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A Review of Working Fluid Combinations used in Diffusion Absorption Refrigeration Technologies

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Abstract: A review of working fluids used in the diffusion absorption refrigeration technologies has been done 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 diffusion absorption refrigeration has increased as a complementary refrigeration system that can utilize the low-grade heat for cooling. Many reviewers have studied in the work to review the viable working fluids that can be used in the system and concluding that there isanumber of fluids that show good working characteristics such as TFE-TEGDME, which has only been studied theoretically and is yet to be studied experimentally shows potential for being good working fluids. It can be said though diffusion absorption refrigeration is relatively new refrigeration technology as compared to conventionally used absorption system but the studies conducted till now shows its potential for being a very good alternative for low power refrigeration, a cooling system which is eco-friendly, noiseless and can use the low-grade heat which can make up for its low coefficient of performance.
Keywords: Absorption-diffusion, Refrigeration, Ammonia-water, Coefficient of Performance, working fluids

I. INTRODUCTION

Interest in research of diffusion absorption refrigeration (DAR) has increased significantly in recent years due to its ability to utilize exclusively low-grade heat to produce a cooling effect. Although coefficient of performance (COP) of is not comparable to vapour compression cycle, it is encouraging because it can use a variety of heat sources and can use waste heat to run the cycle. Diffusion absorption refrigeration systems are quiet and reliable and are often used in hotel rooms. The target application of diffusion absorption refrigeration is to cool down electronic converters in harsh environments with ambient temperature by providing refrigeration without compressors, for passive components of losses about 500 W, with a compact and low-cost solution [1]. Small capacity absorption refrigeration has problems in the solution pump which leads to the inefficient performance of device and DAR system have been developed as a response to such problems [2]. Conventional refrigeration systems are dual pressure cycles where the saturation temperature difference between the condenser and the evaporator is produced by a system pressure difference. This requires a mechanical input to drive three compressors or pump needed to generate this change in pressure. This adds to significantly to the noise level and cost of the system [1]. It operates at single system pressure and uses three working fluids; a refrigerant, an absorbent, and an auxiliary gas to equate the temperatures. The disadvantage of DAR is the low coefficient of performance (COP). The coefficient of performance is low due to the presence of auxiliary gas inside the evaporator reduces the refrigerator mass flow rate in the system and thus the cooling capacity. Natural working fluids such as NH_3/H_2O, $H_2O/LiBr$, $CH_3OH/LiBr$ are used as working pairs instead of harmful CFC and CHFC. Diffusion absorption refrigeration is a valid alternative to the conventional refrigeration system. It represents a viable and complementary alternative in the field of refrigeration technology for small cooling capacity.

II. WORKING PRINCIPLE

Three heat sources are needed to drive the cooling process. A high temperature and high-power heat source, a low temperature or low power heat source and a medium temperature heat sink to reject all the power. The system is composed of seven heat exchangers are generator, rectifier, condenser, evaporator, absorber, solution heat exchanger and gas heat exchanger. Von platen-munters uses three working fluids: a refrigerant (ammonia), absorbent (water) and an inert gas (helium) as shown in figure 1.

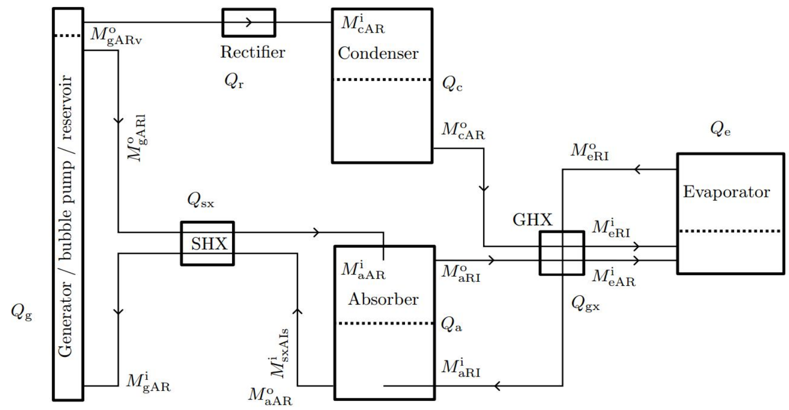

Figure 1. Model of the Von Platen-Munters diffusion absorption refrigeration cycle.

