IIF – Final Report

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Project Name	EO-D-Regeneration—Electroosmosis for Desiccant Regeneration - Innovation Technology for air-conditioning
Project Start Date	20th October, 2011
Project website	

1. Final Publishable Summary Report

As an alternative to classical air-conditioners, desiccant dehumidification systems take increasing applications because of many advantages such as energy-saving, reduction of chlorofluorocarbons application and separate control of latent load to make a more comfortable indoor air quality. In order to apply the solid desiccant repeatedly in the process, the desiccant has to be regenerated. However, the thermal regeneration used in most solid desiccant systems nowadays has high operating energy consumption and needs complicated system. Electro-osmosis is a liquid flow through the capillaries in porous media like solid desiccant driven by the electroosmotic (EO) force, which provide a possible regeneration method for solid desiccants.

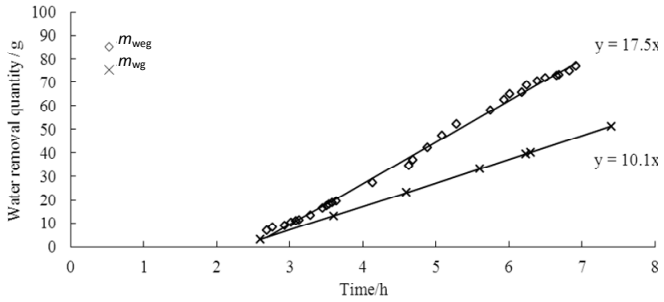
This project aims to develop a novel solid desiccant dehumidification technology with EO regeneration for small air conditioning systems. The system will be suitable for powering with renewable energy sources. The objectives includes: (1) to develop the EO regeneration method for the proposed dehumidification unit; (2) to carry out experimental studies to investigate and optimise the characteristics and influencing factors; (3) to develop the testing system of small dehumidification unit of solid desiccant with the EO regeneration to meet the requirement of practical application; (4) to complete the according economic acceptance analysis.

The research task and objectives of this project had been finished according to the agreed schedule, mainly including set-up of the test bench and experiments of the EO regeneration effect, experiments of influencing factors on EO regeneration, coupling characteristic of the vapour adsorption and EO regeneration, mathematical model and performance simulation, experiments of solid desiccant system with EO regeneration, economic analysis.

The significant results had been concluded as:

(1) The experimental results showed that the electro-osmosis could remove the water from the solid desiccant with the application of the electric field and regenerate the desiccant. The EO regeneration rate was up to 2.1×10^{-6} kg s^{-1}. The

EO regeneration was proved to be a potential regeneration method for the solid desiccant system.



Comparison between m_{weg} (water removal by both EO and gravitational force) and m_{wg} (water removal only by gravitational force) when applied voltage E is 17 V cm^{-1}.

(2) The four improvement methods were obtained, including applying the platinum-plated titanium mesh as anode, laying a piece of filter cloth under the cathode, applying the interrupted power and optimizing the electrical field strength.

(3) The EO regeneration together with the vapour adsorption had been experimentally investigated when the relative humidity of supply air is kept 70%, and 85% respectively. There existed the EO effect under 85% relative humidity of supply air, but there is no EO effect when the relative humidity of supply air is equal to or lower than 70%. And the dehumidifier prototype with EO regeneration had been fabricated and trial test showed it worked well.

(4) Economic analysis showed that the power consumption of desiccant dehumidification with EO regeneration would be 18.6% less than that of condensation dehumidification, and would save 213 kWh power yearly if air conditioning system for one room with 20 m^2 area runs 10 hours each day, and 90 days each year. The operating cost of desiccant dehumidification with EO regeneration would be 30% less than that of thermal regeneration.

The results of this project show that the EO regeneration is one potential regeneration method for the solid desiccant system, which will provide a simple, sustainable, energy saving, healthy approach for small air conditioning systems in Europe.

