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Research on Absorption Refrigerators and Heat Pumps

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ABSTRACT

The paper provides literature review on absorption refrigerators and heat pumps. Basic background on single-effect absorption systems, double-effect absorption systems, absorption heat transformer are discussed. The paper also provides discussion on advanced systems and working fluids. If is hoped that this contribution will stimulate wider inferestin the technology of absorption refrigeration.

1. INTRODUCTION

The aim of this paper is to provide the basic background and review the existing literatures on absorption refrigerators and heat pumps. A number of absorption cycles and working fluid options are provided and discussed.

Development of an absorption refrigeration cycle was motivated by experiments with solutions. In the 1700's it was known that ice could be made by the evaporation of pure water from a vessel contained within an evacuated container in the presence of sulphuric acid, [Herold & Radermacher 1989]. This process was improved in the 1800's, but the use of sulphuric acid and water has two inherent design problems; these are corrosion and leakage of air into the vacuum vessels. A water/ammonia machine was introduced in 1859 by Ferdinand Carré, who took out a US patent in 1860. Machines based on this patent were used to make ice and store food. As the absorbent used (water) is volatile, the system requires a rectifier to strip away the water normally evaporated with the ammonia. To overcome this problem, a system using an aqueous lithium bromide solution was introduced in the 1950's for industrial applications.

The performance of a refrigeration cycle can be characterised in terms of the Coefficient of Performance (COP), defined as the ratio of the cooling capacity to the total energy input to the system. The Coefficient of Performance of a vapour-compression refrigerator (work operated cycle) is normally greater than that of an absorption refrigerator. However, the former requires mechanical work which, if delivered in the form of electrical energy, is more expensive to produce than heat energy used by the heat driven systems. It is interesting to note that a vapour-compression refrigerator that has a COP of 2.5 has an equivalent COP in terms of primary energy input of 0.88, if the compressor is driven by a prime mover with thermal efficiency of 35%, whereas double-effect absorption refrigerators typically have equivalent COP values ranging from 0.9 to 1.2. Thus, a heat operated refrigerator system may be able to provide significant primary energy saving. Moreover, an absorption refrigerator typically operates with relatively low quality heat sources (at 250°C or less). Therefore they can be powered using heat that is rejected or wasted by many industrial processes. Thus the waste heat energy can be converted to useful refrigeration. The use of waste heat can, therefore, cut global CO_2 emissions and reduce the global warming problem.

Another difference between vapour compression systems and absorption systems is the working fluid they use. To date most vapour-compression cycles commonly use chlorofluorocarbon refrigerants (CFCs), because of their thermophysical properties. Other fluids may perform better in heat operated cycles. It is through the restricted use of CFCs, due to depletion of the ozone layer, that will make heat operated cycles more prominent However, even though heat operated refrigerators seem to provide many advantages, the vapour-compression system still dominates all market sectors.

2. SINGLE-EFFECT ABSORPTION REFRIGERATORS

Figure. 1 shows a schematic diagram of a single effect absorption refrigeration cycle. Refrigerant vapour flows from the evaporator to the absorber where it is taken into solution by the absorbent A flow of refrigerant vapour is maintained by a boiling process within the evaporator, thus creating the necessary refrigeration effect. The absorption process is usually exothermic and. therefore, the absorber requires constant cooling to maintain its temperature. As the refrigerant enters the solution with the absorbent, the ability of the latter to absorb decreases. To maintain the strength of the absorbent. a quantity of the solution is continuously pumped, at a high pressure, to the generator where it is heated causing the refrigerant to be driven out of solution, thus drying the absorbent which is then returned to the absorber via a pressure regulator valve. The high pressure refrigerant vapour flows from the generator to the condenser where it is liquefied and returned, via an expansion valve, to the evaporator, thus completing the cycle. A solution heat exchanger may be added to preheat the solution leaving the absorber using the hot solution returning from the generator. Thus the generator input and

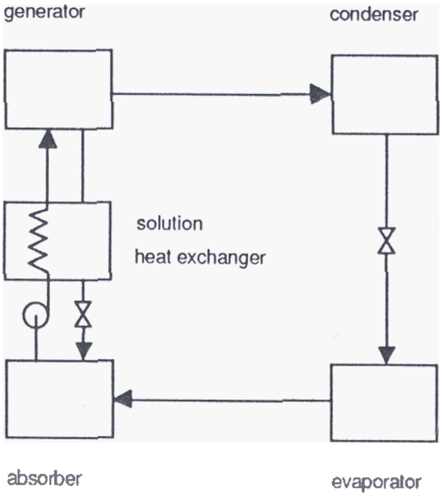


Fig. 1. A single-effest absorption refrigeration cycle.

