BAHAGIAN A – Pengesahan Kerjasama*

Adalah disahkan bahawa projek penyelidikan tesis ini telah dilaksanakan melalui kerjasama antara ______________________ dengan _________________________

Disahkan oleh:

Tandatangan : .... Tarikh : ....

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Jawatan : ....

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ENHANCEMENT AND ANALYSIS OF A HYBRID LIQUID DESICCANT BASED-COOLING SYSTEM

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Mechanical Engineering)

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Universiti Teknologi Malaysia

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To the spirits of my father and mother, to my wife Ghada,
beloved sons Mohamed, Badawi, and Majdi, to my
brother Mohamed and sisters.

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ABSTRACT

Air conditioning has traditionally been achieved by vapour compression equipment, which is considered very efficient when handling loads characterised by high sensible load fraction. These machines would perform poorly when they process air with high latent load fraction as in the case of humid climates. Global energy concern has accelerated the research on alternative technology options to replace traditional method or improve their performance. Hybrid liquid desiccant system has been proposed as an energy saving alternative to reduce the vapour compression unit size used in air conditioning application, and improve its performance. A hybrid system consisting of vapour compression unit, a liquid desiccant system consisting of an absorber and a regenerator, both of which are identical packed spray towers built from fibre glass with a cross sectional area of 600 x 600 mm from five pieces each. Each piece having a height of 200 mm to facilitate testing different heights of packing material, and a flat plate solar hot water collector with an auxiliary electrical heater to be used as supplement when solar energy is not enough or not available. This hybrid system was designed, fabricated and tested with emphasis on liquid desiccant sub-system. In this study, the performance of the absorber and the regenerator, which are the main items in the liquid desiccant system, was studied in terms of effectiveness. Both units were tested over a range of different inlet liquid desiccant concentration of 20% to 40% by weight, and inlet temperature of 20^{o}C, 25^{o}C, and 30^{o}C for the absorber, and 20%, 25% and 30% liquid desiccant concentration at temperature range of 35^{o}C to 55^{o}C for the regenerator. Both components were tested at liquid desiccant flow rate between 3.76 to 5.01 ℓ/min with different air inlet flow rate 4.9 to 6.4 m^3/min. Experimental results were recorded using a complete data acquisition system to collect and log the data of the desiccant sub-system and the vapour compression unit, which enables thermocouples readings. From the data collected, the coefficient of performance of the vapour compression unit was obtained using both refrigerant enthalpy and air enthalpy methods. Absorber effectiveness was found to be between 0.5 and 0.7, while the regenerator effectiveness was found to be between 0.2 and 0.6. A 800 mm packing height is found to be the breaking limit with both air supply either fully through the desiccant or partly (50% through the desiccant), would result in an improvement in the performance of the vapour compression unit ranging from 17.9 % to 54%, which indicate the hybrid system potential for energy savings. Improving indoor air quality by controlling humidity, killing effect of bacteria and fungus by using liquid desiccant are among other benefits realised.