A pre-heated strong liquid solution of ammonia-water enters the generator and is heated with heat load Q_g, produces a strong vapor solution of ammonia-water and weak liquid solution of ammonia-water. A bubble pump creates bubbles which lift the strong ammonia-water solution towards the rectifier and weak liquid ammonia-water towards the solution heat exchanger. The rectifier condenses whatever small amount of vapor is left in strong vapor solution so that ammonia vapor is as pure as possible. Rectification is an exothermic process and rejects heat Q_r to the ambient. The condenser condenses the ammonia above the atmospheric air temperature, which is possible since the partial pressure of ammonia is greater than saturation pressure. Condensation is an exothermic process and rejects heat Qc to the ambient. The solution heat exchanger pre-cools the weak liquidhigh-temperature solution of ammonia-water sent by the bubble pump with the strong liquid low-temperature solution of ammonia-water coming out of the absorber. The gas heat exchanger pre-cools the helium-rich gas from the absorber and the liquid refrigerant from the condenser with the strong ammonia-helium vapor mixture coming out from the evaporator. The evaporator receives the refrigerant from the condenser and pre-cooledhelium-rich gas from the absorber. In the presence of helium, ammonia will evaporate at low partial pressure and temperature. This is an endothermic process and hence absorbs heat from the system which is to be cooled[1].The working fluids have to follow certain constraints for them to be effective and useful: the absorbent-refrigerant mixture should have large boiling point difference to allow good separation between absorbent and refrigerant fluid in the generator. The inert gas should not be able to condense in any condition of temperature and pressure. The refrigerant vapor must be strongly absorbed by the absorbing fluid at the refrigerant partial pressure. The inert gas must not be absorbed by the absorbing fluid at inert gas partial pressure. The fluids must not react with each other or with the surroundings under any conditions. To calculate the COP and other parameters of the diffusion absorption refrigeration system certain mass and energy equations are described, these equations are described under following assumptions:

1) The system is assumed to be in a steady state.
2) Hydrostatic pressure is neglected and so are the losses from pipes.
3) The temperature of liquid and vapor leaving the bubble pump are equal.
4) The vapor leaving the rectifier and evaporator are saturated even though there always will be some amount of moisture content with in the vapor.
5) The condenser and absorber use the same cooling medium.
6) The weak solution entering the absorber and the vapors leaving the absorber has same temperature [3].

