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Overview of Working Pair used in Absorption Refrigeration Technologies

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Abstract: The cycle performance of absorption cooling cycles depends not only on their configuration, but also on thermodynamic properties of working pairs regularly composed of refrigerant and absorbent. A review of potential working fluids used in the absorption cooling technologies presented in this work in order to determine the availability of viable working fluid that can give high cooling power while maintaining efficient system performance. In recent years the interest in absorption refrigeration has increased as a complementary refrigeration system that can utilize the low-grade heat for cooling. Absorption cycles contain absorption heat pumps, absorption chillers, and absorption transformers. Therefore, seeking more advantageous working pairs with good thermal stability, with minimum corrosion, and without crystallization has become the research focus last decades. Many reviewers have studied in the work to review the viable working fluids that can be used in the system and concluding that there is a number of fluids that show good working characteristics, which has been studied theoretically and studied experimentally shows potential for being good working fluids.
Keywords: Absorption , Refrigeration, Coefficient of Performance, working pairs.

I. INTRODUCTION

The increasing concern on environment problems has led to the development of renewable energy sources[1]. During the last few decades, an increasing interest, based on research and development, has been concentrated on utilization of non-conventional energy sources, namely solar energy, wind energy, tidal waves, biogas, geothermal energy, hydropower, hydrogen energy, etc. Among these sources, solar energy, is a highly popular source due to the following facts: direct and easy usability, renewable and continuity, maintaining the same quality, being safe, being free, being environment friendly and not being under the monopoly of anyone[2]. Absorption refrigerators (ARs) can be driven by low-quality heat sources such as process waste heat and solar energy. Replacing the commercially dominant vapor compression refrigerators with ARs can reduce electricity consumption. Furthermore, ARs are environmentally friendly due to their use of green natural materials such as water and ammonia as the refrigerant[3]. The major difference between compression and absorption system is the working fluid used. Mostly chlorofluorocarbons (CFC) are used by compression system and we know that halogens are the reason for depletion of ozone layers. The refrigerant used for the absorption system like ammonia, water etc. are very cheap and easily available [4].

An absorption refrigeration has a working fluid that is a pair/solution comprising a refrigerant and an absorbent. Back in the 1970s,water and sulphuric acid were used in the early absorption refrigeration systems. An absorption refrigeration machine dating back to 1859 used NH_3-H_2O as the working pair; after about a century another working fluid the H_2O-LiBr pair, was introduced for the first time [5].

II. SELECTION OF THE WORKING PAIR

There are several possible absorbent–refrigerant working pairs that can be used in absorption refrigeration systems .The choice should be made carefully ,since the performance of the system differs according to the chosen working pair. The proper selection depends on the temperature of the heat source, the desired characteristics of the refrigeration system, the properties of the working pair constituents and the affinity between them(which depend on the chemical, physical and thermodynamic properties of the substances), and even on their cost, availability and environmental impact.

A. Refrigerant

Regarding the pure refrigerant, the following properties are the design target:

1) Low boiling point at atmospheric pressure

2) High latent heat of vaporization
3) Low heat of mixing with the absorbent
4) Low viscosity
5) Not toxic
6) The normal boiling point and the vapor pressure of the refrigerant should not be close to those of the absorbent to allow easy separation and regeneration by heating. Moreover, ideally, one should have a mixture with separation efficiency that does not require a rectification column, which in turn rebus the capital cost and the operating cost of the AR thus enabling its commercial usage[3].

B. Absorbents

Regarding the pure absorbent, the following properties are the design target:

1) High boiling point at atmospheric pressure Compare to refrigerant.
2) Stability and non-toxicity.
3) Low heat of mixing with the refrigerant.
4) Non- Corrosively and mutual solubility with refrigerant.
5) Normal boiling points above 100°C should satisfy the low volatility requirement of the absorbent Criteria for maximum melting point of absorbent allowable depends on the crystallization possibility of the absorbent, However some absorbents form eutectic solutions with the refrigerants even at temperatures below the melting point of the absorbent[6].

C. Refrigerant- Absorbents mixture:

Regarding the mixture, the properties to be considered are as follows[3]:

1) The boiling point of the solution is in a range that can be provided by low-quality heat sources.
2) High miscibility between the refrigerant and the absorbent .
3) No zoetrope formation .Furthermore, there are a set of properties that both the pure refrigerant and the mixture should have.
4) Completely miscible (it is a necessity to have a completely miscible solution to have a homogeneous solution in the vapour and liquid phases under all conditions).
5) Low heat of mixing (the absorption process is an exothermic one with negative heat of mixing, thus the mixture should be a real one with negative deviation from Raoult's law).
6) No solid formation under operation conditions.
7) Not toxic or at least safe in the allowed range.

III. AVILABLE WORKING PAIRS

Many working fluids are suggested in literature. A survey of absorption fluids provided by Marcriss [7] suggests that, there are some 40 refrigerant compounds and 200 absorbent compounds available. A summary of the possible working pairs for absorption systems is shown in Table (1) and some of working pairs are Described below:

Table 1. Summary of some working pairs for absorption systems

Refrigerant.	Possible absorbent(s).
H_2O	Salts / Alkali halides / LiBr / Ionic liquid / $LiClO_3$ / LiBr based multi-component salt mixtures (LiBr + single salt, LiBr + binary salt systems, LiBr + ternary salt system) / $CaCl_2$ / $ZnCl_2$ / ZnBr / Alkali nitrates / Alkali thiocyanates / Bases Alkali hydroxides / Acids / H_2SO_4 / H_3PO_4.
NH_3	H2O / LiNO3 / LiNO3 + H2O / Alkali / Sodium- Thiocynatc {NaSCN} / Ionic liquid / $MnCl_2.CaCl_2$
TEF	NMP / E181{ TEGDME} / DMF / TEG / DMETEG / DWA /BZL / QUN / Pyrrolidone / H_2O
HFC(R12,R21,R125 ,R22,R134,R134a,….)	DMAC / DMF / DMETEG / Ionic liquid / NMP / MCL / DMEU

Methanol	H_2O / Ionic liquid / LiCl / LiBr / LiI / $ZnBr_2$ / $ZnCl_2$ / $LiBr.ZnBr_2$ / LiI. $ZnBr_2$ / H_2O. LiBr / LiSCN / LiCl. LiBr
Butane	Ocetone / ethanol
Ethanol	H_2O / LiCl / LiBr / LiI / $ZnBr_2$ / $ZnCl_2$ / $LiBr.ZnBr_2$ / Tri and Di-ethylene glycol
MDEA(methyl diethyl amine)	H_2O
n- propanol	LiCl / LiBr / $ZnBr_2$ / $ZnCl_2$
Methyl chloride	DME / TEG

A. Ammonia - Water

Ammonia/water mixture as a working fluid for refrigeration systems have been used since the mid of 19th century. Since then, the use of ammonia/water working fluid has been extended for residential and commercial cooling and heating purposes[8].

