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A Prospective Study on Vapour Absorption System

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ABSTRACT

The aim of this study was to review the past achievements in the area of vapour absorption systems, their prospective and possible guidelines for future development. Various types of vapour absorption systems and research on working fluids were discussed. Although this technology looks promising, it is still in development stage and many issues are open. With respect to the fact, this paper tried to covers all the relevant aspects for further developments of vapour absorption refrigeration system the characteristics of each cycle were assessed from the viewpoints of the ideal cycle COP (coefficient of performance) and its applications. Absorption cycles could be combined with other cycles and power generation cycles for waste heat utilization, use of renewable energy sources for performance improvement.

Highlights

1) *Past achievements of vapour absorption systems analyzed.*
2) *Different component combinations have been studied.*
3) *Present work differentiates all combinations of fluids used in absorption cycle.*
4) *Possible future developments are underlined.*

Keywords: *Ammonia-Water absorption system. Waste Heat, COP.*

INTRODUCTION

The absorption technology was also known in the mid of 17th century. The works of Dr. William Cullen and Nairne, for absorption system as indicated in the broad study of Burgett et al. **[1]**. Water –Ammonia machine was introduced in 1859 by Ferdiand carre' He had taken U.S.Patent in 1860.Machines based on this patent were used for ice and food storage. Especially in the USA the period after the Second World War is known as the golden age of absorption system. With respect to absorption machines HVAC (heating ventilation air conditioning) industry was booming. During those days water was used as absorbent In Ammonia-water absorption system, water was volatile and created problem in evaporator. To overcome this problem in 1950 LiBr solution was introduced for industrial applications. Development of an absorption refrigeration cycle was motivated by experiments with different solutions.

Absorption refrigeration systems were based on extensive development and experience in early years of refrigeration industry, particularly in Ice production. Refrigeration industries are blamed for Ozone depletion and global warming. Future development of refrigeration systems with serious implications for environmental concerns is a major concern. The first major environmental concern was depletion of ozone layer by the emission of manmade chemicals into the atmosphere by refrigeration industries. Second major concern was global warming. This did not appear as a major issue till depletion of ozone layer was not known. The refrigeration industry was well aware about the impact of refrigerants vapour released to the atmosphere. In the last three decades, after Montreal [United Nations (UN), New York, (USA), 1987].and especially after Kyoto protocol [United Nations framework convention on climate change, United Nations (UN), New York, USA, 1997], the interest in absorption refrigeration system had become topical as a possible solution to protect ozone layer.

Researchers in many countries had been working on development of refrigeration systems that deal with the bottlenecks of conventional refrigeration systems. The need for rational energy consumption was a worldwide concern.

New idea for reducing energy wasting comprises not only an optimization of energy use but also to lower consumption. Besides, these goals must be achieved without compromising comfort. Other advantages brought by the use of energy and without affecting efficiency and quality of installations. IIR (International Institute of Refrigeration) estimated that approximately 15% of all the electricity produced in the whole world was employed for refrigeration and air-conditioning processes of various types. **[2-3].**

The use of heat operated refrigeration systems helps in reducing problems related to global environmental, such as the so called greenhouse effect from CO_2 (carbon dioxide)emission from the combustion of fossil fuels in utility power plants. Particularly, absorption systems had emerged as a promising alternative to conventional compression cycles (Florides, Kalogirou, Tassou, & Wrobel, (2002); Herold Radermacher, & Klein, (1996); McMullan, (2002), since they could use low grade energy sources that are eco friendly. By converting available waste heat into useful cooling energy and an Energy efficiency could be improved of an absorption–refrigeration system (ARS) **[4-5].**

The application of absorption–refrigeration systems reduces the electricity consumption as compared to conventional refrigeration systems, but long-established compression systems still dominate the market. Promoting the use of ammonia-water refrigeration systems necessitates the improvement of system performance **[6- 7].** However, from the research point of view, these systems still remain as an active field and could not be considered as a completely developed technology. Nowadays, India, China, and Korea play a very important role in the distribution of world market for absorption equipment **[8].**At present, more effort was required to improve their performance and consistency in order to fulfill satisfactorily the increasing demand and to promote, extend their use in industrial as well as commercial applications.