There are 22 papers published, including 12 refereed journal papers and 10 conference papers. The research results had been disseminated in three international conferences: the 23rd IIR International Congress of Refrigeration, 8th International Conference on Boiling and Condensation heat transfer, and 10th IIF/IIR Gustav Lorentzen Conference on Natural Refrigerants. I gave presentations in the seminar at host Prof. Yuying Yan's Building Services Research Group within the Research Division of Energy & Sustainability. I was integrated with the students and academic staff of Prof. Yan's group through weekly research seminars. I helped Prof. Yan to supervise graduate students in EO regeneration for desiccant and thermal management of low carbon vehicle. And, I also helped Prof. Yan to have developed 'Integrated thermal management for electric vehicles' new research direction in his research group.

2. Public Dissemination Measures

This section should describe the dissemination measures, including any scientific publications relating to foreground and specify any applications for patents etc. Its content will be made available in the public domain thus demonstrating the added-value and positive impact of the project on the European Community.

The research results had been disseminated in three international conferences.

(1) The 23rd IIR International Congress of Refrigeration, Prague, Czech, 2011

IIR congresses are milestone events held once every 4 years, bringing together very large numbers of refrigeration stakeholders from all parts of the world. The 23rd IIR International Congresses of Refrigeration targeted both the industrial and academic stakeholders. Unlike most events that address only a narrow thematic field, the Congress brings together expertise from virtually all refrigeration fields. The technical programme reflected the activities of all IIR's 10 commissions: Commission A1: Cryo-physics, cryo-engineering; Commission A2: Liquefaction & separation of gases; Commission B1: Thermodynamics & transfer processes; Commission B2: Refrigerating equipment; Commission C1: Cryobiology, cryo-medicine; Commission C2: Food science & engineering ; Commission D1: Refrigerated storage; Commission D2: Refrigerated transport; Commission E1: Air conditioning; Commission E2: Heat pumps, energy recovery.

In this congress, an oral presentation titled 'Research on electro-osmotic regeneration method for solid desiccant' had been given. The novel EO regeneration method for the solid desiccant system and some experimental results were presented. EO force could remove water from the zeolite desiccant and the water removal rate was obtained about 2.1×10^{-6}; several improvement methods were proposed.

And lots of listeners were interested in our EO regeneration approach, the Joule heat effect, performance improvement, and application feasibility were discussed after presentation.

(2) 8th International Conference on Boiling and Condensation heat transfer, Lausanne, Switzerland, 2012

Scope of the 8th ECI conference in this series is to discuss and disseminate fundamental and applied research on two-phase heat transfer at the micro- to macro-scale level. Papers related to pool boiling, flow boiling, convective condensation, enhanced boiling, enhanced condensation, flow visualization, physical modelling, numerical simulation and modelling, and various applications including novel micro and macro heat transfer devices were presented and discussed in the conference. There were eight sessions: Session 1: Micro and Mini channel Flow Boiling, Session 2: Pool Boiling, Session 3: Condensation, Session 4: Flow Boiling, Session 5: Numerical Simulations, Session 6: Impinging Jet Heat Transfer, Session 7: Structure Surface and Fluids, Session 8: Miscellaneous.

In the afternoon of 6th June, 2012, an oral presentation 'Experimental Investigation on Spray Cooling with Isobutane (R600A)' was given in the Session 6: Impinging Jet Heat Transfer. The experimental investigation on heat transfer

performance of spray cooling with R600a was introduced. When the coolant mass flow rate is nearly 6.9 kg/h, the heater surface temperature can be kept at 57.3 ^{o}C with the heat flux of 145 W/cm^2. The nozzle inlet pressure and chamber pressure can be controlled according to the experimental requirements. The heat transfer coefficient is achieved up to 35000 W/(m^{2}K) when the nozzle inlet pressure and the chamber pressure are 4.9 bar and 2.3 bar respectively. In the experiments, all the surface temperatures are all less than 60^{o}C, and the heater surface temperature standard deviations are all less than 4^{o}C, which is valuable for device cooling. The experimental results indicate the close spray cooling system with R600a is a promising cooling technique for the device heat dissipation.