the absorber output are reduced and system COP is improved. Similar to an ejector refrigerator, work input required by the solution pump is negligible relative to the energy input at the generator and, therefore, pump work is often neglected for the purposes of analysis. The Coefficient of Performance, for the refrigeration cycle, is equal to the ratio of the heat absorbed at the evaporator to the heat input at the generator, therefore:

$$COP = \frac{Q_{evap}}{Q_{gen}}$$

. Various researchers have studied thermodynamic performance of single-effect absorption systems using various kinds of working fluids. The most common working fluids are lithium bromide/ water ($LiBr/H_2O$) and water/ammonia (H_2O/NH_3) where the components are given as absorbent/ refrigerant. Studies of systems using LiBr/water are provided theoretically [ASHRAE 1985, Kouremenos & Rogdakis 1988 and leng et al, 19891 and experimentally [Eisa et al. 1985, Landauro-Paredes 1982 and Eisa & Holland 1986]. For water/NH_3 systems, papers are provided theoretically [Kaushik & Bhardwaj 1982, Cerepnalkovski 19911 and experimentally [Butz & Stephan 1989, Best & Hernandez 1991].

Fluorocarbon refrigerants combined with organic solvents have been studied. Among these, R22 and R21 have been widely suggested because of their favourable solubility with a number of organic solvents. The most suitable solvents reported are Dimethyl Ether of Tetraethylene Glycol (DMETEG) and Dimethyl Formamide (DMF). A comparative thermodynamic analysis of single-effect absorption cycles using R22 or R21 with DMETEG or DMF was provided by Dan & Murthy [1989] who suggest that DMETEG/R21 stood out as the most suitable combination. Computer simulations of absorption cycles using various kinds of working fluids are available; LiBr/water, water/NH_3, LiBr/water-NH_3, LiBr-$ZnBr_2/CH_3OH$ and $LiNO_3$-KNO_3-$NaNO_3$/water [Grossman & Gommed 1987], LiBr-$ZnBr_2/CH_3OH$ [Iedema 1984], Glycerol/water [Bennani et al. 1989], LiCl/water [Grover et al. 1988], $NH_3/LiNO_3$ [Best et al. 19911, E181/R22 [Yaron et al. 1983, Jelinek et al. 1984].

3. DOUBLE EFFECT ABSORPTION REFRIGERATORS

Performance of a single-effect absorption cycle can be further improved by accommodating a second generator. as in the case of a double-effect absorption cycle. The earliest double-effect absorption unit appears to have been developed between 1956 and 1958, [Vliet et al. 1982]. Figure 2 shows that vapour refrigerant generated by the first-effect generator is condensed at high pressure in the second-effect generator. The heat rejected is used to produce additional refrigerant vapour from the solution coming from the fmt-effect generator. Kaushik & Chandra [19851 showed that if all the refrigerant vapour from the fmt-effect generator was condensed in the second-effect generator, the COP for the system should be twice that of the corresponding single effect cycles. Theoretical studies of a double-effect absorption system have been provided for various working fluid LiBr/water [Kaushik & Chandra 1985], LiBr-$ZnBr_2/CH_3OH$ [Kaushik et al. 1987], LiCl/water [Won & Lee 19911. Higher-effect cycles with greater performance potential are also possible. However. the complexity of their designs combined with diminishing returns on performance with each additional effect have made double effect cycles the practical limit thus far. However, recent research on triple-effect cycles shows promise, [Herold & Radermacher 19891.

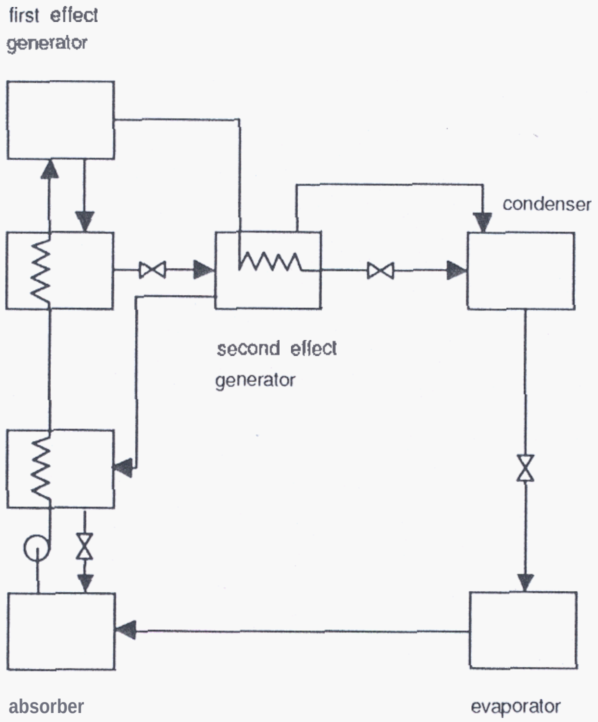


Fig. 2. A double-effect absorption refrigeration cycle.