Working Principle of Absorption Cycle.

The vapour compression and absorption systems have got only two differences in their working. The first difference is that absorption cycle was heat-driven thermal cycle, where only thermal energy is exchanged with environment. But in the case of mechanical compression cycle mechanical energy is converted into heat. The second difference with respect to vapour compression cycle was existence of secondary fluid other than the refrigerant, known as liquid absorbing medium or absorbent .

A basic vapour absorption cycle was a two pressure and three temperatures level cycle which makes use of a liquid can be easily converted into vapours as the refrigerant and a second liquid as an absorbent. It consists of a generator, a condenser, an absorber, an evaporator, a solution pump, expansion valve and pressure reducing valve. Input energy is used to heat the generator and as work to the solution pump. The solution temperature in the generator and absorber were not uniform due to the variation in solution concentration from inlet to outlet in these components. This cause's heat transfer irreversibility's in addition to those due to internal mass exchange.

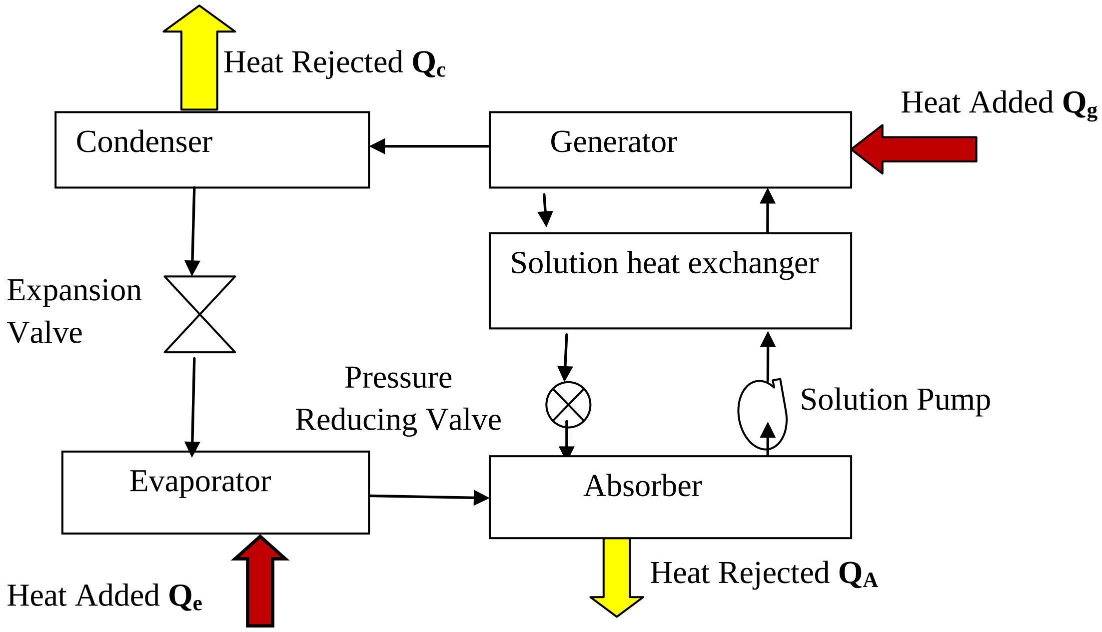

Fig.1. Vapor absorption system

Similarly the solution leaving the absorber was heated to the level of the generator temperature. A solution heat exchanger could be used to transfer the heat from the weak solution leaving the generator and strong solution leaving the absorber. This reduces the input heat required in the generator. This internal heat recovery improves the COP. In the vapor absorption refrigeration system, a physicochemical process replaces the mechanical process of the vapor compression refrigeration system by using energy in the form of heat rather than mechanical work. The main advantage of this system lies in the opportunity of utilizing waste heat energy from industrial processes or other sources like solar energy as an energy input. The vapor absorption refrigeration systems had many encouraging characteristics. Typically a much smaller electrical input was required to drive the solution pump, compared to the power requirements of the compressor in the vapour compression system also; fewer moving parts mean slower noise levels, higher reliability, and improved durability in the VAR systems (vapour absorption system) **[9–13].**

CLASSIFICATION OF VAPOUR ABSORPTION SYSTEM

Vapour absorption system could be broadly classified as per their function, heating arrangement, no of stages and effects, condensing method, working fluids, application, and capacity.

