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New Challenges in Refrigeration

DESIGN AND PERFORMANCES OF A TWO STAGES ABSORPTION HEAT TRANSFORMER

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1. INTRODUCTION

The single stage absorption heat transformer allows to reach a temperature difference between the utilizer and the heat source which may be set slightly smaller (about 10 °C) than the temperature difference existing between the heat supply and the environment. In the most common proposed utilizers for heat transformers (residential heating, hot water supply), a higher temperature is usually needed: that may be attained by a two-stages heat transformer design.

However, a two stages machine presents some disadvantages which cannot be ignored: first, the overall C.O.P. of the engine falls from a theoretical 0.50 to a theoretical 0.25, with reference to the Stierlin scheme [1] ; secondly, a more complicated engine is undesirable because of increasing of costs. So the aim of the present paper is to verify whether a double stage absorption heat transformer can be a technical proposal worth of attention. The refrigerant - absorbent pair H_2O-LiBr is considered [2].

2. THE OPERATING SCHEME

A simplified scheme of the machine is sketched in fig. 1. The principal components are three cilindrical vessels, operating at three different pressure levels. Each of them is divided into two parts, respectively filled with pure refrigerant (sections C, E_1, E_2) and with solution (sections G, A_1, A_2).

The engine is feeded with heat at the generator G and at the evaporator E_1; the heat supply is performed at an intermediate temperature level between the utilizer and the environment temperatures.

The useful process is accomplished within the second absorber A_2, where the quantity of heat Q_u is delivered to the utilizer, at the highest temperature of the cycle.

In the condensing section C the engine releases to the cooling fluid the quantity of heat Q_c. Finally, an internal heat transfer is performed between the two components A_1 and E_2: the evaporation of the refrigerant within E_2 is obtained by the heat released by the absorber A_1.

Four temperature levels exist within the machine and three of them are related with the external heat sources temperatures. The highest one is T_{a2}, which has to be slightly higher than T_u, so that the useful heat Q_u can be exchanged; the second level is that of T_g and T_{e1}, which are slightly lower than T_h, so that G and E_1 can be feeded by the external heat source; finally the lowest temperature is T_c, which has to be slightly higher than T_o, so that the heat Q_c can be rejected to the environment. Besides a fourth

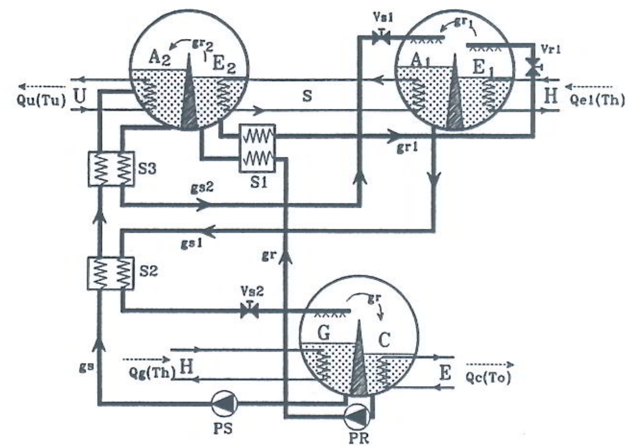

Fig. 1 - Proposed scheme of the two-stages heat transformer.

temperature level exists, connected with the internal operation of the machine: that includes the temperatures T_{a1} and T_{e2} and that is an intermediate one, between the utilizer and the external heat source temperatures; T_{a1} is slightly higher than T_{e2}, because E_2 is feeded by the heat supplied from A_1 (fig. 2).

3. QUALITATIVE OPERATION OF THE MACHINE

Let us examine now the qualitative operation of the machine. The external source H provides the heat Q_g to G, at a temperature T_h, which is not high enough to feed the utilizer directly. As a consequence, a refrigerant flow rate g_r evaporates from the solution contained within G; g_r flows to C, where it condenses and the heat Q_c is rejected to the environment.

