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An Investigative and Concise Review on Evaporation and Condensation Processes Using Vapour Adsorption Technique

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Abstract:
The vapour adsorption refrigeration is based on the evaporation and condensation of a refrigerant combined with adsorption or chemical reaction. The towering fossil fuel price and the responsiveness of environmental problems offer many potential applications to thermal powered adsorption cooling. However, the adsorption cooling machines still have some disadvantages that hinder their wide application. The patents surveyed are classified into four main groups: adsorption system development, adsorbent bed innovation, adsorbent/adsorbate material development and novel application of adsorption cooling system. The adsorption refrigeration is based on the evaporation and condensation of a refrigerant combined with adsorption or chemical reaction. Important targets are to reach a high efficiency through optimization measures at various components and the control system. On the other hand measures are to verify to simplify the construction with regard to a low-cost manufacturing, as well as to reach long periods with maintenance-free operation. This review paper gives a comprehensive review on the work carried out on vapour adsorption refrigeration for cryogenic applications.
Key words: Vapour Adsorption Refrigeration, Evaporation, Condensation, Cooling System, Refrigerant and cryogenic.

I. INTRODUCTION

The research work on adsorption refrigeration in Shanghai Jiao Tong University (SJTU) started in 1993, various adsorption refrigeration cycles have been investigated, such as continuous heat recovery cycle, mass recovery cycle, thermal wave cycle, convective thermal wave cycle, cascade multi effect cycle, hybrid heating and cooling cycle etc. Several prototype adsorption refrigeration systems have been developed and tested, typical examples are continuous heat regenerative adsorption ice maker using spiral plate adsorbers, adsorption heat pump using novel heat exchanger as adsorbers, solar powered adsorption ice maker, solar powered hybrid system of water heater and adsorption refrigerator, waste heat driven air conditioning system for automobiles. For first basic principle investigations a laboratory unit with silica gel/water as working material pair was built up. With this unit basic works were made to investigate the behaviours of different sorts of silica gel as well as investigations for possibilities to simplify various components and to identify useful control strategies. Based on these experiences a prototype model was constructed. With the prototype model further test series are carried out. Important targets are to reach a high efficiency through optimization measures at various components and the control system. On the other hand measures are to verify to simplify the construction with regard to a low-cost manufacturing, as well as to reach long periods with maintenance-free operation.

Two design and development companies, Tchernev and Meunier started to work on adsorption working pairs to be used in adsorption cooling systems. This was used for the cooling of vaccines in developing countries. However, because of this development the interest in this type of technology started to grew rapidly in the 1980s with many cooling system researchers worldwide working on a variety of adsorption cooling system. A company called Nishiyodo Kuchou Manufacturing Company (Japan) in 1986, designed and manufactured the first industrial adsorption cooling system. Anyanwu and Ezekwe designed and experimental studied an active carbon/methanol adsorption cooling system this system had three major components a collector adsorber, condenser and evaporator. Boelman studied the influence of thermal capacitance and heat exchanger UA-valued on the cooling capacity, power density, and COP of a silica gel-water chillier. Tanaka and Hasegawa designed and carried out an experimental study on a compact silica-gel/water adsorption cooling system which they concluded, had a good performance.

II. LITERATURE REVIEW

Research regarding solid adsorption refrigeration technology has mainly focused on five themes: studying new working pairs, proposing advanced thermodynamic cycles, establishing more accurate mathematical models, modifying generator structures, and developing refrigeration systems. In this literature review of working pairs, conventional common combinations of adsorbent/adsorbate are discussed in detail. The purpose of this section of the literature review is to identify appropriate categories of working pairs for a low grade heat driven adsorption refrigeration system. The thermodynamic cycle and the generator structure are reviewed to identify the dominant cycle mechanism and the typical generator structures which will be the physical of the mathematical model.

W.S. Chang et al [1] designed and tested an adsorption cooling system with silica gel as the adsorbent and water as the adsorbate. This was experimentally studied to reduce the manufacturing costs and simplify the construction of the adsorption cooling system.