Main Function, (Cooling /Heating)

Absorption machines could be classified as: absorption chiller (producing chilled water); absorption chiller/heater (producing both chilled and hot water) Absorption heat pump (to produce hot water or steam) and absorption heat transformer.

Heating Arrangements

An absorption machine could be direct fired. Or indirect fired. Driving heat for indirect fired absorption machine was recovered from another process or heat cycle machine. This heat was normally delivered to the generator through a heat exchanger. The heat, in the form of steam, hot liquid or hot exhausted gases, was typically supplied by solar collectors, district heating network, boiler, gas turbine or by some other source. Driving heat in direct fired absorption machines comes from burning of liquid fuel or natural gas by suitable burner.

Effects & Stages

The efficiency, the basic absorption cycle could be increased by extending with one or more components at different pressures or concentrations to the four basic components (generator, absorber, evaporator, and condenser) With respect to the number and type of additional components, absorption machines could be categorized by the number of effects or by the number of stages. According to terminology adopted from**. [14].**

Table-1 Terminology used in vapor absorption system

Terminology	**Description**
Number of effects	Number of refrigerant generation processes
Number of stages	Number of solution circuits for an evaporator/absorber set
Number of solution pair	Number of different solution pairs that are not mixed each other
Basic cycle	Single stage cycle
Exchange unit	Heat exchanger for heat and mass transfer with phase change
Strong solution	Rich in refrigerant
Weak solution	Poor in refrigerant
Temperature lift	Difference between heat rejection temperature and evaporation temperature
Resorption	Dual cycle where the refrigerant generated from the low temperature generator is directly absorbed in the high temperature absorber without condensation process
Cascade	Cycle assembly coupled by heat transfer only
Hybrid	A cycle combined absorption and compression processes or two different processes

The term effect refers to the number of times the driving heat was used by the absorption equipment, or simplified; the number of generator determines the number of effects. In this way, we can differentiate between single-effect, double-effect or triple-effect systems. In the same way multistage absorption systems (single-stage, double-stage or triple-stage) vary by the number of fundamental cycles that were combined; in which the number of evaporator-absorber pairs at different temperatures in absorption machines determines the number of stages

Single-Effect and Double-Effect

Among the varieties of the absorption refrigeration cycles, the single-effect and double-effect machines were the most popular and commercially available. The coefficient of performance of the lithium bromide-water absorption machines, based on single- or double-effect cycles, typically varies over the range $0.7<COP<1.2$ for refrigeration temperatures above 0^0 C. Ammonia-water machines allow refrigeration temperatures down to -77.7^0C but the coefficient of performance is typically around 0.5 **[15].** The single effect absorption machine was mainly used for building cooling loads, where chilled water is required at 6-7^0 C. The COP will vary to a small extent with heat source and cooling water temperatures.

The double effect absorption machine had two stages of generation to separate refrigerant from absorbent thus the temperature of the heat source was required to drive the high stage generator was essentially higher than that needed for single effect machine as in the range of 155 -250^0 C double effect machine had higher COP of about 0.9 **[16]** The double effect machines were more efficient and costly than that of single effect machines. Double-effect absorption refrigeration cycle was introduced during 1956 and 1958**[17].**

Multi-Stage, Multi-Effect Absorption Cycles

The main objective of a higher effect cycle was to increase system performance when high temperature heat source was available. By the term "multi-effect", the cycle had to be configured in a way that heat rejected from a high-temperature stage was utilized as heat input in a low-temperature stage for generation of added cooling effect in the low-temperature stage. Several types of multi-effect absorption cycle had been analyzed such as the triple effect absorption cycle **[19]** and the quadruple-effect absorption cycle **[18].**However, an improvement of COP was not directly associated to the addition of number of effect. It must be noted that, when the number of effects increase, COP of single effect will be always higher in Comperesion with COP of each effect. The higher number of effect leads to more system complications

Condensation Methods and Capacity

Absorption machines could be classified as: air-cooled or water-cooled. Finally, absorption equipment (particularly absorption chillers) can be ranged according to the produced cooling capacity: large-scale absorption chillers higher than 300 kW, mid-scale absorption chillers between 50 and 300 kW) and small-scale absorption chillers up to 50 kW or up to 30 kW).