The refrigerant flow rate g_r is pumped by PR from C into E_2, where g_r is divided into two parts, g_{r1} and g_{r2}, so that:

$$g_{r1} + g_{r2} = g_r \tag{1}$$

The flow rate g_{r1} is expanded, through the valve V_{r1} , into the evaporator E_1. The external source H provides the evaporation of g_{r1} from E_1; g_{r1} is absorbed by the solution in A_1, releasing the heat Q_{a1}, which is carried to the evaporator E_2. Q_{a1} has to be larger than Q_{e2}, to compensate for the heat losses in the exchanger S . The heat Q_{e2} causes the evaporation of the flow rate g_{r2}, which is absorbed by the solution in the absorber A_2, where the useful process of the machine is accomplished: infact in A_2 the quantity of heat Q_u is released to the utilizer U.

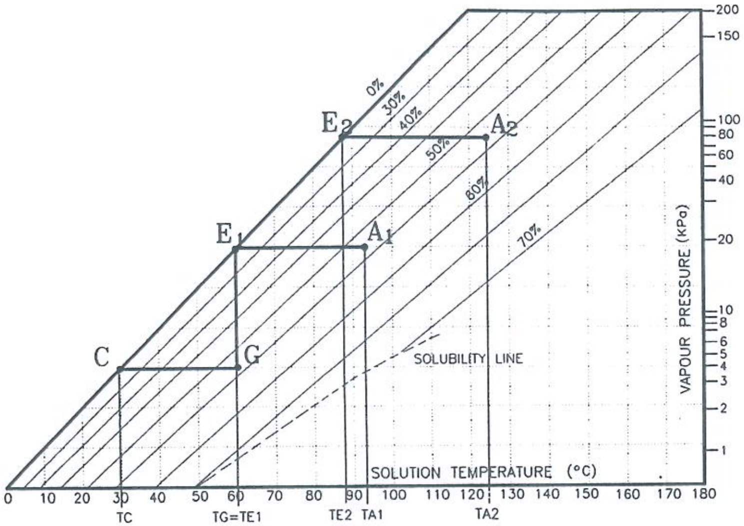

Fig.2 - Working points of the two stages heat transformer on the Water - Lithium Bromide PTX diagram.

The circulation of the solution is accomplished as follows: the pump PS takes the flow rate g_s from G into the absorber A_2. The flow rate g_s is increased by g_{r2} and the solution flow rate becomes g_{s2}, which is taken from A_2 and expanded into the absorber A_1, through the valve V_{s1}. The absorber A_1 receives the flow rates g_{s2} and g_{r1}; the resulting flow rate g_{s1} is expanded into G, through the valve V_{s2}. Three heat exchangers, S1, S2, and S3, are located on the circuits, in order to partially recover sensible heat and so to improve the performances of the machine.

4. THERMAL RATE, C.O.P. AND η_{ex}

The quantity of heat Q_u released to the utilizer is defined as the thermal rate of the heat transformer and it may be calculated as follows:

$$Q_u = Q_{a2} - Q_s + Q_{sr} - Q_{r1} - Q_{r2} \quad (2)$$

where :

$$Q_{a2} = g_{r2}\{r(T_{a2}) + s(X_{a2},T_{a2})\} \quad (3)$$
$$Q_s = g_s \gamma_s (T_{a2}-T_g) \quad (4)$$
$$Q_{sr} = \alpha_2\, g_{s1} \gamma_s (T_{a1}-T_g) + \alpha_3\, g_{s2} \gamma_s (T_{a2}-T_{a1}) \quad (5)$$

$$Q_{r1} = g_{r1} \gamma_{rv}(T_{e1}) (T_{a1}-T_{e1}) \quad (6)$$
$$Q_{r2} = g_{r2} \gamma_{rv}(T_{e2}) (T_{a2}-T_{e2}) \quad (7)$$

The Coefficient of Performance (C.O.P.) of the machine is defined as the ratio of Q_u into the sum of the energies received by the machine during the same interval of time:

$$C.O.P. = \frac{Q_u}{Q_g+Q_{e1}+L_{pr}+L_{ps}} \quad (8)$$

The quantity of heat Qg is given by:

$$Q_g = Q_{gr} - Q_{s1} \quad (9)$$

where :

$$Q_{gr} = g_r \{r(T_g) + s(X_g,T_g)\} \quad (10)$$
$$Q_{s1} = g_{s1} \gamma_s (1-\alpha_2) (T_{a1}-T_g) \quad (11)$$

