Hybrid heat pump optimization

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Abstract

Hybrid heat pumps (aka absorption/compression heat pumps) are machines capable of heat energy transfer from low to high temperature levels using both compression and absorption cooling cycle principles. According to available experimental results, an improvement of COP about 20 % is reported; next possible advantages are more efficient operation for temperatures above 80 ^{o}C and better performance control options by adjusting working mixture concentration. In the first stage a simple steady-state model of a hybrid heat pump in Excel was created, in order to compare its behavior with a standard compression heat pump working under similar conditions. Final COP of heating for a hybrid heat pump is about 10 % higher than for a standard one.

Key words: hybrid heat pump, compression/absorption heat pump, NH_3/H_2O

Abstrakt

Hybridní tepelná čerpadla (též označovaná jako absorpčně/kompresorová) jsou zařízení schopná převodu tepelné energie z nižších teplotních hladin na vyšší za využití jak kompresorové tak absorpční chladicí technologie. Podle dostupných výsledků pokusů je hlášeno zlepšení topného faktoru až o 20 %, dalšími možnými výhodami jsou efektivnější provoz za teplot nad 80 ^{o}C a lepší možnost regulace změnou koncentrace pracovní směsi. V první fázi byl v Excelu vytvořen jednoduchý model ustáleného stavu hybridního tepelného čerpadla za účelem porovnání jeho chování se standardním kompresorovým tepelným čerpadlem, pracujícím za podobných podmínek. Výsledné topné faktory hybridního tepelného čerpadla vycházejí oproti kompresorovému vyšší cca o 10 %.

Klíčová slova: hybridní tepelné čerpadlo, absorpčně/kompresorové tepelné čerpadlo, NH_3/H_2O

Nomenclature:

COP	[-]	Coefficient of performance
h	[kJ/kg]	Specific enthalpy
HP		Heat pump
M	[kg/s]	Mass flow rate
P	[kW]	Power consumption rate
p	[bar]	Pressure
Q	[kW]	Heat transfer rate
R.V.		Reduction valve
x	[kg/kg]	Mass fraction

Subscripts:

a	absorber
c	condenser
comp	compressor
d	desorber
e	evaporator
h	heating
in	inlet
out	outlet
pump	pump
ps	poor solution
rs	rich solution
s	source

1. Introduction

Hybrid heat pumps offer a great possibility for energy savings, especially for outlet temperatures higher than 80 ^{o}C and for high temperature lifts between heat source and heat sink, which may be useful mainly for industrial purposes. COP improvements of about 20 % were reported [2]. Disadvantages are little practical experience, complicated design due to combined heat and mass transfer phenomenon and resulting high investment costs in comparison with standard compression heat pumps.
For solving of these problems an optimization process is needed, which is based mainly on computer modeling. Because of the enormous complexity of this task, making of a detailed model is a very challenging objective, requiring deep knowledge of absorption and compression cooling cycle principles, physical chemistry and process engineering. Intention of this paper is to bring a brief insight into fundamentals of hybrid heat pump technology and to demonstrate its possibilities using results of a simple steady state model.

2. Basics of hybrid heat pump technology

Composition and function principle of a hybrid heat pump is explained in the following pictures of compression (Fig. 1.1) and absorption (Fig. 1.2) heat pump and finally of their combination - the hybrid heat pump (Fig 1.3). Knowledge of principles of standard compression and absorption cooling cycles is expected, they can be studied e.g. in [1], [3]. State-of –the-art of hybrid heat pumps is described in [2], [5].
As can be seen, the hybrid heat pump combines substantial parts of both absorption and compression machines - it utilizes a mixture of absorbent and refrigerant and a compressor as well.
An important difference between hybrid and absorption cycle should be noticed - the absorber and desorber in the hybrid heat pump are placed in a reversed order than in the absorption machine, i.e. desorption in the hybrid cycle occurs under low temperatures and pressures (and absorption under high temperatures and pressures).

