Recent Patents in Absorption Cooling Systems

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Received: June 21, 2007; Accepted: August 30, 2007; Revised: September 24, 2007

Abstract: Absorption cooling offers the possibility of using heat to provide cooling. For this purpose heat from a conventional boiler can be used or waste heat and solar energy. When the latter systems are used absorption systems minimize also the adverse effects of burning fossil fuels and thus protect the environment. Absorption systems fall into two major categories, depending on the working fluids. These are the ammonia-water systems, in which ammonia is the refrigerant and lithium bromide-water systems in which water vapor is the refrigerant. This paper initially introduces the two systems and then outlines recent patents in this area. The future trends of research in this area would be on other refrigerant pairs which will be more effective.

Keywords: Absorption systems, ammonia systems, lithium bromide systems, waste heat, solar energy.

1. INTRODUCTION

Absorption is the process of attracting and holding moisture by substances called desiccants. Desiccants are sorbents, i.e., materials that have an ability to attract and hold other gases or liquids, which have a particular affinity for water. During absorption the desiccant undergoes a chemical change as it takes on moisture, as for example the table salt, which changes from a solid to a liquid as it absorbs moisture. The characteristic of the binding of desiccants to moisture, makes the desiccants very useful in chemical separation processes [1].

Absorption refrigeration systems are based on extensive development and experience in the early years of the refrigeration industry, in particular for ice production. From the beginning, its development has been linked to periods of high energy prices. Recently however, there has been a great resurgence of interest in this technology not only because of the rise in the energy prices but mainly due to the social and scientific awareness about the environmental degradation.

Absorption systems are similar to vapour-compression air conditioning systems but differ in the pressurisation stage. In general an absorbent, on the low-pressure side, absorbs an evaporating refrigerant. The most usual combinations of fluids include lithium bromide-water ($LiBr$-H_2O) where water vapour is the refrigerant and ammonia-water (NH_3-H_2O) systems where ammonia is the refrigerant.

2. BRIEF DESCRIPTION OF BASIC ABSORPTION CYCLES

Compared to an ordinary cooling cycle the basic idea of an absorption system is to avoid compression work. This is done by using a suitable working pair. The working pair consists of a refrigerant and a solution that can absorb the refrigerant. In the $LiBr$-H_2O system, water is the refrigerant. The system is shown schematically in Fig. (**1**). The pressurisation is achieved by dissolving the refrigerant in the absorbent, in the absorber section. Subsequently, the solution is pumped to a high pressure with an ordinary liquid pump. The addition of heat in the generator is used to separate the low-boiling refrigerant from the solution. In this way the refrigerant vapour is compressed without the need of large amounts of mechanical energy that the vapour-compression air conditioning systems demand.

As shown in Fig. (**1**), when the refrigerant vapour is coming from the evaporator (10) it is absorbed in a liquid (1). This liquid is pumped to higher pressure (1-2), where the refrigerant is boiled out of the solution by the addition of heat (3-7). Subsequently, the refrigerant goes to the condenser (7-8) like in an ordinary cooling cycle. Finally, the liquid with less refrigerant returns back to the absorber (6) [2]. The remainder of the system consists of a condenser, expansion valve and evaporator, which function in a similar way as in a vapour-compression air conditioning system.

The NH_3-H_2O system is more complicated than the $LiBr$-H_2O system, since it needs a rectifying column that assures that no water vapour enters the evaporator where it could freeze. The NH_3-H_2O system requires generator temperatures in the range of 125°C to 170°C with air-cooled absorber and condenser and 80°C to 120°C when water-cooling is used. These temperatures cannot be obtained with flat-plate collectors. The coefficient of performance (COP), which is defined as the ratio of the cooling effect to the heat input, is between 0.6 to 0.7.

In the $LiBr$-H_2O system water is used as a coolant in the absorber and condenser and has a higer COP than the NH_3-H_2O systems. The COP of this system is between 0.6 and 0.8 [3]. A disadvantage of the $LiBr$-H_2O systems is that their evaporator cannot operate at temperatures much below 5°C since the refrigerant is water vapour. Commercially available absorption chillers for air conditioning applications usually operate with a solution of lithium bromide in water and use steam or hot water as the heat source. In the market two types of chillers are available, the single and the double effect.

The single effect absorption chiller is mainly used for building cooling loads, where chilled water is required at 6-7°C. The COP will vary to a small extent with the heat source and the cooling water temperatures. Single effect chillers can operate with hot water temperature ranging from about 80°C to 150°C when water is pressurised [4].

The double effect absorption chiller has two stages of generation to separate the refrigerant from the absorbent. Thus the temperature of the heat source needed to drive the high-stage generator is essentially higher than that needed for the single-effect machine and is in the range of 155 to 205°C. Double effect chillers have a higher COP of about 0.9-1.2 [5]. Although double effect chillers are more efficient than the single-effect machines they are obviously more expensive to purchase. However, every individual application must be considered on its merits since the resulting savings in capital cost of the single-effect units can largely offset the extra capital cost of the double effect chiller.

