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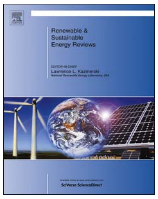

Enhancement aspects of single stage absorption cooling cycle: A detailed review

Azher M. Abed[a,b,***], M.A. Alghoul[c,d,*], K. Sopian[a,**], Hasan Sh. Majdi[b], Ali Najah Al-Shamani[a], A.F. Muftah[a]

[a] Solar Energy Research Institute, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia
[b] Department of Air conditioning and Refrigeration, Al-Mustaqbal University College, Babylon, Iraq
[c] Energy and Building Research Center, Kuwait Institute for Scientific Research, Safat 13109, Kuwait
[d] Center of Research Excellence in Renewable Energy (CoRERE), King Fahd University of Petroleum and Minerals (KFUPM), Dhahran 31261, Saudi Arabia

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ABSTRACT

Multiple simulations, experiments, and review studies on absorption cooling technology and cycles were conducted over the past few decades. However, the absorption cooling systems are not seen as competitive against more established vapor compression systems. Therefore, further research and development (R & D) are needed to enable absorption cooling technology to compete with vapor compression technology via the development of energy efficient, cost effective, environmentally friendly, and compact size systems. This study reviews the R & D enhancement aspects of single-stage absorption cooling cycles in terms of subcomponents, supported components added to the absorption cycle, internal energy recovery, and working fluids options. The R & D efforts on single-stage absorption cycles are detailed in a rich and simple presentation to provide a base for further modifications in the future, i.e., towards the optimization of the design geometry of distillation column inside within the generator, towards using adjustable ejector to work under actual operating conditions, applying new streamlines re-arrangements as a passive heat recovery technique, combination of internal heat recovery and superior (non-conventional) working fluids, and finally the addition of nanoparticles into the working fluid to optimize the duty of the generator. The outcome(s) of this study are detailed in the lessons-learned section, and future research priorities are highlighted in conclusion section.

1. Introduction

Absorption cooling systems are considered promising candidates to replace compressor refrigerating system [1–4]. The main benefits of the absorption cycles are their very low consumption of electricity (only up to 5% of the cooling capacity), possible utilizing of thermal energy obtained from renewable sources (solar radiation, biomass combustion) or whatever source of waste heat energy with temperature above 80 °C for the production of cooling. Also, some absorption machines allow very low refrigeration temperature approach to −77.7 °C. In addition, absorption systems could be cost effective when the natural gas or steam is cheaper than electric rates, or when waste heat or hot water is available. Other advantages include reduced environmental impact, and less noise and vibration.

Disadvantage of the absorption cycles is the overall poor performance, higher initial cost and the bulk size of the system compare to vapor-compression system. However, the high initial cost can be compensated by the lower operating cost compare to vapor-compression systems.

Many authors [5–12] have reported the theoretical and experimental analyses of the performance of single-stage absorption refrigeration cycles under multiple operating conditions, including those utilizing LiBr–H_2O and NH_3–H_2O as working fluids.

Current technologies can be upgraded and optimized via the

Abbreviations: AHT, Absorption heat transformer; ARC, Absorption refrigeration cycle; AARC, Ammonia/water absorption refrigeration cycle; ACH, Air-cooled heat exchanger absorber; COP, Coefficient of performance; CERC, Conventional ejector refrigeration cycle; CAA, Conventional adiabatic absorber; DA, Diabatic absorber; DAR, Diffusion absorption refrigerator; VARS, Vapor absorption refrigeration system; LVHX, Liquid vapor heat exchanger; SHE, Solution heat exchanger; SCA, Solution cooled absorber; RHE, Refrigerant heat exchanger; GAX, Generator–Absorber heat exchanger; RERC, Regenerative ejector refrigeration cycle; TPL, Triple-pressure level; EAA, Ejector-adiabatic absorber; R & D, Research and Development

[*] Corresponding author at: Energy and Building Research Center, Kuwait Institute for Scientific Research, Safat 13109, Kuwait.
[**] Corresponding author: Solar Energy Research Institute, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia.
[***] Corresponding author at: Solar Energy Research Institute, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia.
E-mail addresses: azhermuhson@gmail.com (A.M. Abed), dr.alghoul@gmail.com (M.A. Alghoul), ksopian@ukm.edu.my (K. Sopian).

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development and enhancement of heat recovery technologies, which will inevitably result in lower environmental degradation, reduced power consumption, and the capability of upgrading large quantity of low-grade waste heat at 60–100 °C in within industrial processes [13]. In this context, the absorption heat transformer (AHT) is regarded with interest for waste heat reutilization within industrial processes, due to its favorable economics and mild environmental effects [14–19].

In view of shortage of energy production and fast increasing energy consumption, it is an important to minimize the use of energy and conserve it in all possible ways. Absorption cooling offers the possibility of saving the energy to avoid losses or wastages [20]. Exploiting latent potentials in existing equipments by performing some modifications in optimum way; and recovering energy from waste heat and/or utilizing it for system efficiency improvement are important keys for a higher system efficiency. Therefore, it is desirable to provide a base for energy conservation and energy recovery from vapor absorption system.