Critoph [2] patented an adsorption cooling system comprises two adsorbent beds each with an associated thermal management system. The thermal management systems are identical and consist of a circulating supply of a control fluid which passes through the adsorbent bed, a pump, a heat exchanger and an inert bed. Heat removed from the adsorbent beds by the control fluid is supplied to the inert beds and is store to be subsequently regenerated to heat the adsorbent beds in a later half of the operating cycle of the thermal compressor.

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III. EXPERIMENTAL TECHNIQUE

Working pairs are the essential and critical element in adsorption refrigeration systems. The requirements for appropriate working pairs and status of current research into this topic were reviewed by Wang et al (2009). Two aspects were reviewed: firstly, refrigeration performance requirements: and secondly, basic natural property requirements. In regard to the former requirements, a refrigerant should have large latent heat of vaporization and little adsorption heat so that a high COP can be achieved, while an adsorbent should have significant and varied adsorption capacity that corresponds to the temperature change, in order to generate high specific cooling power. In investigation of common working pairs, numerous adsorbent/adsorbate combinations have been applied and compared. Most research has been done using activated carbon/methanol, activated carbon/ammonia, zeolite/water, silica gel/methanol, silica gel/water as working pairs [3].

The basic cycle consists of 4 processes namely Isosteric Heating, Isobaric desorption and condensation, Isosteric Cooling, Isobaric adsorption and evaporation. In the present research scenario, it has been decided to develop new and efficient methods of achieving refrigeration to combat the current dependence on electricity and harmful refrigerants like CFC’s and HCFC’s. It is intended to use waste heat from an engine or a power plant as the driving force to achieve refrigeration. The two technologies discussed are vastly different and are suitable in different situations. We are performing the preliminary tests in the Adsorption Refrigeration system and in the Thermoacoustic system we are working on achieving cooling using the loudspeaker driven system [4].

The major objective is to characterize the different adsorbent-adsorbate pairs available to determine the most suitable pair for our application. This is done by setting up the Pressure-Temperature-Concentration experiment scheduled at Cryogenic laboratory which will give us the properties of the pairs and their performance under different conditions. It will help in obtaining the variation of concentration of adsorbate adsorbed versus the adsorbent temperature for a fixed adsorbate temperature.

When designing an adsorption refrigeration system, the system of working pair is crucial since the system’s thermal performance largely depends on the adsorptive properties.

In the test, the sample will be tested to obtain five isosteric curves. The purpose of carrying out the experiment is to obtain a correlation between the Pressure-Temperature-Concentration, as these are the parameters that determine the pair’s adsorptive properties and help us predict the thermal performances for various ranges of temperatures. It is essential to plot a graph between lnP (bar) vs (-1/T), the graph gives us a fair idea about the operating pressures and temperature range for a fixed concentration, or the variation of temperature and pressure for that concentration. It helps in determining what pair to be used for a given working temperature range and the thermal performance required. In the present research, three types of working adsorbate and adsorbent, respectively, are favoured for pairing for use in adsorption refrigeration technology: ammonia, methanol and water for adsorbate and activated carbon, silica-gel and zeolite for adsorbent [5].

IV. INVESTIGATIVE SUMMARY

From this investigative and concise review, it can be comprehended that the prospect of using adsorption cooling technology is an alternative to mechanical vapour refrigeration system. The adsorption cooling system compared to the mechanical system has low maintenance and the absence of moving components is also a very important feature that makes this type of system suitable for numerous other applications such as air-conditioning and cooling food storage units [6]. The environmental benefits are also impressive, when compared to conventional compressor cooling technology. The absence of harmful or hazardous products such as CFCs, together with a substantial reduction of CO_2 emissions due to very low consumption of electricity, creates an environmentally safe technology. Low-temperature waste heat or solar energy can be converted into a chilling capacity as low as 5°C. However, the adsorption cooling technology is restricted by the poor thermal conductivity of porous media and large heat transfer.

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