LOW CARBON LIVING CRC

RP1002: Concentrated Solar Thermal Systems and Absorption HVAC Systems

Authors	
Title	
ISBN	
Date	
Keywords	
Publisher	
Preferred citation	

Australian Government
Department of Industry, Innovation and Science

Business Cooperative R Centres Progr

Acknowledgements

All reports must contain the following acknowledgement phrase:

This research is funded by the CRC for Low Carbon Living Ltd supported by the Cooperative Research Centres program, an Australian Government initiative

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- originality
- methodology
- rigour
- compliance with ethical guidelines
- conclusions against results
- conformity with the principles of the Australian Code for the Responsible Conduct of Research (NHMRC 2007) and provided constructive feedback which was considered and addressed by the author(s).

Contents

Executive Summary

The project aimed to explore the feasibility of using solar thermal collectors to drive single, double, and triple effect absorption chillers. While it was originally scheduled to include experiments and a demonstration system with a commercial partner, the partner stopped trading in Australia before the project commenced. Thus, the project became much smaller, with a budget only for a PhD top-up scholarship. Despite this, a lot of new knowledge was gained through the insights of the PhD student, Ali Shirazi, who has now gone on to work a postdoctoral researcher at the Australian National University. Thus, although the project had limited commercial outputs, it did produce ~10 peer-reviewed publications.

Introduction

Solar heating and cooling (SHC) systems are currently under rapid development and deployment due to their potential to reduce fossil fuel use and to alleviate greenhouse gas emissions in the building sector–a sector which is responsible for~40% of the world energy use. The available technologies on the market for thermally driven cooling systems are absorption and adsorption chillers, solid and liquid desiccant cooling systems, and ejector refrigeration cycles. Of these, absorption chillers are considered as the most desirable method for harnessing solar thermal energy due to their relative maturity, reliability, and higher efficiency. In addition, absorption chillers can take advantage of economies of scale in large buildings to obtain a relatively good levelized cost of cooling as compared to other thermally-driven air-conditioning systems. In this project, a comprehensive literature review of the recent existing theoretical and experimental investigations on this technology was conducted.

The project found that the majority of solar absorption chillers installed and much of the research around the world is based on single-effect chillers and low-temperature solar thermal collectors, while less emphasis has been placed on the combination of high-temperature solar thermal collectors and multi-effect absorption chillers, especially triple-effect chillers.

Research studies indicate the use of gas-fired backup systems for single-effect chillers is inefficient due to its very low primary energy savings. It was also found that the storage tank and piping can be major sources of heat losses in solar absorption cooling systems. Thus, special care should be taken to ensure sufficient and appropriate insulation for all heat loss components. In regions with low direct normal incidence solar re-sources (e.g. most of Europe), solar multi-effect chillers are relatively inefficient, so single-effect chiller-based solar cooling systems are the best techno-economic choice in such regions. Conversely, multi-effect absorption chillers with high-temperature collectors are indeed promising in regions with high solar resources. However, the review shows that using currently available technology, SHC absorption chillers are not able to economically compete with conventional cooling without government subsidies and incentives. Therefore, improving the economic performance of these systems is essential. While there is clearly more that can be done on chiller and solar collector components themselves, we believe some R&D emphasis going forward should also be dedicated to the balance of the system, including optimization of the system configuration, minimizing parasitic losses, improved design and integration of thermal storage and auxiliary system, and numerous controls and operational aspects. To date, many of these topics have been largely overlooked in favor of chiller performance studies.

Project Progression

As a relatively small CRC project, one PhD student (Ali Shirazi) and two supervisors (Robert Taylor and Stephen White), these gaps in the literature will filled mainly by conducting simulations and analysis work. The project progressed as follows:

2013/14 (Project Start)

Quarter 2

Although the project scope has been down-sized to a single top-up scholarship, we have made good progress towards the modelling objectives.

Quarter 3

1. Literature review was carried out on the field of solar absorption cooling and heating systems. It was found that there is a lack of research on thermal performance of more efficient absorption chillers (double-effect and triple-effect cycles) to be integrated with concentrating solar thermal collectors, specifically in Australia.

2. Thermal simulation of a large hotel building prototype was performed for various climate zones in Australia to determine the hourly cooling and heating demands of the building.

3. A mathematical model for single-effect and double-effect absorption chillers has been developed based on the characteristic equation method and the results were validated by the chiller's performance data reported by the chiller's manufacturer.

4. A controller was designed to bring the solar thermal collector and gas burner together to logically provide the required hot water for the chiller.

5. An evacuated tube collector (manufactured by Apricus Australia Pty Ltd) was modelled in order to supply hot water for a single effect absorption chiller.