E. D. Rogdakis and K. Antonopoulos [9] studied a two-stage NH_3-H_2O absorption-refrigeration system, which may be used to produce refrigeration temperatures as low as -70 °C. The system could be operated at three pressure levels so that the heat released by the high-pressure condenser and by the medium-pressure absorber rejected to the ambient, while heat released by the low-pressure absorber was received at the medium-pressure evaporator. FZ. Sierra et al. [10] used a solar pond to power an intermittent absorption refrigerator with NH3-H2O solution. It is reported that generation temperatures as high as 73 ^oC and evaporation temperatures as low as –2 ^oC could be obtained. The thermal COP obtained under such conditions was in the range of 0.24-0.28. A.T. Bulgan [11] optimized of the aqua-ammonia absorption refrigeration system (ARS) in the light of the first law of thermodynamics. The system consisted of an evaporator, a generator, a condenser, a pump, expansion valves and two heat exchangers. A theoretical model was developed for the ARS. The coefficient of performance (COP) was maximized for various evaporator, condenser and absorber temperatures. F. R. El-Mahi et al. [12] performed an experimental study on an aqua-ammonia absorption refrigeration apparatus to study the effect of condenser temperature, on the performance of an absorption refrigeration system. The apparatus has been designed and constructed so as to work on the basis of an intermittent cycle. Three values of condenser temperature were considered in the experimental work and the results were found to agree with the theoretical predictions.

J. ABDULATEEF et al. [13] studied a solar single effect ammonia-water absorption refrigeration system. The influences of operating conditions and effectiveness of heat exchanger on the thermal loads of components, coefficients of performance(COPc, COP) and efficiency ratio (η) are investigated. It is concluded that the COPc and COP values increase with increasing generator and evaporator temperatures but decrease with increasing condenser and absorber temperatures. The (η) value varies with these temperatures. Also, the effectiveness of heat exchanger determines the maximum temperature that can be used in order to obtain the maximum COP out of the system.

De Francisco et al.[14] developed and tested a prototype of 2 kW NH_3-H_2O absorption system in Madrid for solar-powered refrigeration in small rural operations. The test results showed unsatisfactory operation of the equipment with COP lower than 0.05.

F. CHIRICAI et al.[15] performed research on ammonia-water absorption refrigeration systems for small and medium powers, operated with renewable energy resources [solar energy, geothermal] and bivalent, with renewable energy and conventional sources. They built two absorption refrigeration machine, one driven only with renewable energy sources, with 5 kW cooling capacity, and another 17 kW cooling capacity, driven bivalent. Refrigeration systems are equipped of the systems are compact heat exchangers, with mini, micro channels and thermal energy storage. Such systems are designed for comfort and commercial climate. Absorption heat pumps and chillers with ammonia-water can save considerably fuel by using renewable heat sources or waste heat available at temperature that is low enough. A reduction of the carbon dioxide emission together with a global warming potential is resulting. Some performance data indicated the viability of this system based on micro/mini channels heat exchangers.

M. Hammad and S. Habali [16] Design and fabrication of solar-powered absorption refrigeration cycle using NH_3-H_2O solution to cool a vaccine cabinet in the Middle East. A year round simulated indicated that thermal COP ranged between 0.5 and 0.65 with generation temperature at 100-120 ^oC and the cabinet inside temperature at 0-8 ^oC.

H. A.K. Shahad and D. A. Hamzah [17] Design and fabrication an intermittent solar absorption refrigeration operated at Hillah city in Iraq (32.4^o, 44.4^o). The absorption solar unit consists of parabolic trough concentrator (PTC) used as solar rays mirror reflector with aperture area of 2 m^2 , carbon steel pipe inside a vacuum glass envelop with a diameter of 1.5 in as tubular receiver, condenser, storage tank, evaporator. The aqua ammonia solution (NH_4OH) is used as working fluid with different concentration (25%, 30%, 35%, 40%). The validity and visibility of the unit were evaluated by measurements of pressures and temperatures at different parts of the unit during a year from May month 2014 to July month 2015. The maximum pressure and temperature were found to be 12 bar and 120°C respectively. The minimum evaporator temperature is 10°C and The coefficient of performance was in the range of 0.01-0.09.

B. Lithium Bromide (LiBr) - H_2O

An experimental procedure conducted by W. Pichel [18] on a 3517W capacity Li–Br absorption refrigeration machine showed that the machine can operate with hot water at 80 and 120 ^{0}C, and it was found that the cooling water connected in parallel to both absorber and condenser is more efficient than series connection. The coefficient of performance was between 0.68 and 0.72.

S. A. Abdul Ameer [19] Design and fabrication a continuous solar absorption refrigeration . The experimental system is tested under Iraqi weather conditions at Babylon province at 32.39°N latitudes and 44.39° E longitudes. The system consists of a compound parabolic concentrator (CPC), generator, condenser, absorber and evaporator units, storage tank, and set of pumps. The (CPC) has an absorber plate with (0.2*2.5m) an aperture area of (0.9*2.5m). A serpentine copper tube is fixed on the absorber plate and coated with selective black paint. Experimental results showed that maximum thermal efficiency at 12:00 pm at 21st for each month from (0.48-0.67) when the flow rate is 0.0277 kg/s while the thermal efficiency becomes (0.5-0.69) when the mass flow rate of water is 0.0377 kg/s. A theoretical model of the collector is developed and tested under the same weather conditions. Thermal efficiency (0.67-0.73) at the total flow rate (0.0277 kg /s) for a concentration ratio of 4.5 at 12:00 pm at 21st per month. Two pairs of working fluid are tested namely, lithium bromide-water and diethyl ether-ethanol. The theoretical and experimental coefficient of performance of the absorption system for two pairs and at different solution concentrations are ((0.31-0.72) for lithium bromide/water while (0.6-.82) for Diethyl Ether/Ethanol). The steady-state model and dynamic model are analyzed by using linking between Matlab software and EES program. The results of the model satisfied the experimental results for temperatures and pressure as well as the coefficient of performance.

Y. Singh et al.[20] developed a program for thermodynamic analysis of a single effect absorption chiller using LiBr-H_2O solution as working fluid. The working temperature of generator, absorber, condenser, evaporator and effectiveness of solution heat exchanger are used as input data. The program then gives the thermodynamic properties of all state points and the overall cycle performance. The results deduced are used to study the effect of parameters on cycle performance. For example, decreasing the evaporator and increasing the condenser temperatures can improve the efficiency of the cycle. The results of this program can be used either for sizing a new refrigeration cycle or rating an existing system. It can also be used for optimization purposes.

M. Izquierdo etal. [21] designed a solar plant with LiBr/water. The plant contained flat-plate collector to feed the generator with double-stage absorption cycle. They showed that within a condensation temperature of 50 °C, the COP was 0.38 while providing a generation temperature of 80 °C. They also conducted an exegetics analysis of this system and found that the single-effect system had 22% more exegetics efficiency than the double-stage half-effect system.

GA. Florides et al. [22] modeled a complete system, comprised of a solar collector, a storage tank, a boiler and a LiBr–water absorption refrigerator, which can cover a typical house load for the whole year. The TRNSYS program was used to model the system, together with the weather values of a typical meteorological year (TMY) file for Nicosia, Cyprus. Using this approach, a system optimization was performed in order to select the right equipment, i.e. the collector type, the storage tank volume, the collector slope angle and area and the optimum setting of the auxiliary boiler thermostat. The collector area was decided by performing an economic analysis of the system. Also the long-term integrated system performance and the dynamic system's behavior was evaluated.

F. Assilzadeh et al. [23] studied a solar cooling system designed for Malaysia and similar tropical regions using evacuated tube solar collectors and LiBr absorption unit. The modeling and simulation of the absorption solar cooling system is carried out with TRNSYS program. The typical meteorological year file containing the weather parameters for Malaysia is used to simulate the system. The results showed that the system is in phase with the weather, i.e. the cooling demand is large during periods that the solar radiation is high. In order to achieve continuous operation and increase the reliability of the system, a 0.8 m^3 hot water storage tank is essential. The optimum system for Malaysia's climate for a 3.5 kW (1 refrigeration ton) system consists of 35 m^2 evacuated tubes solar collector sloped at 20^0.