4. ABSORPTION HEAT TRANSFORMERS

An absorption heat transformer is sometimes known as an absorption temperature booster or a reverse absorption heat pump. This cycle includes the same components as a single-effect absorption cycle, except that the expansion valve between the condenser and evaporator is replaced by a pump. Figure 3 shows a schematic diagram of the cycle, an amount of waste heat at relatively low temperature is added at the generator to separate the refrigerant from the solution in the usual way. The refrigerant vapour is liquefied at the condenser and then pumped to a high pressure prior to enter the evaporator, where it is vaporised by means of the same low temperature waste heat used to drive the generator (absorption heat transformers are usually operated so that the generator and evaporator temperatures are equal). The vapour refrigerant is then absorbed in the absorber, where high temperature heat is rejected to the cooling medium. Absorption heat transformers have the capability of raising the temperature of fluid above that of the source of waste heat. The temperature boost obtained with absorption heat transformers depends on the temperature of the low grade heat source as well as that of the heat sink. For a single-stage cycle, the dimensionless temperature boost (TB), defined below, is limited at 1 and the COP is limited at 0.5, [Grossman 19851.

$$TB = \frac{T_{abs} - T_{gen,\,evap}}{T_{gen,\,evap} - T_{con}}$$

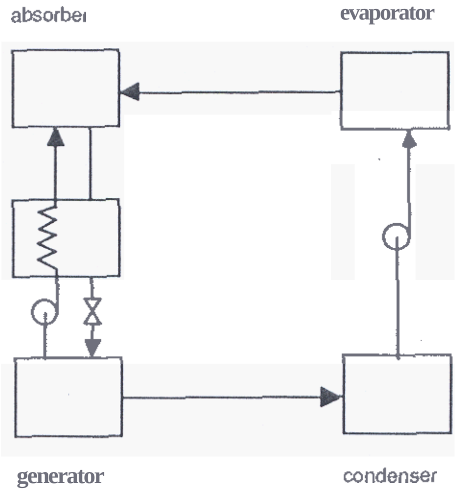


Fig. 3. An absorption heat transformer.

$$COP = \frac{Q_{abs}}{Q_{gen} + Q_{evap}}$$

Two-stage absorption heat transformers can be divided into two groups: systems designed for a greater COP but lower TB (TB≤ 0.5, COP≤ 2/3) and systems designed for greater TB but lower COP (TB≤ 2.0, COP ≤1/3). The thermodynamic performance of absorption heat transformers with various kinds of working fluids have been studied theoretically, e.g., LiBr/water [Grossman & Perez-Blanco 1987, Grossman & Childs 1983, Pereira-Duarte & Bugarel 1989, Siddig-Mohammed 1982], DMETEG/R21 & DMF/R21 [George & Murthy 1989a,b,c], $LiBr-ZnBr_2/CH_3OH$ [Antonopoulos & Rogdakis 19921. Various kinds of low grade heat can be upgraded using absorption heat transformers, e.g., solar pond [Grossman 1991, Antonopoulos & Rogdakis 19921, solar collector [Kiatsiriroat et al. 1986], industrial waste heat [Ikeuchi 1985, Nakanishi et al. 1981].

5. ALTERNATIVE ABSORPTION REFRIGERATORS AND HEAT PUMPS

A periodically operating absorption heat pump (PAWP) designed and built for space-heating applications is shown in Fig. 4, [Knoche & Grabenhenrich 1984, Seitz et al. 1990]. The working fluid in this case was a ternary mixture of $LiBr/water-CH_3OH$. The system was designed to recover heat from the ambient air and powered by a 10 kW gas burner. There was no mechanical pump in this cycle, making it more reliable and potentially less expensive than a continuously operating device. Although the cycle is operated periodically, heat is supplied continuously and alternately in each mode of operation by the condenser, the absorber and flue gas. The cycle operates in three different modes. In the boiler mode. valve 1 and 2 are closed, the burner is on, the solution is circulated between the generator and the absorber by a bubble pump action. The refrigerant vapour from the generator is passed to the condenser. The heat output is obtained at the condenser and the flue gas economiser. In the generator mode, after sufficient liquid refrigerant has been condensed in the condenser, valve 1 is open and liquid refrigerant transfers to the evaporator and as the boiler mode, the heat output is

