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Research Paper

Two-stage double-effect ammonia/lithium nitrate absorption cycle

R. Ventas *, A. Lecuona, C. Vereda, M. Legrand

Departamento de Ingeniería Térmica y de Fluidos, Universidad Carlos III de Madrid, Avda. Universidad 30, 28911, Leganés, Madrid, Spain

HIGHLIGHTS

- A two stage double effect cycle with NH3-LiNO3 is proposed.
- The cycle operates at lower pressures than conventional.
- Adiabatic absorber offers better performance than the diabatic version.
- Evaporator external inlet temperatures higher than –10 °C avoids crystallization.
- Maximum COP is 1.25 for driving water inlet temperature of 100 C.

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ABSTRACT

The two-stage configuration of a double-effect absorption cycle using ammonia/lithium nitrate as working fluid is studied by means of a thermodynamic model. The maximum pressure of this cycle configuration is the same as the single-effect cycle, up to 15.8 bars, being an advantage over the double-effect conventional configuration with three pressure levels that exhibits much higher maximum pressure. The performance of the cycle and the limitation imposed by crystallization of the working fluid is determined for both adiabatic and diabatic absorber cycles. Both cycles offer similar *COP*; however the adiabatic variant shows a larger margin against crystallization. This cycle can produce cold for external inlet evaporator temperatures down to –10 °C, but for this limit the crystallization could happen at high inlet generator temperatures. The maximum *COP* can be 1.25 for an external inlet generator temperature of 100 °C. This cycle shows a better *COP* than a typical double effect cycle with in-parallel configuration for the range of the moderate temperatures under study and using the same working fluid. Comparisons with double effect cycles using H_2O/LiBr and NH_3/H_2O as working fluids are also offered, highlighting the present configurations advantages regarding *COP*, evaporation and condensation temperatures as well as crystallization.

1. Introduction

There are some technologies that allow producing cold by means of solar energy. The synchronicity between cold demand and solar radiation makes these technologies very attractive for reducing the use of fossil fuels and CO_2 emissions. On the other hand these technologies tend to use natural refrigerants, devoid of potential ozone depletion. One of the most appropriate possibilities of solar cooling technologies is the use of solar collectors that heat a fluid, which activate an absorption chiller (e.g. [1–5]). Among them the typical configuration is based on flat plate or evacuated tubes solar collectors and a single-effect absorption chiller [1], both of which are commercially available.

For air-conditioning purposes absorption chillers using a water/lithium bromide solution offer the best efficiency to date. With this working fluid there is risk of salt crystal formation, called solution crystallization. This happens when there is one of the following causes or a combination of them, according to Reference 6: high absorber temperature (too much heat input to the desorber – i.e. full load), low ambient temperature for high absorber temperature, air leak into the machine, failed dilution after shutdown and too low chilled water delivery when the weather is hot, although cycle details can vary. Moreover, this solution is not suitable for evaporator temperatures near or below 0 °C to avoid solidification of the refrigerant, in this case, water. For refrigeration purposes, absorption chillers based on the pair ammonia/water are the most used ones (e.g. [2,7]), as ammonia is the refrigerant. The absence of salt avoids crystallization. The need of a rectification column aimed at separating water from the refrigerant downstream the generator reduces its efficiency and adds a new component to the cycle, increasing the size and cost of the chiller.

Currently other working pairs that have been studied in the last decades are being experimentally tested to document their possibilities. One of them is ammonia/lithium nitrate. This solution can produce cold at temperatures lower than 0 °C and offers a better *COP* (Eq. (22)) than the ammonia/water solution as it doesn't need

* Corresponding author. Tel.: +(34) 91 624 6224; fax: +(34) 91 624 9430.
E-mail address: rventas@ing.uc3m.es (R. Ventas).

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a rectification column. A fair amount of experiments with this solution have been carried out the last years, showing the potential of this solution [8–11]. Among others Reference 8 shows the performance of a thermochemical compressor using this solution as a part of a booster compression/absorption hybrid cycle; Reference 9 shows the results of a solar direct ice production chiller using this solution; and Reference 10 studies the two-phase heat transfer and pressure drop inside a plate-type generator. A single-effect chiller of 3 kW has already been tested [11], in addition to small-scale laboratory-like prototypes; one of them is air-cooled while another one is water-cooled [12]. The drawbacks of this fluid are its high viscosity at low temperatures, when compared with the ammonia/water solution, and its low thermal conductivity. These problems have been fought by adding a portion of water that does not evaporate (e.g. [13]). For air-conditioning purposes the single-effect cycle with this fluid offers a smaller *COP* than the single-effect cycle using water/lithium bromide, according to the abovementioned references.

The absorption cycle *COP* depends on three external temperatures: ambient, evaporation and generation (driving) temperatures. For air-conditioning purposes the thermal *COP* (Eq. (22)) of water/lithium bromide single-effect cycle falls in the range 0.6–0.8 [7]. The whole solar cooling efficiency, called solar *COP*, namely *SCOP*, is obviously smaller, being in the range of 0.2–0.4 [14,15], as it includes the solar thermal energy collection efficiency. If only cold production is considered, these figures make this technology to eventually fall in a position barely competitive with a combination of high efficiency PV electricity and a mechanical compression inverse Rankine cycle [16,17], both from a primary energy and costs points of view.