F. Asdrubali and S. Grignaffini [24] studied the performance of a 17 kW single effect LiBr/H_2O absorption cooling system powered by a 30 kW electric boiler. In their work they reported that the highest coefficient of performance (COP) occurred at temperatures around 70^0C. They also developed a numerical model to simulate the experimental conditions, and reported a good agreement between the numerical and experimental data.

F. Agyenim, I. Knight, M. Rhodes [25] developed A domestic-scale prototype experimental solar cooling system based on a LiBr/H_2O absorption system and tested during the 2007 summer and autumn months in Cardiff University, UK. The system consisted of a 12 m^2 vacuum tube solar collector, a 4.5 kW LiBr/H_2O absorption chiller, a cold storage tank and a 6 kW fan coil. The system performance, as well as the performances of the individual components in the system, were evaluated based on the physical measurements of the daily solar radiation, ambient temperature, inlet and outlet fluid temperatures, mass flow rates and electrical consumption by component. The average coefficient of thermal performance (COP) of the system was 0.58, based on the thermal cooling power output per unit of available thermal solar energy from the 12 m^2. Thermomax DF100 vacuum tube collector on a hot sunny day with average peak insolation of 800 W/m^2 (between 11 and 13.30 h) and ambient temperature of 24^{0}C. The system produced an electrical COP of 3.6. Experimental results prove the feasibility of the new concept of cold store at this scale, with chilled water temperatures as low as 7.4^{0}C, demonstrating its potential use in cooling domestic scale buildings.
Z. F. Li, K. Sumathy [26] studied the simulation of a solar-powered absorption air conditioning system with the absorption pair of lithium bromide and water. An attempt is made to increase the COP of the system by partitioning a single storage tank into two parts. In the morning when sunshine is low, the upper part is activated, and in the afternoon, the whole (upper and lower) tank is connected to the collector. The analysis indicates that it is preferable to utilize a partitioned water tank rather than the normal stratified water tank because the cooling effect can be realized much earlier compared to the normal stratified water storage tank. Also, the overall cooling efficiency (cooling load to total solar energy ratio) was found to be higher for the partitioned storage air conditioning system.
M. Li et al. [27] Investigated the performance of a 23 kW solar powered single-effect lithium bromide–water (LiBr–H_2O) absorption cooling system. Furthermore, the space heating mode was also investigated, analyzed and discussed. The cooling system was driven by a parabolic trough collector of 56 m^2 aperture area and used for cooling a 102 m^2 meeting room. Research results revealed that the chiller's maximum instantaneous refrigeration coefficient (chiller efficiency) could be up to 0.6. Most of the time, in sunny and clear sky days the daily solar heat fraction ranged from 0.33 to 0.41 and the collectors field efficiency ranged from 0.35 to 0.45. At the same time, chiller efficiency was varied from 0.25 to 0.7 and the daily cooling COP was varied from 0.11 to 0.27, respectively.
K.F. Fong et al. [28] studied the feasibility of a solar hybrid cooling system coupling desiccant dehumidification and absorption refrigeration in the subtropical Hong Kong. The solar system consisted of a field of 100 m2 flat-plate collectors coupled to a single effect H_2O/ LiBr absorption chiller, used to cool a 196 m^2 office building. The analytical results found by using the TRNSYS software showed that, compared to the conventional centralized air-conditioning system; the solar system could reach 36.5% of primary energy savings.

C. Ammonia-Lithium Nitrate

The use of ammonia/$LiNO_3$ as working fluid has been proposed in order to remove the necessity of rectification process. Based on simulation and theoretical study, this solution can produce cold at temperatures lower than 0 °C and offers a better *COP* than the ammonia/water solution .However, the ammonia/$LiNO_3$ solution has higher viscosity than that of ammonia/water which may affect the overall heat transfer coefficient of the components[29].
C.O. Rivera and W. Rivera [30] reported the theoretical performance of an intermittent absorption refrigeration system operating with ammonia/ lithium nitrate mixture. The system consists of a generator–absorber, a condenser, a valve and an evaporator. A compound parabolic concentrator (CPC) with a glass cover, operates as the generator–absorber of the cooling system. Since lithium nitrate does not evaporate during the generation, it is not necessary to use a rectifier. The results showed that with the proposed system it is possible to produce up to 11.8 kg of ice at generation temperatures around 120 ^{0}C and condensation temperatures between 40^{0}C and 44^{0}C allowing the system to be chilled with air or water. The overall COP were between 0.15 and 0.4.
W. Rivera et al.[31] Studied a solar intermittent refrigeration system for ice production developed in the Centro Investigation Energy's of the Universidad National Autonomic Mexico . The system operates with the ammonia/lithium nitrate mixture. The system developed a nominal capacity of 8 kg of ice/day. It consists of a cylindrical parabolic collector acting as generator–absorber. Evaporator temperatures as low as -11 ^{0}C were obtained for several hours with solar coefficients of performance up to 0.08. It was found that the coefficient of performance increases with the increment of solar radiation and the solution concentration. A dependency of the coefficient of performance was not founded against the cooling water temperature. Also it was found that the maximum operating pressure increases meanwhile the generation temperature decreases with an increase of the solution concentration.

G. Moreno-Quintanar et al [32] Developed a solar powered intermittent absorption refrigeration system with the ammonia/lithium nitrate ($NH_3/LiNO_3$) and ammonia/lithium nitrate/water ($NH_3/LiNO_3/H_2O$) mixtures. The system, designed to produce up to 8 kg/day of ice, was developed in the Centro de Investigation en Energies of the Universidad National Autonomic México. It consists of a Compound Parabolic Concentrator (CPC) with a cylindrical receiver acting as the generator/absorber during the generation and evaporation stages respectively, a condenser, an evaporator and an expansion device. The system operates solely with solar energy and no moving parts are required. Several test runs were carried out at different solution concentrations for both mixtures under study. Evaporator temperatures as low as -8 ^{0}C were obtained for a time period of 8 h. Comparing the performance of the system operating with the two mixtures, it was found that with the ternary mixture the solar coefficients of performance can be
up to 24% higher than those obtained with the binary mixture, varying from 0.066 to 0.093. In addition, with the ternary mixture the initial generation temperatures resulted to be up to 5.5 ^{0}C lower than those obtained with the ammonia/lithium nitrate mixture, at the same time the maximum operating pressures were around 1.5 bar higher.

J. A. Hernandez et al. [33] studied absorption heat transformers (AHT) which are interesting devices for recovering and upgrading thermal energy which consume very low amount of primary energy. H_2O-LiBr is the most common working pair used in absorption heat transformers. However, H_2O-LiB mixture has several well-known drawbacks. On the other hand, heat transformers operating with NH_3-H_2O are not so common because they should operate at very high pressures. The use of a desorption circuit in heat transformers is an interesting alternative to reduce the high pressure level. A desorption heat transformer (RHT) is very similar to an absorption heat transformer, where the evaporator-condenser circuit is replaced by a second disrober-absorber circuit. In the literature very few studies were reported about desorption heat transformers operating with the NH_3-H_2O working pair. The modeling and thermodynamic analysis of a single stage absorption heat transformer (AHT) and a single stage desorption heat transformer (RHT) operating with the NH_3-$LiNO_3$ mixture . The systems using the NH_3-$LiNO_3$ do not require rectification process; therefore the systems using this mixture are simpler than those operating with NH_3-H_2O. they studied the coefficients of performance, the exegetic efficiencies and the gross temperature lifts are analyzed as function of the main operating system temperatures.