The influence of spray size and droplet diameter on heat transfer was discussed after presentation.

(3) 10th IIF/IIR Gustav Lorentzen Conference on Natural Refrigerants, Delft, the Netherlands, 2012

The IIR's Gustav Lorentzen conferences is the leading cutting-edge series of events covering all natural refrigerants. The IIR's focus on the importance of the exchange of knowledge in the field of refrigerants is reflected not only in the Gustav Lorentzen events but also in other IIR events: a series of conferences on ammonia technology, another series of events on the thermo-physical properties of refrigerants, and a number of technical sessions staged during IIR congresses. The main scope: CO_2 Ejector Systems, CO_2 Compressors, CO_2 Components / Heat pumps, CO_2 Supermarket Systems, Absorption Refrigeration, Sorption / Desiccants, HC Compressors, HC Drop In/Systems, HC safety / Low charge / Drop-in, NH_3 Compressors, NH3 Heat Pumps / Chillers, Heat Exchangers / Heat Transfer, Secondary Refrigerants, High Temperature Heat Pumps, Thermal Storage, Control, Emissions Policy.

In the afternoon of 26th June, 2012, an oral presentation 'Experimental Investigation on R1270 as Alternative Refrigerant of R22 in Residential Air conditioners' was given in the session "HC safety / Low charge / Drop-in". And the inflammability, safety, and potential application of R1270 were discussed after presentation.

3. Publications (peer reviewed)

List of scientific (peer reviewed) publications, starting with the most important										
Title	Main author	Title of periodical or series	Number, date or frequency	Publisher	Place of Publication	Date of publication	Relevant pages	Permanent identifier (3)	Open access? (yes/no) (4)	D.O.I
Experimental investigation on performance improvement of electro-osmotic regeneration for solid desiccant	Qi Ronghui, Tian Changqing, Shao Shuangquan, Tang Mingsheng, Lu Lin	Applied Energy	88(8)			2011	2816-2823		No	
Dehumidification performance of [EMIM]BF4.	Yimo Luo, Shuangquan Shao, Hongbo Xu, Changqing Tian	Applied Thermal Engineering	31 (2011),			2011	2772-2777		No	
Two-phase flow instabilities in horizontal straight tube evaporator	Nan Liang, Shao Shuangquan, Changqing Tian, Yuying Yan	Applied Thermal Engineering	31 (2011)			2011	181-187		No	
Experiment investigation of R134a flow boiling process in micro-channel with	Hongzhang Cao, Hongbo Xu, Nan Liang,	Heat Transfer Engineering	32(7-8)			2011	542-553		No	

cavitation structure	Changqing Tian									
Piston Stroke Design Optimization for Linear Compressor	Huiming Zou, Liqin Zhang, Guohong Peng, Changqing Tian	Advanced Materials Research	189-193 (2011)			2011	1635-1640		No	
Self-Sensing Control Research on a Linear Compressor	Liqin Zhang, Guohong Peng, Huiming Zou, Changqing Tian	Advanced Materials Research	189-193 (2011)			2011	2385-2390		No	
Development and experimental investigation of a novel spray cooling system integrated in refrigeration circuit	Si Chunqiang, Shao Shuangquan, Tian Changqing, Xu Hongbo	Applied Thermal Engineering	33-34 (2012)			2012	246-252		No	
Experimental investigation and performance analysis of a dual-cylinder opposed linear compressor	Huiming Zou, Liqin Zhang, Guohong Peng, Changqing Tian	Journal of Mechanical Science and Technology	25(8)			2011	1-8		No	
Dynamic simulation of multi-unit air conditioners based on two-phase fluid network model	Shuangquan Shao, Hongbo Xu, Changqing Tian	Applied Thermal Engineering	40(2012)			2012	378-388		No	
Investigation on feasibility of ionic liquids used in solar liquid desiccant air	Yimo Luo, Shuangquan Shao, Fei Qin,	Solar Energy,	86(2012).			2012	2718-2724		No	