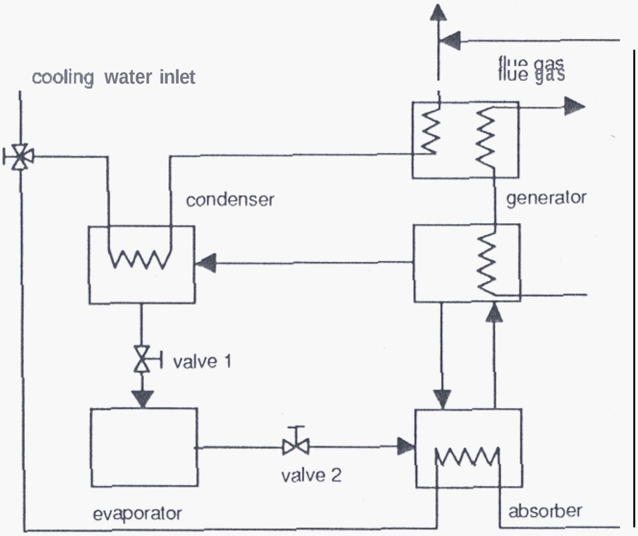
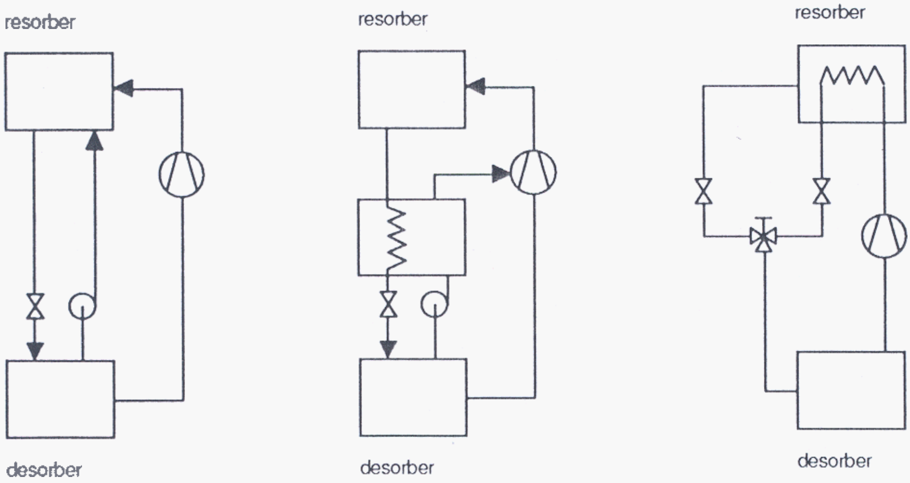


Fig. **4. A** periodically **operating** absorption heat pump **(PAWP).**

obtained at the condenser and flue gas economiser. In the absorption mode, after the liquid refrigerant has completely transferred from the condenser to the evaporator, valve 1 is closed, valve 2 is opened and the burner is turned off. Liquid refrigerant in the evaporator boils, absorbing heat from the environment. The resulting vapour is transferred to the absorber producing a heating effect and temperature lift. Relatively low COP values were obtained. For heat pump operation, values of around 1.2 (including all losses) were claimed when the cycle was operated with an ambient temperature of 0°C to produce hot water at between 30 and 60°C.

A combination of vapour-compression and absorption cycles can be achieved in a number of ways, [Morawetz 1989]. This system is usually known as the sorption-compression system. Figure 5-A shows a schematic diagram of a typical combined sorption-compression cycle. The performance is expected to be better than that of the conventional vapour-compression cycle. The heat pump cycle shown in Fig. 5-B was developed in the Netherlands [Machielsen 1990]. Coefficient of Performance values for heat pump operation of 4.3 were claimed with *25°C* heat source and *55°C* heat sink. Water/NH_3 was used as a working fluid in the experimental stage. A screw compressor capable of pumping liquid phase simultaneously with the vapour was designed and tested. The cycle shown in Fig. 5-C was designed as a vapour-compression heat pump combined with a chemical heat storage device, [Wilson et al. 1984]. The working fluid used is Water/NH_3. Ammonia used in the absorption cycle is also suitable for use with reciprocating compressor and, therefore, can be used in the vapour-compression side of the cycle. The system was devised so that the compressor is operated only when off-peak electricity is available. The heat rejected during the condensing process of the high pressure refrigerant is used to separate vapour refrigerant from the solution in the resorber. During the following day, liquid refrigerant in the desorber boils. absorbing heat from the environment The resulting vapour is transferred to the resorber producing a heating effect and temperature lift. Even though these sorption-compression systems seem to provide very high COP, the system required work operated-mechanical compressor and can no longer be operated with low grade heat energy.



5-A 5-B 5-C

Fig. 5. Combined vapour compression-absorption heat pumps.

