RESEARCH REPORT

SABBATICAL STAY AT CREVER, UNIVERSITY ROVIRA i VIRGILI
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SUMMARY

The main objectives of the research project presented for my sabbatical stay were accomplished.

A three-year research proposal of international impact and quality was developed together with CREVER researchers, taking into account the infrastructure and research lines already being carried out at CREVER. The project is related to the study of new mixtures in thermal activated systems, by the addition of a third component to help the heat transfer processes. The project proposes the use of water and lithium nitrate as absorbents in ternary ammonia mixtures, varying the concentration with the objective of optimising the mixture for solar air conditioning purposes. Also, the research proposal will promote an intensive collaboration in the following years between CREVER and The Centro de Investigación en Energía-UNAM, Mexico.

Complying with the other specific objectives of the research project presented, I participated and provided input to the research in order to advance in the design of advanced components for thermal activated absorption systems and in the modelling of waste heat or solar driven cooling systems. I participated in discussions with researchers and students of the various projects being carried out at CREVER and was able to contribute for a better advance in the research. This was reflected in my participation as co-author in various papers that will be presented in specialised conferences in the following months or that are being prepared to be sent to international research journals.

During my stay at CREVER I participated in preparing a draft proposal for a collaboration agreement between the Universidad Rovira i Virgili and the University of Mexico. This agreement will formalise the exchange between students and researchers at CREVER and CIE-UNAM and other researchers and postgraduate students in Engineering. The agreement is being revised to be signed.

I participated in the "XII Congreso Ibérico y VII Congreso Iberoamericano de Energía Solar", at Vigo, Galicia, 14 -18 of September 2004. I was invited by the organisers to participate in the technical committee and to chair a plenary session.

I participated in discussions on the objectives of the new joint international Erasmus Mundus Master Course, MBA in "European Energy Economics EEE". The MASTER Programme is being prepared by CREVER with other four European Universities. I also participated in the formulation of the contents of some of the URV courses of the modules for Engineers and Scientists. I have been invited as lecturer of the course "Solar Energy Systems" once the Master Course is approved.

Finally I delivered lectures in three different courses carried out at CREVER.

1) A two-hour lecture for PhD students in the "Tecnología de Climatización y Eficiencia Energética en Edificios course" where I gave a lecture in advanced absorption systems.

2) A conference for researchers and students explaining the most important parts of the proposed research project.

3) A nine-hour course on Biomass sources and technology as part of the course "Especialista Universitario en Energías Renovables". I produced all the material for CREVER to use in further courses.

ACKNOWLEDGEMENTS

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I would like to thank Dr. Alberto Coronas for his stimulating discussions and guidelines in order to make my stay at CREVER a gratifying professional and personal experience.

I would like to acknowledge the excellent disposition and the high professional level of the research staff and postgraduate students at CREVER. I will like to specially thank the collaboration of the following persons in the various projects that were developed. Dr. Alberto Coronas, Dr. Mahmoud Bourouis, Dr Joan Carles Bruno, Dr. Manél Vallès, Dr. Xavier Esteve, and to the PhD. students Jesús Cerezo, Francisco Taboas, Gustavo Figueredo Alvaro Mestra, Daniel Salavera and Simona Libotean. Special thanks also to Raquel Chaves for all her administrative support. I also want to thank the technicians Alberto Montiel and Alex Ruiz.

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I. RESEARCH PROPOSAL:

Project Title: "Improvement of thermophysical properties and transport phenomena in plate heat exchangers by the addition of water to NH_3-$LiNO_3$ mixture in solar absorption refrigeration"

Summary

In the cooling of buildings with absorption systems, lithium bromide-water based systems are typically used. On the other hand, ammonia-water systems allow heat rejection to the ambient air and can operate below freezing temperatures. The performance of ammonia-water equipment is lower than lithium bromide as it needs rectification of the refrigerant vapour at the generator outlet. Alternatives have been studied, as the utilisation of lithium nitrate salt as an ammonia absorbent instead of water, producing a working pair that does not require rectification. Besides this advantage, for below freezing applications, this mixture operates at generator temperatures below those required by the ammonia-water mixture. However, this mixture does have disadvantages, as it has a very high viscosity that hinders the heat and mass transfer processes in the generator and absorber.

The project proposes the use of water and lithium nitrate as absorbents in ternary ammonia mixtures, varying the concentration with the objective of optimising the mixture for solar air conditioning purposes. The purpose of the project is to increase the efficiency of the ammonia-water absorption refrigeration cycle reducing the need of rectification by the introduction of lithium nitrate as a third component. In the same manner, it is proposed to reduce the viscosity of the ammonia-lithium nitrate mixture by the introduction of water as a third component. The mixture with the highest amount of water without the need of rectification will be determined.

The project will cover the experimental determination and the calculation of thermophysical properties such as vapour liquid equilibrium, solubility, viscosity, density and heat capacity, necessary for the design of the main components, such as the generator and absorber. Experimental and theoretical studies will also be carried out on the heat and mass transfer processes with this mixture in absorbers and generators, based in the use of advanced heat transfer surfaces such as plate heat exchangers. Finally a mathematical model will be developed that simulates the solar driven absorption cycle with ice slurry storage, with the modelling of the cycle components.