The Carrier Corporation pioneered lithium-bromide absorption chiller technology in the United States, with early single-effect machines introduced around 1945. Due to the success of the product soon other companies joined the production. The absorption business thrived until 1975. Then the generally held belief that natural gas supplies were lessening, let to U.S. government

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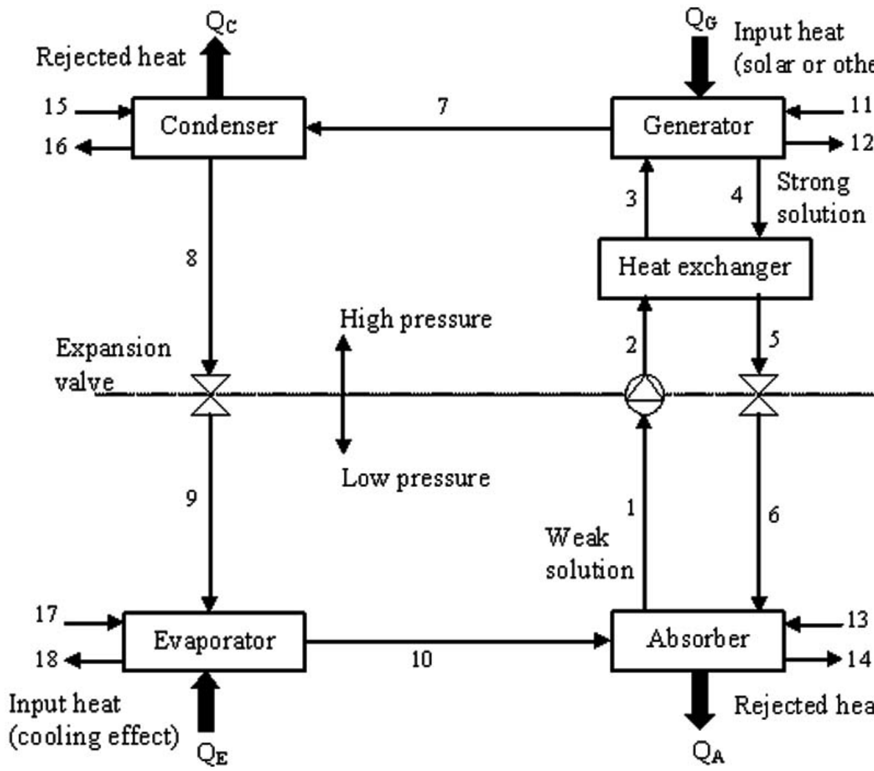

Fig. (1). Schematic of a single effect LiBr-water absorption system.

regulations prohibiting the use of gas in new constructions and together with the low cost of electricity let to the declination of the absorption refrigeration market [6]. Today the major factor on the decision on the type of system to install for a particular application is the economic trade-off between the different cooling technologies. Absorption chillers typically cost less to operate, but they cost more to purchase than vapour compression units. The payback period depends strongly on the relative cost of fuel and electricity assuming that the operating cost for the needed heat is less than the operating cost for electricity.

The technology was exported to Japan from the U.S. early in the sixties, and the Japanese manufacturers set a research and development program to improve further the absorption systems. The program led to the introduction of the direct-fired double-effect machines with improved thermal performance.

Today gas-fired absorption chillers deliver 50% of commercial space cooling load world-wide but less than 5% in the U.S., where electricity-driven vapour compression machines carry the majority of the load [6].

Many researchers have developed solar assisted absorption refrigeration systems. Most of them have been produced as experimental units and computer codes were written to simulate the systems.

A method to design, construct and evaluate the performance of a single stage lithium bromide - water absorption machine is presented in [7]. In this, the necessary heat and mass transfer relations and appropriate equations describing the properties of the working fluids are specified. Information on designing the heat exchangers of the LiBr-water absorption unit is also presented. Single-pass vertical-tube heat exchangers have been used for the absorber and for the evaporator. The solution heat exchanger was designed as a single-pass annulus heat exchanger. The condenser and the generator were designed using horizontal tube heat exchangers.

Contrary to compression refrigeration machines, which need high quality electric energy to run, ammonia-water absorption refrigeration machines use low quality thermal energy. Moreover, as the temperature of the heat source does not usually need to be so high (80-170°C), the wasted heat in many processes can be used to power absorption refrigeration machines. In addition, ammonia-water refrigeration system uses natural substances, which do not cause ozone depletion as working fluids. For all these reasons, this technology has been classified as environmentally friendly [2, 8].