ABSTRAK

Penghawadinginan biasanya dilakukan oleh alat mampatan wap, yang boleh dianggap cekap apabila mengelolakan beban yang berciri pecahan beban ketara yang tinggi. Mesin ini akan berkelakuan dengan tidak memuaskan apabila memproses udara dengan pecahan beban pendam yang tinggi seperti dalam kes iklim lembab. Kebimbangan global tenaga telah mempercepatkan penyelidikan keatas opsyen teknologi alternatif untuk menggantikan kaedah tradisional atau meningkatkan prestasinya. Sistem pengering cecair hibrid yang telah dicadangkan sebagai penjimatan tenaga alternatif untuk mengurangkan saiz unit mampatan wap yang digunakan untuk penghawa dingin serta memperbaiki prestasi. Sistem hibrid mengandungi unit wap mampatan, sistem pengering cecair yang mengandungi penyerap dan penjana semula, kedua-duanya adalah menara penyembur padat yang serupa dibina daripada kaca gantian dengan luas keratan rentas 600 x 600 mm dari lima kepingan dimana setiap kepingan dengan ketinggian 200 mm untuk memudahkan ujian pada ketinggian berlainan bahan padat, dan satu pengumpul air panas suria plat rata dengan pemanas elektrik untuk digunakan sebagai tenaga tambahan sekiranya tenaga suria tidak mencukupi atau tidak ada. Sistem hibrid ini direkakan, dibina dan diuji dengan tumpuan kepada sub-sistem pengering cecair. Dalam kajian ini, prestasi penyerap dan penjana semula yang menjadi komponen utama dalam sistem pengering cecair dikaji dari segi sebutan keberkesanan. Kedua-duanya diuji pada julat kepekatan pengering cecair pada salur masuk yang berlainan dari 20% hingga 40% secara berat dan suhu salur masuk 20^{o}C, 25^{o}C dan 30^{o}C bagi penyerap dan kepekatan pengering cecair 20%, 25% dan 30% pada julat suhu dari 35^{o}C ke 55^{o}C bagi penjana semula. Kedua-dua komponen diuji pada kadar aliran pengering cecair diantara 3.76 dan 5.01 ℓ/min, dengan kadar aliran salur masuk udara dari 4.9 hingga 6.4 m^3/min. Keputusan ujikaji direkod dengan menggunakan sistem pengumpulan data yang lengkap untuk mengumpul dan menyimpan data sub-sistem pengering serta unit mampatan wap yang mencatat bacaan termogandingan. Dari data yang dikumpul, pekali prestasi unit mampatan wap telah diperolehi dengan kedua-dua kaedah entalpi penyejukan dan udara. Keberkesanan penyerap didapati antara 0.5 dan 0.7, manakala keberkesanan penjana semula didapati antara 0.2 dan 0.6. Padatan setinggi 800 mm adalah dikenalpasti sebagai had pecahan dengan kedua-dua bekalan udara samada sepenuhnya melalui pengering atau sebahagiannya (50% melalui pengering) yang akan mengakibatkan peningkatan prestasi unit mampatan wap berjulat dari 17.9% hingga 54%. Ini menandakan potensi sistem hibrid bagi penjimatan tenaga. Peningkatan kualiti udara dalaman dengan mengawal kelembapan, membunuh bakteria dan fungus dengan menggunakan pengering cecair adalah antara faedah lain yang terhasil.

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LIST OF SYMBOLS

C	-	Concentration of liquid desiccant (% by weight)
C.O.P	-	Coefficient of performance (dimensionless)
cp	-	Specific heat (kJ/kg. ^{o}k)
h	-	Enthalpy (kJ/kg)
m	-	Air mass flow rate (kg/s)
P	-	Pressure (kPa)
P_e	-	Corresponding water vapour pressure (kPa)
T	-	Temperature of dry air or refrigerant (^{o}C)
Tb	-	Wet bulb temperature of air (^{o}C)
V	-	Volumetric flow rate of air (m^3/s)
W	-	Humidity ratio (kg of water/kg of dry air)
W_e	-	Electricity consumption (kW)

Subscript

atm	-	Atmospheric
e	-	Electrical
equ	-	Equilibrium

Greek Symbol

β	-	Regenerator effectiveness (dimensionless)
ϵ	-	Absorber effectiveness (dimensionless)
ρ	-	Density (kg/m^3)

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CHAPTER 1

INTRODUCTION

1.1 Background

The 1990s and 1980s were challenging decades for the Heating, Ventilation and Air- Conditioning (HVAC) industry. The need for ever more efficient heating, cooling, ventilation and dehumidification technologies was more urgent than during the energy crisis of the 1970s. Energy resources were more depleted and the energy demands of a growing global population continued to increase with the increase in the demand for comfort cooling even in the developing countries, due to the present modernisation. Mankind are continuously endeavouring to improve their surroundings and make the working and residential environment more comfortable and healthy to the human beings. Started with the first fire set at the mouth of a cave, people have created heating systems to remain comfortable when outside conditions turn cold. However, only within the last century has mechanical cooling equipment been used to provide comfort in buildings. Comfort in buildings can be more than a luxury; a recent study by Rensselaer Polytechnic Institute suggests that comfortable working environment can lead to a 2% improvement in job performance (Bobenhausen, W. 1994). Furthermore is the reduction in absentees due to a reduction in Sick Building Syndrome (S.B.S.).