INTRODUCTION

Ammonia is an extensively used refrigerant that has many advantages, due to its excellent thermodynamic and thermophysical properties. In absorption refrigeration systems, ammonia is traditionally absorbed in an aqueous solution. This mixture has been widely used in industrial and commercial applications, especially when evaporator temperatures lower than 0º C are required.

The main disadvantage of the ammonia-water mixture is the need for rectification to remove water from the ammonia vapour coming out from the generator, due to the

small boiling point difference between ammonia and water. A relatively large amount of energy is required to remove water from the ammonia vapour in the rectification process.

Lithium nitrate has been proposed as an alternative absorbent for ammonia as a working pair that does not require rectification. Additionally, and of most interest in solar or any low temperature heat source based absorption cooling systems, it can operate at lower generation temperatures than ammonia-water. An extensive literature has been accumulated through the years analysing its possible advantages. However this mixture does have the disadvantages such as the risk of crystallisation and especially, a very high viscosity that causes low mass and heat transfer processes in the absorber.

It is evident that there is no ideal absorbent for ammonia and all have different limitations and disadvantages.

The study presented here proposes the use of water and lithium nitrate as absorbents for ammonia in ternary mixtures, varying the concentration in order to optimise the ternary solution for a specific application.

Water or lithium nitrate are used as additives in order to reduce disadvantages of the original working pair, such as the need of rectification or the need to reduce high solution viscosity or temperature limitations.

Proposal for further studies in a research project.

1. Try to simulate in ASPEN the ternary system, confirming the advantage of 25% water. Is the advantage of no rectification worth while for such a large increase in viscosity?
2. On the basis of the result of the model, determine thermo-physical and thermodynamic properties for the mixture selected.
3. Determine the mass and heat transfer behaviour in components and systems, absorbers, generators). Try heat transfer enhancement through surfactants and enhanced heat transfer.

Justification.

Solar cooling of buildings has always been attractive as being environmentally friendly and as a conventional energy resource saver. Although many systems have been proposed there is still not an economically feasible system.
A system that can operate at below freezing evaporating temperatures to allow efficient cold storage and to operate efficiently with available solar collector technology is a goal yet to be achieved.
Ammonia based absorption systems have the potential of operating below freezing temperatures allowing ice making or cold storage. This cannot be done with the commercial units available based in water -lithium bromide solutions. The only ammonia based commercial absorption system available is the ammonia-water system that has many thermodynamic advantages, but requires a rectifier and relatively high generator temperatures.

Lithium nitrate has been proposed as an alternative absorber for ammonia with the advantage of not requiring a rectifier and lower generating temperatures. However, experimental data have shown that the considerably high viscosity of the solution reduces the heat and mass transfer processes in the absorber and therefore the efficiency is reduced.

Objectives

The objective is to obtain ammonia based absorption system for refrigeration applications operating with solar collectors on a ternary mixture that optimises operation by reducing the rectification and viscosity problems encountered in the actual proposed systems.

The present work proposes the use of water and lithium nitrate as absorbents for ammonia in ternary mixtures, varying the concentration in order to optimise the ternary solution for a specific application.

Specific objectives

To improve the performance of ammonia based absorption systems through the use of ternary mixtures using lithium nitrate and water as absorbents.

To reduce disadvantages of the ammonia based systems such as the need of rectification or the need to reduce high solution viscosity or temperature limitations.

Optimise the concentration of the mixture in order to combine the best characteristics of the binary mixtures in the ternary system

Specific objectives for ammonia/water absorption systems

To reduce or the water content of the vapour phase in ammonia water systems through the use of lithium nitrate as additive.

A simulation of the ternary absorption system using a commercial software package such as ASPEN PLUS will be is required in order to simulate the performance of the ternary system at different concentrations.

It is necessary to obtain PTX equilibrium data of the percentage of salt (5, 10, 20, and 30, % salt), needed in order to produce this effect, without creating a solution viscosity problem.

Specific objectives for ammonia lithium nitrate systems

Reduce the viscosity of the binary system through the use of water as an additive in order to reduce the viscosity of the solution, without creating a rectification need.

It is necessary to obtain data on the thermophysical properties (viscosity, specific heat, and crystallisation temperature) for the selected ternary mixture concentrations

Bokelmann proposed 25% weight percent water content, but the viscosity seems to be still very high.

The heat and mass transfer performance of the selected ternary mixture will be measured experimentally in key equipment components such as the absorber and the generator in order to optimise the design of the absorption system.

The main points were included in a three year research proposal presented at the "Convocatorias de Ayudas a Proyectos de Investigación (2005) by CREVER for funding for the year 2005.

The project: "**Mejora de las propiedades termofísicas y de los fenómenos de transporte en intercambiadores de placas mediante la adición de agua a la mezcla NH_3-$LiNO_3$ en refrigeración solar por absorción",** is included in Appendix **I.**

Simona Libotean a PhD student has already started experimental work in order to determine the liquid vapour equilibrium of the ternary mixture at an specific range of concentrations for operation at low temperature energy sources activation.

