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Theoretical and experimental evaluation of an indirect-fired GAX cycle cooling system

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Abstract

A theoretical and experimental evaluation of an indirect-fired GAX-Prototype Cooling System (GAX-PCS), using ammonia–water as the working fluid, is presented. The GAX-PCS was designed for a cooling capacity of 10.6 kW (3 tons). A simulation model was developed, calibrated and validated with experimental values in order to predict the performance of the system outside the design parameters. Experimental results were obtained using thermal oil, at temperatures from 180 to 195 °C, as heating source. An internal heat recovery in the system of ~55% with respect to the total heat supplied in the generator was obtained. Also the performance of the GAX absorption system, integrated to a micro gas turbine (MGT) as a cogeneration system was simulated. Overall efficiencies for the cogeneration system from 29% to 49% were obtained for cooling loads from 5 kW to 20 kW, respectively. With the theoretical and experimental study of the proposed cycle, it is concluded that the GAX-PCS presents potential to compete technically in the Mexican air conditioning market.

Keywords: Ammonia–water; Absorption; Waste heat; Air conditioning; Microturbine

1. Introduction

Nowadays, there is a worldwide interest in energy systems that can work recovering waste heat or that use renewable energy and less primary energy from fossil fuel combustion, which products contribute to climate change and the greenhouse effect.

The Generator Absorber heat eXchange (GAX) absorption cooling cycle has a great potential to decrease electrical energy consumption for air-conditioning in the residential and small commercial sectors. An indirect-fired system also offers the possibility of using alternative thermal energy technologies such as advanced concentrating collectors in high beam irradiance areas, as the northern part of Mexico, hybrid systems (i.e. solar–natural gas) or to make use of waste heat from microturbines, increasing the efficiency of cogeneration systems [1–3].

The absorption systems typically work with a binary mixture, the refrigerant and the absorbent (e.g. ammonia–water, lithium bromide–water), these mixtures substitute the conventional refrigerants (CFCs and HCFCs) which are responsible in a part of the global warming and the depletion of the stratospheric ozone layer. A common binary mixture used in absorption systems is ammonia–water, which is environmentally friendly with a lower cost.

The traditional single effect ammonia–water system reaches typically a coefficient of performance (COP_{th}) of around 0.5–0.6 [4,5]. However, it can be reach up to 0.75 for water cooled systems (with water condensation temperatures from 20 to 25 °C) and radiant ceiling cooling applications (evaporation temperature from 5 to 10 °C). The lithium bromide–water systems with a COP_{th} around of

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Nomenclature

AB	absorber
AC	air compressor
AHX	absorber heat exchangers
CC	combustion chamber
CO	condenser
COP_{th}	thermal coefficient of performance
$COP_{th\text{-}aux}$	thermal coefficient of performance with parasite power auxiliary
EC	economizer
EG	electric generator
EV	evaporator
Ex_{FU}	fuel exergy
F	air filter
FR	flow ratio
GAX	generator–absorber heat exchangers
PCS	prototype cooling system
GE	generator
GHX	generator heat exchangers
m	mass flow (kg/min)
MGT	micro gas turbine
P	pressure (bar)
PR	precooler
Q	heat rate (kW)
Q_{EL}	electrical load (kWe)
Q_{FU}	fuel energy (kW)
$Q_{ir\text{-}ab}$	internal heat recovery in the absorber (kW)
$Q_{ir\text{-}ge}$	internal heat recovery in the generator (kW)
RE	rectifier
R_{Ex}	exergy efficiency
REG	regenerator
SP	solution pump
T	temperature (°C)
TUR	turbine
TV	throttle valve
T_0	reference temperature (°C)
W	power (kW)
$\eta_{I,cog}$	first law cogeneration efficiency (%)
$\eta_{II,cog}$	second law cogeneration efficiency (%)

0.7–0.8 for the same applications [4]. The GAX cycle is a system that provides the highest coefficient of performance of any single effect absorption cycle. Theoretical studies report for GAX systems COP_{th} 30% higher than single effect cycles [4,5]; recently some experimental studies of GAX cycle for air-conditioning and refrigeration have been reported [6,7]. The GAX technology was theoretically developed by Altenkirch in 1913 [4], but the first prototype working with natural gas was constructed in 1980. This technology is nowadays a reality, but research and developed in this subject continues. In the last two decades important contributions in order to increase the performance of these cycles has been achieved. For example, the GAX cycle with the addition of a pump, to recycle part of the solution from the absorber to the generator in order to equalise the quantities of heat exchanged, is known as Branched GAX cycle (BGAX) [8]; different types of recirculations have been proposed, reporting increases in the COP_{th} up to 30% higher than the simple GAX cycle. Many other advanced cycles are based on the principles developed by Altenkirch, such as the Vapour Exchange GAX cycle (VXGAX) [9], Multi GAX cycle (MGAX) [10], the Polybranched GAX (PBGAX) [10], and Regenerative GAX cycle (RGAX) [11], amongst other. Kang et al. [12] proposed the waste heat driven GAX cycle (WGAX) in order to reduce the required temperature levels in the generator and therefore, opening the possibility of utilising waste heat and avoiding corrosion problems. In the Centro de Investigación en Energía of UNAM a GAX absorption prototype has been designed and constructed for a nominal capacity of 10.6 kW (3 ton) [13]. In this type of systems the priority is the internal energy integration, which increases the cycle efficiency. The system was designed to be air-cooled for ambient temperatures of 40 °C, at these conditions a theoretical coefficient of performance (COP_{th}) of 0.82 including electricity consumption was numerically calculated. In this paper, a comparison between theoretical results and experimental results obtained with the GAX-PCS working under different conditions will be presented.

2. Methodology

2.1. GAX effect

The GAX cycle conserves the essential elements of a single effect water–ammonia cooling absorption cycle: generator (GE), rectifier (RE), absorber (AB), condenser (CO), precooler (PR), economizer (EC), evaporator (EV), throttled valves (TV) and a solution pump (SP). The difference between a traditional single effect cycle and GAX is the internal heat recovery; part of the absorption heat is recuperated by the generator, which leads to a decrease of the thermal energy supply in this device, increasing the COP_{th} of the system. In order to obtain this effect it is necessary to add to the system a pair of heat exchangers and a pump if a hydronic loop for the heat transfer is used. Fig. 1(a) and (b) shows the schematic comparison of a traditional single effect absorption system and the GAX system.

2.2. Description of GAX-PCS

The Hybrid GAX-PCS, have the same essential elements of a single effect water–ammonia cooling absorption cycle.