Comparison of the performances of working fluids for absorption refrigeration systems

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Abstract: This paper compares the performance of working fluids for absorption refrigeration systems that are used for refrigeration temperatures below 0^{o}C. Since the most common vapor absorption refrigeration systems use ammonia-water solution with ammonia as the refrigerant and water as the absorbent, research has been devoted to improvement of the performance of ammonia-water absorption refrigeration systems in recent years. In this paper the performances of the ammonia-water and possible alternative cycles as ammonia-lithium nitrate, ammonia-sodium thiocyanate, monomethylamine-water, R22-DMEU, R32-DMEU, R124-DMEU, R152a-DMEU, R125-DMEU, R134a-DMEU, trifluoroethanol (TFE)-tetraethylenglycol dimethylether (TEGDME), methanol-TEGDME and R134a-DMAC are compared in respect of the coefficient of performance (COP).

Key-Words: Absorption, refrigeration, working fluids, COP

1 Introduction

Most of industrial process uses a lot of thermal energy by burning fossil fuel to produce steam or heat for the purpose. After the processes, heat is rejected to the surrounding as waste. This waste heat can be converted to a useful refrigeration by using a heat operated refrigeration system, such as an absorption refrigeration cycle [1]. Despite a lower coefficient of performance (COP) as compared to the vapor compression cycle, absorption refrigeration systems are promising for using inexpensive waste energy from industrial processes, geothermal energy, solar energy etc.

Performance of an absorption refrigeration systems is critically dependent on the chemical and thermodynamic properties of the working fluid [1]. Thermodynamic properties of presented working fluids can be obtained from publications [2 - 11]. Evaluation of potential working fluid for the absorption cycle is a problem because of a lack of published thermodynamic data. The ideal absorbent-refrigerant pair does not exist, all possible combinations present advantages and disadvantages [10]. Many working fluids are suggested in literature but for the refrigeration temperatures below 0^{o}C the most common working fluid is NH_3-H_2O. NH_3-H_2O system exhibits a relatively low COP, therefor efforts are being made to search for better refrigerant-absorbent pairs that can improve system performance [11]. Among different options of working fluids that can be used as alternative to NH_3-H_2O the following working fluids: NH_3-$LiNO_3$, NH_3-NaSCN, monomethylamine-water, R22-DMEU, R32-DMEU, R124-DMEU, R152a-DMEU, R125-DMEU, R134a-DMEU, TFE-TEGDME, methanol-TEGDME and R134a-DMAC are presented in this paper. As a result, COP was used to evaluate the performances of working fluids.

2 Cycles description

Fig. 1 - 3 describes the cycles compared in this paper. Figure 1 illustrates the main components of the Single-effect absorption refrigeration cycle.

Fig. 2 illustrates single-stage triple pressure level (TPL) absorption cycle.

Fig. 3 illustrates double-lift and half-effect cycle respectively. A half-effect absorption cycle is a combination of two single-effect cycles but working at different pressure levels. Letting heat source temperature be lower than the minimum temperature is necessary for a single-effect cycle working at the same pressure level. The half-effect absorption system was introduced for an application with a relatively low-temperature heat source. It must be noted that COP of the half-effect absorption system is relatively low as it rejects more heat than a single-effect absorption cycle around 50%. However, it can be operated with the relatively low temperature heat source [1].