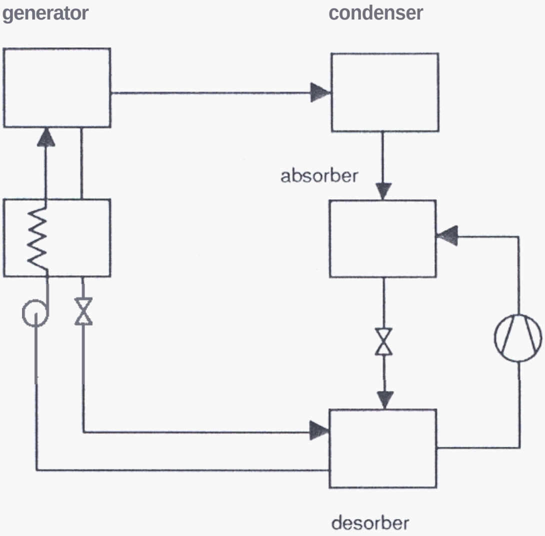


Fig. 6. *An* absorption heat pump by Cacciola

Cacciola et al. [1990] analysed the absorption heat pump using two combinations of working fluids, water/NH_3 and KHO/water. Figure 6 shows a schematic diagram of the cycle. The cycle is a compromise between the KHO/water and water/NH_3 systems. This cycle reduces the highest system pressure and avoids the need for a rectifier in the water/NH_3 system. It can operate with environmental temperature below 0°C without problems of freezing and crystallisation. The disadvantages of this system are its complexity and mechanical work is required to drive the compressor.

The diffusion absorption cycle, commonly known as an Electrolux system, has been used for more than 60 years mainly for domestic refrigerators. Unlike conventional absorption systems, this cycle does not require a circulation pump, [Herold & Radermacher 19891. Instead, a bubble pump circulates the solution of water/NH$_3$. The pressure levels in a conventional water/NH$_3$ cycle are much too high for a bubble pump to overcome. To surmount this difficulty, an inert gas is added to the evaporator and absorber so that the total pressure in all components are equal. The bubble pump must then overcome only the hydrostatic head results from the position of the components. The inert gas, typically hydrogen degrades the mass transfer performance of the cycle, but this is usually tolerable. However, the performance of the cycle is relatively poor (COP for refrigerator is less than 0.2). The design of the generator and bubble pump was studied by Stierlin & Ferguson [1991], who reported that 50% improvement in COP was possible. For safety reason, helium replaced the hydrogen in their system.

A dual cycle absorption refrigerator and heat pump was developed in the U.S.A. for space cooling and heating, [Hanna et al. 1984]. The cycle consists of two separated single effect absorption cycles using different working fluids: water/NH$_3$ and LiBr/water. The condensers and the generators of both cycles are integrated in a single module component in which the LiBr/water solution is heated by flue gas and the vapour refrigerant generated (steam) is condensed in the generator section of the water/NH$_3$ cycle. This heat is used to generate vapour refrigerant (NH$_3$) which is similar to a second-effect generator in a double effect absorption cycle. The vapour NH$_3$ rejects heat to the cooling water and condenses to liquid as usual. The operating temperature of the evaporator and absorber of the LiBr/water cycle are respectively higher and lower than those of the water/NH$_3$ system and this prevents crystallisation of the LiBr/water solution. Coefficient of Performance values of 0.94 were reported when operating as a refrigerator and 1.8 when in heat pump mode. Theoretical studies of a similar cycle are provided by Rogdakis & Antonopoulos [1991].

The absorption process in the absorber releases a large amount of heat, which results in major irreversible loss to the system, [Kandlikar 1982. Kaushik & Kumar 1987]. The heat rejected during the absorption process may be used to preheat the solution coming out of the absorber (as shown in Fig. 7) thereby reducing generator heat input and hence improving the cycle performance. In the first paper, systems using water/NH$_3$ as a working fluid were compared. The cycle with an absorber heat recovery was found to have 10% improvement in COP. In the second paper, a comparative study of a system using water/NH$_3$ and LiNO$_3$/NH$_3$ as working fluids, similar improvement was found. The LiNO$_3$/NH$_3$ cycle yielded better performance than the water/NH$_3$ cycle over a wide range of operating temperatures. However, the machine based on this absorber design has not yet been built.

The size and cost of the absorption system can be reduced by increasing the heat and mass transfer performance of the system components. The Rotex system was developed in the U.K., [Ramshaw & Winnington 19881. In this system the transfer of heat and mass takes place on rotating discs; the fluid flows outwards from the centre of the spinning discs. Shear rates higher than those found in conventional falling-film devices are experienced. These produce large increases in heat and mass transfer which lead to a reduction in the size and cost of the system. The proposed Rotex system comprises several rotating discs contained within a hermetic shell and the discs are rotated at 500 rpm. KOH-NaOH/water is used as the working fluid. The solution pump is eliminated, as the centrifugal pressure from the rotating disc is sufficient to overcome the low pressure difference of the water-refrigerant-based system. The system is designed to produce hot water at 70°C and recover heat from the ambient air at 2°C. A Coefficient of Performance of 1.4 for heat pump operation was claimed.