6. One configuration of a solar assisted single-effect absorption chiller is modelled in TRNSYS and the parametric study on this system is under progress which is necessary to determine the optimal size of the system.

Quarter 4

7. A detailed environmental and economic model is developed which will be applied to all the considered configurations. The environmental analysis evaluates primary energy saving and carbon dioxide emission reduction associated with the proposed solar assisted cooling and heating system. The economic model is based on the annuity method, where all cash flows connected with the solar heating and cooling plant are converted into a series of annual payments of equal amounts discounted to the present value. The levelized total cost of the system is divided into four categories: capital investment cost, operating and maintenance cost, fuel cost, and the social cost of CO2 emission which is also added to the total cost of the plant to take into account the monetary saving in the social scale. Five economic indicators obtained from this model are life cycle cost, unit cost of cooling, payback period, net present value, and internal rate of return, which will be used together with thermodynamic indicators to select the best configuration that could possibly be implemented in each Australian climate zone.

8. Different control scenarios in the solar collector loop have been studied and modelled in TRNSYS in detail. These control strategies are listed below:

- Fixed collector outlet set point temperature with a variable speed pump
- Variable collector outlet set point temperature with a variable speed pump
- Single speed pump with an on/off controller

It should be mentioned that all the models are complete and ready for parametric/sensitivity analyses.

9. In addition to parallel connection between the tank and the burner, the series configuration was also modelled to prove the fact that most of the work in literature picks series configuration as the wrong layout for the solar absorption systems using gas burner as backup system. This model is also ready for parametric study.

2014/15

Quarter 1

Initial modelling and parametric studies complete.

Quarter 2

As for the simulation results for a solar heating and cooling single-effect absorption chiller, two research papers have been prepared, which represent significant progress in Shirazi's PhD outputs. The first one is entitled "Solar-powered absorption chillers for air-conditioning applications: simulation and techno-economic evaluation", which basically investigates the techno-economic feasibility of solar-powered absorption cooling and heating systems for a large-sized hotel building in Sydney, Australia. This paper was submitted to a top conference, ASME Power & Energy 2015, to be held in the US in late June. However, due to a cut back in PRSS funding, it is not clear that travel to this conference will be possible.

The second paper is entitled "Solar-assisted absorption air-conditioning systems in buildings: control strategies and operational modes". In this paper, three control scenarios are introduced for the solar collector loop and the performance of the modeled system configurations is systematically examined under two different arrangements of the auxiliary burner and the storage tank – series and parallel. Finally, the yearly performance results from the parametric study of the different configurations are compared in order to select the most efficient configuration and control scheme. The results presented in this paper demonstrated that many papers published in the top journals employed have used an inefficient control strategy and inappropriate equipment arrangement. Therefore, the obtained results seem to be a good fit to be published as a journal paper, shedding light on the fact that control strategies can make a bit difference in the performance of solar cooling systems. This paper is almost ready for submission to "Solar Energy", which is regarded as the top journal in the field of solar technology.

Quarter 3

The two papers mentioned above have been submitted and are under review. Nothing more to report on those from Q2, but hopefully they will soon be outputs of this project. We have produced some very interesting results for the IEA Task 48, "Collection of criteria to quantify the quality and cost competitiveness for solar cooling systems", which defines under which conditions evacuated tubes, evacuated flat plates, and concentrating collectors should be used with single, double, and triple effect absorption chillers. These findings are the beginning of a design guide and a solar cooling map for absorption cooling technology in Australia and around the globe. Based on the literature review done for this project nobody has done this type of study as yet, even though it is critical to determine which climates (% direct normal irradiance vs global horizontal irradiance) respond best to which set of technology.

Quarter 4

Using real data from manufactures, a solar-assisted double- and triple-effect absorption chiller has been modeled in TRNSYS. Three types of common solar thermal collectors available on the market were selected to be coupled with these chillers. The double-effect chiller was integrated with parabolic tough, linear Fresnel, and evacuated flat plate collectors respectively, while parabolic toughs were used to supply the required heat source to drive the triple-effect chiller. A detailed parametric study was conducted to investigate the effect of key design parameters (solar collector area and storage tank volume) on the performance of each solar cooling plant. Including the solar assisted-single-effect chiller which had been molded last year, five different configurations were compared to investigate the feasibility of solar absorption chillers under different climate zones. As such, a parametric study was conducted by varying the fraction of direct normal irradiance (DNI) under several climate zones to determine which configuration results in the most efficient and cost-effective performance of the plant under a given climate. The simulation results revealed that there is no energetic or economic advantage in using solar multi-effect absorption chillers over the single-effect chiller when the DNI fraction is less than 60% of the total solar global irradiance. However, a significant decrease in the size of solar field for both double- and triple-effect chillers can be achieved in climates where the DNI fraction is above 60%. The cost analysis results indicate that a minimum DNI fraction of about 70% is required in order for solar-driven multi-effect chillers to be cost-competitive compared to single-effect chillers. In fact, although the higher COP of multi-effect chillers in relatively high DNI regions (i.e. ~60% <DNI< ~70%) results in less collector area per kW of cooling, the high capital cost of concentrating optics makes the total cost of the solar field higher.