D. Ammonia-sodium Thiocynatc (NaSCN}

Similar to ammonia/$LiNO_3$ working fluid, the use of ammonia/NaSCN as working fluid for absorption refrigeration systems does not require rectification process as NaSCN is non-volatile. At certain operation condition, the *COP* of the systems operating with ammonia/NaSCN is higher than those of systems working with ammonia/$LiNO_3$ and ammonia/water[8].

Sun [29] reported the thermodynamic analyses of refrigeration systems operating with the ammonia/water, ammonia/lithium nitrate and ammonia/sodium thiocyanate mixtures. It was found that the ammonia/lithium nitrate and ammonia/sodium thiocyanate mixtures are suitable alternatives to ammonia/ water absorption systems. The performance of the ammonia/sodium thiocyanate cycle is slightly better than the ammonia/lithium nitrate cycle.

L. Zhu and J. Gu [34] performed a theoretical analysis of the vapor absorption refrigeration (VAR) system using NH_3–NaSCN solution, where the NaSCN is used as the absorbent and the NH_3 is used as the refrigerant. They found that the solution is advantageous for lower generator temperatures compared to NH_3–H_2O solution, because of the fact that the COP is about 10% higher than the ones for NH_3– H_2O system at the same working conditions.

B. Anusha and B. Chaitanya [35] analyzed the thermodynamic of three combination of the absorption pairs namely NH_3/H_2O, $NH_3/LiNO_3$, NH_3/NaSCN were. The best alternative to the ammonia water absorption pair proposed ammonia lithium nitrate and ammonia- sodium thiocyanate. It is very much important to select a prominent working substance and their properties have great effect on the system performance. Detailed thermodynamic properties of these fluids are expressed in polynomial equations. Energy and entropy balance equations are applied to analyse each of the process to estimate the individual heat transfer and entropy generation rates for all the systems. Among these three pairs NH_3/ NaSCN yields the highest coefficient of performance. Cooling/Heating of the generator/absorber results in significant entropy generation in all the systems. The solution heat exchanger significantly improves the performance of the cycle and yields in the better cooling output.

L. Garousi Farshi at el.[36] studied absorption refrigeration systems using ammonia/$LiNO_3$ and ammonia/NaSCN as working fluids as alternatives to ammonia/water systems, since they have higher coefficients of performance and no need to purify the vapor. Many analyses of these cycles reported in the literature use thermophysical properties correlations based on old data, which recently have been shown not to be sufficiently reliable and sometimes not to have adequate working ranges for absorption refrigeration applications. Properties of the working fluids used in absorption refrigeration cycles are important and need to be accurate. Also, it is increasingly accepted that exergy analysis provides more meaningful information when assessing the performance of energy conversion systems. In order to perform exergy analysis of absorption refrigeration cycles the entropy of solutions are needed as well. Enthalpy and entropy data for these solutions are calculated using the most recently published property data. The procedures for these calculations are described in detail and the results are compared with data from the literature.

L. Zhu and J. Gu [37] used the first and second law of thermodynamics are used to analyze the performance of a novel absorption system for cooling and heating applications. The active component of the sorbent used in this study is sodium thiocyanate (NaSCN). Ammonia (NH_3) is chosen as sorptive. A mathematic model based on exergy analysis is introduced to analyze the system performance. Enthalpy, entropy, temperature, mass flow rate and exergy loss of each component and the total exergy loss of the system are evaluated. Furthermore, the coefficient of performance (COP) and exergetic efficiency of the absorption system for cooling and heating processes are calculated from the thermodynamic properties of the working fluids under different operating conditions. The results showed that the COP of cooling and heating increases with the heat source temperature and decreases with the cooling water inlet temperature, but the system exergetic efficiency does not show the same trends for both cooling and heating applications. The simulation results can be used for the thermodynamic optimization of the current system.

E. Tfe-Tegdme

Z. CREPINSEK at el. [38] compared the performance of absorption refrigeration cycles that used for refrigeration temperatures below 0°C. They studied the performances of the ammonia-water and possible alternative cycles as ammonia-lithium nitrate, ammonia sodium thiocyanate, monomethylamine-water, R22-DMEU (Dimethylol ethyleneurea), R32-DMEU, R124-DMEU, R152a-DMEU, R125- DMEU, R134a-DMEU, trifluoroethanol (TFE)-tetraethylenglycol dimethylether (TEGDME), methanol TEGDME and R134a-DMAC (Dimethylacetamide) are compared in respect of the coefficient of performance (COP) and circulation ratio (f). The highest COP and the lowest f, were found as a function of the generator, condenser, absorber and evaporating temperature.

D. Boer at el. [39] claimed that working pairs of trifluoroethanol (TFE)–tetraethyleneglycol dimethyether (TEGDME or E181) and methanol–TEGDME have some advantages over classical water– LiBr and ammonia water working pairs in absorption cycles. One of the most important features is the wide working range caused by the absence of crystallization, the low freezing temperatures of the refrigerants and the thermal stability of the mixtures at high temperatures. The performance of a double effect absorption cycle for these organic mixtures can be improved if a compression stage is introduced between the evaporator and the absorber. The coefficient of performance (COP) and primary energy ratio (PER) values in the cooling mode are significantly increased over a wide working range: the cycle can work with temperature lifts of 50ºC at 5ºC in the evaporator or it can also be powered by low grade heat. For these conditions COP and PER values are higher than 1.0 and 0.7 respectively, and the power supplied to the compressor represents up to 15% of the thermal energy supplied to the generator. As it is possible to work at high temperatures lifts, the absorber and condenser can be air cooled.

Z. Long at el. [40] investigated numerically the potential of TFE–TEGDME used in the DAR system with two cooling mediums, viz. water (32 ◦C) and air (35 ◦C). It was found that with the absorber effectiveness of 0.8, the optimum generation temperature for the air-cooled TFE–TEGDME DAR (diffusion absorption refrigeration) system is around 170 ◦C, and the corresponding coefficient of performance (COP) is up to 0.45. In comparison, the performance of the water-cooled system is better with a lower optimum generation temperature around 130 ◦C and a higher COP reaching 0.56. Parametric studies are also conducted to analyze the effects of the cooling medium, generation temperature, evaporation temperature and absorber effectiveness on the system performance. Finally, the performance of the TFE–TEGDME and NH3–H2O DAR cycles is compared in terms of the COP and circulation ratio. it was concluded that the TFE–TEGDME mixture is a good working fluid for the DAR cycle.

M. Medrano at el.[41] Studied and discusses the potential of the organic fluid mixtures trifluoroethanol (TFE)- tetraethylenglycol dimethylether (TEGDME or E181) and methanol-TEGDME as working pairs in series flow and vapour exchange double-lift absorption cycles. The ammonia-water mixture was used for comparison purposes. The results show that the performances of these cycles improve significantly when the above mentioned organic fluid mixtures were used as working pairs. For example, the coefficient of performance of the vapour exchange cycle working with TFE-TEGDME is 15% higher than with ammonia-water.

