INTERNATIONAL JOURNAL OF REFRIGERATION 31 (2008) 1398–1406

available at www.sciencedirect.com

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

Performance studies on mechanical + adsorption hybrid compression refrigeration cycles with HFC 134a

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ARTICLE INFO

Article history:
Received 20 September 2007
Received in revised form
23 March 2008
Accepted 29 March 2008
Published online 4 April 2008

Keywords:
Refrigeration system
Compression system
R134a
Adsorption
Activated carbon
Two-stage system
Survey
Performance

ABSTRACT

This paper presents the results of an investigation on the efficacy of hybrid compression process for refrigerant HFC 134a in cooling applications. The conventional mechanical compression is supplemented by thermal compression using a string of adsorption compressors. Activated carbon is the adsorbent for the thermal compression segment. The alternatives of bottoming either mechanical or thermal compression stages are investigated. It is shown that almost 40% energy saving is realizable by carrying out a part of the compression in a thermal compressor compared to the case when the entire compression is carried out in a single-stage mechanical compressor. The hybrid compression is feasible even when low grade heat is available. Some performance indictors are defined and evaluated for various configurations.

Etudes sur la performance des cycles frigorifiques mécaniques à adsorption hybrides utilisant le HFC134a

Mots clés : Système frigorifique ; Système à compression ; R134a ; Adsorption ; Charbon actif ; Système biétagé ; Enquête ; Performance

1. Introduction

The refrigeration industry is intrigued by the two of the most pestering environmental issues, namely, global warming and ozone depletion. It is logical that these two seemingly distinct, *albeit*, intricately related challenges be addressed together not only through new working fluids but also through innovative thermodynamic cycles. At the same time the novelty must

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0140-7007/$ – see front matter
doi:10.1016/j.ijrefrig.2008.03.009

Nomenclature

C	concentration (kg kg^{-1})
COP	coefficient of performance
E	exergy (J)
h	enthalpy (J kg^{-1})
m	mass of refrigerant compressed in one cycle of thermal compressor (kg)
n	number of time constants
p	pressure (bar)
Q	heat input
s	entropy (J kg^{-1} K^{-1})
t	temperature (°C)
W	work (J)

Greek letters

η	efficiency
ρ	density (kg m^{-3})
t	time (s)

Subscripts

a–h	state points
ad	adsorption
c	mechanical compressor
ch	charcoal
con	condensing
des	desorption
e	evaporator
eff	effective
ex	exergetic
i	interstage
r	refrigerant
ref	reference
s	solid
u	uptake
1	one stage mechanical compression
l	lower stage
2	upper stage
′	with void volume

be tempered by practical viability keeping in view the current state of system practices. The vapour compression refrigeration (VCR) with the positive displacement compressors (such as reciprocating, rotary, scroll or screw compressors) continues to be the workhorse of cooling demands. Liquid absorption, solid adsorption, thermoelectric and thermo-acoustic cycles offer limited other options. Among them, vapour absorption has been the most tested out. Yet, it lacks the benefit of scalability to low cooling capacities and is limited by the choice of working pairs. The most investigated combination is lithium bromide + water system, which cannot be used below about 5 °C, and is handicapped by operation at subatmospheric pressures. Further, it cannot be used in a hybrid compression system with conventional compression of water vapour. The other most widely investigated pair, ammonia + water, has the problem of carry over of water vapour into the refrigeration circuit, need for high pressures and reservations on acceptability of ammonia in small scale refrigeration units. Thermoelectric systems are seldom scalable to large capacities and the thermo-acoustics is still in developmental stages.

In principle, solid adsorption based refrigeration systems have the advantage of scalability to all capacities, ranging from a few watts to several kilowatts (Gordan and Ng, 2000). A considerable amount of work on solid sorption systems has been done in the last couple of decades. The adsorbents most investigated are silica gel (e.g. Ng, 2003; Chua, 1998; Chua et al., 1999; Saha et al., 2000), zeolite (e.g. Meunier and Douss, 1990; Guilleminot et al., 1980; Ramos et al., 2003) and activated carbons (Critoph, 1989; Hamamoto et al., 2006; Cacciola et al., 1995; El-Sharkawy et al., 2006) while water, ammonia, methanol and ethanol are proposed as refrigerants. Only recently, activated carbon + HFC 134a systems have been explored. (Banker, 2003, 2006; Banker et al., 2004a; Akkimaradi et al., 2002; Srinivasan, 2006). The debate on whether to continue with hydrofluorocarbon (HFC) refrigerants or if a time has come to switch to natural refrigerants, such as ammonia and carbon dioxide or even flammable hydrocarbons is gaining prominence in the wake of the global warming issue that is rocking the world. Ozone friendly refrigerant, HFC 134a, will continue in several countries at least for the next two decades and also in small systems. Although, it can address the ozone depletion issue, it does not alleviate the problem of the need for high grade energy used in mechanical compression. New developments in scroll and screw compressor technologies have considerably reduced the mechanical energy requirements. It may be recalled that HFC 134a based mechanical compression systems require special lubricants. Adequate advances have been made in system practices using this refrigerant. Yet, any means of reducing energy of compression will be viewed favorably.

A cascade refrigeration system which reduced the energy consumption of a HCFC-22 compression system with ammonia–water absorption system provided a clue to possible energy saving (Chinnappa et al., 1993). It was shown that, the performance improves when the pressure limits during compression are such that corresponding saturation temperatures are separated by 25–30 °C. (Srinivasan, 1994) This has two benefits, namely improving the volumetric efficiency, which results in smaller compressor dimensions and a higher isentropic efficiency. Multistage mechanical compression is an option, but it doubles the number of moving parts leading to other maintenance problems.

The possibility of supplementing the energy needs of conventional mechanical compression with adsorption based thermal compression deserves investigation. The added benefit is that a thermal compressor has virtually no moving parts and can be operated with heat sources close to the ambient (Saha et al., 2006). The adsorption option obviates the need for solution heat exchangers and pumps. Except ammonia,