The single-stage ammonia-water absorption refrigeration system cycle consists of four main components, namely, condenser, evaporator, absorber and generator, as shown in Fig. (**2**). Other auxiliary components include expansion valves, pump, rectifier and heat exchanger. Low pressure, weak solution is pumped from the absorber to the generator through the solution heat exchanger operating at high pressure. The generator separates the binary solution of water and ammonia by causing the ammonia to vaporize, and the rectifier purifies the ammonia vapor. High pressure ammonia gas is passed through the expansion valve to the evaporator as low pressure liquid ammonia. The high pressure transport fluid (water) from the generator is returned to the absorber through the solution heat exchanger and the expansion valve. The low pressure liquid ammonia in the evaporator is used to cool the space to be refrigerated. During the cooling process, the liquid ammonia vaporizes and the transport fluid (water) absorbs the vapor to form a weak ammonia solution in the absorber [1, 2].

The performance of both cycles is measured by the coefficient of performance (COP), which is defined as the heat load in the evaporator per unit of heat load in the generator and can be written as:

$$COP = \frac{Q_E}{Q_G} \quad (1)$$

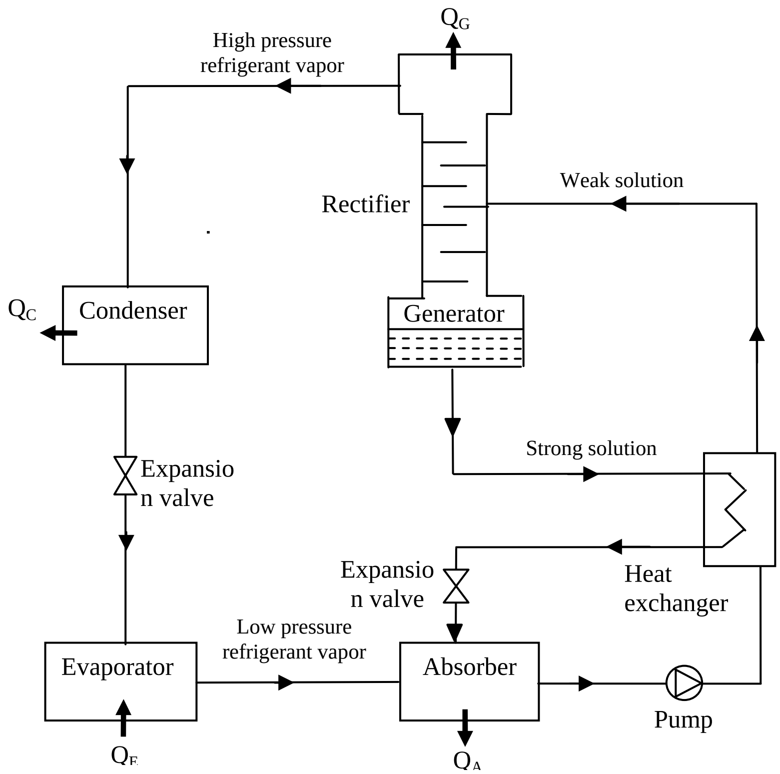

Fig. (2). Schematic of ammonia-water refrigeration system cycle.

3. RECENT PATENTS IN ABSORPTION COOLING SYSTEMS

The patents outlined below are about absorption cooling systems patented in the last three years. They are not differentiated by subject or chronological order.

The first patent [9] is about an aqua-ammonia absorption cooling and/or heating apparatus comprising an absorber assembly, a generator assembly, a condenser, an evaporator and a refrigerant loop comprising piping for directing refrigerant between the absorber assembly, generator assembly, condenser and evaporator. It includes also an absorption fluid loop for directing absorption fluid between the absorber assembly and the generator assembly. The absorption fluid loop includes one pipe for directing ammonia-rich absorption fluid from the absorber assembly to the generator assembly and a second pipe for directing ammonia-weak absorption fluid from the generator assembly to the absorber assembly. It includes also a valve assembly comprising one or more valves cooperating with the second pipe which open and close for controlling the flow rate of weak absorption fluid therein. The apparatus is characterized by a sensing device positioned for sensing a condition of the ammonia-weak absorption fluid upstream from one or more valves and operatively communicating with one or more valves for opening and/or closing the valves in response to a sensed condition. The sensed condition can be the temperature, concentration or correlated property or condition of the ammonia-weak absorption fluid for maintaining the ammonia concentration in the weak solution within the desired range.

The same patent, is published in Europe as a European patent [10]. In this patent some more details are given. The invention relates to aqua-ammonia absorption cooling and/or heating systems utilizing ammonia refrigerant and aqueous absorbents. Improvements in the efficiencies of such systems include the use of generator/absorber heat exchange (GAX) cycles utilizing rich and weak absorption working fluids and/or separate heat exchange loops referred to as GAX cycles. Weak liquor flow control as described in the patent may be used with any aqua-ammonia absorption cooling and/or heating system having an absorber assembly, a generator assembly and an absorption fluid loop for directing absorption fluid between the absorber and generator assemblies. Such systems include a condenser, an evaporator and a refrigerant loop including piping for directing refrigerant from the generator assembly to the condenser and from the condenser to the evaporator. The aqua-ammonia absorption apparatus may perform cooling and/or heating functions.