Ki-Sub Kim at el. [42] investigated the potential used of 2,2,2-trifluoroethanol (TFE)+quinoline mixture as working fluid in an absorption chiller. Heat capacity was measured and correlated by a polynomial equation as a function of temperature and concentration, and the parameters of the regression equation were determined by a least-squares method. The cycle. simulation for a double effect absorption cycle was carried out at various operation conditions. The appropriate operation condition and COP values

were calculated for the absorption cycle by using the proposed working fluid. TFE+quinoline solution could be a promising working fluid as an alternative to the LiBr+H_2O and H_2O+NH_3 systems based on the operation range and simulation results.
C. Alberto at el. [43] claimed that a binary mixture trifluoroethanol (TFE)-tetraethylene glycol dimethyl ether (TEGDME) can be more advantageous for absorption cycles at high temperature levels than classical working systems such as H_20-LiBr and NH_3-H_20. This system is non-corrosive, completely miscible over a wide temperature range, thermally stable up to 250°C and has low working pressures. The low thermal conductivity and enthalpy of evaporation of TFE can be improved by using the TFE-H_20 mixture as a refrigerant, instead of pure TFE, with TEGDME as an absorbent. The effect of adding water on the performance of a single-effect absorption heat pump has been analysed. The simulation of such a cycle with a partial evaporator has been carried out for binary and ternary systems, in order to recover thermal wastes at 80°C and upgrade them to 120°C. The maximum COP of about 1.6 obtained for the TFE-TEGDME system in these conditions is hardly affected by the addition of water, although the solution and reflux flow ratios increase with the water content. The results showed that about 15 mass% of water gives optimum performance in terms of the COP and flow ratios.

F. Hydro Fluorocarbon -DMAC

V. Muthu at el. [44] investigated experimentally a Vapour Absorption Refrigeration System of 1kW capacity using R134a–DMAC as the working fluids. The system was designed using hot water as heat source for a heat input of 4 kW at various generator temperatures and tested at sink temperature of 25^{o}C. An average COP of 0.34 was obtained under the above test conditions. The study revealed the feasibility of using environmental friendly R134a-DMAC as working fluids in the absorption system using low potential heat sources for the Heating, Ventilation, Air Conditioning and Refrigeration applications. The hot water source can be replaced with solar panel heater to harness solar energy.
R. Subhadip and M.P. Maiya, [45] suggested that the R134a–DMAC vapour absorption refrigeration system (VARS) needs rectifier. Because of incomplete rectification, a small amount of DMAC is carried to evaporator. It resulted in a temperature gradient and also formation of residual liquid in the evaporator. This liquid caused cooling loss which can be recovered significantly by using liquid vapour heat exchanger (LVHX). The same cooling temperature can be attained at a range of evaporator pressures due to the temperature gradient. For fixed cooling temperature, the system COP enhances with evaporator pressure. The enhancement rate is more when efficiencies of rectifier and LVHX are high. Efficient solution heat exchanger (SHX) is vital owing to its large heat duty. Rectifier loses its importance if high efficiency LVHX is used. Roles of these three components increase at low cooling and high sink temperatures.
M. B. ARUN at el. [46] studied a double-effect series flow vapour absorption refrigeration system (VARS). The found that an optimum value of the low-pressure generator temperature exists at which all the vapour generated at the high-pressure generator is condensed. At these conditions, a comparative study of the performance of VARS using environment friendly refrigerants such as, R32, R134a, and R124 with N,N-dimethyl acetamide (DMAC) as the absorbent is made. It was found that the system with R32-DMAC gave the best performance at high evaporator temperatures. R124-DMAC may be preferred at extreme operating conditions like low evaporator and high heat rejection temperatures. Influence of operating temperatures (high-pressure generator, evaporator, condenser and absorber) and the effectiveness of heat exchangers on the optimum low-pressure generator temperature, cut-off temperature, circulation ratio and coefficient of performance are studied.
A.K. Songara et al. [47] concluded that R-134a-DMAC based VARS is capable of operating at low heat source temperature thereby making it suitable for exploiting low potential heat sources such as solar energy waste heat, etc.
S. Tharves Mohideen at el. [48] performed a thermodynamic analysis on half-effect, single-effect and double-effect VARS with R-134a-DMAC as working fluid to study the influence of absorber mass transfer effectiveness (Ea) at various generator and evaporator temperatures on performance parameters namely circulation ratio, Coefficient of performance (COP) and second law efficiency. The variations in heat quantities of absorber and generator were also studied, using a computer simulation which revealed that the single, double and half effect system can efficiently be applied, where the heat source is available at 80, 130 and 55°C, respectively. Double-effect system yielded maximum percentage increase in COP, when Ea varied from 0.5 to 1. The thermo-dynamic penalty of half-effect system is its high rate heat rejection at the absorbers.
S. Arivalagan et al. [49] performed a simulation studies on R134a – DMAC based half effect absorption refrigeration and found COP of the cycle to be 0.4, with an evaporator temperature of 5°C, generator temperature of 70°C and condenser temperature of 25°C. This system is mostly applicable in industries, where low temperature waste heat (70°C) is available.

V. Mariappan at el. [50] study focused a primarily on the thermodynamic analysis of single stage vapor absorption refrigeration system using R134a – DMAC solution as the working fluid. Variations in the performance parameters of the system are studied against various operating temperatures of generator and absorber. The result of this theoretical study showed that coefficient of performance (COP) value can be improved by elevating generator temperature up to certain level and lowering absorber temperature. At such elevated generator temperature, value of circulation ratio (CR) is lowered. The scope of this study was limited to the system with 1kW evaporator capacity and effectiveness of solution heat exchanger (SHX) as 0.8. For the proposed condition of source and sink temperature 120°C and 40°C respectively the maximum value of COP was found to be 0.41 and corresponding CR value as 3.90.
V. Muthu [51] performed experimental studies on performance of R134a – DMAC based absorption cooling system using low potential thermal sources. The study proved that R134a – DMAC based absorption cooling system yielded an optimum COP of 0.4, when the heat source temperature is 70°C.
Z. Crepinsek et al. [52] performed a simulation studies on a half effect vapor absorption refrigeration cycle for solar energy based cold storage system using R134a – DMAC as working fluids. The study showed that the COP of this cycle is about 0.35 - 0.46 for an evaporating temperature of -5 to 5°C, heat input at 70°C and a condensing temperature at 25°C. COP was improved up to 13% using a condensate pre-cooler.