Kuhlenschmidt [1973] used an ejector to improve the performance of an absorption refrigerator. The aim was to develop an absorption cycle (Fig. 8) using a working fluid based on salt absorbent,

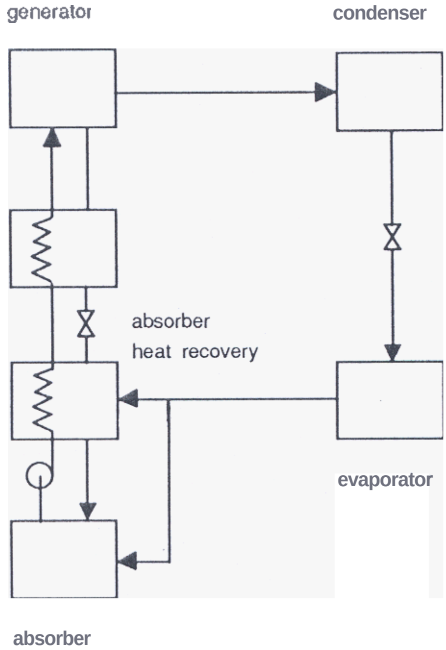


Fig. 7. An absorption refrigeration cycle with an absorber heat recovery.

capable of operating at low evaporator temperatures and employing an air-cooled absorber, without the problem of crystallisation. This cycle used double-effect generators. However, in contrast to a conventional double-effect absorption system, the low pressure vapour refrigerant from the second-effect generator was used as the motive fluid for the ejector that entrains refrigerant vapour from the evaporator. The ejector exhaust is discharged to the absorber to maintain the pressure differential between the evaporator and the absorber. There is no condenser in this cycle, as the high-pressure refrigerant vapour is condensed in the second-effect generator and the low-pressure refrigerant vapour is used as the primary fluid for the ejector. Neither theoretical nor experimental results of this system are yet available. However, one can expect that the COP of this system will not be higher than a conventional absorption system as some of the refrigerant vapour generated by the generator is discharged directly to the absorber (the cooling capacity is reduced). Moreover, the absorber needs to have a far greater absorption capacity because both primary and secondary flow need to be absorbed.

Chung et al.[1984] and Chen [1988] studied an absorption system using DMETEG/R21 and DMETEG/R22 respectively as working fluids. Their proposed system operated with an ejector using high temperature concentrated solution returning from the generator as a primary fluid and a refrigerant vapour from the evaporator as a secondary fluid. The ejector exhaust was discharged to the absorber as shown in Fig. 9. Between the absorber and the evaporator, pressure ratios of 1.2 were expected. The increase in absorber pressure results in the circulation rate of the solution being reduced lower than that for a conventional cycle operated at the same conditions. Thus an improvement of the system performance was expected. However, this system can only be operated using high density refrigerant vapour. because a liquid driven ejector is not suitable to operate with low density vapour such as water vapour, as in the case for systems using aqueous lithium bromide solutions.

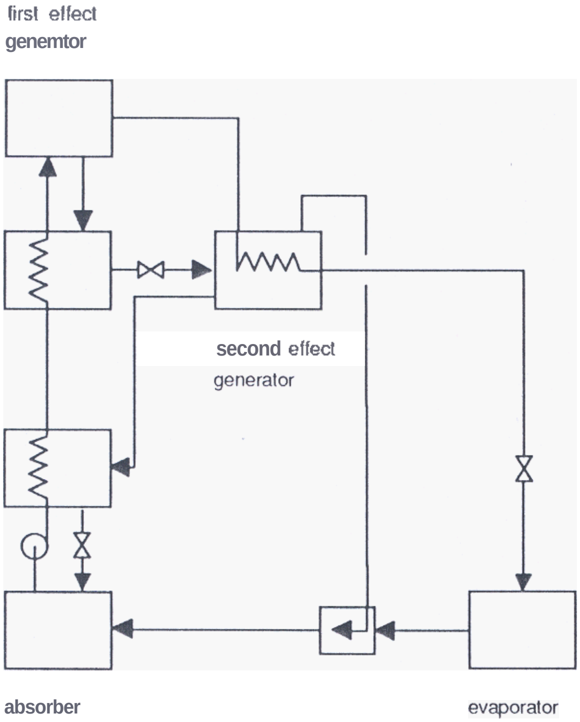


Fig. 8. An absorption refrigeration cycle by Kuhlenschmidt.