III. LITERATURE REVIEW

Commercial used diffusion absorption refrigeration system uses hydrogen as an inert gas, water as absorbent and NH_3 as refrigerant [4].NH_3/H_2 is for cooling at lower temperatures of range -10°C to 30°C, depending on the configuration which requires moderately high generation temperature of about 150°C [5]. In the source temperature of 200°C (solar) the system was able to achieve a coefficient of performance of 0.126 with a cooling capacity of 22.3 W at 26°C ambient temperature. Bubble pump and boiler were at 47°C temperature and power of 130 Watts [6][7].For the ambient temperature of 23.04°C, it has a condensation temperature of 29.46°C. The ambient temperature of $NH_3/H_2/H_2O$ system were to increase to 32.56°C then condensation temperature rises to 31.51°C at best evaporation temperature of 3°C with minimum starting temperature of 152°C and electric power of 63.8 W [8]. The COP of $NH_3/H_2/H_2O$ can vary from 0.01-0.38 depending on the generation temperature and operating conditions. Though the minimum generation temperature required should be greater than 135°C and it can work with generation temperature upto 225°C[2]. It can be used for refrigeration as well air conditioning systems. But Thermal conductivity and thermal capacity of hydrogen is greater, so it causes a lot of energy to be wasted in the process and hence the lower coefficient of performance [9] and also requires a high operating pressure. Helium was studied as a substitute for hydrogen as secondary balance gas or inert gas. An experiment that indicated that the COP of He as inert gas was 40% higher than of the system using H2 as inert gas[10][11].It investigated the use of helium as an alternative to hydrogen. The authors observed similar system performance for both [9][12][13]. The coefficient of performance of standard NH_3/H_2O/He was going to be around 0.298 with heat source generation temperature of 150°C and evaporator temperature of -15°C. Minimum generation temperature required for NH_3/H_2O/He for efficient working is 100°C and and it can work upto 220°C where the COP can vary from 0.1-0.4[2]. The mixture with Helium was applicable to both refrigeration and air conditioning systems. $LiNO_3$, NaSCN, and H_2O were compared as absorbent substances on the basis of COP and the operating conditions by using NH_3 as a refrigerant at an evaporator temperature of -15°C, a generator temperature of 120°C and absorber and a condenser temperature of 40°C and it used Helium as inert gas. The performance achieved by NH_3-$LiNO_3$-He mixture with COP of 0.48 was superior and approximately 50% more efficient than a conventional NH_3/H_2O mixture and 27% more efficient than NH_3/NaSCN mixture [14][15].As a refrigerant ammonia (NH3) has excellent thermo-physical properties but it is toxic, explosive and corrosive to copper(Cu) and other nonferrous metals. It can be used to maintain temperature under 0°C but is not a very good pair for low generation temperatures [4]. The minimum temperature at which ammonia boils is 140°C [16]. The best performance of ammonia was for 0.35 ammonia mass fraction rich solution and worst performance was for a weak solution with a concentration of 0.1 mass fraction [17]. Different working fluid pairs are experimented to substitute for ammonia as a refrigerant. A study was conducted on the performance of simplified diffusion absorption refrigeration system working with an organic absorbent (DMAC-dimethylacetamide) and five different refrigerants with helium as an inert gas. The system was analyzed numerically, with the aim of lowering generation temperature and system pressure along with determining the most efficient fluid for the system. The refrigerants used were; chlorodifluoromethane(R22), difluoromethane(R32), 2-chloro-1, 2-tetrafluoro-ethane(R124), pentafluoroethane (R125), and 1, 2-tetrafluoro-ethane(R134a)[1]. The results were compared with the performance of system working with NH_3/H_2O/He with same operating conditions. Similar behavior was found for all system with lower COP and generation temperature of 150°C [18]. TheoreticallyDMAC-R22 has the highest COP of 0.22 among all 5 refrigerants with generation temperature of 143°C and evaporation temperature of -9°C. It can work between temperature range of 138°C and 160°C with COP varying between 0.19-0.22. In the study observed that the experimental values, DMAC-R134a has the highest COP of 19.5. DMAC-R125 and DMAC-R32 were poor working refrigerants with COP of 0.157 and 0.136 with an evaporator temperature of -8°C and -7°C at generation temperature of 143°C and 138°C respectively. DMAC-R124 COP varied from 0.05-0.4 for generation temperature between 90-180°C [2]. In an experiment, nonane was used as an absorbent, propane as a refrigerant and helium as an inert gas with a cooling capacity of 1KW and maximum generation temperature 130° C [19]. The propane/nonane mixture was inflammable and required high activation energy. R23/R130 and R23/R32/R134a were used as mixed refrigerants and tested experimentally. N, N-dimethyl form amide(DMF) and helium were used as the absorbent and inert gas. DMF was used with R22 as fluid mixtures at generation temperature of 130°C with maximum COP of 0.612 at the cooling capacity of 139.1 W [20].For R32 optimal refrigeration temperature of -28.8°C was obtained with generation temperature 106.9°C and refrigeration temperature of -23.5°C was obtained at generation temperature of 83.3°C [21]. A water-cooled system was experimented by using different binary mixtures, (C_3/n-C_6,cycle-C_6, C_3/cycle-C_5, propylene/cycle-C_5, propylene/i-C_4 and propylene/i-C_5) as working fluids and helium(He) as an inert gas. C_3/n-C_6 was found to be most viable working the fluid mixture with generation temperature of 126 degree Celsius. R124/DMAC as working fluid was more performing than conventionally used working fluids[22]. At generation temperature be of 140°C, COP of NH3/H2O is Maximum with 0.22 with is 50% lower than COP of R124/DMAC that is 0.32[23]. Using hydrocarbons such as propylene as refrigerant and hexane, heptane, octane and nonane as absorbents requires minimum generation temperature of 106°C and can work for generation temperature up to 300°C as other absorption cycle doesn't exceed 180°C [24].N-butane/octane (C_4H_{10}/C_8H_{10}) were used for a prototype of power about 55W based on von platen and munters cycle for air conditioning applications with maximum COP of 0.3. The system was tested at different heating powers from 112.2 W to 270.6W,