COLLABORATION IN RESEARCH PROJECTS THAT ARE CURRENTLY BEING CARRIED OUT AT CREVER.

II.1 ABSORPTION/DESORPTION PROCESSES WITH AMMONIA/WATER IN PLATE HEAT EXCHANGERS.

I participated in the projects related to the use of plate heat exchanges as desorbers and absorbers of ammonia absorption refrigeration systems. The experimental and theoretical work being carried out by CREVER researchers and students to optimise the design of these components are the basis for producing in a near future a compact and efficient ammonia/water absorption refrigeration system. During my stay data was being taken of the operation of the desorber. I participated in the analysis of the experimental data produced by the desorber and providing detailed information related to a previous work carried out in Mexico where heat transfer coefficients were measured during the desorption of ammonia in vertical tubes.

The plate absorber rig was being tested during my stay tested and some suggestions were also formulated for a better operation of the experimental set up . The absorber model produced by CREVER was also analysed and discussed. I participated in the discussion of the best way to model the bubble absorber and the calculation of gas holdup, bubble diameter in relation to the calculation of the mass and heat transfer coefficients for an efficient design.

I participated in producing a research a paper that was sent and accepted in the specialised conference on sorption research, the International Sorption Heat Pump Conference to be held in Denver Colorado in June 22-24 2005. I will attend the conference and I will present the paper "Absorption/desorption processes with ammonia/water in plate heat exchangers for chillers of small capacity and thermal activation at low temperature" on behalf of all the authors. The paper is included in Appendix II.

A series of papers with a more detailed analysis of the systems studied are being prepared to be sent to specialised journals. The collaboration and exchange of information on these research lines will continue in the following years as the Energy Research Centre will start a three-year research project on the use of compact heat exchangers for use in thermal cooling systems.

Also as part of the aforementioned research project proposal, the experimental rigs and most of its components will be used to carry out research on the heat and mass transfer processes for the proposed ternary mixture.

II.2 COGENERATION AND TRIGENERATION WITH MICROTURBINES.

A collaboration between CREVER researchers, myself and Mr Adrian Vidal, a Mexican PhD student that I supervise that carried out a short stay at CREVER. The work was related to a simulation study in order to predict the performance of a micro-turbine at high ambient temperatures, that will be found when integrating a thermally activated cooling system with the turbine.

Experimental data produced at CREVER and the components of the turbine were modelled utilising Aspen Plus. The results of this work have been the basis of a research paper in preparation: "Performance characteristics and modelling of a micro gas turbine operating at high ambient temperatures". This paper presents a modelling methodology for micro gas turbines in order to predict the system performance. In this case the model parameters were obtained using real data from the 30 kWe microturbine in the experimentañ facility at CREVER.

The model is useful for obtaining the performance of the microturbine at the high temperatures found when microturbines are integrated with thermally activated cooling technologies during the high temperature season. The manuscript prepared is almost in final form for possible publication in an international journal. It will be sent to the International Journal of Energy Research published by Wiley. A draft version is included in Appendix III.

II.3 **MODELING OF ADVANCED SOLAR OR WASTE HEAT DRIVEN ADVANCED ABSORPTION COOLING SYSTEMS**

The study of advanced absorption cooling systems such as the double stage water-lithium bromide absorption system that is being tested at CREVER is of major interest as it can operate both with solar heat from solar collectors or a conventional fossil fuel such as natural gas. As a first stage in collaboration between CREVER and CIE-UNAM a theoretical study was carried out in order to simulate the performance of this absorption system coupled to the building cooling and heating load. The possibility of operating the system with this hybrid heat source was analysed in order to satisfy the cooling and heating demand of the building was carried out.

This work will continue in order to incorporate in the simulation the use of high temperature solar collectors such as parabolic trough concentrators, for the high temperature operation of the system as an alternative to fossil fuels.

A part of the results of the study will be presented at the XXIX Semana Nacional de Energía Solar, that will be held in October 2005 in Tuxtla Gutiérrez Chiapas, Mexico. This is the annual solar energy conference organised by the Asociación Mexicana de Energía Solar (ANES). The paper, "Análisis energético de una instalación de climatización solar con una máquina de absorción de doble etapa" is included in Appendix IV.

III. LECTURES AND COURSES.

During the stay in CREVER I participated in the following lectures or courses.

1. A 2-hour lecture explaining the main content to the CREVER researchers of the proposed research project on ternary mixtures of ammonia, water and lithium nitrate.

2. A three hour lecture named "Sistemas avanzados de absorción e integración con otros sistemas energéticos, as part of course given in CREVER **"Curso de Teconologías de los componentes y equipos de absorción, February 11, 20055"**

3. A 12 hour lecture in April 2005, on Biomass as a renewable energy source was prepared and taught as part of the course **"Especialista Universitario en Energias Renovables", During April 5 to 19 2005.**

A copy of the flyers or first copies of the Power Point presentations of the courses are included in Appendix V