Figure **3** shows a schematic diagram of the generator assembly and a valve and temperature-sensing bulb for controlling the flow of weak solution. In the valve and temperature-sensing bulb shown in Fig. (**3**) the temperature-controlled valve (60) is used for controlling the flow of the weak solution from the generator (11) to the absorber, which is not shown. The valve is controlled by a temperature-sensing bulb (62) charged with a composition that produces pressure responsive to the temperature sensed by the bulb. The temperature-sensing bulb is installed in thermal contact with the weak solution in the generator or as it passes through piping or heat exchange coils of the generator. Changes in bulb pressure resulting from changes in the pressure of the bulb are directed to a movable member such as a diaphragm or bellows in the valve resulting in opening and closing of the valve in response to the pressure changes, or pressure differential between surfaces of the diaphragm. The valve is controlled with one side of the diaphragm exposed to the temperature-sensing bulb pressure and the other side to generator pressure. The valve components shown include inlet port (71), outlet port (72), diaphragm (73), actuator rod (74), valve plug (75), valve chamber (76) and spring (77).

The apparatus include chillers, heat pumps, refrigeration equipment, heating-only appliances, and dual-temperature appliances. The latter are a special type of heat pump that is not reversed and in which both heating and cooling are produced simultaneously for beneficial use. Such apparatus includes conventional aqua-ammonia systems as well as high-efficiency GAX apparatus.

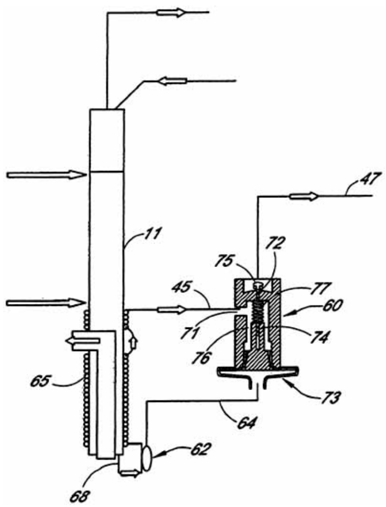

Fig. (3). Schematic diagram of the generator assembly and a valve and temperature-sensing bulb for controlling the flow of weak solution (for the complete description of the numbers see [9]).

Figure **4** shows schematically an aqua-ammonia GAX chiller system with continuous control of weak solution flow using the valve shown in Fig. (**3**). As shown in Fig. (**4**), weak solution passes from the generator assembly (11) to absorber assembly (10) via valve (60) which continuously modulates the flow rate of the weak solution for maintaining the ammonia concentration therein within desired range. The major components of the chiller system includes an absorber assembly (10) and absorber (12), and an absorber heat exchange section (30), which includes an absorber heat exchanger (31), also referred as solution cooled absorber (SCA), and a GAX heat exchanger (33). The generator assembly (11) includes a generator heat exchanger (15), a boiler (26), burner (19), an adiabatic section (16), a rectifier section (17) with reflux coil (13), a condenser (14) and an evaporator (20).

The objective of the next invention [11] is to provide an ammonia/CO_2 refrigeration system in which the ammonia cycle and CO_2 brine cycle can be combined without problems even when refrigeration load such as a refrigerating showcase, is located at any place in accordance with circumstances of customers' convenience.

The system comprises equipment working on an ammonia refrigeration cycle, a brine cooler for cooling and condensing CO_2 by utilizing the latent heat of vaporization of the ammonia, and a liquid pump in a supply line, used for supplying the cooled and liquefied CO_2 to a refrigeration load side cooler. The liquid pump is a variable-discharge pump allowing CO_2 to be circulated forcibly and the forced circulation flow is determined so that CO_2 is recovered from the outlet of the cooler of the refrigeration load side in a liquid or liquid/gas mixed state. The same system is patented in US [12].

Figure **5** show a detail of the construction of the evaporator type condenser of the ammonia refrigeration unit. As shown in Fig. (**5**), the inclined multi-tubular heat exchanger comprise a number of inclined cooling tubes (60g), which penetrate the tube supporting plates (60a) and (60b) on both sides and inclining from an inlet side header (60c) downward to an outlet side header (60d). Because of the inclination of the cooling tubes the refrigerant gas introduced from the inlet side header is cooled and condensed in the process of flowing towards the outlet side header by the air and sprinkled water. The liquid film of the refrigerant formed on the inner surface of the cooling tubes does not stagnate and moves downwards towards the outlet side header. Therefore, the refrigerant gas is condensed with high efficiency.

