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Comparative analysis between constant pressure and constant temperature absorption processes for an intermittent solar refrigerator

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ABSTRACT

This paper presents a detailed comparative analysis between constant pressure and constant temperature aqua-ammonia absorption processes for an intermittent solar refrigerator. The results of the analysis indicate that constant pressure processes results in as high as 20% increase in coefficient of performance compared to constant temperature processes. Also, the results indicate that there is a critical temperature below which both the constant pressure and constant temperature processes exhibit the same performance. Furthermore, it has been observed that the optimum generator temperature for constant pressure processes is approximately 12% higher than constant temperature processes. Finally, the effect of maintaining a constant temperature or constant pressure absorption processes on the heat duties of both, the absorber and the evaporator, is addressed in the paper.

Analyse comparative de processus d'absorption à pression et à température constantes pour un réfrigérateur solaire intermittent

Mots clés : Ammoniac-eau ; Systèmes intermittents ; Absorption à pression constante ; Absorption à température constante ; Réfrigérateur solaire

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Nomenclature

Symbols

E	Specific Energy supplied or rejected (kJ kg^{-1})
h	Specific Enthalpy (kJ kg^{-1})
P	Pressure (bar)
T	Temperature (°C)
x	Ammonia Mass Concentration

Subscripts

abs	Absorption process including depressurization
abs,only	Absorption process excluding depressurization
cond	Condenser or condensate
deph	Dephlegmator
depress	Depressurization process
evap	Evaporator
gen	Generation process including pressurization
gen,only	Generation process excluding pressurization
h	high
l	low
pres	Pressurization process
ref	Pure ammonia refrigerant
sol	Aqua-Ammonia solution
ss	Strong solution (Comparatively higher ammonia mass concentration)
vap	Aqua-Ammonia vapor
ws	Weak solution (Comparatively lower ammonia mass concentration)

1. Introduction

Out of the various renewable sources of energy, solar energy proves to be the best candidate for Refrigeration and air conditioning because of the coincidence of the maximum cooling load with the period of greatest solar radiation input. Solar energy can be used to power a refrigeration system in two ways. First way is that, solar energy can be converted into electricity using Photo-Voltaic Cells and used to operate a conventional vapor compression refrigeration system. Second way is that, solar energy can be used to heat the working fluid in the generator of a vapor sorption (absorption or adsorption) refrigeration system. Kim and Ferreira (2008) made a comparison between solar electric and solar thermal refrigeration systems both from the point of view of energy efficiency and economic feasibility. The comparison resulted that solar electric refrigeration systems using Photovoltaic appear to be more expensive than solar thermal systems.

Many experimental and theoretical investigations on the intermittent solar absorption refrigeration systems have been reported in the literature. For instance, Said et al. (2012) studied the alternative designs for a 24-h operating solar-powered absorption refrigeration system. The alternatives included continuous operating systems with refrigerant, cold and heat storages as well as the intermittent system with cold storage. Their analysis indicated that continuously operating system with refrigerant storage was the most suitable alternative design for an uninterrupted supply of cooling effect.

Moreno-Quintanar et al. (2012) developed a solar powered intermittent absorption refrigeration system producing 8 kg day^{-1} ice at −8 °C using ammonia/lithium-nitrate (NH_3/$LiNO_3$) and ammonia/lithium-nitrate/water (NH_3/$LiNO_3$/H_2O) mixtures. Their results indicate that with the ternary mixture the coefficient of performance achieved is 24% higher than those obtained with the binary mixture. Rivera et al. (2011) presented a novel solar intermittent refrigeration system for ice production operating with the ammonia/lithium nitrate mixture. Their system achieved the evaporator temperatures as low as −11 °C with coefficient of performance up to 0.08.

Chidambaram et al. (2011) reviewed research articles in the field of solar cooling techniques, solar collectors, storage methods and their integration, along with performance improvement studies using thermal stratification and cascaded thermal storage systems. Yijian and Guangming (2007) proposed a novel auto-cascade absorption refrigeration system. Their system achieved a refrigerating temperature of −47.2 °C under the generating temperature of 163 °C. Tangka and Kamnan (2006) designed, fabricated and tested a simple solar energy powered aqua-ammonia intermittent absorption refrigeration system. The coefficient of performance (COP) of the system was estimated to be 0.487 at the refrigeration temperature of 4 °C.

Rasul and Murphy (2006) performed an experimental analysis of NH_3–$CaCl_2$ solutions for intermittent solar absorption refrigeration. The COP of the system was found to be 0.26 because ammonia is found to have less affinity towards $CaCl_2$ compared to water. Thus higher absorption area is required which resulted in low COP for their system. Rivera and Rivera (2003) presented a theoretical analysis of an intermittent absorption refrigeration system operating with ammonia-lithium nitrate mixture. They showed that 11.8 Kg of ice could be produced at a generator temperature of 120 °C and a condensation temperature of 40 °C.

El-Ghalban (2002) designed and constructed a prototype for an intermittent absorption refrigeration system to examine its operating characteristics. Their results indicated that a COP of 19% which was 2% less than their designed value. El-Shaarawi and Ramadan (1986) manufactured and tested an experimental intermittent solar refrigerator using aqua-ammonia in the Egyptian climate. It was found difficult to prevent water from being transferred into condenser. It was suggested that the rectifier needs to be re-designed for efficient performance in refrigeration applications.

El-Shaarawi and Ramadan (1987a) also investigated the effect of varying the condensing temperature on the performance of an intermittent solar refrigerator using water-ammonia solutions. It was found that for certain specified initial temperature and solution concentration and a given maximum generator temperature, decreasing the condensing temperature causes an increase in the COP of the cycle. However, for every condensing temperature, there is an optimum maximum generator temperature beyond which the COP decreases gradually. El-Shaarawi and Ramadan (1987b,