the saline or brackish source. The vapour is then passed through a bed of silica into which it adsorbs until the silica is saturated. Once saturated, the bed of silica is heated using further low-grade heat to drive off the now desalinated water before being re-condensed in a receiving vessel.

Adsorption-based desalination has a range of advantages, including: (1) it is driven by low-grade heat that is free and/or would otherwise go to waste; (2) it has few moving parts, leading to reduced maintenance costs; (3) fouling and corrosion is reduced due to the low operating temperatures and confinement of the saline/brackish water to a fraction of the total system; and (4) it offers the ability to treat/desalinate saline and brackish waters containing organic compounds. Besides these advantages, which may be shared in part with some conventional desalination methods, AD also offers two unique benefits: (1) it has the ability to co-generate cooling along with the potable water; and (2) it yields double distillate, minimizing the possibility of so-called '(bio) gen-contamination'.

Despite the many advantages of AD, it has received remarkably little attention by researchers. Given how established existing desalination technologies are, take-up of AD is unlikely until we have a far greater understanding of the effect of process parameters on the productivity of AD – the work therefore reported here addresses directly this need.

This thesis reports a detailed study of the impact of operational and design parameters such as operating heating and cooling water temperatures and cycle times on the nature of the thermodynamic cycles of AD and its performance in terms of, for example, system water productivity and specific energy consumptions. This aim is achieved by using a range of novel models validated by experimental data also obtained as part of the research. Key findings of this study include: 1) In AD, an optimum hot water temperature existing for the minimum energy consumption of per unit mass fresh water produced. The optimum temperature depends on the cooling water temperatures and other operating parameters of the system; 2) the performance of the AD cycles is bounded by the capacity of the adsorbent used, the optimal water production rate of the cycles increases directly with the capacity whilst the corresponding energy consumption rate per kg of water produced decreases at a diminishing rate; 3) the evaporator temperature relative to cooling water temperature can significantly impact on the nature of the AD cycles and the performance of the AD systems. At different evaporator temperature relative to the cooling water temperature, the thermodynamic cycles had been theoretically and experimentally identified to form three unique cycle categories when they are presented on the set of *P-T-X* relationship coordinates. Analysis of these cycles showed that the best performance is achieved when the temperature of the evaporator is greater than that of the water used to cool the silica-gel bed and condenser; 4) an optimum system cycle time existing for the maximum fresh water production over a specific period of time under the given operational conditions using validated dynamic model.

This thesis is presented in the form of a collection of published or submitted journal articles that are the results of research by the author. These five articles have been chosen to best demonstrate the study of an AD system (both theoretical and experimental studies). Additional background information is provided in order to establish the context and significance of this work.

Declaration

This work contains no material which has been accepted for the award of any other degree or diploma in any University or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree.

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Jun Wei Wu Date

Thesis by Publication

This thesis is submitted as a portfolio of publications either published or submitted for publication by peer-reviewed journals according to the 'Academic Program Rules' of the University of Adelaide. The international journals that these papers have been published in or submitted to are all closely related to the field of the research of this work.

The thesis is based on the following publications:

1. Wu J. W., Biggs M. J., Hu E. J. (2012) Dynamic Model for the Optimisation of Adsorption-based Desalination Processes. *Chemical Engineering Science,* under review.

2. Wu J. W., Biggs M. J., Pendleton P., Badalyan A., Hu E. J. (2012) Experimental Implementation and Validation of Thermodynamic Cycles of Adsorption-based Desalination. *Applied Energy*, 98, 190-197.

3. Wu J. W., Hu E. J., Biggs M. J. (2012) Thermodynamic Cycles of Adsorption Desalination system. *Applied Energy*, 90, 316-322.

4. Wu J. W., Hu E. J., Biggs M. J. (2011) Thermodynamic Analysis of an Adsorption-based Desalination Cycle (part II): Effect of Evaporator Temperature on Performance. *Chemical Engineering Research and Design*, 89, 2168-2175.

5. Wu J. W., Biggs M. J., Hu E. J. (2010) Thermodynamic Analysis of an Adsorption-based Desalination Cycle. *Chemical Engineering Research and Design*, 88, 1541-1547.

The Following conference papers are of close relevance to the present work and are included in the appendices:

1. Wu J. W., Biggs M. J., Hu E. J. (2010) Comparison of Adsorption-based Desalination Plant Performance Models. *Chemeca 2010: The 40th Australasian Chemical Engineering Conference*, Adelaide, September 26-29, ISBN: 978-085-825-9713.

2. Wu J. W., Biggs M. J., Hu E. J. (2010) Thermodynamic Analysis of Adsorption-based Desalination Cycles. *Chemeca 2010: The 40th Australasian Chemical Engineering Conference*, Adelaide, September 26-29, ISBN: 978-085-825-9713.

The following journal publication was completed as part of this research candidature, but not included as part of this thesis.

1. Wu J. W., Hu E. J., Biggs M. J. (2012) Low Energy Adsorption Desalination Technology. *Advanced Materials Research*, 347, 601-606.

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