ABSORPTION HEAT RECOVERY CYCLES

Generator-Absorber Heat Exchange (GAX) Cycles

The concept of GAX (generator absorber solution heat exchanger) was to simplify this two stage-double-effect absorption cycle but still produce the same performance. The ideal of GAX was introduced in 1911 by Altenkirch and Tenckhoff **[19].** There were many possible GAX cycle arrangements. Anand and Ericson **[20]** conceptualized and documented a total of 21 advanced GAX cycles for space conditioning. Among these cycles, they recommended a SVX GAX cycle as the most promising cycle which had a COP improvement of at least 30% over that of the basic GAX and was independent of any untested advances in pumping technology. The generator absorber heat exchange (GAX) cycle essentially appears to be a single stage configuration. However, it provides a higher COP than any other single effect cycle due to the temperature overlap between the generator and the absorber. The fundamental concept of the GAX cycle was absorption heat recovery by the temperature overlap. The key problem for a GAX cycle was the heat transfer between the absorber and the generator, which was carried out by a hydraulic loop between them. So, the normal GAX configuration requires the use of two pumps. The second pump was used to circulate a heat-transfer fluid between the absorber and the generator. If the second pump could be eliminated, a large cost saving would be achieve.

Dence *et al.* **[21]** suggested positioning the high-temperature section of the absorber directly in the generator. To achieve this, the generator and absorber must have similar temperature profiles. Further, one had to assure that heat transfers between the absorber and the generator must be matched accurately. They proposed a method for designing such a GAX heat exchanger.

The overlapped heat was transferred from the absorber to the generator within the cycle, leading to a higher COP than 1.0. This overlapped heat was a striking characteristic of the GAX cycle using NH_3-H_2O, Recently, the GAX cycles had been adopted in many applications such as space heating and cooling, ice-making/food processing, panel heating (PGAX) and waste heat recovery. **[22].**

It can be combined with a vapor compression process to obtain a higher COP or to obtain a lower refrigerant temperature. This cycle was named GAX hybrid (HGAX) cycle Kang.et al. **[23]** developed an advanced GAX cycle for the utilization of waste heat (WGAX), and suggested that the corrosion problem by the high generator temperature in conventional GAX cycles be solved by incorporating the WGAX cycles with a equivalent COP. Kang et al. **[24]** proposed an advanced GAX cycle to obtain an evaporation temperature of -50^0C using two stages of evaporation-absorption processes for low temperature applications (LGAX).

Sabir. et. al **[25]** analyzed the performance of a novel GAX re-sorption heat driven refrigeration cycle. The novel system was as simple as that of a single effect cycle and the performance was found to be responsive to the inlet temperature of the cooling / chilled water. The COP of the system was better than that of the conventional single effect vapour absorption and re-sorption cycles, but less than that of the GAX cycles. However, it was anticipated that, a wide range of water temperatures, and mass and heat transfer effectiveness would result in a better performance than that of a simple GAX system.

A GAX absorption -compression cycle simulated **[26]** with the ammonia-water operated working fluid pair. The degassing range (difference between the mass fraction of the weak and strong solutions) of the cycle was optimized for the maximum COP and the effect of the absorber pressure on the component heat duties was investigated. It was found that the maximum COP occurs at an optimum degassing range of about 0.4 kg of ammonia per kg of strong solution.

The hybrid GAX cycle showed an increase of 30% COP compared to that of the simple GAX cycle. It was reported that the required COP of the hybrid cycle could be attained in the lower degassing ranges, and it can be operated by utilizing low temperature energy sources. A single stage ammonia absorption system**[27]** simulated and a GAX cycle, and reported that the COP and the exergy efficiency of the latter were 31% and 78% respectively higher than those of the former, for the heat source temperatures of T_H = 120°C, T_M = 25°C and T_L = 5°C.