During recent years, researchers aimed to develop techniques that can improve absorption systems performance and make them more competitive than vapor compression systems. Current researches on absorption cycles (NH_3–H_2O and LiBr–H_2O systems) are essentially focused on reducing the energy consumption by ~30–50% and determining new refrigerants. There are limitations inherent in the common working fluid pair (NH_3/H_2O) in absorption refrigeration systems, and in order to address this limitation and reduce the activation temperature of the system and refrigerant vapor rectification at the generator outlet for NH_3/H_2O cycles researchers look to new and more efficient fluid mixtures [21]. Besides, the performance of an absorption refrigeration system is greatly reliant upon the physical–chemical properties of its working fluid [22,23]. The main advantage of these working fluid pairs compared with the conventional NH_3/H_2O is the high boiling temperature difference between the absorbent and refrigerant, which eliminates the need for a rectification process [24–26]. However, in order to further enhance the performance of the absorption cycle, nanoparticles are added into the working fluid for the purpose of inducing the separation of ammonia in its vapor phase from the ammonia/water mixture to prevent the occurrence of the rectification process.

A drawback of a single-effect absorption cycles is that they are averse to the higher temperature of the heat sources in realizing higher COPs. This prompted researchers to attempt to alter this cycle to accommodate higher temperature heat source to enhance system performance. The double-effect absorption refrigeration cycle was introduced in 1956–1958 [27]. Recently, many works on the double-effect series and parallel flow cycles were reported in literature, utilizing water–lithium bromide as its working fluid [28–32]. The results proved that the double-effect absorption exceeds the single-effect system by ~15–35%. The triple-effect cycle is expected to exhibited 18% higher cooling efficiency (COP =1.41 compared to COP =1.2 for a double-effect), lower pressure (701 psi instead of 1000 psi), significantly reduced pumping power (less than one half that of the double-effect cycle), and potentially lower construction cost (33% less total heat exchange needed) [33]. However, increased effect is not necessarily beneficial to the performance of the system, as the COP of each effect will not stack to exceed a single-effect system. It should also be pointed out that the number of effects is directly proportional to the system cost. The performance of the cycle and the usage of low-grade energy source can be possible by combining technologies, or techniques or approaches. Several researchers have worked on hybrids systems [34,35]. Kern et al. [36] developed a program for hybrid solar energy collectors that converts solar radiation into a balance of low-grade thermal energy and direct-current electricity. In their system, solar energy was used as an alternative power source, as it is clean and safe. When the plant utilizes solar thermal energy, its COP reached 0.801 at a generator temperature of 91 °C. However, the system's efficiency remained at ~11.68% during the test. Supported components include solution heat exchanger (SHE), refrigerant heat exchanger (RHE), and the rectifier, which are essential in the provision of a base to recover energy and to obtain high purity ammonia vapor.

This study will cover comprehensively the enhancement aspects of absorption cooling cycle in the context of subcomponents, supported components added to the cycle, internal energy recovery, and available working fluids options.

2. R & D on effect of sub-component and supported components on optimizing absorption cooling cycle

There are many subcomponents (i.e., stripping/exhausting section and rectifying sections in generator) and supported components added to basic single-stage absorption cycle to optimize its performance. The main available subcomponents and supported components, as taken from literature, are as follows: distillation column in generator [43], rectifier [44–49] SHE and RHE [55–70], ejector [75–134], and flash tank [136–145].

2.1. Effects of distillation column design inside the generator

In order to obtain high purity ammonia vapor and minimize energy consumption at the generator, the geometry of distillation column inside the generator should be designed to ensure that the refrigeration cycle works properly. The distillation column is vital vis-à-vis optimal generator efficiency. Fig. 1 shows the enriching/rectifying section and stripping/exhausting section within the generator/distillation column. At maximum temperature, the generator is designed to heat the strong solution up till a point where a minimum concentration is realized. However, it should be pointed out that the strong solution being directed into the generator should already be at its saturated temperature. This is to allow the refrigerant to evaporate almost immediately. In the event the solution's temperature is less than its optimal value, the refrigerant vapor being produced at the generator during the process will be lower [37,38]. Also, a higher fraction of water vapor in the water/ammonia mixture will inevitably increase the vaporization temperature linked to binary solutions in the event of phase change, in a process called temperature glide. In case the vaporization temperature keeps increasing, the system will hit a point where it will be able to lower the temperature of a designated medium via an evaporator.

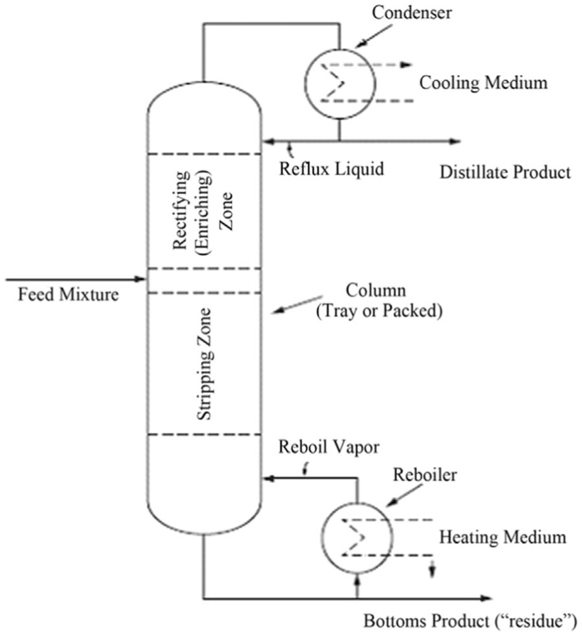

Fig. 1. Generator/distillation column.