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the bubble pump was able to work at lower frequencies [25]. 1-3-dimethylimedazolylium dimethyl phosphate/ methanol/ helium was studied as working fluid mixture. They had the advantage of non-crystallization and non-corrosion and could operate at higher boiler temperature. The COP of this system is greater than butane/nonane/helium working fluid mixture [26].A study was conducted on a diffusion absorption refrigeration system using NH3-NaSCN-He as a working mixture. A distributed heated bubble pump and an enhanced absorber were used to enhance the performance of the system. It worked for low source temperature below 130^oC and evaporation temperature below 5^oC. Refrigeration COP of 0.11-0.26 can be achieved by design conditions ambient temperature equals to 24^oC with low source temperature 110-130^oC theoretically [27]. Experimentally the system worked for evaporation temperature of 6^oC to 3^oC and refrigeration COP of 0.06. Internal COP was 30 % higher than external [28]. The mixture could work for generation temperature between 115-135^oC and can achieve COP of 0.1-0.45. It investigated that if helium was replaced by hydrogen as inert gas, than COP of the system was increased and now it varied from 0.1-0.6. It could also work between larger range of generation temperature from 100-150^oC [29]. $H_2O/NH_3$with Al_2O_3 in nano size are analyzed in diffusion absorption refrigeration system studying the system performance. Due to nanoparticles, the operation time was reduced and provided better absorption of heat from the generator. COP of a system working with nanoparticles were 51% higher than COP of the system working without nano-particles [30], but NH_3-NaSCN crystallize readily, which affects system performance. A study suggested that LiBr/H_2O can be used as working fluid mixture in the diffusion absorption refrigeration system for generation temperature between 66^oC to 78^oC. Dimethyl acetamide/ chloro-difluoro methane (R22) as working can achieve evaporator temperature below 0^oC at generation temperature of 50-90^oC and a COP of 35% [31, 32]. TFE-TEGDME was studied as a working fluid for the diffusion absorption refrigeration system. TFE-TEGDME has good thermo-physical properties. It was found that with absorber effectiveness of 0.8, the optimum generation temperature for air-cooled TFE-TEGDME DAR system is 170$^oC$and the corresponding COP is 0.45. In the water-cooled system, generator temperature is 130^oC and COP is 0.56[33]. Although air-cooled NH3-H2O gives better performance than TFE-TEGDME, the water cooling system has obvious advantages. All in all, TFE-TEGDME is a good working fluid though this model is not verified experimentally [34].The summary of working fluids used in diffusion absorption refrigeration cycle as shown in table 1.

Table1. Summary of working fluids used in the diffusion absorption refrigeration cycle.

