Solar Energy 155 (2017) 130–141

Contents lists available at ScienceDirect

Solar Energy

journal homepage: www.elsevier.com/locate/solener

Experimental evaluation of single stage ejector-absorption cooling cycle under different design configurations

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ARTICLE INFO

Article history:
Received 17 June 2016
Received in revised form 31 March 2017
Accepted 4 June 2017

Keywords:
Solar-assisted absorption cycle
Single ejector
Dual ejectors
Flash tank
Thermal COP
Evacuated tube collector
Ammonia-water solution

ABSTRACT

Experimental performance of a solar assisted single stage absorption cooling system with three different design configurations operating on ammonia-water have been conducted. The system was developed and tested under the tropical climate conditions of Malaysia. The prototype cooling capacity was between 3 and 5 kW with 40 evacuated tube collectors sloped at 14° and orientated towards the south. The experimental unit has been designed to operate using three different configurations namely (a) single stage absorption cycle with single ejector (b) single stage absorption cycle with single ejector and flash tank, and (c) single stage absorption cycle with dual ejectors and flash tank. Results indicated that the dual ejectors configuration with flash tank has lower generator thermal loads and higher cooling effect compared to the other two configurations. The solar absorption system with dual ejectors and flash tank has the highest thermal COP between 0.2338 and 0.465. The COP for the basic configuration and single ejector were between 0.127–0.282 and 0.17–0.362 respectively. The theoretical model for the dual ejector flash tank cycle was validated by experimental results.

1. Introduction

The ejector offers an attractive solution for the operation process of low-grade energy absorption cycle for cooling due to the simple design, low cost and without moving part (Cizungu et al., 2005; Wongwises and Disawas, 2005). However, the basic mechanisms that make up the ejector operation are quite intricate due to interactions during the combination of two fluid streams in subsonic and supersonic conditions. This precludes the fact that the geometry of the ejector should be designed with extra care to maximize the overall efficiency. Numerous theoretical and experimental studies with ejectors have been conducted to characterize the cooling system performance (Chen et al., 2014; Dennis and Garzoli, 2011; Li et al., 2013; Nguyen et al., 2001). (Sankarlal and Mani, 2006); Sankarlal and Mani (2007) carried out an experimental study on a vapor ejector refrigeration system operate with ammonia. It was found that the entrainment ratio and coefficient of performance of the system increase with increase in ejector area ratio. Moreover, the expansion ratio increase with decrease in the compression ratio.

The application of ejector in solar refrigeration system using different working fluids were reported by (Abdulateef et al., 2009; Chen et al., 2013). (Ma et al., 2010) conducted an experimental study on a solar-assisted ejector cooling system. The primary flow of the ejector was controlled using a spindle to affect fine-tuning for ejector operation and realize optimal COP. The influences of spindle position, boiler temperature, and evaporator temperature upon the system's performance were assessed as well. Maximum entrainment ratio (0.34) and COP (0.323) were obtained from spindle position of 8 mm with a cooling capacity of 2.05 kW. The COP of the ejector-absorption cooling system is highly reliant upon the entrainment of ejector (i.e. the ratio of secondary flow rate to primary flow rate) (Sun, 1997). Entrainment is relative to the primary flow inlet state, secondary flow inlet state, and mixing outlet state of the ejector. The three primaries, secondary, and backpressures are main factors that influence the entrainment ratio (Aphornratana, 1995; Eames et al., 1995; Huang et al., 1985).

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http://dx.doi.org/10.1016/j.solener.2017.06.005
0038-092X/

Nomenclature

A_t	cross sectional area at nozzle throat (m^2)	g	generator
COP	coefficient of performance	amb	ambient
COP_{th}	thermal coefficient of performance	hot	hot water
Cp	specific heat (kJ/kg °C)	coll	collector
h	enthalpy (kJ/kg)	ch	chilled water
$\dot{m}$	mass flow rate (kg/s)	cw	cooling water
P	pressure (kPa)	w	water
Q	thermal load (kW)	i	inlet
T	temperature (°C)	o	outlet
v	specific volume (m^3/ kg)	abs	absorber
w_p	pump work (kW)	cond	condenser
ω	flow entrainment ratio, secondary stream to primary stream	gen	generator
		evp	evaporator