Effect of the compressor pressure ratio studied the on a 3.5 kW ammonia-water GAX absorption compression cooler **[28]**. The effects of the generator sink and evaporator temperatures on the performance of the cycle as a function of the pressure ratio were studied. The COP increased with an increase in the low side pressure ratio and generator temperature, and decreased with an increase in the absorber and condenser temperatures. The low side pressure ratio of the cycle was optimized for the optimum COP. The optimum COP corresponding to the optimum pressure ratio was found to be independent of the sink and evaporator temperatures, for a given value of the generator and approach temperatures. The performance of the analyzed cycle was nearly 25% higher than that of the standard GAX cycle .As compared the energy and exergy analyses of GAX and HGAX hybrid absorption refrigeration cycles. It was incidental from the parametric analyses that the generator temperature had more influence on the second law efficiency that that on the COP of the cycles. The generator, absorber and the expansion valve contributes to the highest and the lowest exergy destruction respectively, in both the cycles. **[29]**

Absorption Refrigeration Cycle with an Absorber-Heat-Recovery

The absorber of the vapour absorption system affects the overall performance of the system by controlling the residence temperature, time for solution, heat and mass flow rates. The appropriate design of the absorber might also bring down the operating cost of the system. Several Investigators had worked on unishell with recirculation pump **[30]** on absorber evaporator unishell solution cooled absorber, absorber evaporator mixer absorber and plate-heat exchanger and packed bed absorber to increase the performance of vapour absorption refrigeration systems and to minimize the cost of absorber. Improvement of about 10% in COP can be obtained with the modified absorber heat recovery cycle as compared to the conventional cycle **[31].** The effect of operating variables,like codenser temperatureare not straight forward studied.

Similar to the GAX system, the absorber was divided into two sections. Heat was rejected out at a different temperature. The lower temperature section rejects heat out to the atmosphere as normal However, the higher temperature section was used to preheat rich-refrigerant solution. Therefore, it was observed that the quantity of heat input to the generator was reduced resulting an increase in COP This system was studied theoretically by using a variety of working fluids; Like water/NH3and LiNO3/NH3 **[32-33].** The cycle having an absorber-heat-recovery system observed an improvement of 10% in COP. However, the machine based on this absorber design had not yet been commissioned

ABSORPTION SYSTEMS COMBINED WITH OTHER SYSTEMS

Ejector-Absorption Combined Refrigeration Cycle

Ejector was the key component in the combined cycle. Evidently the COP of the system depends sturdily on the performance of ejector. Ejector was regarded as an attractive component used to improve the performance of the absorption refrigeration cycles **[34-36],** proposed an ejector-absorption combined refrigeration cycle, high-pressure vapor from generator injects part of the vapor out from evaporator to condensing pressure, so the injected vapor does not need to be separated from generator and the COP of this cycle was much higher than that of the conventional single-effect cycler **[37-38]** proposed a novel ejector-absorption combined refrigeration cycle.

Osmotic-Membrane Absorption Cycle

Membrane separation of absorption solutions had potential application in refrigeration technology. Operating osmotic pressure was a basic parameter governing the design and evaluation of a membrane separation absorption system. The studies were often conducted at conditions that had not allowed full realization of the potential of the membrane-based absorption and desorption processes. In a recent theoretical study, Yu et al. (2012) showed that significant enhancement in the absorption rate could be achieved through optimization of the flow and membrane properties.

HYBRID ABSORPTION CYCLES

While research activities to improve the absorption system efficiency had focused on the multi-stage, multi-effect absorption cycles, some researchers had been working on combining other refrigeration cycles with absorption cycles to achieve improved energy performances. The majority of those reported were the combination of the vapour-absorption and vapour-compression cycles. This, perhaps, was the result of the similarity between them. Either mechanical or thermal compressors had been found in the combinations. A combination of vapour-compression and absorption cycles, which was known as the sorption-compression system, can be achieved in a number of ways **[39].** Hybrid absorption-cycles provide an alternative way to improve the energy efficiency of absorption cycle. Since mechanical compressors require high-grade energy to drive them, the hybrid absorption cycles using mechanical compressors lose the ability to utilize low-grade heat sources, which was the one of the most important features of the absorption cycle. Many researchers had done work on hybrid compression –absorption cycle **[40-51]**