G. Hydro fluorocarbon –DMF (Dimethylformamide) :

k. Badarinarayana et al [53] presented the concentration-enthalpy chart for R21-DMF refrigerant-absorbent combination for solar-driven cooling applications. Their analysis of the vapour absorption refrigeration system (VARS) working with R21- DMF is observed to be advantageous over R22-DMF systems at lower evaporator temperatures as they are able to operate at lower generator temperatures. They also reported that R 21- DMF systems perform better than R22-DMETEG systems.
S. Kumar and A. Mani [54] studied the absorber for heat and mass transfer analysis to improve the performance of Vapour absorption refrigeration system (VARS). Tangential injection of refrigerant gas into liquid solution in a bubble absorber increases the heat and mass transfer characteristics by following rotary and translation path. In this study, a vertical absorber is considered for heat and mass transfer studies with refrigerant, R134a (1,1,1,2 – Tetrafluoroethane) and absorbent, DMF(dimethyl formamide). R134a vapour is injected into the absorber using two injectors of 4.8 mm inner diameter at an injection angle of 30° to the vertical axis and parallel to the azimuthal axis of the absorber which enhances mixing of R134a with liquid to increase the heat and mass transfer. Heat and mass transfer characteristic were presented in this paper in terms of operational parameters. Effect of solution pressure, solution flow rate, gas mass flow rate on heat and mass transfer rate, absorption rate, absorption efficiency, heat and mass transfer coefficients were computed numerical results.
S. Mariappan and M. Annamalai [55] performed experimental investigation to measure performances of a vapor absorption refrigeration system of 1 ton of refrigeration capacity employing tetrafluoro ethane (R134a)/dimethyl formamide (DMF). Plate heat exchangers were used as system components for evaporator, condenser, absorber, generator, and solution heat exchanger. The bubble absorption principle is employed in the absorber. Hot water is used as a heat source to supply heat to the generator. Effects of operating parameters such as generator, condenser, and evaporator temperatures on system performance were investigated. System performance was compared with theoretically simulated performance. It was found that circulation ratio is lower at high generator and evaporator temperatures, whereas it is higher at higher condenser temperatures. The coefficient of performance is higher at high generator and evaporator temperatures, whereas it is lower at higher condenser temperatures. Experimental results indicated that with addition of a rectifier as well as improvement of vapor separation in the generator storage tank, the R134a/DMF-based vapor absorption refrigeration system with plate heat exchangers could be very competitive for applications ranging from –10◦C to 10◦C, with heat source temperature in the range of 80◦C to 90◦C and with cooling water as coolant for the absorber and condenser in a temperature range of 20◦C to 35◦C.
L .J. He at el. [56] studied theoretically the coefficient of performance of R22 + DMF, R134a + DMF, R32 + DMF as working fluids, for a single-stage and intermittent absorption refrigerator which allows the use of heat pipe evacuated tubular collectors. The modeling and simulation of the performance considers both solar collector system and the absorption cooling system. The typical meteorological year file containing the weather parameters for Hangzhou was used to simulate the system. The results showed that the system was in phase with the weather. In order to increase the reliability of the system, a hot water storage tank was essential. The optimum ratio of storage tank per solar collector area for Hangzhou’s climate for a 1.0 kW system was 0.035–0.043L. Considering the relative low pressure and the high coefficient of performance, R134a + DMF mixture presents interesting properties

for its application in solar absorption cycles at moderate condensing and absorbing temperatures when the evaporating temperatures in the range from 278 K to 288 K which are highly useful for food preservation and for air-conditioning in rural areas.

P. Balamurugan and A. Mani [57] carried out experimental investigations to study heat and mass transfer during desorption of Tetrafluoro ethane (R134a) from R134a and Dimethyl formamide (DMF) solution in a tubular generator. Absorption refrigeration system has been built with brazed plate heat exchangers as condenser, absorber, evaporator and solution heat exchanger and with stainless steel concentric tubes as the generator. Effects of operational parameters viz., solution two phase Reynolds number, driving temperature ratio, driving pressure ratio, solution initial concentration on generator performance are analyzed. Desorption ratio, Sherwood number and Nusselt number increase as the solution Reynolds number, solution initial concentration, driving temperature ratio increase whereas these parameters decrease as the driving pressure ratio increases. Finally a correlation for Nusselt number and Sherwood number were proposed based on the experimental studies.

H. Hydro Fluorocarbon - Ionic Liquid

The involvement of an ionic liquid as a working fluid to an absorption refrigeration system has the ability to overcome some of the safety and environmental impacts of the current conventional working fluids. S. Kim and Paul A. Kohl [58] investigated a new working fluid pair{ 1,1,2,2-Tetrafluoroethane (R134) and ionic liquid (IL) 1-butyl-3-methylimidazolium hexafluorophosphate ([bmim][PF6])} in an absorption refrigeration system. The R134/[bmim][PF6] pair was compared to previous studies using 1,1,1,2-tetrafluoroethane (R134a) and the same IL. The R134/[bmim][PF6] fluid pair had up to 92.3% greater cooling-to-total-energy efficiency than the R134a/[bmim][PF6] fluid pair even though R134 and R134a are isomers and have nearly identical physical properties. The coefficient of performance of the R134/[bmim][PF6] fluid pair was up to 3 times larger than that of the R134a/[bmim][PF6] fluid pair when only waste heat was used at the desorber. A working refrigeration system with R134/[bmim][PF6] was constructed, and the measurements of its performance showed that R134/ [bmim][PF6] had 1.9 times larger cooling capability than R134a/[bmim][PF6] at a desorber temperature as low as 63 °C.

I. H_2O - Ionic Liquid

Water can be considered as a green refrigerant, nontoxic, having high latent heat and excellent thermal characteristics.

M. Khamooshi et al. [59] studied the performance of different working fluids containing ILs and different types of refrigerants in order to define the most suitable binary system. The coefficient of performance obtained on binary systems {H_2O + ILs} in absorption cooling cycle is lower than {H_2O + LiBr}. Nevertheless, the COP of these systems is higher than 0.7.

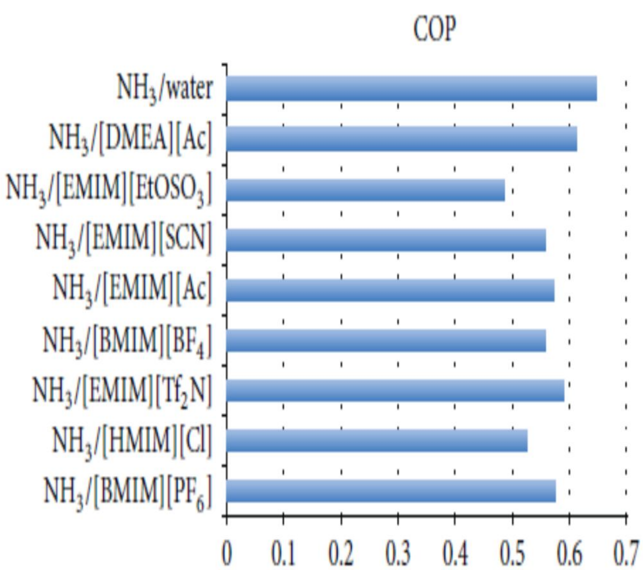
Y.J. Kim et al. [60] studied the thermo physical properties of H_2O+[EMIM][BF_4] with the saturation temperatures at the evaporator and condenser being 25^0C and 50^0C, respectively. A power dissipation of 100W is estimated, while COP value of the system reaches 0.91. The suitable compatibility of water with [EMIM][BF_4] and the superior properties of water as a heat transfer fluid, such as large latent heat of evaporation, followed by extremely small refrigerant (water) flow rate, resulted in its high performance. Higher viscosity ILs cause an increased pressure drop in the compression loop, which would result in larger pumping power or larger pipes and system volume .The viscosity increases with cation mass: EMIM < BMIM < HMIM. The viscosity is more dependent on the anion with the following order: Tf2N < BF4 < PF6. The viscosity of [EMIM][Tf2N] is only 31.3MPa s at 294K, which is 10 times smaller than that of [HMIM][PF6] .

D. Zheng et al. [61] presented a compilation of thermodynamic properties of binary systems containing {H2O , NH3 , HFCs , alcohols + ILs}. The simulation of IL working fluids for single effect absorption cooling cycles showed that several binary systems have a real potential.

