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A TRIPLE-EFFECT ABSORPTION SYSTEM

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ABSTRACT

This paper describes a series triple-effect gas-fired absorption system for heating/cooling applications. Modelling of the cycle indicates that a theoretical increase in performance of around 21% over a double effect system could be achieved when using a series triple-effect absorption system.

INTRODUCTION

The continuing increase in atmospheric levels of chlorofluorocarbons (CFCs) and oxides of carbon, sulphur and nitrogen from fossil fuel sources makes the development of non-chlorinated, or partially chlorinated alternative refrigerants and energy-efficient systems of immediate concern.

Refrigerants R134a and R123 are being investigated as "ozone-friendly" alternatives for R12 and R11, respectively, in vapour compression systems. However, there is still some doubt over the effect on efficiency and capacity of replacing R12 with R134a [1-3], and recent toxicity testing has resulted in the lowering of the allowable exposure limit of R123 to 10 ppm [4]. In addition, it is necessary to find lubricants and construction materials which are compatible with the new refrigerants.

All current gas-fired absorption systems are based on single-effect and double-effect cycles. The coefficients of performance of single-effect and double-effect systems are about 0.7 and 1.1, respectively. Although the double-effect cycle gives a significant improvement in performance over the single-effect cycle, it does not match that of vapour-compression systems which operate at an electrical coefficient of performance of about 5. As a result, the double-effect absorption machine does not provide a practical alternative to existing vapour-compression systems.

The described system is "environmentally friendly" (avoids the use of CFCs) and is powered by natural gas. Unlike other fuels, the burning of natural gas produces only a small amount of sulphur dioxide and does not give rise to solid residues of ash or dust. The development of a dual purpose natural gas driven chiller/heat pump capable of providing heating and cooling is clearly an attractive proposition.

This paper describes a triple-effect absorption system with the objective of determining whether improved performance of the system justifies the more complex design.

THE TRIPLE-EFFECT ABSORPTON CYCLE

The basic circuit of the series triple-effect absorption cycle is shown in Figure 1. Liquid refrigerant (H_2O) at low temperature and pressure enters the evaporator through line 10. Heat is extracted from a source, causing the refrigerant to evaporate. The refrigerant vapour leaving the evaporator, line 11, is absorbed by the liquid absorbent (LiBr solution) in the absorber and heat is generated by the absorption process. The pump receives a low pressure "strong" solution from the absorber, line 12, elevates the pressure of the solution and delivers it to generator 1 through line 13. The solution is heated by an external gas burner, causing refrigerant to boil out of solution and leave the generator through line 1 as hot, high pressure vapour. The "weakened" solution leaves generator 1 and enters generator 2 through line 15, after passing through expansion valve 4. The heat supplied to the second generator comes from two sources; firstly, the heat of condensation rejected between lines 1 and 2 and secondly, by passing the combustion products leaving the first generator over the second generator. The weakened solution, line 16, leaves generator 2 and enters generator 3 through line 17 after passing through expansion valve 5. The heat supplied to generator 3 comes from three sources; firstly, the heat rejected between lines 2 and 3, secondly, the heat rejected between lines 5 and 6 and thirdly, by passing the combustion products leaving generator 2 over generator 3. The weak solution from generator 3, line 18, enters the absorber through line 19, after passing through expansion valve 6. The condensed refrigerant vapour, line 9, returns to the evaporator through expansion valve 3 which reduces its pressure and completes the cycle. The terminology "strong" and "weak" refers to high and low concentrations, respectively, of the refrigerant in the solution.

Parallel and combination series/parallel arrangements are also possible.