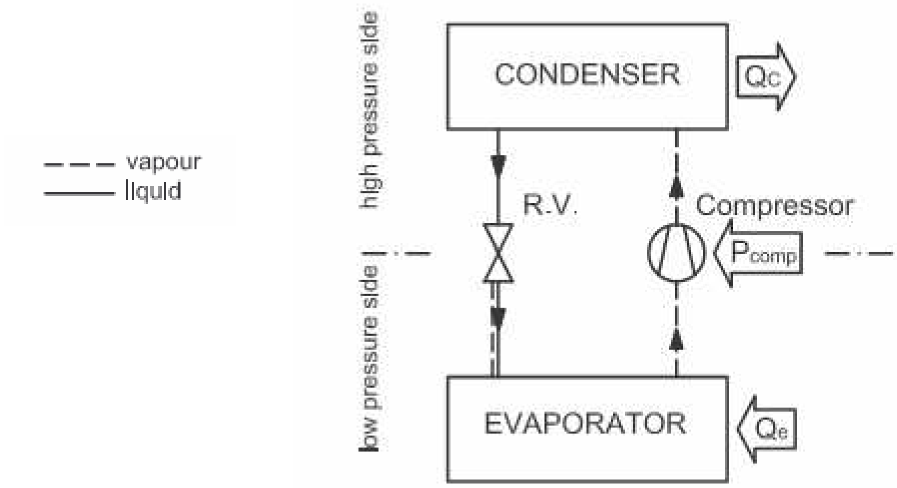

Fig. 2.1, Compression heat pump

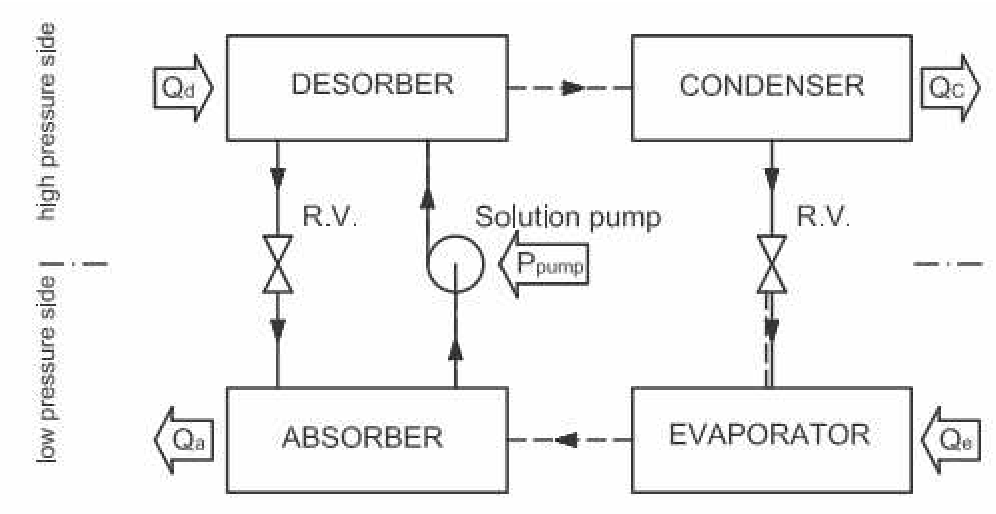

Fig. 2.2, Absorption heat pump

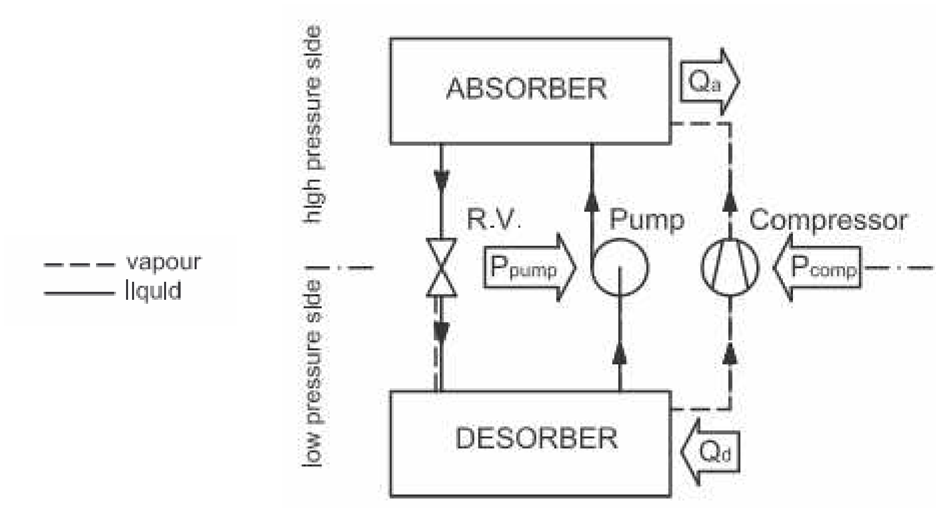

Fig. 2.3, Hybrid heat pump

3. Theoretical considerations

Two important features should be mentioned – the first is heat of mixing and the second are gliding temperature intervals. They are caused by utilization of a mixture instead of a pure refrigerant. While mixing two or more soluble components a specific amount of heat is either produced or consumed, depending on the components. For binary mixture of ammonia and water, the heat is produced, which can theoretically lead to a better COP, because the same amount of refrigerant in a mixture can deliver more heat energy then a pure one.

Gliding temperature intervals (Fig. 3.1) are caused by the fact, that by heating of a mixture, evaporation is followed with concentration change of the mixture and a consequent shift of boiling temperature. This affects performance and design of heat exchangers that operate under different conditions, compared to standard heat pumps. Theoretically, a better efficiency could be achieved, due to possible constant temperature difference between the streams along the heat exchanger length. Also it changes the point of view on the whole hybrid cycle - in an ideal case, it should be close or equal to a so called Lorenz cycle, here compared with classic Carnot cycle (Fig. 3.2), more in [4].