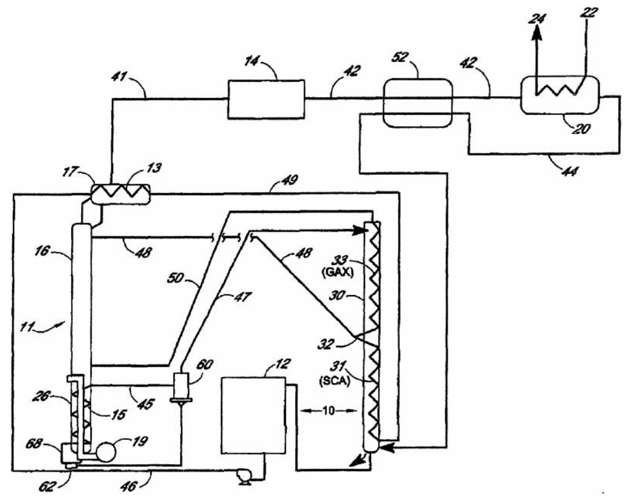

Fig. (4). Schematic diagram of the aqua-ammonia absorption cooling system incorporating the valve and temperature sensor shown in Fig. **3** (for the complete description of the numbers see [9]).

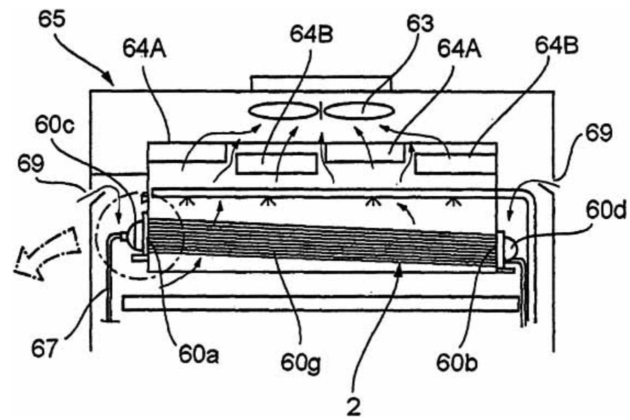

Fig. (5). Detail of the construction of the evaporator type condenser of the ammonia refrigeration unit (for the complete description of the numbers see [11]).

The problem to be solved in the third patent [13] is to further enhance efficiency, by reducing a heat radiating loss of solution, while reducing motive power of an auxiliary machine, by arranging an exhaust heat regenerator in a triple effect type absorption cooling and heating machine. This triple effect type absorption cooling and heating machine recovers and uses exhaust heat from an external part as a heating source. The exhaust heat regenerator is arranged on the side of a low temperature regenerator for increasing the concentration of an absorbing liquid by heating and evaporating a refrigerant absorbed in the absorbing liquid by heating the absorbing liquid. After operating a low temperature pump, an intermediate temperature pump and a high temperature pump for a specific time by confirming that heating combustion energy is not used in a low load operable only by the exhaust heat from the external part. The operation of the intermediate temperature pump and the high temperature pump is stopped by detecting that the absorbing liquid temperature of a high temperature regenerator outlet part or an intermediate temperature regenerator outlet temperature of a refrigerator vapor drain is set to a preset value or less and the absorbing liquid is heated and regenerated only by the exhaust heat regenerator just as a single effect cycle operation.

Another patent is about a refrigerating unit, which can be operated by means of a thermal solar system as energy source [14]. In this system, the refrigerating unit is formed as a diffusion-absorption refrigerating unit. The refrigerating unit has an expeller, a triple heat exchanger, a condenser, an evaporator, a gas heat exchanger, an absorber and a fuel reservoir which are actively connected to form a closed fuel circuit with one another. A refrigerating unit, which is formed as a diffusion-absorption refrigerating unit, consists of a closed fuel circuit having a triple heat exchanger for preheating a solution which is high in fuel and precooling a solution which is low in fuel and for rectification of a mixture of fuel and water vapor. It includes also a thermal solar system as an energy source wherein the thermal solar system is actively connected to an expeller formed as a gas bubble pump for the desorption and vaporization of a fuel contained in a solution. Ammonia (NH_3) vapor with low percentages of H_2O is thus conveyed from the expeller to the triple heat exchanger, from which NH_3 vapor flows into the condenser and is cooled to liquid NH_3 where the liquid NH_3 subsequently flows into the evaporator in which NH_3 diffuses into a precooled helium (He) atmosphere forming a "heavy" cold He-NH_3 gas mixture. This cold gas mixture flows into the gas heat exchanger in which it is heated due to a heat transfer from a warm He stream flowing in the opposite direction through the gas heat exchanger and subsequently flows from the absorber. The solution which is high in NH_3/H_2O flows away from the absorber to the triple heat exchanger and from there to the expeller. The solution which is low in NH_3/H_2O flows on the contrary to the triple heat exchanger and from there to the absorber. Furthermore, the withdrawal of cooling capacity of the refrigerating unit is done by means of the refrigerating medium circuit, which is actively connected to the evaporator.