FLUID MIXTURE	AUTHORS	COP(Coefficient of Performance)	Generation Temperature	Application	Remarks
NH_3-H_2O-H_2	Izzendineet al.[8] Taieb et al.[6] Taieb et al.[7] Zohar et al.[11]	0.01-0.38	135^oC-225^oC	Refrigeration & Air Conditioning	For cooling at lower temperatures of range -10^oC to 30^oC. Low COP due to high thermal conductivity and thermal capacity of hydrogen.
NH_3-H_2O-He	Zohar et al.[11] Kouremenos et al.[13] Acuna et al.[15] Bourseau & Baragel [29]	0.1-0.4	100^oC-220^oC	Refrigeration & Air Conditioning	COP 40% higher than NH_3-H_2O-H_2 mixture
NH_3-$LiNO_3$-He	Acuna et al.[15]	0.48	120^oC	Refrigeration & Air Conditioning	50% more efficient than NH_3-H_2O-H_2 mixture 27% more efficient than NH_3-NaSCN-He At this generation temperature.
R22-DMAC-He	Zohar et al.[18]	0.19-0.22	138^oC-160^oC	Refrigeration	Better refrigerant than ammonia at low source temperatures and non

					reactive to coppers A good working fluid having highest theoretical COP among organic fluids.
R134a-DMAC-He	Zohar et al.[18]	0.195(max. COP)	150°C	Refrigeration	Highest experimental COP among all the organic fluids.
R125-DMAC-He	Zohar et al.[18]	0.157(max.COP)	143°C	Refrigeration	Poor working fluid.
R32-DMAC-He	Zohar et al.[18]	0.136(max. COP)	138°C	Refrigeration	Poor working fluid.
R124-DMAC-He	Zohar et al.[18]	0.05-0.4	90°C-180°C	Refrigeration	More performing than conventionally used working fluids.
C_3H_8-C_9H_{20}-He	Dardour et al.[19]	N/A	130°C	Refrigeration & Air Conditioning	Inflammable and require high activation energy
R22-DMF-He	Aryanto et al.[20]	0.612	130°C	Refrigeration	Good working fluid with high COP.
NH_3-NaSCN-He	Rattner & Garimella [27] Rattner & Garimella [28]	0.1-0.45	115°C-135°C	Refrigeration	Good alternative fluid for NH_3-H_2O-H_2 with higher COP
NH_3-NaSCN-H_2	Rattner & Garimella [27] Rattner & Garimella [28]	0.1-0.60	100°C-150°C	Refrigeration & Air Conditioning	Good alternative fluid for NH_3-H_2O-H_2 with higher COP
TFE-TEGDME-He	Long et al.[33]	0.45(Air-cooled-system)	170°C	Refrigeration	Lower COP than conventionally used Refrigeration system For air cooled systems.
TFE-TEGDME-He	Long et al.[33]	0.56(water-cooled-system)	130°C	Refrigeration	Higher COP than conventionally used refrigeration system for water cooling systems. All in all a good fluid.

IV. CONCLUSIONS

A review of working fluids used in the diffusion absorption refrigeration technology has been done in this work, starting with the conventional $NH_3/H_2O/H_2$ fluid mixture to Potentially good working fluids such as TFE-TEGDME. It can be concluded that diffusion absorption refrigeration provides a viable mode of refrigeration for low cooling capacity. 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. Though coefficient of performance is low use of waste heat and variety of heat generation methods make this method attractive. Though there is still lack of working fluid that can be used in as a substitute for conventional ammonia/water/helium or ammonia/water/hydrogen but fluids such as TFE-TEGDME, nano-particle mixture, ammonia with NaSCN and ammonia with $LiNO_3$ provides an upside and had the potential of being very good working fluid. Further growth of this technology can help in creating aneco-friendly, effective and efficient refrigeration system.

V. FUTURE SCOPE

Diffusion absorption refrigeration cycle represents a viable refrigeration technology which is eco-friendly and sustainable in nature. Conventionally used refrigeration systems are not available for a cooling capacity of over 400W and refrigeration systems used for cooling capacity between 1KW and 2KW are absorption refrigeration system which uses CFC and CHFC as refrigerants which are becoming an environmental problem. Diffusion absorption refrigeration provides a perfect solution for theanew mode of the refrigeration system. Even though COP of the diffusion absorption refrigeration system may be low but working fluids such as TFE-TEGDME or nanoparticle technology seems to be providing a potential future solution for this concern. Considering the fact that diffusion absorption refrigeration cycle is comparatively new to the other conventionally used refrigeration technologies, its research over the years has progressed effectively.

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