Based on the obtained results, two papers − one conference paper and one journal paper − are being prepared. The first one is almost complete, and it will shortly be submitted to The 2015 Solar Heating and Cooling for Buildings and Industry Conference held in Istanbul, Turkey in December 2015. We are now drafting the journal paper which will hopefully be ready for submission by Mid-September.

2015/16

Quarter 1

We submitted as full-draft paper to the SHC 2015 Conference in early October. The final version of the draft journal paper mentioned in Quarter 4 (2014-21015) is now complete and will be submitted shortly.

Furthermore, we developed a detailed multi-objective optimization algorithm to determine the optimal design of the most promising technologies obtained from the parametric study under different climate zones in Australia. Genetic algorithm technique was used to optimize the system performance from energetic, economic, and environmental standpoints. In order to link TRNSYS, the simulation program used in this project, to MATLAB and vice versa, an interconnecting code was developed so that the TRNSYS simulation results can be called in MATALB environment to determine the objective functions (primary energy consumption and the annual cost of the system which are supposed to be minimized) and finally to perform the optimization process.

Quarter 2

I had my annual progress review on November 5th at UNSW, which was satisfactory according to my review panels' comments.

In late November 2015, we submitted a journal paper to Energy Conversion and Management based on the results described in Quarter 4 2014/15. After addressing the reviewers' comments, we submitted the revised version of the manuscript and are waiting for the final decision of the paper on this paper.

In early December, I presented a conference paper at Solar Heating and Cooling 2015 Conference in Istanbul, Turkey.

In addition, the optimization runs for the system configurations described in Quarter 1 2015/16 are now complete. We are post-processing the raw optimization results at the moment. Based on these results, a journal paper will be drafted, which is expected to be complete by the end of February.

Quarter 3

A detailed multi-objective optimization algorithm was developed to determine the optimal design of the most promising technologies obtained from the parametric study under different climate zones in Australia. Genetic algorithm technique was used to optimize the system performance from energetic, economic, and environmental standpoints. In order to link TRNSYS, the simulation program used in this project, to MATLAB and vice versa, an interconnecting code was developed so that the TRNSYS simulation results can be called in MATALB environment to determine the objective functions (primary energy consumption and the annual total cost of the system which are set to be minimized) and finally to perform the optimization process. Three most promising solar absorption chiller configurations were selected in order to be optimized from energetic, economic, and environmental perspectives simultaneously through genetic algorithm multi-objective optimization process. These configurations were (i) a solar-assisted single-effect chiller with an auxiliary mechanical chiller as cooling backup, (ii) a solar-assisted double-effect chiller using evacuated flat plate collectors, and (iii) a solar-assisted triple-effect chiller using parabolic trough concentrating collectors. Based on the optimization results, a journal paper was drafted, which will be submitted to Energy Conversion and Management by mid-June.

Moreover, several experimental tests were conducted on a solar cooling prototype at CSIRO, Newcastle. In this prototype, a 10 kW double-effect absorption chiller is coupled with 24 m^2 linear Fresnel micro-concentrating collectors. The initial results were not promising due to some technical issues on the chiller side and inaccuracy of the readings from temperature sensors. Through the data collected from the second set of tests, however, we characterized the performance of the collectors and gained more insights into the performance of the systems and identified some key challenges that technology may have ahead. The CSIRO technical engineers involved in this project are now trying to simulate a building load and impose it on the whole plant. If this happens soon enough, more understanding of the system under real-world conditions can be obtained. Apart from that, everything is on the right track, and the thesis will be submitted by the end of August.

Quarter 4

The goals of this project have been achieved. The optimization results were wrapped as journal paper and submitted to Energy Conversion and Management. This paper is now "under review". A conference paper based on the obtained results was also prepared and is now ready for submission to a conference which will be confirmed soon. The PhD thesis is being written up at this stage, which consists of nine chapters – the first seven chapters are complete now and the other two will be complete by the end of July. Overall, everything is on track, and the thesis was submitted for evaluation in August.

2016/17

Ali Shirazi was awarded his PhD upon completion of revisions.

Conclusions

Overall, despite the limited scope of the project, a lot of academic progress in the field was made and the training outcomes of the project were excellent. The supervisors and Ali Shirazi (now Early Career Academic at ANU) were very grateful to the CRC for continuing to sponsor this work after the industrial partner left the project.