The next invention relates to an absorption cycle, which includes a refrigerant pair comprising at least one refrigerant and at least one ionic liquid [15]. This invention also provides an absorption cycle that utilizes fluorocarbon gases in fluorinated ionic liquids. The invention provides also a method of cooling and heating using an absorption cycle which includes a refrigerant pair comprising at least one refrigerant and at least one ionic liquid. This invention relates to the discovery that refrigerants are soluble in ionic liquids and provides refrigerant pairs comprising refrigerants and ionic liquids, wherein the refrigerant exhibits good solubility and diffusivity in the ionic liquid. The refrigerant/ionic liquid pairs are useful in absorption cooling and heating systems. The invention describes also the operation of absorption cycles and the process for cooling or heating utilizing refrigerant/ionic liquid pairs. As a new type of solvent with immeasurable vapor pressure, room-temperature ionic liquids are used herein for absorption cooling or heating. In the present invention, the solubility and diffusivity of fluorinated refrigerants, and other gases such as carbon dioxide, ammonia and non-fluorinated hydrocarbons, in various ionic liquids, determined for example using a gravimetric microbalance, indicates their usefulness for absorption cooling or heating.

The invention provides also the refrigerant pair compositions for use in absorption refrigeration cycles. Although referred to as absorption refrigeration cycles, absorption cycles can be used for cooling, or for generating heat, depending on the application. One member of the refrigerant pair comprises at least one refrigerant selected from the group consisting of hydrofluorocarbon, hydrochlorofluorocarbon, chlorofluorocarbon, fluorocarbon, nitrogen (N_2), oxygen (O_2), carbon dioxide (CO_2), ammonia (NH_3), argon (Ar), hydrogen (H_2), water (H_2O), and non-fluorinated hydrocarbon, wherein the non-fluorinated hydrocarbon is selected from the group consisting of C_1 to C_4 straight-chain, branched or cyclic alkanes and C_1 to C_4 straight-chain, branched or cyclic alkenes. The second member of the refrigerant pair comprises at least one ionic liquid, which is used as an absorbent.

Non-fluorinated hydrocarbon refrigerants include methane, ethane, ethylene, propane, cyclopropane, propylene, butane, and isobutane. Mixtures of refrigerants are also useful for achieving proper boiling temperature or pressure appropriate for absorption equipment. In particular, mixtures which form azeotropes or constant boiling mixtures are preferred because minimal to no fractionation of the mixture will occur if the refrigerant leaks from the absorption cooling system. Azeotropic or constant boiling compositions of difluoromethane (HFC-32), pentafluoroethane (HFC-125), and 1,1,1,2-tetrafluoroethane (HFC-134a) suitable for use as refrigerants are described.

The ionic liquid used can in principle be any ionic liquid that absorbs the refrigerant gas, however ionic liquids that have minimal absorption of the refrigerant gas will be less effective as absorption cycle working fluids. Ideally, high absorption and diffusivity are desired to achieve a high-energy efficiency cycle. Ionic liquids may be synthesized, or obtained commercially from several companies. A cation or anion of an ionic liquid can be in principle any cation or anion such that the cation and anion together form an organic salt that is liquid at or below about 100°C. The same invention is patented in both the World Intellectual Property Organization [16] and the US [17].

Another invention relates to a refrigeration or air-conditioning apparatus which utilizes a vapor compression refrigeration system having a refrigerant circulating [18]. The unit comprises a compressor powered by an engine exhaust gas driven turbine. A mini centrifugal compressor may advantageously be used with such a system, thus allowing the use of low global warming potential refrigerants. The present invention further relates to methods for powering a compressor, such as a mini-centrifugal compressor, in a refrigeration or air-conditioning apparatus and methods for controlling compressor surge, impeller speed and cooling capacity. An alternative variation of the present invention involves the use of an exhaust gas driven turbine as an alternative to using merely the exhaust heat from the internal combustion engine to provide heat to a building, or drive an absorption cooling system. The present invention is particularly useful in remote locations where access to electrical power is limited, if available at all. Mobile refrigeration apparatus or mobile air-conditioning apparatus refers to any refrigeration or air-conditioning apparatus incorporated into a mobile transportation unit for the road, rail, sea or air.

The next patent is about an apparatus for conditioning air in a space [19]. The apparatus includes a cooling system for cooling and thereby dehumidifying received air to form supply air. A heat recovery system is then used to recover waste heat from the cooling system and heat a fluid, which is in turn used for heating air supplied to the space. A heat storage system is also provided for storing heat from the heated fluid.

This system can be applied in a number of cases. In one example described, an absorption chiller is used. In particular, the absorption chiller includes an evaporator having an inlet and an outlet. The evaporator is coupled to an absorber, via a pipe, which is in turn connected to a generator with pipes. A pipe receives heat from an appropriate heat source and transfers it to the generator. The generator is connected to a condenser via another pipe. The condenser typically generates waste heat and is also coupled to the evaporator via another pipe.

The system utilises a solution formed from a combination of a refrigerant and an absorber in order to provide heat transfer mechanisms. Typically the solution is either a water/lithium bromide or an ammonia/water combination as will be appreciated by a person skilled in the art. During operation, the evaporator operates to receive liquid refrigerant from the condenser. The refrigerant is provided into a low-pressure environment within the evaporator and by evaporation, extracts heat from fluid supplied, via an appropriate heat exchanger. The chilled fluid is then output, whilst the evaporated refrigerant is transferred to the absorber, where it is absorbed by a refrigerant- depleted solution.