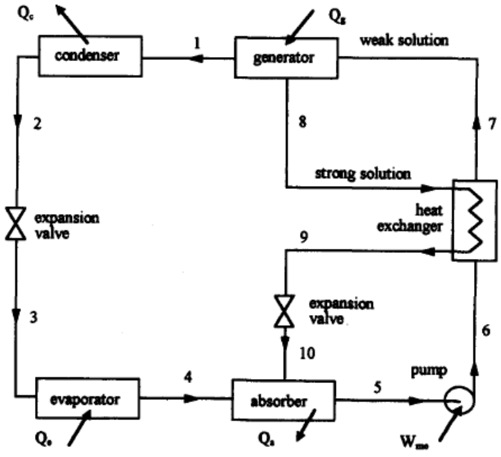

Fig. 1: The schematic of the single-effect absorption refrigeration cycle

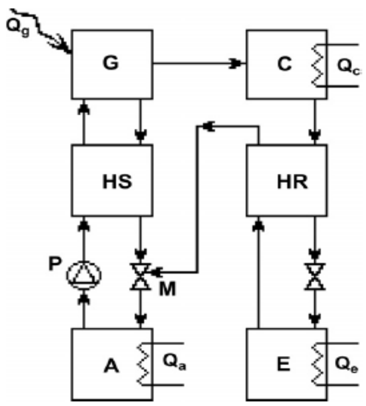

Fig. 2: Schematic illustration of a single-stage TPLAC absorption cycle. G-generator, A-absorber, C-condenser, E-evaporator, HR-refrigerant heat exchanger, HS-solution heat exchanger, P-solution pump, M-jet ejector.

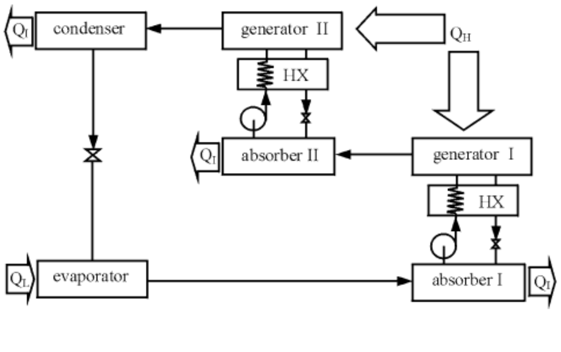

Fig. 3: A half-effect absorption cycle

The COP of the single-effect absorption refrigeration cycle is defined as the ratio between the heat removed at the evaporator to the heat supplied to the generator (Eq. 1).

$$\mathrm{COP} = \frac{\Phi_e}{\Phi_g} \tag{1}$$

The COP of the half-effect absorption refrigeration cycle is defined as the ratio between the heat removed at the evaporator to the heat supplied to the low generator and high generator (Eq. 2).

$$\mathrm{COP} = \frac{\Phi_e}{\Phi_{lg} + \Phi_{hg}} \tag{2}$$

3 Comparison between working fluids

Fig. 4 shows the comparison of COP values vs. generator temperatures for NH_3-H_20, NH_3-$LiNO_3$ and NH_3-NaSCN absorption cycles. The COP values for these three cycles increase with generator temperatures. For the NH_3-$LiNO_3$ cycle a lower generator temperature can be used than for the others. This is an important point for utilizing solar energy since fluid temperatures for flat plate solar collectors are generally below 90°C. It is shown that, for generator temperatures higher than 80°C, the NH_3-NaSCN cycle gives the best performance, and the NH_3-H_2O cycle has the lowest COP. However, the differences among them are not very remarkable. For low generator temperatures, the NH_3-$LiNO_3$ cycle gives the best performance.

Comparison in fig. 4 shows that the system performance for the NH_3-NaSCN and NH_3-$LiNO_3$ cycles is better than that for the NH_3-H_2O cycle, however the improvement is not very remarkable. Considering the fact that, for the NH_3-NaSCN and NH_3-$LiNO_3$ cycles, no analysers and rectifiers are needed, these two cycles are suitable alternatives to the NH_3-H_2O cycle. The advantages for using the NH_3-NaSCN and NH_3-$LiNO_3$ cycles are very similar, however, for the NH_3-NaSCN cycle, it cannot operate below -10°C evaporator temperature because of the possibility of crystallization [11].