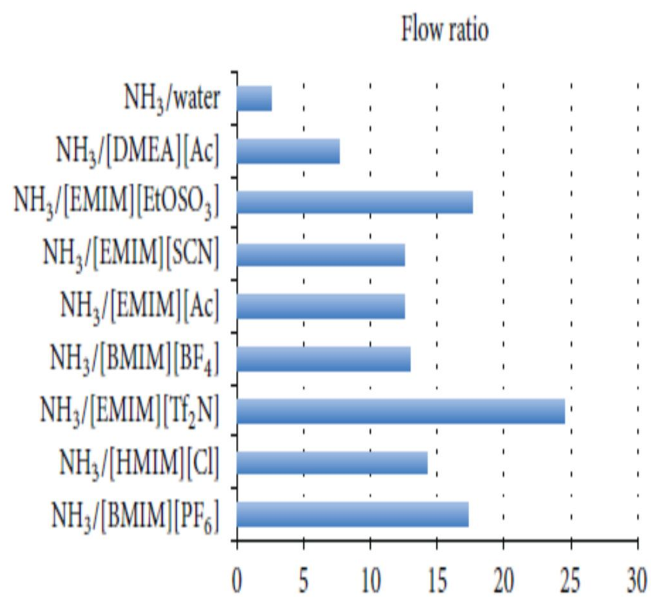
J. NH_3 - Ionic Liquid

M. Wang et al.[62] investigated NH_3/ILs pairs and compared in terms of their applications in the single-effect absorption heat pumps (AHPs) for the floor heating of buildings. Among them, 4 pairs were reported for the first time in absorption cycles (including one which cannot operate for this specific heat pump application). The highest coefficient of performance (COP) was found for the working pair using [mmim][DMP] (1.79), and pairs with [emim][Tf_2N] (1.74), [emim][SCN] (1.73) and [bmim][BF_4] (1.70). These pairs had better performances than that of the NH_3/H_2O pair (1.61). Furthermore, an optimization was conducted to investigate the performance of an ideal NH3/IL pair. The COP of the optimized mixture could reach 1.84.

A. Yokozeki at el. [63] studied the solubility of ammonia in four ILs which contain [EMIM][Ac], [EMIM][SCN], [EMIM]-[$EtOSO_3$], and [DMEA][Ac]. The very high solubility behavior has been clearly demonstrated in terms of the thermodynamic excess functions based on the present EOS (Equation of State) . Discussion shows that there is opportunity for the absorption cycle application using ammonia-IL systems replacing the traditional ammonia– water system. Also, the COPs and flow ratios of series of ammonia-IL and NH_3 + water have been reported with the temperatures of 100, 40, 30, and 10^{0}C corresponding to the generator, condenser, absorber, and the evaporator temperatures, respectively. These COPs and flow ratios obtained from studies are displayed in graphical form in Figures 4 and 5.



Fig(1) COP of series of NH3+ IL and NH3 +water



Fig(2) Flow ratio of series of NH3+ IL and NH3 +water

Li et al. [64] determined the solubility of ammonia into four ionic liquids [CnMIM][BF4] (n=2, 4, 6,and 8) and studied the effect of alkyl side chain length of ionic liquids on ammonia solubility. The measurements were carried out using static method at isothermally fixed temperatures of 293.15, 303.15, 313.15, 323.15 and 333.15 K and the pressure from 0 to 0.6 MPa. In addition to the high solubility of ammonia into studied ionic liquids, they found that, for ionic liquids having same anion, the solubility of ammonia into ionic liquid increase when the length of cations' alkyl increases, that is: [C8mim]+ > [C6mim]+ > [C4mim]+ > [C2mim]+. They found that increase of carbon chain length leads to the decrease of ionic liquids density, and thus generating more free volume and dissolving more ammonia molecules. Furthermore, the thermodynamic properties such as solution enthalpy, solution Gibbs free energy, solution entropy, and solution heat capacity of these systems were also obtained.

The solublity of ammonia into metal ion-containing ionic liquid [bmim][Zn2Cl5] has been investigated by W. Chen et al [65] using static method. The measurements were performed at ammonia mole fraction of (0.83–0.94) and the temperature of (323.15–563.15) K. The total uncertainties of measurement were lower than 4.3%. The solubility data were then correlated using modified UNIFAC model, creating new group interaction parameters. Their results showed that the solubility of ammonia in [bmim][Zn2Cl5] is higher than that in the other ionic liquids studied by Yokozeki and Shiflett [63].

K. Methanol - Ionic Liquid

S.P. Verevkin et al. [66] studied the vapor-liquid equilibrium (VLE) of binary mixtures containing methanol, ethanol, 1-propanol and benzene in the ionic liquid [BMIm]NTf2 by using a static method. VLE measurements were carried out over the whole concentration range at four different temperatures in the range from 298.15 K to 313.15 K. Activity coefficients γi of these solvents in the ionic liquid have been determined from the VLE data and are described formally by using the NRTL (Non-Random-Two-Liquid) equation.

SQ. Liang et al.[67] measured the saturated vapor pressure of the [BMIm]Cl-methanol solutions at 30°C~80°C on condition that the mole fraction of [BMIm]Cl is 19.2%, 21.6%, 31.6%, 43.8% and 51.7%, respectively. The experimental data were correlated with the NRTL model, and the model parameters and the correlation deviation were calculated. The data of experiment and prediction by the NRTL model is shown in Fig 3.

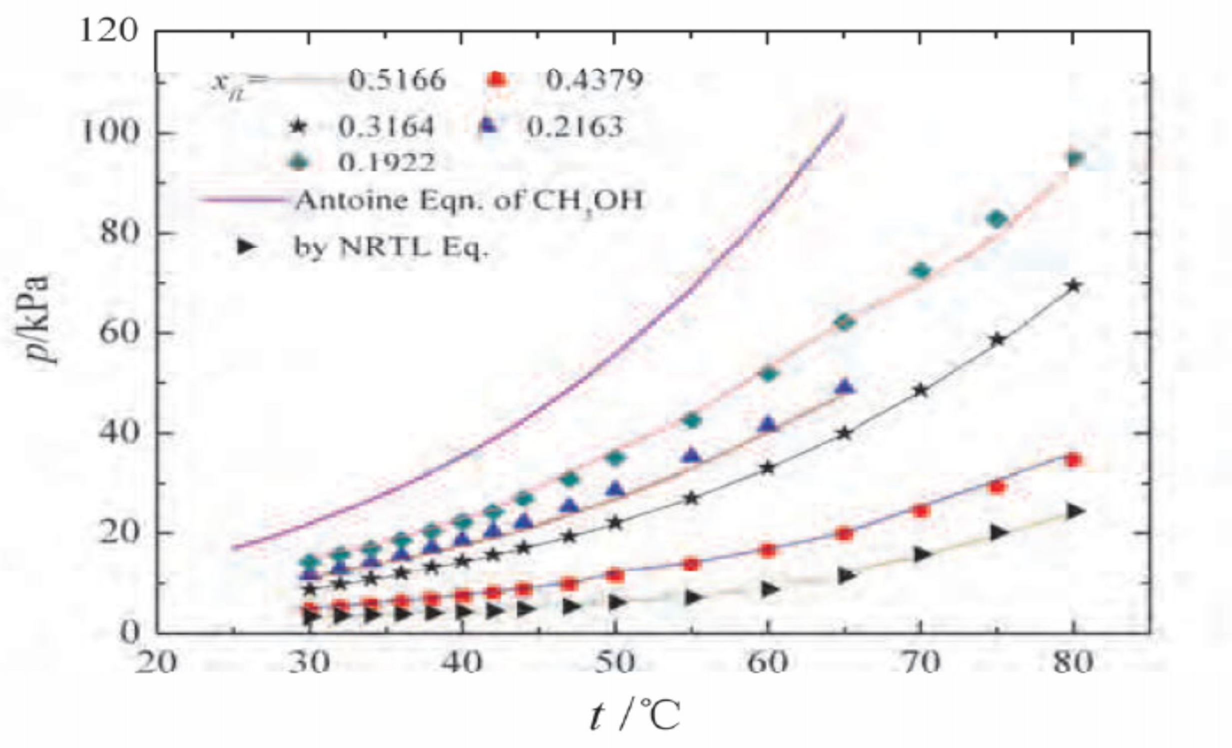


Fig. 3. Saturated vapor pressure of [BMIm]Cl/CH3OH solutions.