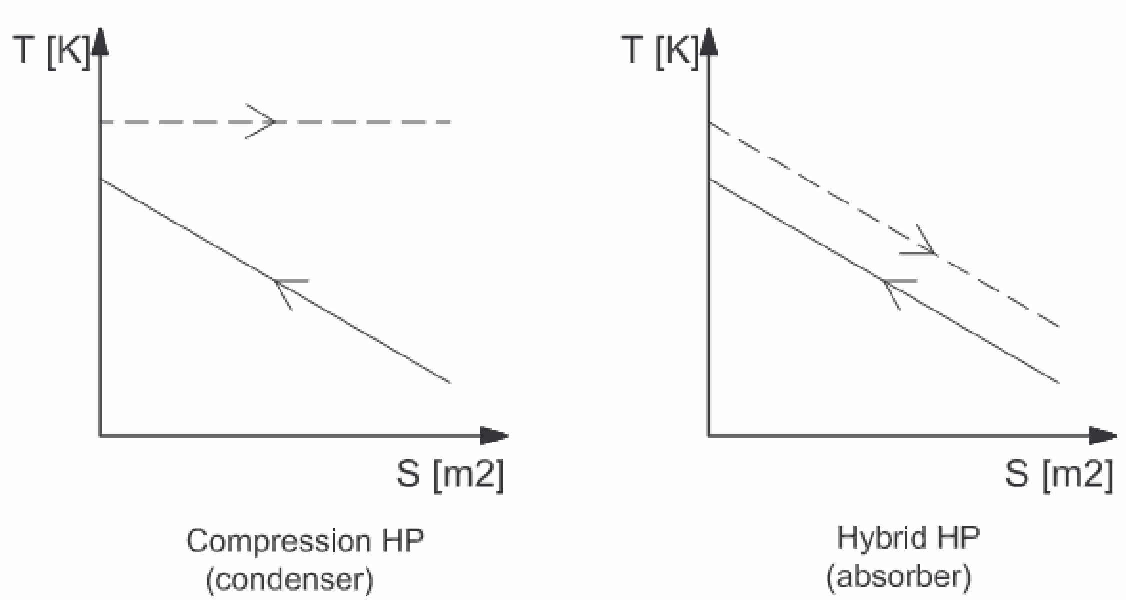

Fig. 3.1, Gliding temperature intervals

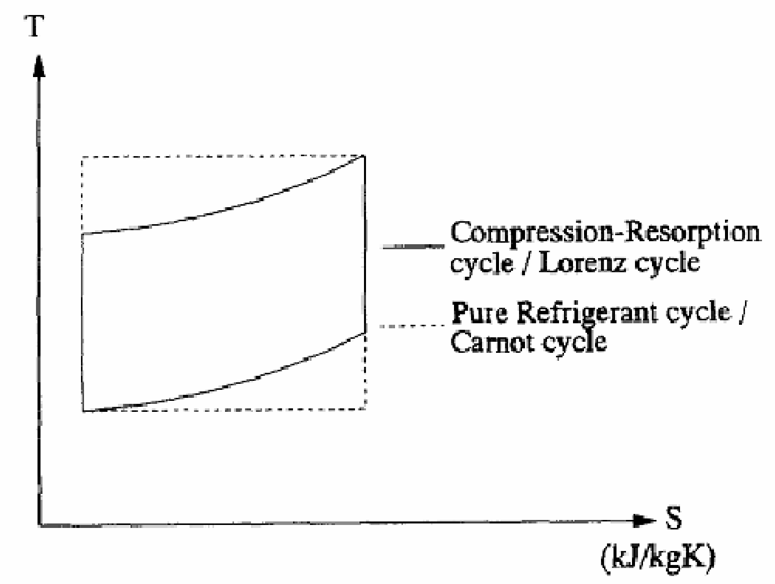

Fig. 3.2, Lorenz and Carnot cycle comparison [4]

4. Simple model

Intention was to compare COP of a compression and hybrid heat pump with ammonia as refrigerant under similar conditions.

Both models were created in MS Excel, this software is sufficient for a steady state model based on idealized equations of state and mass balances. Basic principles for computation of such a model can be found e.g. in [1], [3].

Model of a compression heat pump uses sequentially solved system of idealized steady state equations, its advantage is simplicity and transparency; it doesn't require special software tools for solving complex system of equations. Disadvantage is the level of idealization, it can be hardly used for exact prediction of real states of the machine, but it can deliver good information about their trends. As input for this model were taken: temperatures of heat source (connected to desorber -Ts1 - inlet, Ts2 - outlet) and heat sink (connected to absorber - Tin - inlet, Tout - outlet), temperature differences at heat exchangers and mass flow in the heat sink and heat source, temperature values are shown in Tab. 4.1. State properties of ammonia were computed using "FluidProp" - refrigerant property database, available online from TU Delft, Netherlands. Result is the COP depending on the outlet temperature Tout (Fig. 5.2).