Diffusion Absorption Refrigeration Cycle

The diffusion absorption refrigerator (DAR) was first disclosed by Platen and Munters in 1926. A diffusion absorption refrigeration (DAR) cycle was driven by heat and utilizes a binary solution of refrigerant and absorbent as working fluid, together with an auxiliary inert gas. Commercial DAR systems operate with ammonia–water solution and with inert gas may be hydrogen or helium. Zohar et al. numerically investigated the influence of cycle configuration, the generator and bubble pump configuration on the performance of the DAR system based on a full thermodynamic model for the ammonia-water DAR cycle with hydrogen as the auxiliary inert gas **[52-53].** Since its invention, several attempts had been made to make it more competitive with dual-pressure cycles by improving its efficiency, but at refrigeration temperatures, a COP of approximately 0.3 is the best attained by Chen, **[54]**.

WORKING FLUIDS

The efficiency of an absorption cycle was determined not only by the cycle design, but also by the working fluid used in the cycle. Performance of an absorption refrigeration system was critically dependent on the chemical and thermodynamic properties of the working fluid **[55].** A fundamental requirement of absorbent-refrigerant combination was that, in 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. Therefore, the working fluid was an important subject in order to improve the efficiency of absorption cycles. For absorption refrigerators, the following pairs were frequently employed or discussed **[56]**

1) NH_3/H_2O
2) H_2O/H_2O-LiBr
3) CH_3OH/CH_3OH-salt solution
4) R_{22} ($CHClF_2$)/E181 or other organic solvent
5) R134a (CH2ClCF3)/ETFE

The criteria for working fluids for absorption systems had been discussed by **[57].**Among the working fluids, H_2O/H_2O-LiBr and NH_3/NH_3-H_2O were the most widely used in proprietary absorption refrigerators. This was because these two working-pairs have so far provided best energy performances compared with others. However, the water-LiBr solution was corrosive at high temperatures and crystallization occurs at high concentrations. Water as the refrigerant also freezes at sub-zero temperatures, which limit its applications. Although the ammonia-water pair does not crystallize and could work at sub-zero temperatures, the volatility of water with ammonia and the high vapour-pressure of the solution result in increased complexity of construction and high cost. In addition, the efficiency of the ammonia-water systems is lower than that of the LiBr-water system. Many working fluids were suggested in literature. A survey of absorption fluids provided by **[58]** suggests that, there were some 40 refrigerant compounds and 200 absorbent compounds available. However, the most common working fluids were Water-Ammonia$_3$ and Lithium Bromide-water. Since the invention of an absorption refrigeration system, water -Ammonia had been widely used for both cooling and heating purposes. Both ammonia (refrigerant) and water (absorbent) were highly stable for a wide range of operating temperature and pressure. Ammonia had a high latent heat of vaporization, which was necessary for efficient performance of the system. It could be used for low temperature applications, as the freezing point of ammonia is -77°C. Since both ammonia and water were volatile the cycle requires a rectifier to strip away water that normally evaporates with ammonia. Without a rectifier, the water would mount up in the evaporator and unbalance the system performance. Ammonia was a colorless, alkaline gas at ambient temperature and pressure, with a distinct pungent odor, (McKee and Wolf 1963) and is highly soluble in water. Ammonia and Water are highly polar substances and have the hydrogen bonding. Major properties of ammonia and water are given in Table -2.

Table. 2. Properties of Ammonia and Water

Properties	AMMONIA	WATER
Molecular weight (kg/kmol)	17	18
Boiling point at 1 bar (°C)	-33.2	100
Freezing point at 1 bar (°C)	-77.6	0
Critical pressure (bar)	113.5	221.2
Critical temperature (°C)	132.5	374.3

The required thermodynamic and transport properties of the ammonia-water mixture that had been presented and discussed by various researchers were explained as under:

A correlation used to calculate the equilibrium properties of ammonia-water mixtures for a pressure and temperature range of up to 50 bar and 500 K respectively presented. **[59]** The equations of state used were based on those of Schulz. The values of the specific volume, vapor pressure, enthalpies and equilibrium constants for mixtures were compared with the experimental data and the results are presented in the form of vapor pressure and enthalpy concentration diagrams. The thermodynamic properties of water-lithium bromide and ammonia-water mixtures presented. **[60]** The results could be used to select the operating conditions for absorption systems, and to realize automatic control for the operation of these systems at optimum conditions.