L. Butane - Octane, Ethanol

R. Mbarek1, W. Mbarek [68] Investigated experimental of a driven n-butane/ octane (C4H10/ C8H18) diffusion absorption cooling machine according to the cycle of Platen and Munters. For that purpose, they construct a prototype design for air-conditioning applications. The cooling capacity of the constructed machine was 55 W. were reported, our major challenge is to design and choose the kind, the shape and dimensions of all components, which will afford a final and complete machine. In experimental case, the value of COP reached was 0.3. Experimental results showed that such refrigerator, simply fabricated, gives promising results and could be used for clean and safe use where there were a growing interest.

E. Abdel-Hakim Tora [3] studied to find an alternative pair via a three-step approach. The first is computer-aided molecular design using ICAS-ProCAMD software to preliminarily find a pair with analogous thermo physical properties. The second step is plotting Dühring curves to display the thermodynamic behavior of the proposed pair, the required data for which are obtained from Aspen plus. Upon obtaining satisfactory results from the second step, the third step is simulation of an absorption refrigerator operating under different conditions. The results showed that n-butane–ethanol can act as a suitable pair, where butane is the refrigerant and ethanol the absorbent. It has an acceptable pressure range (high pressure of approximately 4 atm, low pressure of around 1 atm) and generator temperature (91°C). In addition, there is no crystallisation probability at 0°C. However, the coefficient of performance is up to 0.33, which is low compared to both of the conventional pairs.

M. Methanol - LiBr

S. C. Kaushik et al. [69] investigated the feasibility of a methanol-LiI.ZnBr2 mixture as a potential working fluid in vapour absorption refrigeration systems. At the first stage, the thermodynamic properties' state equations, viz. P-T-X and H-T-X, for the proposed mixture have been developed, and then, a numerical computer simulation, based on mass, material and heat balance equations for various components of the single/double effect absorption cycles have been carried out for the methanol-LiI.ZnBr2 mixture. A comparative study with methanol-LiBr.ZnBr2 and water-LiBr mixtures has also been undertaken. It has been found that the COP of the methanol-LiI.ZnBr2 and methanol-LiBr.ZnBr2 mixtures are almost the same, while for the water-LiBr mixture, the COP is slightly higher than for the two above mentioned mixtures. The alcohol-salt mixtures can work at lower generator temperatures and can be used for air-conditioning as well as for low temperature applications. The advantage of the methanol-

LiI.ZnBr2 mixture over the methanol-LiBr.ZnBr2 mixture is that the former has a wide working range and lower viscosity, which may be feasible for vapour absorption solar refrigeration and air-conditioning applications.

IV. CONCLUSIONS

Renewable energy sources have been of considerable interest because of their promising advantages. Solar thermal cooling technologies are being used all over the world for industrial and home cooling purposes. A review of working fluids used in the diffusion absorption refrigeration technology has been done in this work, starting with the conventional NH_3/H_2O fluid mixture to Potentially good working fluids such as TFE-TEGDME and ionic liquid . Any refrigerant must has high latent heat of evaporation, non toxic, environment friendly and not expensive. A lot of researches had been carried out to improve refrigerants properties. The different working fluid pairs of solar powered absorption cooling systems give various results in terms of system performance and environmental impact despite their limitations. The recent interest in its study has increased the growth of this technology and variety of working fluids experimented provides a blueprint for the development of this technology. A detailed literature survey of an absorption based refrigeration and air conditioning systems that are powered by solar energy is presented. Different system designs operating with different absorbate–absorbent working pairs along with the related theoretical and experimental work are discussed and demonstrated. As a consequence, this present review is very helpful in terms of development and performance enhancement for each of these systems. According to the researchers' summary, the advantage and disadvantage of some working pair are listed in the Table (2).

Table (2) Advantages and disadvantages of each working pair.

Working pair	Advantage	Disadvantages
Ammonia - Water	• Used where lower temperature is required. • In nature, ammonia is produced by biological processes, is naturally decomposed, and does not add to the global greenhouse effect. • Ammonia is readily soluble in water. • The odor of ammonia has a highly alerting effect. Refrigerant leaks are therefore detected at once. • NH3 has a high latent heat of vaporization. • NH_3 and water are highly stable for a wide range of operating temperature and pressure. • water/NH_3 is environmental friendly and low cost.	• the freezing point of NH3 is -77°C. Since both NH3 and water are volatile, the cycle requires a rectifier to strip away water that normally evaporates with NH3. • NH_3 is toxicity. • NH_3 is corrosive action to many metals .
Lithium Bromide (LiBr) - H_2O	• LiBr/water are non-volatility absorbent of LiBr (the need of a rectifier is eliminated). • high heat of vaporization of water. • Low toxicity.	• At high concentrations, the solution is prone to crystallization. • corrosive to some metal and expensive. • water as a refrigerant limits the low temperature application to that above 0°C. • As water is the refrigerant, the system must be operated under

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		vacuum conditions.
Ammonia-lithium nitrate	• Ammonia-lithium nitrate not require a rectification tower. • Lower cost from water/NH_3. • Lower size from water/NH_3. • solution can produce cold at temperatures lower than 0 °C . • offers a better COP than the ammonia/water.	• the ammonia/$LiNO_3$ solution has higher viscosity than that of ammonia/water. • At high concentrations, the solution is prone to crystallization. • corrosive to some metal . • NH_3 is toxicity.
Ammonia-sodium Thiocynatc (NaSCN}	• Ammonia/NaSCN does not require rectification process as NaSCN is non-volatile. • At certain operation condition, the COP of ammonia/NaSCN is higher than with ammonia/$LiNO_3$ and ammonia/water. • lower generator temperatures compare to NH3–H2O solution.	• NH_3 is toxicity. • corrosive to some metal.
TFE-TEGDME	• Used for refrigeration temperatures below 0°C. • absence of crystallization. • the low freezing temperatures of the refrigerants. • the thermal stability of the mixtures at high temperatures. • non-corrosive. • completely miscible over a wide temperature rang.	• low thermal conductivity. • low enthalpy of evaporation of TFE. • toxicity and inflammability but they are much less toxic than ammonia.
Hydro fluorocarbon -DMAC	• HFC -DMAC is environmental friendly. • HFC -DMF systems used to lower evaporator temperatures. • absorption machines using low potential heat sources.	• HFC -DMAC vapour absorption refrigeration system (VARS) needs rectifier. • lower enthalpy of vaporization compared with ammonia
Hydro fluorocarbon –DMF	• HFC -DMF systems used to lower evaporator temperatures. • HFC -DMF systems operate at lower generator temperatures.	• HFC -DMF vapour absorption refrigeration system needs rectifier. • lower enthalpy of vaporization compared with ammonia.
Hydro fluorocarbon, water,NH_3,methanol - Ionic Liquid	• Ionic liquid as a working fluid has the ability to overcome some of the safety and environmental of the current conventional working fluids.	• COP for {H2O + ILs} lower than {H2O + LiBr}. • Nevertheless, the COP of H2O + ILs is higher than 0.7.

	• Water can be considered as a green refrigerant, nontoxic, having high latent heat and excellent thermal characteristics. • non-corrosive expected when used ammonia.	• Higher viscosity ILs cause an increased pressure drop. • Ionic Liquid is expensive.
n-butane - octane, ethanol	• absence of crystallization. • absorption machines using low potential heat sources. • systems used to lower evaporator temperatures compared to both of the conventional pairs.	• Coefficient of performance is low compared to both of the conventional pairs. • Expensive.

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