Model of a hybrid heat pump in Excel uses similar approach, state properties of ammonia/water mixture were taken from "EES" software tool, evaluation copy available online. Scheme of the model with designation of streams and state properties control points is shown in Fig. 4.1. Determination of suitable input values was an important decision, since the binary system ammonia/water in the two-phase vapor/liquid region has two degrees of freedom and some combinations of temperatures and pressures used for compression heat pump model either don't exist or lead to extreme conditions for the ammonia/water mixture. Considering these facts, following input values were chosen: heat sink and heat source temperatures and refrigerant mass flow with the same values as for compression heat pump model to enable comparison and finally the initial concentration of rich solution (30 % mass fraction of NH_3). Resulting COP is displayed in Fig. 4.2 together with results of the previous model.

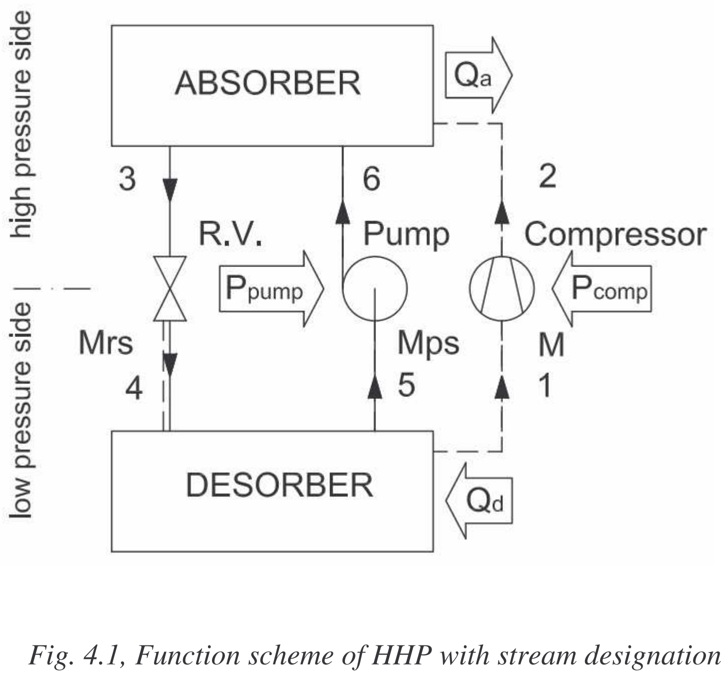

Fig. 4.1, Function scheme of HHP with stream designation

Heat source		Heat sink	
Ts1 [^{o}C]	5	Tout [^{o}C]	45 - 95
Ts2 [^{o}C]	0	Tout-Tin [^{o}C]	10

