DEVELOPMENT OF HYBRID MICROFLUIDICS CHIP FOR WATER DESALINATION AND PURIFICATION

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SUPERVISOR’S DECLARATION

I hereby declare that I have checked this thesis and, in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Doctor of Philosophy.

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STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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ABSTRAK

Kaedah penyahgaraman pengekstrakan pelarut arah (DSE) diperkenalkan sebagai salah satu teknik penyahgaraman bebas membran. Namun, kaedah DSE ini tidak dikaji dengan lebih lanjut atau diaplikasikan secara komersial kerana dua kelemahan ketara yang mempengaruhi kecekapannya. Kelemahan pertama adalah langkah pencampuran dan pemisahan yang besar dan rumit. Selain itu, proses pemisahan hanyalah proses mendapan yang memerlukan masa dan ruang yang luas. Kelemahan kedua adalah adanya sisa pelarut dalam produk air kerana teknik penyahkesan selektif yang buruk, yang bergantung pada daya graviti. Kajian ini, untuk pertama kalinya, memperkenalkan ekstrak pelarut arah (DSE) dalam sistem skala mikro menggunakan teknologi mikrofluidik. Cip ini direka bentuk dengan dua bahagian, untuk pengekstrakan dan pemisahan. Di kedua bahagian, cecair dipisahkan menggunakan saluran kapilari yang berserenjang dengan arus utama. Saluran utama dibentuk dengan lebar 400 µm dan tinggi 100 µm. Dua aliran masuk diperkenalkan melalui persimpangan Y, asid oktanoik sebagai fasa organik, dan air masin sebagai fasa berair. Prestasi penyahgaraman dikaji pada empat suhu yang berbeza dan lima kadar aliran pelarut yang berbeza. Kecekapan pencampuran dan penyatuan dengan sistem fotokatalis berdasarkan sistem rambut manusia didapati menyumbang secara signifikan untuk mengatasi dua kelemahan utama yang telah dikenalpasti sebelum ini, di mana aliran dalam sistem sedemikian dikuasai sepenuhnya oleh sifat fizikal yang nyata seperti ketegangan permukaan dan kelikatan cecair yang mengalir. Cip hibrid telah menunjukkan prestasi yang besar dalam pengambilan air dari air masin pada suhu rendah dan dengan menggunakan asid oktanoik sebagai pelarut. Pengunaan kapilari meningkatkan hasil air hingga 47% pada suhu rata-rata dan kadar aliran pelarut maksimum. Selain itu, kemasinan produk air berkurang dengan pemisahan kapilari dari 0,35% hingga 0,04%, yang 83% lebih rendah daripada salinitas produk air yang diperoleh pada skala makro. Selain itu, sisa pelarut berkurang ketika menggunakan cip mikrofluidik dan didapati serendah 13.5 ppm pada 65 °C dengan nisbah kadar aliran 2. Berdasarkan hasilnya, diyakini bahawa dengan suhu yang sesuai dan sistem automatik bersepadu, cip ini dapat menjadi pengganti masa depan untuk kaedah penyahgaraman saat ini. Pengembangan alat sedemikian berdasarkan mikrofluidik menawarkan penyahgaraman air yang mudah dan rendah tenaga pada masa hadapan, yang dapat digunakan di mana-mana kawasan kekurangan air. Oleh itu, bahan fabrikasi peranti rendah dan bekalan tenaga (yang dapat diperoleh dengan mudah dari panel solar kecil), akan memungkinkan penggunaannya walaupun di negara-negara yang tidak mempunyai kestabilan ekonomi.

ABSTRACT

Directional solvent extraction desalination (DSE) desalination method was introduced as an alternative, membrane-free desalination technique. Despite all the promising advantages of this technique, it is not further investigated or commercially applied due to two significant drawbacks that affect its efficiency. The first drawback is the massive and complicated mixing and separation steps. Additionally, the separation is simply a settling process, thus requiring time and vast space. The second drawback is the existence of solvent residuals in the effluent product water due to the poor selective decanting technique, which relies on gravitational forces. This study, for the first time, introduces the directional solvent extract (DSE) in a micro-scale system using microfluidics technology. The chip was designed with two sections for extraction and separation. In both parts, the liquids were separated using capillary channels perpendicular to the mainstream. The main channels were designed to be 400 µm in width and 100 µm in height. Two streams inlets will be introduced through a Y-junction, octanoic acid as the organic phase, and saltwater as the aqueous phase. The desalination performance was investigated at four different temperatures and five different solvent flow rates. The mixing efficiency and the integration with photocatalyst-based on the human-hair system were found to contribute significantly to overcome the two major drawbacks identified earlier where the flow in such systems is entirely dominated by the apparent physical properties like the surface tension and viscosity of the flowing liquids. The hybrid chip has shown a substantial performance in extracting water from the saltwater at low temperatures and by using octanoic acid as solvent. Using the capillary improved the water yield up to 47% at the average temperature and maximum solvent flow rate. Additionally, the product water salinity reduced with the capillary separation from 0.35% up to 0.04%, which is 83% lower than the salinity of the water product obtained at the macroscale. Besides, the solvent residuals reduced when using the microfluidics chip and were found to be as low as 13.5 ppm at 65 ℃ and the flow rate ratio of 2. Based on the results, it is believed that with appropriate temperature and integrated automated systems, this chip can be a future replacement to the current desalination methods. The development of such devices based on microfluidics offers a future easy and low energy water desalination, which can be used in any water scarcities region.

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LIST OF SYMBOLS

Θ	The Thickness of Layer
$\pi_{F,b}$	Feed Osmotic Pressure
$\pi_{D,b}$	Bulk Osmotic Pressure
$\pi_{D,b}$	Draw Solution Osmotic Pressure
$C_{D,b}$	Bulk Concentration of DS
$C_{F,b}$	The Bulk Concentration of FS
D	Bulk Diffusion Coefficient
λ	Mean Free Path Of The Molecules
ΔG	Gibb's free energy
Re	Reynolds number
W_p	Weights of The Recovered Water
W_s	Weights Octanoic Acid

LIST OF ABBREVIATIONS

DSE	Directional Liquid Extraction
MSF	Multi-Stage Flash Distillation
MED	Multiple Effect Distillation
VCD	Vapor Compression Desalination
RO	Reverse Osmosis
ED	Electro Dialysis
VCD	Vapor Compression Desalination
GR	Geometry Ratio
EP	Electrophoresis
AOPs	Advanced oxidation processes
UV	Ultraviolet
QY	quantum yield
H-L	Langmuir-Hinshelwood
TNAs	Titania Nanotube Arrays
XRD	X-ray diffractometry
TEM	Transmission Electron Microscopy
RS	Raman spectroscopy
CNTs	Carbon Nanotubes
HH	Human Hair
TNP	Titanium Dioxide Nanoparticle
MB	Methylene Blue
DSSCs	Dye-Sensitized Solar Cells
PDMS	Polydimethylsiloxane
PVA	Polyvinyl Alcohol
HHDMs	Human Hair-Derived Microfibers
SEM	Electron Scanning Microscopy
EDS	Energy Dispersive Spectroscopy
XPS	X-Ray Photoelectron Spectroscopy
FTIR	Fourier transform infrared spectroscopy
MPSi	Microporous silicon wafer
BET	Brunauer-Emmett-Teller

TDS	Total Dissolved Solids
Kn	Knudsen number
FO	Forward Osmosis
PRO	Pressureized Reversed Osmosis
AL-DS	Active Layer facing Draw Solution
AL-FS	Active Layer facing Feed Solution

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