The introduction of the ASHRAE code to increase the ventilation air requirement in building so as to improve Indoor Air Quality (IAQ), "ASHRAE - Standard 62-1989 Minimum ventilation rates for acceptable indoor air quality" even makes the situation worse for conventional air conditioning equipment. Their capacities need to be increased to accommodate the newly imposed loads. However, with the increased efficiency of the vapour compression equipment the additional sensible load can be easily handled. But the additional latent load is the remaining problem bearing in mind that the ventilation air contributes about 60% of the principal source of moisture load especially in commercial buildings (Harriman, L. G. et al 1999) that adds to the latent load required to be removed.

Traditionally air conditioning has been achieved by vapour compression equipment, that are usually very efficient in handling air conditioning load which is characterised by high sensible heat ratio. These equipment performed poorly when a situation of low sensible heat ratio arises (high latent heat ratio). In this case they use the technique of lowering the dew point temperature of the process air to a degree that satisfies the latent heat load removal by condensing the water vapour out of the process air. This dew point temperature will be below the desired temperature level, then reheat or if possible mixing with the re-circulating air to bring the supply air temperature to the desired level. This process of sub-cooling followed by reheat is an energy consuming process which increase the operational costs as well as the capital cost due to the purchase of the reheat equipment.

1.2 Global Warming and Refrigerants

The development of more efficient HVAC technology is much constrained now than it was 30 years ago. In recent years, ozone layer depletion and greenhouse effect have created considerable public concern. The fully halogenated chloroflourocarbons “CFCs” which have provided much needed refrigeration and air-conditioning for about 60 years, are among the gases responsible for the depletion of ozone layer, and for creating global warming. These CFCs must be phased out by now, but in fact they are still being produced and about 65 % produced annually are being used only to replace the leaked out CFCs and the remaining 35 % are used in manufacturing new refrigerators, air-conditioners and other cooling appliances. Knowing that these CFCs have an average lifetime of 100 years in the atmosphere and today's emission will continue to affect the ozone layer for another century or so, one can realise how it is important to find other refrigerants or other methods for cooling that did reduce the use of the refrigerant while meeting the same cooling load. This leads to a considerable research for new refrigerants and the adaptation of the existing machinery to the alternative refrigerant. Also efforts have been devoted to the development of alternative methods of refrigeration and air-conditioning and one of these alternative methods is desiccant cooling.

It is unlikely that a single cooling and dehumidification technology will emerge as the perfect solution to today's CFCs /HCFCs systems in all applications. And in order to find a solution to this situation, designers, owners, and manufactures have to examine other options or systems that can solve this to eliminate or reduce the emission of these CFCs / HCFCs, independently or by integration with the conventional methods. One of the most attractive option is the desiccant based cooling system. Desiccants are materials that have strong affinity for water, they adsorb/ absorb water from the air when brought into direct contact with them, hence, the air become drier and warmer and requires to be cooled by other conventional method before being delivered into the conditioned space. The desiccant becomes saturated or diluted after adsorbing/ absorbing the moisture from the air, and needs to be regenerated by adding heat to drive-off the adsorbed/ absorbed moisture. Any integration of desiccant based cooling system with the vapour compression system will result in a hybrid system, which will benefit from the characteristics of both systems (vapour compression system is very efficient in handling the sensible load, while the desiccant system has the superiority of handling the latent load effectively) and hence, separating the load between them. This also results in high coefficient of performance of the vapour compression system, because it's evaporator will work at higher temperature, making the size of the unit to be used smaller.

1.3 Market Forces

In the late 1980s a number of market forces accelerate the demand for desiccant based cooling system equipment, these forces are:

(i) Indoor Air Quality (IAQ):

The application of new ASHRAE standard (ANSI/ASHRAE STANDARD 62-1989, Ventilation for acceptable indoor air quality) to address the IAQ problems, increased the ventilation air on average from 5 cfm per person to 15-20 cfm per person, increasing the latent load fraction that the HVAC system should handle (McGahey, K.1998).