Tab. 4.1, Input boundary conditions for HP models

5. Results and discussion

Computation results displayed in Fig. 5.1 are in a good agreement with theoretical assumptions, predicting better COP for hybrid heat pump, as well as with previously reported results of experiments e.g. in [2]. As can be seen, hybrid heat pump has a higher COP (about 10 %) for a wide range of outlet temperatures (from 45 to 95 ^{o}C).
However, concerning the level of simplification of models and unexpected results of property databases for some points, they should be used carefully.

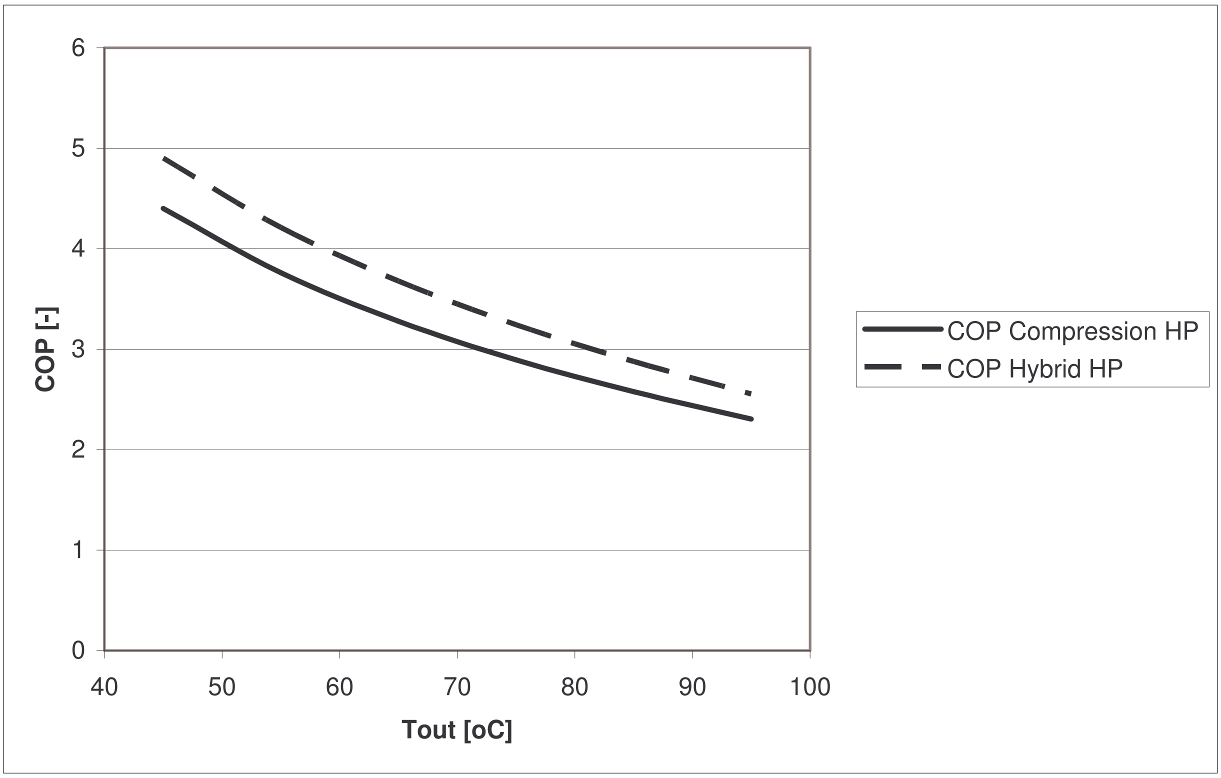

Fig. 5.1, Comparison of COP for two types of heat pumps over defined range of outlet temperatures

6. Conclusion

Simple steady state model of a hybrid heat pump proved theoretical expectations about better COP of a hybrid heat pump with ammonia/water working pair compared to a standard compression heat pump with ammonia as a refrigerant. Although the result (10 % higher COP for hybrid HP) agrees with other reports [2], considering the idealized theoretical modeling approach, this result should be taken rather as an impulse for future work on a more realistic model.

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