conditioning system	Changqing Tian									
Dynamic Simulation of Variable Refrigerant Flowrate Air-Conditioning System	Shao Shuangquan, Liang Nan, Tian Changqing	Journal of Refrigeration,	2011(1)			2011	16-22		No	
Heating performance analysis of quasi two-stage compression air source heat pump for electric vehicle air conditioning	Shuangquan Shao, Changqing Tian, Fei Qin, Yuying Yan	The 2012 International Conference on Advanced Vehicle Technologies and Integration (VTI2012)			Changchun,China	July 16-19, 2012	VTI2012-SSP(TM)-06		No	
Feasibility Study of Ionic Liquid in solar driven liquid desiccant dehumidification system for air conditioning	Hongbo Xu, Shuangquan Shao, Yimo Luo, Changqing Tian	4th International Conference Solar Air-Conditioning,			Larnaka, Cyprus,	October 12-14, 2011			No	
Investigation on performance of fin-tube internally heated regenerator in liquid desiccant air conditioning system	Fei Qin, Shuangquan Shao, Changqing Tian, Guiying Zhang	. International conference on applied conference			July 5-8, 2012,	Suzhou,China	ICAE2012-A10298		No	
Numerical optimization on the mass flow distribution	Guiying Zhang, Hongbo Xu, Changqing Tian,	International conference on applied			July 5-8, 2012,	Suzhou,China	ICAE2012-A10374		No	

in rectangular microchannel heat sink	Shuangquan Shao, Fei Qin	conference								
Development of linear compressor for refrigerators	Huiming Zou, Liqin Zhang, Guohong Peng, Changqing Tian	The 23rd IIR International Congress of Refrigeration			2011	Prague, Czech	No.412		No	
Research on electro-osmotic regeneration method for solid desiccant	Luo Yimo, Shao Shuangquan, Qi Ronghui, Tang Mingsheng, Tian Changqing	The 23rd IIR International Congress of Refrigeration			2011	Prague, Czech	No.427		No	
Experimental study with novel spray cooling system for high power devices	Tian Changqing, Si Chunqiang, Shao Shuangquan, Xu Hongbo	The 23rd IIR International Congress of Refrigeration			2011	Prague, Czech	No.406		No	
Two-phase fluid network model for steady-state and dynamic simulation of multi-unit air conditioners	Shuangquan Shao, Hongbo Xu, Changqing Tian	The 23rd IIR International Congress of Refrigeration			2011	Prague, Czech	No.425		No	
Experimental investigation on spray cooling with Isobutane (R600A)	Changqing Tian, Chunqiang Si, Shuangquan Shao, Yuying Yan	8th International Conference on Boiling and Condensation heat transfer			2012	Lausanne, Switzerland	No. 1453		No	

Experimental investigation on R1270 as alternative refrigerant of R22 in residential air conditioners	Tingxiang Jin, Changqing Tian, Zuyi Zheng	10th IIF/IIR Gustav Lorentzen Conference on Natural Refrigerants			2012	Delft, the Netherlands,	No. 238		No	

4. List of applications for Patents, Trademarks, Registered designs etc

Type of IP Rights	
Application Reference (eg EP123456)	
Subject or title of application	
Confidential (yes/no)	
Foreseen embargo date	
Applicant (as on application)	
URL of application	

5. Exploitable foreground and plans for exploitation

Type of exploitable foreground	New products
Exploitable Foreground (description)	Electroosmosis regeneration technology can be applied in dehumidifier, small air conditioning system, and desalinator.
Confidential (yes/no)	No
Foreseen embargo date (dd/mm/yyyy)	
Exploitable product(s) or measure(s)	Electroosmosis regeneration dehumidifier, electroosmosis desalinator
Sector(s) of application	Air conditioning, sea water desalination
Timetable for commercial use or any other use	Electroosmosis regeneration dehumidifier is planned for application before June of 2013, and the electroosmosis desalinator is planned to use before the end of 2013.
Patents or other IPR exploitation (licenses)	No
Owner & Other Beneficiary(s)	No

involved	