(ii) Demand for comfort:

Controlling the humidity level has shown a great effect on some air conditioning application economics, typical applications are hotels, hospitals, clean rooms (McGahey, K.1998).

(iii) New economics of air conditioning:

The economic cost involved in some applications that require tight control of humidity accelerated the implementation of desiccant based cooling system to address the high cost in such applications, typical applications are museums, libraries, and others (McGahey, K.1998).

1.4 Problem Statement

Desiccant systems (solid and liquid) are available for around 30 years or so, but surprisingly their full potential is yet to be realised. Part of that is due to the precedence that they can only be used in special applications mainly in industrial process and industrial air conditioning which resulted in a lack of knowledge within the Heating, Ventilating, and Air Conditioning (HVAC) engineers about their potential applications in the area of residential and commercial air conditioning, especially when integrated with other technologies. Questions like the following have to be answered:

i) How can these systems be operated to achieve their optimal working conditions (with emphasis on liquid desiccant)?

ii) What are the main components of the liquid desiccant system that need special consideration to help achieve such goal?

iii) What is the benefit of using liquid desiccant in the air conditioning field and how they can be integrated with the most common technology like vapour compression equipment?

iv) What kind of improvement is expected from such proposed system?

Vapour compression units are well known for their superiority in the applications characterised with or dominated with higher sensible load fractions, and the desiccants are known for their ability to tackle humid air and they are superior in terms of dehumidification compared to the vapour compression. Based on these facts the proposed hybrid system consisting of vapour compression unit and a liquid desiccant sub-system may offer better performance and have to be proven practically, hence the research problem/hypothesis can be formulated as:

"*What a hybrid liquid desiccant cooling system would offer in terms of improvement in the performance, and what are the optimal working conditions for the liquid desiccant sub-system in order to achieve such improved performance in terms of coefficient of performance and better humidity control".*

1.5 Research Scope

The scope of this research is to study of a hybrid desiccant based cooling system. This system containing vapour compression system is integrated with a liquid desiccant system and a flat plate solar hot water collector. Development of the system and testing its performance and operational potential is undertaken to reduce the use of the conventional air conditioning methods with more emphasis on the liquid desiccant sub-system. Different liquid desiccant system arrangement and different modes of operation will be studied to find the optimal system configuration and hence to determine the available and economical method for regeneration (solar energy, waste heat reclaim) that is to be used to obtain improvement in the system coefficient of performance. Also the effect of liquid desiccant on the coefficient of performance of the vapour compression unit will be studied.

1.6 Research Objectives

The objectives of the research can be summarised in the following points:

i. To determine the effect of liquid desiccant-based cooling system on the performance of the vapour compression system when both systems are integrated together (hybrid system).

ii To determine the working condition for the absorber and the regenerator of the liquid desiccant sub-system.

iii To determine the methods and options of regeneration process (solar energy, waste heat recovery) and selecting the proper option to reduce energy consumption and hence reduce the system operating cost.

iv To determine the improvement in the coefficient of performance of the vapour compression unit when it works at higher evaporator temperature.

1.7 Thesis Outline

Chapter Two covers the literature review and work done in the field of desiccant application in the air-conditioning field. Solar cooling and solar energy usage related to the same field are also given in Chapter Two with applications in regeneration of desiccant materials with more emphasis on applications in liquid desiccant regeneration

Chapter Three gives the theoretical framework of different air-conditioning cycles and systems, mainly the vapour compression cycle and the desiccant systems, and the principles of how desiccant sub-system works when integrated with the above mentioned cycle. More theory about what desiccant materials are and how they work, their cycle, and their classifications are also explained.

Chapter Four is devoted to the methodology and system configuration and the setting of the testing facility with full description. Data logging system and its features and limitations are also given. Independent and dependent variables and all measurable values with details of how these measurements were conducted are fully explained.

Chapter Five deals with the results and calculations carried out with the discussion given. Also Absorber effectiveness and regenerator effectiveness were calculated and discussed and the benefits from using desiccant sub-system are given.

Conclusions and recommendations for future work are discussed in Chapter Six.

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