

AN ENVIRONMENTALLY FRIENDLY SYSTEM FOR HEATING AND COOLING APPLICATIONS

S.B. RIFFAT and N.J. SHANKLAND

School of Architecture, University of Nottingham, University Park,
Nottingham, NG7 2RD, U.K.

ABSTRACT

There is growing international concern about pollution caused by chlorofluorocarbons (CFCs) and emissions of carbon, sulphur and nitrogen from fossil fuel sources.

This paper describes the integration of an intermittent absorption system with a vapour-compression heat pump. The intermittent absorption circuit contains a low vapour pressure refrigerant/absorbent pair ($\text{CH}_3\text{OH}/\text{CaCl}_2$) whilst the vapour compression circuit contains the zero-ozone-depletion potential refrigerant, R134a. The intermittent absorption/vapour-compression system could operate using the off-peak "Economy 7" electricity tariff, or could be coupled directly to gas engines with the possibility of heat recovery from the engines. The use of a self contained gas engine provides the system with complete operational flexibility. Unlike other fuels, burning of natural gas produces only small amounts of sulphur dioxide and does not give rise to solid residues of ash and dust.

KEYWORDS

R134a; R12; refrigeration; heat pumps; absorption; vapour-compression

NOMENCLATURE

COP	Coefficient of performance (dimensionless)
Δh	Change in enthalpy (kJ/kg)
K	Heat of absorption (kJ/kg absorbent)
m	Mass flowrate (kg/s)
P	Power (kW)

Subscripts

comp	Compressor
cond	Condenser

INTRODUCTION

As international restrictions on the production and use of chlorofluorocarbons (CFCs) become more stringent, several "ozone friendly" alternative refrigerants have been developed as potential replacements for the fully halogenated CFCs affected by the Montreal Protocol. R134a is now marketed as a replacement for R12, one of the CFCs most destructive to stratospheric ozone and a contributor to global warming (Miro and Cox, 1990).

The development of the intermittent absorption system has been attributed to Faraday in 1824 (Stephen, 1983), and since then numerous refrigerant/absorbent pairs have been proposed (Hainsworth, 1944). The intermittent absorption system has previously been tested as a heat store for use with solar panels (Bougard and Jadot, 1984, Brunberg and Bakken, 1981, Offenhartz, 1980), but it is believed that the combination of this system with a vapour compression cycle is a novel application.

Tests were carried out to establish the performance of a prototype system when used as a heat pump, the electrical power consumption of the compressor and the required frequency of the defrosting process. Both heat pumping/refrigeration and regeneration cycles were demonstrated.

A comparison of the performance of refrigerants R12 and R134a was made by initially charging the vapour compression circuit of the heat pump with R12 and mineral oil. After several cycles of the heat pumping and regeneration phases, the system was purged and recharged with R134a and an ester-based lubricant, and was fitted with an R134a thermostatic expansion valve.

THERMOCHEMICAL/COMPRESSOR HEAT PUMP

Operation of the heat pump

The basic circuit of the chemical storage/vapour compression heat pump is shown in Fig.1. The heat pump has two main operational phases; regeneration and heat pumping. The regeneration phase occurs overnight, when cheap rate electricity is available under the "Economy 7" tariff. Initially, the refrigerant/absorbent pair is chemically combined in the generator/absorber. As the compressor starts to operate, the latent heat rejected at the condenser causes the refrigerant vapour to separate from the absorbent. The evaporator coil removes the heat of condensation of the refrigerant which is stored as a liquid in the accumulator/evaporator. Subcooling of the R134a or R12 provides heat for domestic hot water.

The heat pumping/refrigeration phase occurs during the day. Heat for the vaporisation of the refrigerant is extracted from a low-temperature heat source, e.g. air or water, providing a refrigerating effect at the accumulator/evaporator. The vapour produced is recombined with the absorbent, resulting in the emission of heat in the generator/absorber. This heat is used to warm the interior air of a building.

Heat pump construction

The chemical side of the heat pump consists of two interconnected mild steel cylinders, containing 4.13kg CH₃OH and 7.15kg CaCl₂ in the mole ratio 2:1 (Bougard and Jadot, 1984). Vertically stacked steel trays in the generator/absorber cylinder hold granular CaCl₂. The condenser coil of the vapour compression system is soldered to the bases of the trays and a second coil embedded in the absorbent allows the removal of heat by circulating water. The evaporator coil of the vapour compression system is formed around the outside of the liquid accumulator/evaporator cylinder. A fan passes air through an enclosure formed around the liquid accumulator/evaporator.