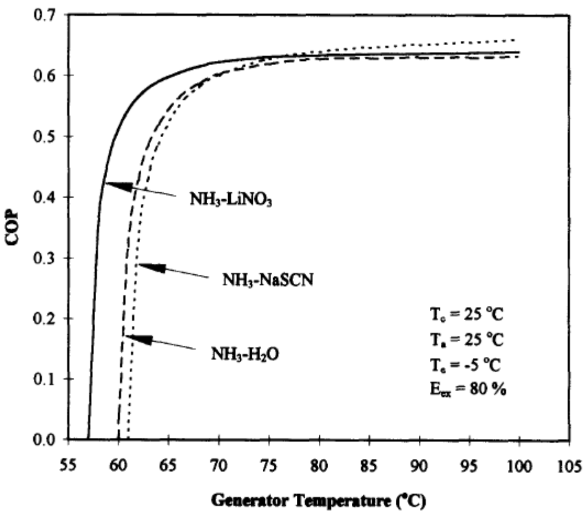

Fig. 4: Comparison of the effect of COP values on generator temperatures

Fig. 5 compares the performances of monomethylamine-water and ammonia-water working pair as a function of generator temperature at three different absorber and condenser temperatures (25, 30 and 35^{o}C for monomethylamine-water and 30, 40^{o}C for ammonia-water). It shows that the COP values increase sharply until a maximum value is reached and after that the value diminishes smoothly on increasing the generation temperature and it also diminishes on increasing the condensation and absorption temperatures. In the case of the ammonia-water solutions, the values of the COP are higher for generation temperatures above 80^{o}C corresponding to t_c = t_a = 30^{o}C and t_g above 97^{o}C for temperatures of t_c = t_a = 40^{o}C.

It can be observed that the higher values of COP for the monomethylamine-water system is found in a short range of generation temperatures between 63 and 80^{o}C, with COP values from 0.35 to 0.51, these are bigger than the corresponding ones in the ammonia-water system. The ammonia-water system has a higher COP at higher temperatures and it declines as well when the generation temperature increases. The monomethylamine-water system is a good potential pair for refrigeration cycles for absorption which can be operated at lower generation temperatures that allow the use of heat sources like solar, geothermal, industrial waste or others. An additional advantage of the monomethylamine-water system is the lower vapour required pressures. This capability would allow slighter devices to require smaller wall thickness in the components of the system. Due to the normal boiling point of the monomethylamine (-6^{o}C) and to avoid vacuum operation problems, this system can be used for air conditioning and product conservation purposes [10].

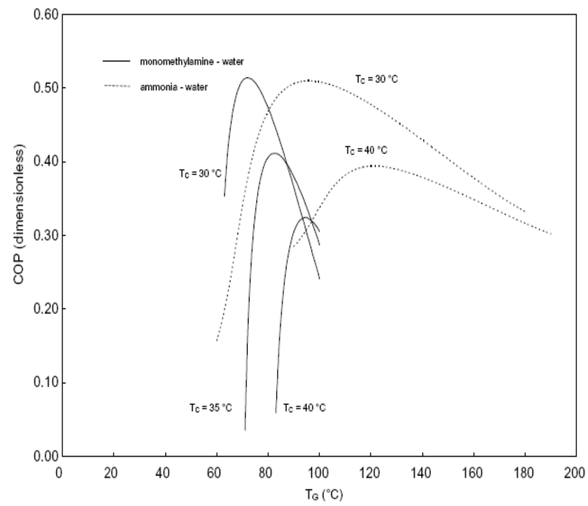

Fig. 5: Coefficient of performance for monomethylamine-water and ammonia-water

Fig. 6 compares the performances of a single-stage triple pressure level (TPL) absorption cycle with four HFC refrigerants namely: R32, R125, R134a and R152a which are alternative to HCFC, such as R22 and R124, in combination with the absorbent dimethylethylenurea (DMEU). As can be seen in fig. 6, the highest maximum of COP was achieved with the solution R22-DMEU followed by R32-DMEU, R124-DMEU, R152a-DMEU, R125-DMEU and R134a-DMEU. The lowest generator temperature at maximum COP was achieved by R125-DMEU followed by R124-DMEU, R22-DMEU, R134a-DMEU, R32-DMEU and R152a-DMEU.