subscripts

a	absorber
c	condenser

The principal modifications via the addition of a two-phase ejector and a liquid–vapor separator (flashing liquid) were studied in single/multi-stage compression and multi-evaporator cycles (Aprile et al., 2009) and (Lin et al., 2012). (Kornhauser, 1990) first studied the ejector expansion refrigeration cycle using R12 as a refrigerant, which resulted in a COP improvement of ~ 21% over the standard cycle under standard operating conditions. This is attributed to the fact that the ejector utilizes kinetic energy generated by the flash gas to elevate suction pressure from the compressor. (Elbel and Hrnjak, 2008; Xu and Ma, 2010; Shuxue and Guoyuan, 2011) utilized an ejector in a quasi two-stage compression heat pump system coupled with vapor injection compressor. For a multi-evaporator cycle, (Tomasek and Radermacher, 1995) and (Elakdhar et al., 2007) proposed a compression–ejection hybrid cycle for domestic refrigeration to decrease energy losses due to the large temperature gradient between the fresh food section and the freezer section. The ejector and separator have been use to elevate the suction pressure of the compressor and undercut the compressor pressure ratio. (Xu et al., 2012) analyzed the transcritical CO_2 heat pump cycle with adjustable ejector. It was conclusively proven that the high-side pressure positively influence the performance of a system and ignored lower ejector efficiencies, which falls within 20–30%. Sarkar (2012) reviewed the various ejector technologies enhanced vapor compressor system configurations, and their performance characteristics have been reviewed by Sarkar (2012).

This paper is a continuation of the authors' previous work. The authors have studied theoretically the potential of enhancing the COP of absorption cooling cycle, by adding an ejector (Abdulateef et al., 2009), and then by adding flash tank to the ejector-absorption cycle (Sirwan et al., 2013a, 2013b). Next, (Abed et al., 2015b, 2015c) studied the effect of the solution streamlines, heat recovery and adding a refrigerant heat exchanger (RHE) on the COP of the ejector-flash tank cycle and enhanced the COP by avoiding the use of flash gas valve or booster in the cycle. This will allow the ejector to work only under the intermediate pressure of the flash tank (Abed et al., 2015a). Recently, (Abed et al., 2016) developed the mathematical model and optimized the performance of the cycle using two ejectors. The results indicated that the overall theoretical COPs increment in dual ejector-flash tank system were 11.56%, 12.42%, 13.46% and 14.05% at generator temperature of 80 °C, 85 °C, 90 °C, and 95 °C respectively over the single ejector flash tank cycle.

This paper presents the experimental studies of the performance of three different design configuration including the single stage ejector–absorption system, ejector –flash tank absorption system and dual ejectors –flash tank absorption system. Furthermore, the comparisons between theoretical and experimental results have been performed to determine the validity of the theoretical model.

2. Theoretical model

The theroretical model has been developed for evaluating the performance of dual ejector –flash tank cycle by (Abed et al., 2016). The detailed thermodynamic property equations of NH_3/H_2O have been obtained using the Engineering Equation Solver (EES) software (Klein and Alvarado, 2002). The working fluid, which is a binary mixture of ammonia and water, requires three independent parameters to define its state at any location in the system. For these state points, the additional required parameter is typically either concentration or quality. The quality at any given state was chosen as a third independent parameter (wherever appropriate), and other properties such as enthalpy and specific volume are typically obtained using these three known independent parameters. (In some instances, the enthalpy obtained from energy balances is used as an input to compute quality or concentration, depending on the specific state point under consideration.) Also, qualities of 0 or 1 as appropriate have been used to obtain concentrations at two locations in the test rig from measured temperatures and pressures: generator outlet, rectifier vapor outlet. Such state points, measured temperatures and pressures, and the expected quality (e.g., saturated liquid or saturated vapor) are used to obtain the solution concentration. The energy balance equations adopted in this study were the equations used in the previous work of (Abed et al., 2016). To evaluate the COP for the cycle, the first law of thermodynamics yields the energy balance of each component (each component can be treated as a control volume with inlet and outlet streams, and work interactions) of the absorption system as follows:

- **Mass balance**

$$\sum_e \dot{m}_e = \sum_i \dot{m}_i \quad (1)$$

- **Pump**