One of the possibilities to increase the *SCOP* of the solar cooling system is to work with medium temperature (MT) solar collectors [2,18] that allows reaching higher driving temperatures with higher efficiencies. Among them we find high efficiency vacuum flat plate collectors, vacuum tube collectors, and more appropriate for the MT range, we find concentrating solar collectors, such as CPCs, parabolic trough and Fresnel collectors [19,20]. The availability of a higher temperature heat allows working with double-effect absorption chillers, yielding a higher *COP*, around 1.1 [7], and also offering the added advantage of sub-zero cold production possibility. Nowadays there is a high interest on MT technology as it also allows producing usable heat or steam for industry and buildings, especially in winter when cold could be not necessary. This interest is enhanced by the availability of downgraded high temperature concentrating collectors developed for solar thermal power plants. They offer interesting procurement prices and, owing to sun concentration, offer efficiencies comparable with that of low temperature collectors at their operating temperatures, typically in the order of 0.5–0.6, yielding heat at 150 to 250 °C under nominal conditions. Defocusing is another advantage to avoid overheating and damages from meteors. In comparison with fixed orientation non-concentrating collectors the loss of diffuse solar radiation is balanced by the enhancing solar tracking, while collector cleaning is still an open question.

Residual heat at high enough temperature offers the possibility of increasing the efficiency of its conversion into cold, if a suitable thermodynamic cycle is available, with the double effect layout the main possibility.

Within this framework double-effect means that the same driving heat source produces refrigerant vapour twice, so that two vapour generators are needed. The additional one generates with an internal heat input from a component of the cycle at a higher temperature than its own, thus not consuming external energy, obviously at a lower temperature than the driving external heat input.

There are many configurations of double-effect cycles (e.g. [7]). The most common ones analysed in the literature use water/lithium bromide and ammonia/water for in-parallel and in-series cycle layouts, incorporating three pressure levels. In-parallel means

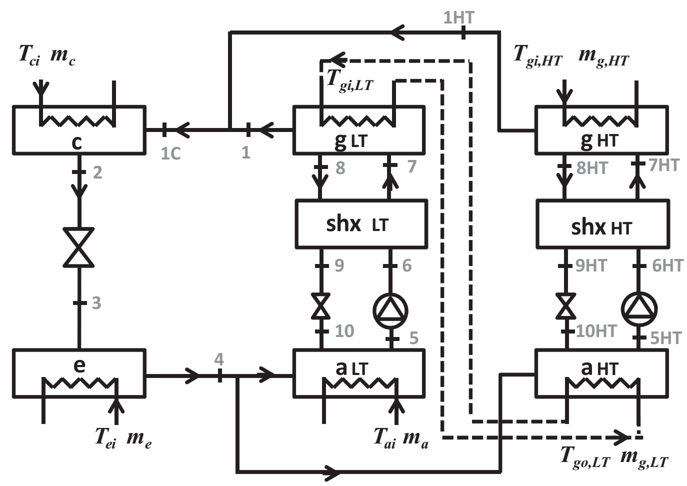

Fig. 1. Layout of the *TSDE* cycle with diabatic absorbers. Second effect circuit with dash lines.

that the solution stream going to the higher temperature generator, *gHT* in Figs. 1 and 2, does not go to the lower temperature generator; it is split among both. On the other hand, in-series means that the entire flow goes through both generators; it is not divided into two streams. Even so, there are many possible configurations, but in general it is stated that the in-series layouts favour the cooling capacity and the in-parallel ones favour the *COP* [7]. Some of them have been summarized in a review paper [22]. The high temperature generator works at a higher temperature, which implies working at a higher pressure. For the ammonia/water solution it can be as high as 70 bars; it is controlled by the condensing temperature of ammonia when delivering heat to the *LT* generator. This brings mechanical difficulties and increased cost.

For the case of ammonia/lithium nitrate solution, the studies on double-effect cycles are scarce (e.g. [21,23]). The first one [21]

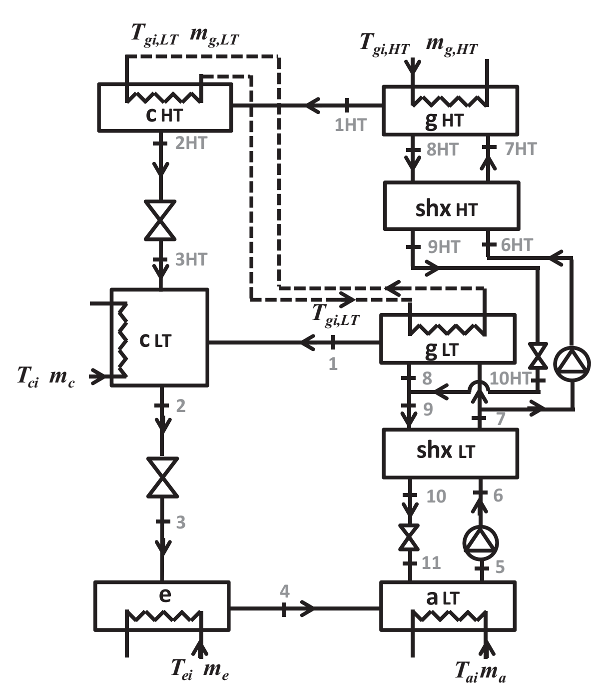

Fig. 2. Layout of the double-effect in-parallel *PDE* cycle from Vasilescu and Infante Ferreira [21], used as reference.