As can be seen in fig. 6 there are two groups in terms of the generator temperature and circulation ratio (f) at maximum COP. The lower generator temperature obtained with the working fluids R22-DMEU, R124-DMEU and R125-DMEU which includes refrigerants from group 1 followed by the working fluids R32-DMEU, R134a-DMEU and R152a-DMEU which include refrigerants from group 2 and group 4. As can be seen in fig. 6, the working fluids of group 1 shows much lower generator temperature and circulation ratio [12] than those associated with group 2 and group 4. The solutions R22-DMEU followed by R124-

DMEU and R125-DMEU matches the definition of the preferable working fluid. Among the HFC refrigerants, the solution R125-DMEU (group 1) is the preferable despite the solution R32-DMEU (group 2) that shows the second highest COP but at much higher generator temperature and circulation ratio. The solutions R134a-DMEU and R152a-DMEU (group 2) showed the worst performances. Based on this analysis it can be said that R124-DMEU is the preferable pair among the compared working fluids while among working fluids based on HFC the preferable pair is the R125-DMEU. The fig. 6 shows that maximum value of COP is obtained at different generator temperatures depending on the working fluid.

The preferable working fluid can be considered as a solution with the highest COP, lower required generator temperature and f as low as possible. R124-DMEU is found to be the preferable pair among the compared working fluids in figure 6 while among working fluids based on HFC the preferable pair is the R125-DMEU [12].

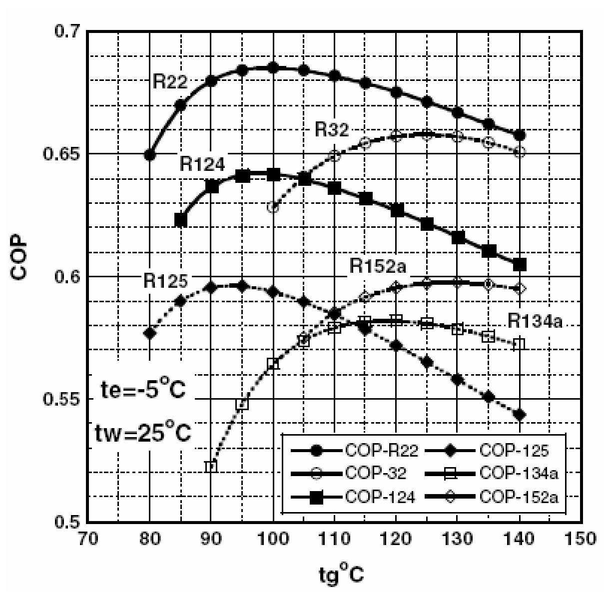

Fig. 6: Variation of the COP with generator temperature, t_g, for evaporator temperature of -5^{o}C and cooling water temperature of 25^{o}C

Fig. 7 shows the effect of the generator temperature on the COP for the vapour exchange double-lift cycle working with TFE-TEGDME, MeOH-TEGDME and ammonia-water. The performances of vapour-exchange absorption double-lift cycles working with the organic fluid mixtures TFE-TEGDME, MeOH-TEGDME and ammonia-water were compared for refrigerating applications driven by low-grade thermal energy (70 - 100^{o}C). The double-lift absorption cycles can operate in this range of heat source temperatures with a COP of about 0.45 for both TFE-TEGDME and MeOH-TEGDME, which is slightly higher than for the working pair ammonia-water. The COP of the vapour exchange double-lift cycle is better for the TFE-TEGDME fluid mixture with a minimum generator temperature of about 65^{o}C. First of all, it can be observed that the vapour-exchange cycle can be driven by a low-temperature energy source (60 - 100^{o}C) for refrigerating at 0^{o}C. The cycle performances of the three mixtures shows that the working pair TFE-TEGDME has the highest COP (0.45) in the stable range. It is about 15% higher than that of MeOH-TEGDME and ammonia-water. MeOH-TEGDME also requires at least 80^{o}C at the generators, whereas TFE-TEGDME and ammonia-water can operate at lower generator temperatures of about 65^{o}C [13].