A set of five simple and explicit functions for the determination of the vapor-liquid equilibrium presented **[61]**. There were other disadvantages such as its high pressure, toxicity, and corrosive action to copper and copper alloy. However, NH_3-H_2O was environmental friendly and low cost Thermodynamic properties of water/NH3 could be obtained from **[62-66]**. The research interest on working fluids tended towards ternary and quaternary working-fluids **[67-68]** As many as 16 working-fluid combinations compared for a vapour-absorption refrigeration system and concluded that the H_2O-LiCl combination was better from the cut-off temperature and circulation ratio point-of-view and the H_2O-LiBr+LiCl+$ZnCl_2$ combination was better from the coefficient of performance and efficiency ratio point-of-view. **[69]**

TRENDS AND APPLICATIONS

With respect to the trends in absorption machines, research and development of new working fluids was never-ending subject of interest. The advantages of capable binary, ternary and quaternary salt mixtures were discussed thoroughly in working fluids. Lower efficiency and cost of absorption machine were still the burning issue. These were the reasons why a lot of research work was focused on enhancing the heat and mass transfer in order to improve the performance. Further efficiency improvement and importance of inexpensive, compact components (compact heat exchangers) were pointed out **[70]**.

The developments in solar energy collecting and transferring technology had produced the meaningful impact on absorption technology. The focus was more on system integration. How to integrate absorption machines in complex, poly-generation systems in the most efficient way. This further implies the interest in optimization.

A good control strategy of the absorption machine and whole system was essential. Combination of absorption technology with other technologies could be performed by using various applications. However, combination with absorption does not assure that these applications would be efficient and able to compete with other technologies, in particular with conventional vapour compression technology.

The absorption becomes attractive in specific applications when there were possibilities to use waste heat or thermal energy from renewable energy sources. Some of specific applications when absorption technology could be beneficial were;

1) When there were a large amount of thermal energy generated through solar collectors or waste energy usually discarded from industrial processes; in facilities that had concurrent need for heat and power
2) In cases when electricity supply was unpredictable, costly or when absorption can help to decrease peak loads.
3) In cases when governmental policies support the use of clean energy. The absorption technology was the most profuse in two types of applications: solar assisted systems for refrigeration and poly-generation systems

FUTURE PROSPECTS FOR THERMALLY ACTIVATED COOLING TECHNOLOGIES

Increasing the Energy Efficiency of Cooling Systems Based on the Principle of Cascade

Utilization of Thermal Energy

The improvement of energy efficiency needs to give preference to the cascade utilization of thermal energy. The energy fluxes should be properly provided to the subsystems based on the principle of energy cascade utilization according to their temperatures In a cascaded technology system, for example, waste heat in high level (in the temperature range of 120-550 ^{0}C) can be applied to an triple effect or double-effect absorption chiller; waste heat in middle level (in the temperature range of 80 -300 ^{0}C) could be applied to an single-effect absorption chiller; while the thermal energy rejected from an absorption chiller in low level (in the temperature range of 0-150^{0} C) could be used to drive a desiccant dehumidifier or adsorption chiller.

Use of Solar Energy

The major advantage of solar refrigeration is that it can be planned to operate without a electrical supply.

Applications exist in which this facility is essential, such as storing medicines and perishable items in remote areas. The solar refrigeration system can be used in three ways.

- First one is the photovoltaic system is most appropriate for small capacity systems
- Secondly Absorption and solar mechanical systems are automatically larger and heavier and require more piping work as well as electrical connections.
- Thirdly In situations where the cost of thermal energy is high, absorption systems may be practicable for larger capacity refrigeration systems.

