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Preliminary experimental characterization of a three-phase absorption heat pump

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ABSTRACT

In this paper a recently commercialized three-phase absorption heat pump that is capable of storing energy internally in the form of crystallized salt (LiCl) with water as refrigerant has been experimentally investigated during summer period. The tests have been performed with the aim to investigate the operation logic of the machine and to highlight both the reliability and the efficiency of the system over an operating conditions range of great practical interest.

The measured performance have been compared with those of a conventional electrically driven vapor compression refrigerating system from an energy, environmental and economic point of view in order to assess the suitability of the absorption heat pump: this comparison showed that the absorption system is potentially able to guarantee an energy saving, a reduction of carbon dioxide emissions and a lower operating cost only in case of the most part (at least 70%) of required thermal energy is supplied by solar collectors.

Caractérisation expérimentale préliminaire d'une pompe à chaleur à trois phases

Mots clés : cycle à absorption ; refroidisseur à entraînement thermique ; pompe à chaleur chimique ; chlorure de lithium ; refroidissement solaire ; trigénération

1. Introduction

The worldwide cooling demand has drastically increased over the last few years. This has led to the installation of a large number of electrically driven air conditioning systems (Balaras et al., 2007; Henning, 2007) with a dramatic rise in electricity consumption, which is nowadays mostly generated from fossil fuels. This trend has caused important environmental problems such as ozone layer depletion and global warming.

In this context, there is a clear need to develop more sustainable technologies in order to minimize the environmental impact of cooling applications. Absorption heat pumps have emerged as a promising alternative to conventional vapor compression cycles (Fiskum et al., 1996; Florides et al., 2002; McMullan, 2002; Wang et al., 2011), since they

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Nomenclature

Latin letters

B	natural gas-fired boiler
c	specific heat (kJ kg^{-1} K^{-1})
C	operating cost (€)
CO_2	carbon dioxide equivalent emission (kg CO_2)
COP	coefficient of performance
CW10	ClimateWell10
CWIC2	CW10 internal software
CU_{ng}	natural gas Unit Cost (€ Nm^{-3})
CU_{el}	electric energy Unit Cost (€ kWh^{-1})
E	energy (kJ)
EDC	electrically driven chiller system
EF_B	fraction of $E_{th,TDC}$ produced by natural gas-fired boiler
FC	fan-coil
IHE	internal heat exchanger
HD	heat dissipator
HWS	hot water storage
LHV	lower heating value (kWh Nm^{-3})
M	water mass flow meter
MCHP	micro combined heat and power generation
MG	natural gas volumetric flow meter
P	power (kW)/pump
PER	primary energy ratio (%)
PES	primary energy saving (%)
PHE	plate heat exchanger
R	electric resistance
SUN	Second University of Naples
T	temperature/resistance thermometer
TC0	temperature of water going towards heat dissipator before by-pass valve (°C)
TDC	thermally driven chiller
$\dot{V}$	volumetric flow rate (m^3 s^{-1})

Greeks

α	CO_2 emission factor for electric energy (kgCO_2 kWh^{-1})
β	CO_2 emission factor for primary energy (kgCO_2 kWh^{-1})
Δ	difference (%)
η	efficiency
ρ	density (kg m^{-3})

Subscripts

B	boiler
cool	cooling
el	electric
FC	fan-coil
HD	heat dissipator
in	inlet
IHE	internal heat exchanger
MCHP	micro combined heat and power generation
ng	natural gas
out	outlet
th	thermal
TDC	thermally driven chiller
w	water

can use low grade energy sources that are environmentally friendlier instead of electricity. Several scientific papers studied the integration of different types of commercially available absorption systems with cogeneration units by using the surplus of heat coming from the cogeneration device during the warm season for activating the absorption cycle and providing a combination of electric, heat and cooling energy (Angrisani et al., 2012; Chicco and Mancarella, 2009; Hernandez-Santoyo and Sanchez-Cifuentes, 2003; Serra et al., 2009). In comparison to the traditional units based on separate energy production, these plants (called trigeneration systems) showed a significant potential in terms of energy savings and reduction of CO_2 emissions (Huicochea et al., 2011; Kavvadias et al., 2010; Li et al., 2006; Lin et al., 2007).

There are several technologies of thermally activated chillers commercially available today, e.g. standard absorption system using LiBr/water or NH_3/water and salt-water absorption chiller (Srikhirin et al., 2001) and/or chemical heat pump (Wongsuan et al., 2001). Chemical heat pump is a new and promising technology which is capable of operating with low temperature heat sources: salt-water solutions such as lithium chloride (LiCl)/water, sodium sulphite (Na_2S)/water, and calcium chlorides ($CaCl_2$)/water, etc. have been used (Boer et al., 2002; Conde, 2004; Ogura et al., 2003). Absorption chillers are more common at medium or larger scale, while small scale units are in process of becoming commercial.

In this paper a recently commercialized chemical heat pump using LiCl/water as a working fluid pair has been experimentally investigated. It is a three-phase absorption system that is capable of storing energy internally in the form of crystallized salt (LiCl) with water as refrigerant; the triple-state process, so called because it uses solid, liquid and vapor at the same time, makes this thermally driven chiller (TDC) particularly different from other chemical heat pumps or standard absorption processes (which use liquid and vapor phases).

The unit was patented in 2000 (Olsson et al., 2000) and it has been developed by the Swedish company ClimateWell® via five generations of prototypes. The 4th generation of machines, that was the first to be sold commercially as from 2007 under the name CW10, is installed at the laboratory of Second University of Naples (Fig. 1). It consists of two identical units, so called barrels, that work together. Each barrel consists of four different vessels: the reactor (absorber/generator), the condenser/evaporator, the solution vessel and the refrigerant vessel. The reactor and condenser/evaporator are the active parts of the unit with a vapor channel between them, while the two other vessels are stores for salt solution and the refrigerant; the unit is operated as a closed system under vacuum conditions and there are heat exchangers in the reactor and condenser/evaporator; solution and refrigerant are pumped from the storage vessels over these heat exchangers and then flow under gravity back to the storage vessels (Bales and Ayadi, 2009).

The machine is connected to three external circuits: the thermal supply, the heat sink and the cooling supply. The