The vapour-exchange double-lift cycle using TFE-TEGDME as the working pair seems to be the most promising combination in terms of COP and the minimum generator temperature required for the operation of the cycle [13].

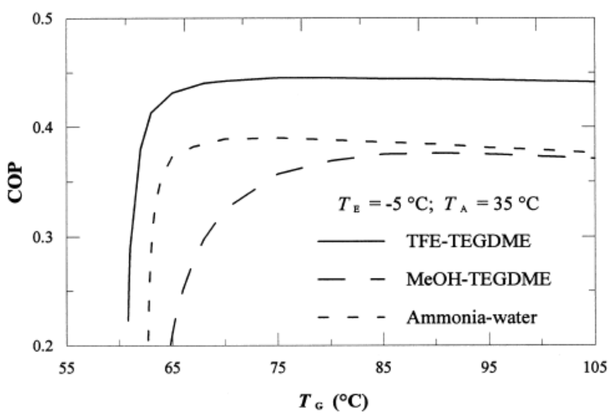

Fig. 7: Effect of generator temperature on COP for the double-lift vapour-exchange cycle

Fig. 8 shows the effect of generator temperature on the performance of the half effect vapour absorption refrigeration cycle for both R134a-DMAC and ammonia-water at different high absorber temperatures. At low generator temperature, the absorber temperature is found to be more significant, and its effect becomes negligible at high temperature. It can be concluded that the ammonia-water system cannot be operated with source temperatures below 70^{o}C under these operating conditions. When compared to ammonia-water, R134a-DMAC gives a marginally higher COP in the half effect cycle at low heat source temperatures. From these, it is evident that the R134a-DMAC refrigerant absorbent combination may be considered as one of the most favorable working fluids when a half effect system is to be operated with low temperature heat sources [14].

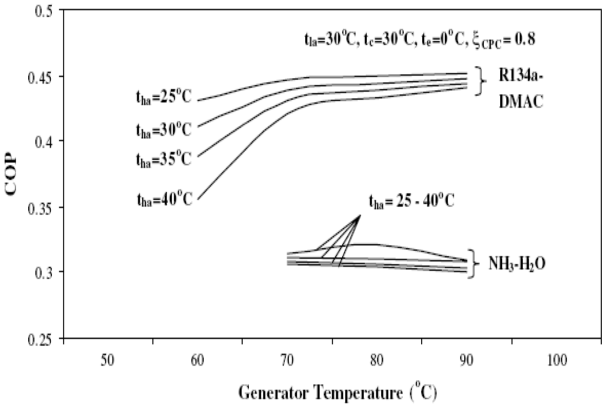

Fig. 8: Variation in COP with generator temperature at different high absorber temperature

4 Conclusion

The performance of NH_3-H_2O, NH_3-$LiNO_3$, NH_3-NaSCN, monomethylamine-water, R22-DMEU, R32-DMEU, R124-DMEU, R152a-DMEU, R125-DMEU, R134a-DMEU, TFE-TEGDME, methanol-TEGDME and R134a-DMAC as working fluids for refrigeration temperature below 0^oC were presented in this paper. The preferable working fluid can be considered as a solution with the highest COP, lower required generator temperature and circulation ratio as low as possible [12]. It is evident that COP strongly depends on working conditions such as generator, absorber, condenser and evaporating temperature.

Each cycle cannot be operated at generator temperatures lower than its limits. If the low-temperature heat source is used the half-effect absorption cycle gives the best performance.

Among presented working fluids it is evident that R124-DMEU, R125-DMEU, NH_3-$LiNO_3$ and NH_3-NaSCN are possible alternatives in terms of COP compared to NH_3-H_2O if single-effect cycle is used and R134a-DMAC and TFE-TEGDME respectively if half-effect cycle is used.

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