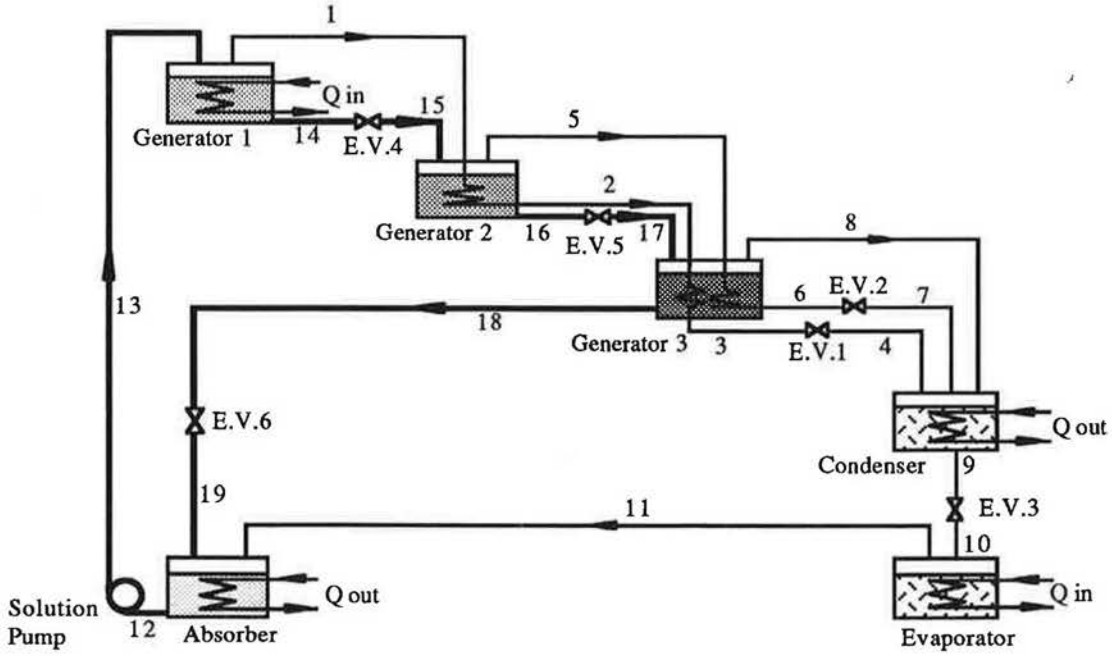

Figure 1. Series triple-effect absorption cycle

REFRIGERANT/ABSORBENT COMBINATIONS

The intermittent absorption cycle can be traced back to 1824 when Faraday developed a refrigeration unit in which the NH_3/Ag Cl pair was used as the working media. A real break through was achieved in 1859 when Ferdinand Carré developed intermittent and continuous absorption systems working with the NH_3/H_2O pair [5]. The intermittent system was used for domestic ice-making and continuously operated machines for industrial applications.

Early continuous absorption systems generally used the NH_3/H_2O pair. However, the high affinity between ammonia and water leads to migration of some water from the generator to the evaporator, producing an increase in the evaporation temperature which, in turn, reduces the efficiency of the system. Other limitations include the toxicity of ammonia, the restriction that the generator cannot be heated above 180°C as this would cause the ammonia to decompose and the fact that the NH_3/H_2O pair operates under high pressure.

The H_2O/LiBr pair has been used as an alternative to the NH_3/H_2O pair. As the H_2O/LiBr system cannot operate below 0°C, it is used mainly in large scale chillers to produce chilled water for air conditioning systems.

ANALYSIS OF THE SYSTEM

A spreadsheet-based computer program was written to analyse the double-effect and triple-effect absorption cycles. The basic cycle was modified to include solution and refrigerant heat exchangers. To allow comparison of the double-effect and triple-effect cycles, the evaporator, condenser and absorber conditions were the same for both cycles. The analysis was based on evaporator, condenser and absorber conditions of 7°C, 25°C and 53% solution concentration, respectively.Subcooling of the liquid refrigerant leaving the condenser was maintained at 10°C for both cycles.

Triple-effect cycle

The temperature and concentration of Generator 1 of the triple-effect cycle were set at 174°C and 57%, respectively, i.e. around the upper limits tabulated by A.S.H.R.A.E.[6]. The conditions of Generators 2 and 3 and of the solution heat exchangers were then adjusted to give the maximum refrigerating coefficient of performance, $C.O.P._R$.

Double-effect cycle

The conditions in Generator 1 of the double-effect cycle were set at 174°C and 57% to allow as close as possible a comparison between the double-effect and triple-effect cycles. Again, the conditions of Generator 2 and of the solution heat exchanger were adjusted to give the maximum value of $C.O.P._R$.

Results

Under the above operating conditions, the following values of $C.O.P._R$ were obtained:

Series triple-effect cycle $C.O.P._R = 1.54$

Series double-effect cycle $C.O.P._R = 1.27$

This represents an increase in $C.O.P._R$ of 21.3% for the triple-effect cycle when compared to the double-effect cycle.

CONCLUSIONS

It has been demonstrated that under certain conditions, an increase in theoretical $C.O.P._R$ can be achieved over a double-effect system when using a series-triple effect $LiBr/H_2O$.absorption system.

The 21.3% increase may be sufficient to offset the increased cost required for the more complex design with reduced running costs.

REFERENCES

1. Sand J.R., Vineyard E.A. and Nowak P.E., "Experimental performance of ozone-safe alternative refrigerants", A.S.H.R.A.E. Transactions 96(2), 173-178, 1990.
2. Kamei A. et al, "Thermodynamic charts and cycle performance of FC-134a and FC-152a", A.S.H.R.A.E. Transactions 96(1), 141-149, 1990.
3. Riffat S.B., Shankland N. and Nicholson S., "A storage heat pump using an 'ozone-friendly' refrigerant, International Journal of Energy Research, 16(1), 21-30, 1992.
4. Building Services, the C.I.B.S.E. Journal, "R123 exposure limits tightened", 13(8), 5, 1991.
5. Stephan K., "History of absorption heat pumps and working pair developments in Europe", International Journal of Refrigeration, 6(30), 160-165, 1983.
6. A.S.H.R.A.E. Handbook and Product Directory, Fundamentals. American Society of Heating, Refrigerating and Air Conditioning Engineers, 1989.