Solar collector tracing system is essential in solar mechanical refrigeration systems to produce high temperature; due to this heat power cycle efficiency would be competitive. If the total cost and efficiency of tracking solar collectors can be appreciably reduced, this refrigeration system operating on solar energy would be effective in larger scale refrigeration applications.

CONCLUSIONS

The potential on the field of primary energy savings and environmental benefits were the main advantages which encourage further development of absorption system .Reduced electricity consumption and low CO_2 emission had been confirmed by numerous studies. At the end, all the facts mentioned above indicate that absorption system had a good potential for further development under the two emerging technologies such as solar thermal and micro-CCHP, but a lot of research work to be incorporated ahead. Appropriate standards, test procedures and best practices guides together with intensified work on simulations, optimization and control strategies improvement were some of the needs which were necessary to accelerate the progress to compete with conventional systems. The following conclusions and suggestions were drawn from the present paper.

NH_3-H_2O Systems

NH_3-H_2O systems had been widely adopted for residential cooling and heating applications, and commercial refrigeration applications. Because this pair was volatile, a rectifier was required to separate the water from the ammonia; otherwise, system performance would decrease. Although this pair had a highly corrosive and toxic reaction with copper, its use is pollution-free and cost-effective compared to other pairs. The performance of NH_3-H_2O systems could be improved by internal heat recovery due to its thermal characteristics such as temperature gliding. It can be combined with adsorption cycles and power generation cycles for waste heat utilization. Recently, the GAX cycles had been extensively investigated and some GAX chillers were already commercialized for residential applications. Advanced GAX cycles such as WGAX, HGAX, PGAX and LGAX had been developed for waste heat utilization, performance improvement, panel heating, and low temperature applications, respectively. NH_3-H_2O cycle was better for low temperature applications. It was suggested that the cycle performance could be significantly improved by combining the advanced H_2O-LiBr and NH_3-H_2O systems. Researchers had proposed addition of NaOH to the conventional water-ammonia mixture in absorption refrigeration cycles to improve the separation of ammonia in the generator. Both chiller driving temperature and rectification losses were reduced. Cycle simulation shows that the COP was approximately 20% higher than that of a conventional water-ammonia chiller working under the same conditions. Using a 3A molecular sieve module for ammonia purification was a presented result indicates the concentration of ammonia could be enriched from 82% up to 99% if molecular sieves are properly packed in-series arrangement

Water-Lithium Bromide (H_2O-LiBr)

One of the two most common working pairs was water-lithium bromide, which had been used in absorption equipment since 1950s. The advantages of this working pair include high safety, volatility ratio, affinity, stability, and latent heat .Water was the refrigerant, which evaporates at very low pressures producing the cooling effect. Since water freezes at below 0 ^{0}C, the minimum chilled water temperature in the absorption system with H_2O-LiBr is around 5^{0}C. These systems operate under high vacuum pressures. The main draw back in this system was crystallization. The LiBr crystallization occurs at moderate concentrations, which normally limits the pair where the absorber was water-cooled and the concentrations are lower normally, an internal control system was installed inside the absorption equipment to assure operation under predetermined range and to avoid crystallization.

Ammonia-Lithium Nitrate (NH3-LiNO3)

Ammonia-lithium nitrate as the alternative working fluid for absorption cycles had been studied in the past by several authors. It was reported in the study which ammonia/lithium nitrate had been proposed as a working pair for absorption refrigeration systems driven by low temperature heat sources **[70]**. The authors pointed out the main advantages and disadvantages of the NH_3-$LiNO_3$ mixture compared with conventional working fluids.
When compared with H_2O-LiBr mixture, the advantages of NH_3-$LiNO_3$ are:

1) The absorption cycle does not operate under vacuum conditions (this permits less volume and not so heavy raw materials for absorption equipment),
2) No risk of crystallization at the operation conditions of interest, and
3) No required cooling tower (higher dissipation temperature than H_2O-LiBr).

The refrigeration cycle with NH_3-$LiNO_3$ could be operated at lower generator temperatures than with NH_3-H_2O and does not require rectification of the refrigerant vapour leaving the generator. On the other side, the main disadvantage of this mixture is high viscosity, which penalizes heat and mass transfer processes, especially in the absorber.

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