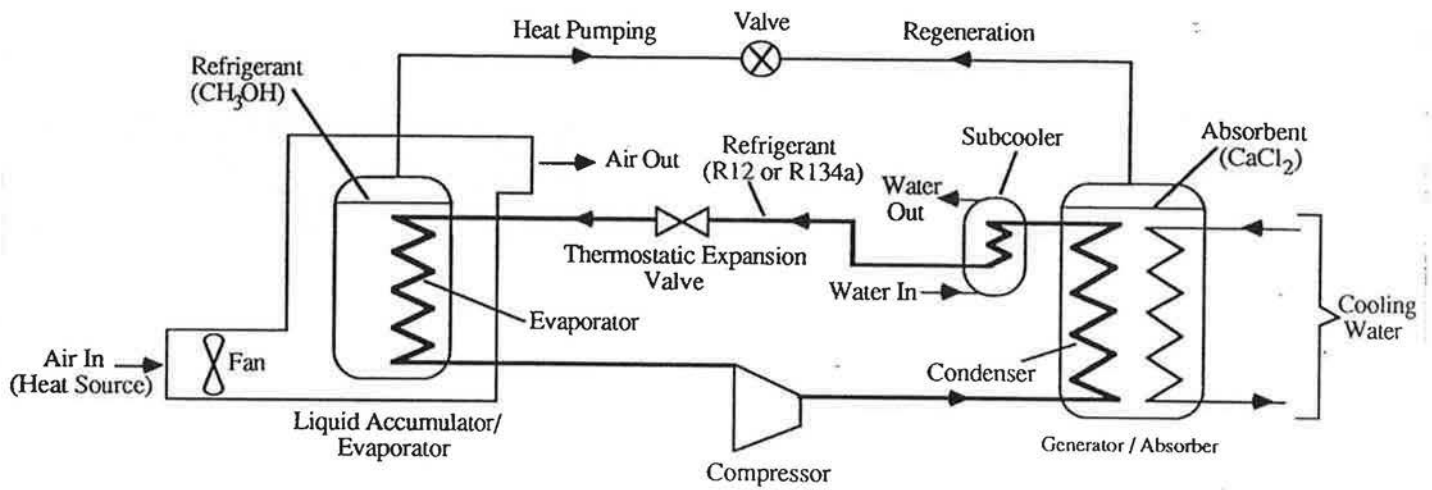


Figure 1. Schematic diagram of thermochemical/compressor heat pump.

ANALYSIS OF THE HEAT PUMP SYSTEM

The thermochemical/compressor heat pump system is analysed for the test conditions given in Table 1.

Table 1. Thermochemical heat pump test conditions.

Refrigerant charge	R12	R134a
Heat pumping heat source temperature, °C	18.8	21.2
Regeneration heat source temperature, °C	68.3	68.7
Condenser pressure, bar abs.	23.1	26.3
Evaporator pressure, bar abs.	2.0	2.1
Chemical side pressure (heat pumping), mmHg abs.	100	100
Chemical side pressure (regeneration), mmHg abs.	74	74

The theoretical and practical performance of the heat pump is evaluated using equations 1 and 2 (Riffat *et al.*, 1992).

$$\text{COP}_{(\text{theoretical})} = \frac{\Delta h_{\text{cond}} [1 - (\Delta h_{\text{CH}_3\text{OH}} / K)]}{\Delta h_{\text{comp}}} \quad (1)$$

$$\text{COP}_{(\text{practical})} = \frac{m_{\text{CH}_3\text{OH}} \cdot K}{P_{\text{comp}}} \quad (2)$$

where the value of K for the $\text{CH}_3\text{OH}/\text{CaCl}_2$ refrigerant/absorbent pair is taken as 1619.9 kJ/kg (Offenhartz, 1980) and $m_{\text{CH}_3\text{OH}}$ is the flowrate during regeneration.

Equation 1 yields theoretical COPs, based on refrigerant property tables, of 4.64 and 4.87 for systems charged with R12 and R134a, respectively. Under the given conditions, the maximum practical COPs achieved by the prototype heat pump when charged with R12 and R134a were 0.54 and 0.28, respectively. The practical COPs are based on the electric power consumed by the compressor.

The average power consumption of the compressor over the duration of the regeneration tests was found to be 924W when operating with R12 and 907W when charged with R134a.

From observation of the vapour compression system, it was found that a defrosting interval of around two hours was required to prevent excessive frosting of the evaporator coil.

Ideally, the complete charge of CH_3OH should be absorbed and desorbed during heat pumping and regeneration phases, respectively, i.e. $\text{CaCl}_2 \cdot 0 - 2\text{CH}_3\text{OH}$. However, the mean reaction obtained with the R12 charge was $\text{CaCl}_2 \cdot 0.34 - 1.52 \text{CH}_3\text{OH}$, whilst the R134a charge yielded a mean reaction of $\text{CaCl}_2 \cdot 0.47 - 1.69 \text{CH}_3\text{OH}$.

Subcooling of the refrigerant leaving the condenser provided about 20 litres of hot water at 50°C

CONCLUSIONS

A prototype thermochemical/compressor heat pump has been tested with R12 and R134a in the vapour compression circuit. Both heat pumping and regeneration phases were demonstrated, with results indicating that regeneration of the system can be achieved when using the condenser of a vapour compression circuit as a heat source.

The reduction in COP found when the system contained R134a is a result of a lower CH_3OH flowrate during regeneration (Equation 2). Since the condensing temperatures for the tests using R12 and R134a were very similar, it is believed that this reduction is caused by a change in the behaviour of the refrigerant/absorbent complex rather than a drop in performance of the vapour compression cycle. In fact, the metered power consumption of the compressor when charged with R134a was found to be around 2% lower than when charged with R12. It is concluded, therefore, that the performance of the vapour compression cycle is essentially unaffected by changing the refrigerant from R12 to R134a when the correct lubricant and expansion valve are used.

Further testing of refrigerant/absorbent combinations is currently under way. Initial results indicate that the use of the methylamine/calcium chloride refrigerant/absorbent pair will significantly improve the performance of this system by increasing the rate of refrigerant desorption during the regeneration phase, thus reducing the compressor power required. This combination also produces a lower temperature at the accumulator/evaporator and a higher temperature at the generator/absorber when the system is used for cooling and heating applications respectively.

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