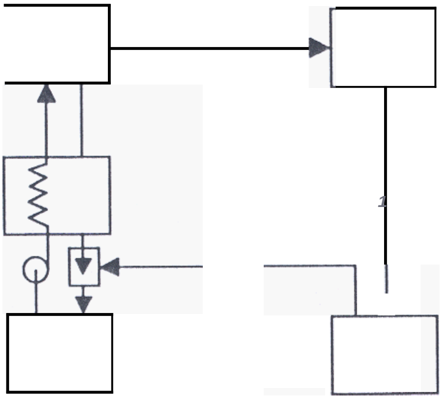


Fig. 9. An absorption refrigeration cycle with an ejector absorber.

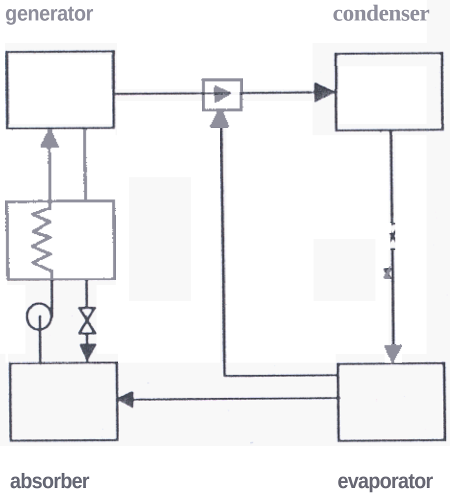


Fig. 10. A combined ejecta-absorption refrigeration cycle.

A combined ejector-absorption refrigerator (Fig. 10) was developed to operate with heat source temperature between 190 to 210°C [Aphomratana 1994, Aphornratana & Eames 1994]. An ejector is installed between the generator and the condenser of a singleeffect absorption refrigerator using lithium bromide/water. The ejector allows the generator to be operated at a pressure higher than that of the condenser and so allows the temperature of the solution to be increased without danger of crystallisation. Therefore, the heat input to the generator is only slightly increased while its temperature and pressure are increased simultaneously (maintaining a constant solution concentration). As the ejector entrains an extra amount of low pressure refrigerant from the evaporator and discharge its exhaust to the condenser, the mass flow of the refrigerant condensed in the condenser and evaporated in the evaporator is greater than that generated by the generator and absorbed by the absorber. Thus the performance of this system is increased significantly over a conventional single-effect absorption system, since the cooling capacity can be increased with slightly increase in the generator input The COP values between 0.86 to 1.04 were found.

6. WORKING FLUIDS FOR ABSORPTION SYSTEMS

The operating performance of an absorption system is critically dependent on the chemical and thermodynamic properties of the working fluids, Perez-Blanco 1984. Eisa & Holland 1987, Narodoslawsky et al.1988]. A fundamental requirement of the absorbent/refrigerant combination is that, in a liquid phase, they must have a margin of miscibility within the operating temperature range of the cycle. The mixture should also be chemically stable, non-toxic and non-explosive. In addition to these requirements, the following are desirable, [Holmberg & Berntsson 19901.

- The elevation of boiling point (the difference in boiling point between the pure refrigerant and the mixture at the same pressure) should be as large as possible.
- Concentration of refrigerant should be as large as possible, to avoid circulation losses. The

specific heat of the mixture should be as low as possible, for the same reason.

- The heat of vaporisation for the refrigerant should be high.
- Transport properties that influence heat and mass transfer, e.g., viscosity, thermal conductivity and diffusion coefficient, should be favourable.
- The mixture should be non-corrosive and low cost.

Many working fluids are suggested in the literature. A survey of absorption working fluids yielded some 40 refrigerant compounds and 200 absorbent compounds, [Macriss et al. 1988]. Despite this. the most common working fluid for absorption cycles are LiBr/water and water/NH_3.

Since the invention of the absorption cycle, the water/NH_3 system has been widely used for both cooling and heating purposes. Both NH_3 (refrigerant) and water (absorbent) are highly stable and NH_3 has a high latent heat of vaporisation which is necessary for efficient performance of the system. As the freezing point of NH_3 is -77°C, the system can be used for low temperature applications. However, the water/NH_3 cycle requires a rectifier to strip away the water that normally evaporates with the ammonia Without a rectifier the water would accumulate in the evaporator and offset the system performance. There are other disadvantages such as its high condensing pressure, toxicity and corrosive action to copper and copper alloy.

The use of LiBr/water for absorption systems began about 1930 {Berestneff 19491. Two outstanding features of LiBr/water are the non-volatility of LiBr (thus eliminating the need for a rectifier) and the high latent heat of vaporisation of water. However. using water as the refrigerant limits the low temperature applications to those above 0°C. Furthermore the system is operated under vacuum conditions. Another drawback is. at high concentrations, the solution is prone to crystallise. It is also corrosive to some metals.