The solution is transferred via a pipe to the generator, which operates to heat the solution, thereby causing the refrigerant to be evaporated. The remaining refrigerant-depleted solution returns to the absorber, whilst the vaporised refrigerant is transferred to the condenser. The vaporised refrigerant is allowed to condense with waste heat before being transferred to the evaporator, thereby allowing the cycle to be repeated.

Accordingly, the above described absorption chiller utilises heat provided generally to allow fluid, such as air, supplied to be chilled.

A method of operating a multi-effect cooling system using heat generated from an engine having an exhaust and a cooling system is described in the next patent [20]. The multi-effect cooling system includes a primary and a secondary desorber. The primary desorber is heated using heat from the exhaust system. The secondary desorber is heated using heat from the cooling system.

As seen in section 2, an absorption cooling system provides a method of cooling using a primary heat source as a primary energy source. Absorption systems function in a similar manner to vapor compression systems. However, instead of using a compressor to compress refrigerant and supply the refrigerant to a condenser, absorption systems use a solution circuit. The solution circuit consists of an absorber and a generator (also known as a desorber) supplied with an absorbent. The absorbent absorbs the refrigerant in the absorber and desorbs the refrigerant in the generator, thus bringing the refrigerant from a low pressure, low temperature state to a high pressure, high temperature state. The generator then supplies the refrigerant to a condenser.

As an example, a method of operating a multi-effect cooling system uses the heat generated from an engine having an exhaust system and cooling system. In adsorption type multi-effect cooling systems, the primary desorber is one of at least two primary adsorber chambers that desorbs refrigerant from an adsorbent while the secondary desorber is one of at least two secondary adsorber chambers that desorbs refrigerant from an adsorbent. The refrigerant may be water while the adsorbent may be silica gel. Reference is also made to heat generated by an engine having an exhaust system and a cooling system. The heat generated by the engine may be defined as any heat produced as a result of fuel combustion by the engine. The engine may be any liquid cooled combustion engine that produces heat. The exhaust system may be defined as a system of pipes or conduits that carry waste gases and heat from the combustion engine to a predetermined location, usually outside of a compartment housing the engine. The cooling system maybe defined as a system of pipes or conduits that carry a liquid from the engine to a radiator, which cools the liquid and returns it to the engine, in order to reduce the engine's temperature. Regarding the engine, reference is also made to a vehicle having the engine. The vehicle may be defined as any mobile apparatus including an engine as defined above. For example, the vehicle may be a boat, airplane, truck, car, train, or any other mobile device having an engine that generates heat.

According to an example of the invention given, a multi-effect cooling system operates to cool an area. The area may include an insulated room or container for holding items (food and medicine are examples) at a predetermined temperature. The area may also include a room or container for holding heat producing devices such as electrical equipment. Additionally, the area may include a room or compartment occupied by humans or animals. For example, the area maybe the interior of a passenger car, a cabin on an airplane or a room located within a cruise ship.

Microchannel or fractal plate desorption retains the advantage of high-flux, thin-film desorption without using membranes and allows for lightweight, compact desorbers for either LiBr and water or ammonia and water [21]. Specific equipment of the process provide a droplet desorber, feeding a multi-component fluid mixture comprising at least a first fluid and a second fluid to the desorber, and performing a desorption process on the mixture using the desorber. The primary fluid mixtures used are ammonia and water, and aqueous lithium bromide. Various working embodiments of desorbers are disclosed, including several desorbers comprising a number of substantially straight, substantially parallel microchannels in an array, and a fractal plate desorber, such as a bifurcating fractal plate. The method also comprises ways of separating a first fluid from a second fluid using a separation process, such as gravity separation, wicking separation, electro hydrodynamic separation, centrifugal separation, cyclone separation, and combinations of these.

Disclosed parts of the system useful for performing the desorption process include a desorber, a manifold positioned to deliver a mixture of fluids to the desorber (the mixture comprising a refrigerant), a heater (including thin film deposited heaters, operatively associated with the desorber) and a separator downstream of the desorber for separating a refrigerant vapor from a liquid fraction remaining from the mixture following vaporization of the refrigerant. Such systems typically include also an expansion valve through which the refrigerant flows, where the pressure is reduced and the refrigerant boils at a low temperature and may include additional optional devices useful for practicing the desorption process, such as pumps and fluid collectors [21].

The key to applying microtechnology-based absorption cooling to civilian applications is the development of a compact desorption scheme that does not depend on membranes for the formation of thin films. Some of the equipment described in the patent concern microchannel or fractal plate desorption followed by a separations process using, for example, gravity or electro hydrodynamic (EHD) separation techniques. Microchannel or fractal plate desorption reduces the diffusion lengths for heat and mass transfer to the width of the channel (10 to 100 microns), which provides performance that is comparable to a membrane-constrained, thin-film desorber having a film thickness on the order of 100 microns.