Although LiBr/water and water/NH_3 have been widely used for many years and their properties are well known, much extensive research has been carried out to investigate new working fluids. Table 1 lists some of the research into working fluids.

7. CONCLUSIONS

In order to achieve an improvement in performance of absorption refrigerators, generally two approaches have been followed. These are to develop new advanced cycles or working fluids. Systems with different cycle configuration have been developed. however, the system complexities were increased over a conventional single-effect absorption system.

This paper describes a number of absorption refrigeration cycle and provides a review of research in this area. It is hoped that this will simulate wider interest in the technology of absorption systems.

Table 1. Properties, correlations and investigations relating to working fluids for absorption cycles

T solution temperature (°c)
X mass concentration (%)

Investigator	Year	Fluid	Source of Data	Range	Form of Results
Park & Sonntag	1990	water/HN_3	thenretical	TOO	enthalpy, entropy
El-Sayed & Tribus	1985	water/NH_3	theoretical	-62<T<500	enthalpy. entropy. density
Ziegler & Trepp	1984	water/HN_3	theoretical	-45<T<230	density, enthalpy, vapour pressure, entropy
McNeely	1979	LiBr/water	experimental	45<X<70 16<T<165	vapour pressure, enthalpy
Patterson & Perez-Blanco	1988	LiBr/water	experimental	0<X<70 0<T<180	vapour pressure. enthalpy, density, thermal conductivity, surface tension. viscosity
Gupta & Sharma	1976	LiBr/water	theoretical	0<X<70 0<X<200	entropy
Herold Hemld & Moran	1985 1987	LiBr/water	theoretical	0<T<180 0<T<100 0<T<250 0<T<130 0<T<200 1<X<70	enthalpy density vapour pressure specificheat capacity entropy
Koehler et al.	1987	LiBr/water	theoretical	0<T<100 0<X<70	entropy
Anand & Kumar	1987	LiBr/water	theoretical	0<T<130 0<X<70	entropy
Modahl & Lynch	1971	LiBr/water	experimental		corrosion inhibiton
wen & Lin	1992	LiBr/water	experimental		corrosion inhibitors
Iyoki & Uemura	1978	LiBr/water	experimental		corrosion inhibiton
Albertson & Krueger	1971	LiBr/water	experimental		heat transfer additives
Chang et al.	1968	LiBr/water	experimental		alcohol additives
Iyoki & Uemura	1989’	LiBr/water	experimental	40<T<160 10.2<X<62.5	specific heat capacity
Iyoki & Uemura	1989^b	LiBr/water	experimental	94<T<182 38.9<X<70.3	vapour pressure
Hou & Tan	1992 .	LiBr/water	experimental	0<X<55	boiling heat transfer

Table 1 Properties, correlations and investigations relating to working fluids for absorption cycles

T solution temperature (°c)
X .mass concentration (%)

Investigator	Year	Fluid	Source of Data	Range	Form of Results
Jeter et al.	1992	LiBr/water	experimental	$100<T<200$ $45<X<65$	specific heat capacity
Lenard et al.	1992	LiBr/water	experimental	$120<T<210$ $43.7<X<65.2$	vapour pressure
Zaltash et al.	1991	LiBr/water	experimental	$80<T<135$	heat and mass transfer coefficient
Iyoki & Uemura	1989'	$LiBr-ZnBr_2-LiCl$/ water	experimental	$100<T<160$ $48.8<X<74.0$	specific heat capacity
Iyoki & Uemura	1989^b	$LiBr-ZnBr_2-LiCl$/ water	experimental	$100<T<150$ $50.8<X<63.6$	vapour pressure
Iyoki & Uemura	1990	$LiBr-ZnBr_2-LiCl$/ water	experimental	$1<T<160$	vapour pressure, surface tension, density, viscosity. specific heat capacity
Hemld et al.	1991	NaOH-KOH-CsOH/ water	experimental		heat and mass hansfer
Krueger	1911	$LiBr-ZnBr_2/CH_3OH$	experimental		corrosion inhibitors
Bhaduri & Verma	1988	5 different adsorbents/R22	experimental	$T=0$	heat of mixing
Bhaduri & Verma	1986	5 different adsorbents/R22	experimental	$0<T<100$	vapour pressure
Ando & Taeshita	1984	DEGDME/R22	experimental	$-20<T<190$	vapour pressure, specific heat capacity, heat of mixing, enthalpy
Agarwal & Bapat	1985	DMF/R22	experimental	$-25<T<120$	solubility data

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