Microchannel and fractal desorption enables the deployment of small, heat-actuated absorption heat pumps for distributed space heating and cooling applications, heat-actuated automotive air conditioning, and man-portable absorption cooling units. Absorption heat pumps using water or ammonia as the refrigerant will not contribute to ozone depletion or green house gas loading.

Two excellent variations of a desorber, a substantially straight and parallel microchannel desorber and a disk-shaped fractal channel desorber, are discussed in further detail in the patent.

In mechanically-constrained ultra-thin-film desorbers, the membrane serves two functions. First, it forces the film to be extremely thin. Second, it separates the vapor refrigerant from the liquid solution. The need for the membrane can be eliminated by separating these processes. A desorption mechanism for LiBr- H_2O solution based on evaporation of the volatile phase (H_2O) in microchannels has been evaluated [21].

A cooling or heating device in an absorption heat pump of GAX type, including a generator, a GAX heat exchanger, an absorber, a condenser, an evaporator, a pump connected to the absorber and generator, and a first circuit for refrigerant solution circulating through the device and connecting together at least the generator, GAX heat exchanger, absorber, condenser, evaporator and pump is presented in [22].

Known devices comprise a valve for inverting the absorption cycle at the evaporator and condenser, so that those heat exchangers which during operation in heating mode act as the condenser and evaporator are arranged to act respectively as the evaporator and condenser during operation in cooling mode. These devices comprise at least two distinct and separate hydraulic circuits for dispersing the heat generated in the absorber, which function as an evaporator during operation in cooling mode and as condenser during operation in heating mode. The presence of these two distinct hydraulic circuits for dispersing the heat considerably complicates the control and design both of the overall device and of the plant to which this device is connected.

Moreover in known devices, the circuit through which the refrigerant solution passes and which connects together the various components of the device requires relatively complicated and costly valve and control means to ensure reliable passage of the device from one operating mode to the other. For example, difficulties can arise because of the possible accumulation of solution and/or refrigerant within those circuit sections which are not in use, leading to uncertainties in the solution and refrigerant level within the circuit, to cause operating instability and substantial variations in efficiency.

Therefore, the objective of the present invention is to provide an absorption cooling and/or heating device of GAX type which is more compact and of easier operation and handling than traditional devices. A further objective is to provide a simplified device which will enable the hydraulic exchange circuit for the thermal energy generated or provided within the absorber and in the evaporator/ condenser. An additional objective is to provide a device which enables the valve and control equipment present in the circuit for passage of the refrigerant solution to be simplified.

A valve device modifies the first circuit to vary the manner in which the absorber, condenser and evaporator are connected together. The first and second heat exchanger units enable at least one phase of the circulating solution to be changed and enable thermal energy to be exchanged against an external fluid. The first and second heat exchanger units include at least two mutually separate sub-heat exchangers configured to function either as an evaporator or as an absorber and condenser, depending on an operating mode of the device [22].

An over-concentration control system for use with an absorption machine of the type having either a single, double and triple effect cooling and heating cycle, which uses lithium bromide in solution with water as the operating liquid is described in [23]. The operating liquid being characterized by a concentration indicative of the quantity of lithium bromide dissolved in water, and by a phase diagram having a crystallization boundary that defines the combinations of concentration and temperature which correspond to a condition of saturation in the solution. A sensor is provided at a predetermined location within the system which is responsive to the depth of the solution for generating a concentration signal indicative of the concentration of the liquid. A temperature sensor is also provided for generating a temperature signal indicative of the temperature of the liquid.

Further means are provided which are responsive to the temperature signal and the concentration signal for calculating a representation of the absorption cycle of the machine which may be plotted on a phase diagram for the lithium bromide system. The representation includes a number of critical state points which are defined by predetermined respective combinations of concentration and temperature. Means are also provided for comparing the actual concentration and temperature of the liquid to concentrations and temperatures which lie on the crystallization boundary for lithium bromide for generating a difference signal. Control equipment are provided which are responsive to the magnitude of the difference signal for changing the operating state of the machine as necessary to prevent the liquid from reaching a combination of concentration and temperature that lie on the crystallization boundary [23].

4. CURRENT & FUTURE DEVELOPMENTS

It is obvious from the introductory part of this paper, that the basic absorption refrigeration systems can be based either on lithium bromide-water (LiBr-H_2O) where water vapour is the refrigerant and ammonia-water (NH_3-H_2O) systems where ammonia is the refrigerant. The future trends of research in this area would be on other refrigerant pairs which will be more effective as these could extend the solubility range of the LiBr aqueous solutions for the development of air-cooled absorption chillers. Some work is already performed in this area and some examples are given in the presented patents. Two such examples is the use of carbon dioxide and of ionic liquids as shown in few of the patents presented. Other material combinations include lithium chloride - water (LiCl - H_2O) and lithium bromide + lithium nitrate + lithium iodide + lithium chloride - water (LiBr + $LiNO_3$ + LiI + LiCl - H_2O) solutions. All these pairs can be used in absorption heat pump systems and their main advantage is that they do not cause ozone depletion.

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