The quantity of heat Q_{e1} may be calculated as follows:

$$Q_{e1} = Q_{er} - Q_{r1} + Q_l - Q_{lr} \quad (12)$$

where:

$$Q_{er} = g_{r1}\, r(T_{e1}) \quad (13)$$
$$Q_{r1} = g_{r1} \gamma_{rl}(T_{e2}) (T_{e2}-T_{e1}) (1-\alpha_1) \quad (14)$$
$$Q_l = g_r \gamma_{rl}(T_c) (T_{e2}-T_c) \quad (15)$$
$$Q_{lr} = \alpha_1\, g_{r1} \gamma_{rl}(T_{e2}) (T_{e2}-T_{e1}) \quad (16)$$

Finally the pump works are given by :

$$L_{pr} = g_r v_r (P_{e2}-P_c)/\eta_{pr} \quad (17)$$
$$L_{ps} = g_s v_s (P_{a2}-P_g)/\eta_{ps} \quad (18)$$

The exergetic efficiency η_{ex} is defined as the ratio of the exergy of the useful heat Q_u into the sum of the exergies entering the machine :

$$\eta_{ex} = \frac{W_u}{W_g + W_{e1} + L_{pr} + L_{ps}} \quad (19)$$

where:

$$W_u = Q_u\, (1 - T_o/T_u) \quad (20)$$
$$W_g = Q_g\, (1 - T_o/T_h) \quad (21)$$
$$W_{e1} = Q_{e1}\, (1 - T_o/T_h) \quad (22)$$

For sake of completeness we remember the relations among the flow rates of the solutions:

$$g_{s2} = g_s + g_{r2} \quad (23)$$
$$g_{s1} = g_{s2} + g_{r1} \quad (24)$$

5. THE REAL OPERATION WITH WATER - LITHIUM BROMIDE

The theoretical scheme proposed in the precedent sections is applicable to pairs which need no rectification. The operating conditions will depend on the particular substances and on the temperatures of the external sources. Moreover, the temperatures of an absorption machine are not independent from each other [3], but they may be correlated by means of the P-T-X diagram. So a parametric study is needed to

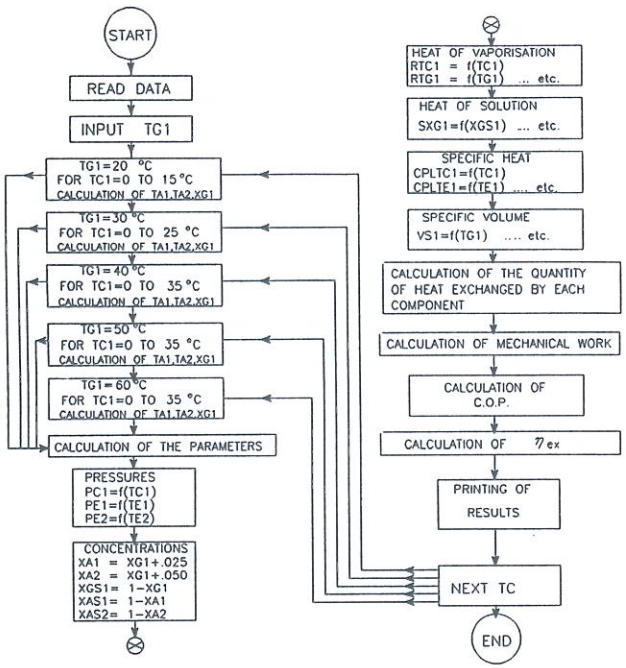

Fig.3 - Block diagram of the computer program.

evaluate the performances of the machine with varying of the design conditions, such as : environment temperature, utilizer temperature, temperature of the supplying heat .

A computer program has been developed, following the block- diagram sketched in fig. 3; that consists of the following principal items :

- two operating conditions are fixed (the environment and the external heat source temperatures);
- with a sub-routine program the P-T-X diagram of Water- Lithium Bromide is explored and the third temperature (in this case the temperature T_u of the heat released to the utilizer) is calculated;
- the data of the thermophysical properties of the solution Water-Lithium Bromide are introduced into the program, in the form of equations depending on temperature and concentration [4]. These equations are not reported for sake of brevity;
- the calculations of heat rate, C.O.P. and η_{ex} are carried on;
- the calculation is repeated for other values of design conditions so that the diagrams of fig. 4, 5, 6 and 7 are obtained.

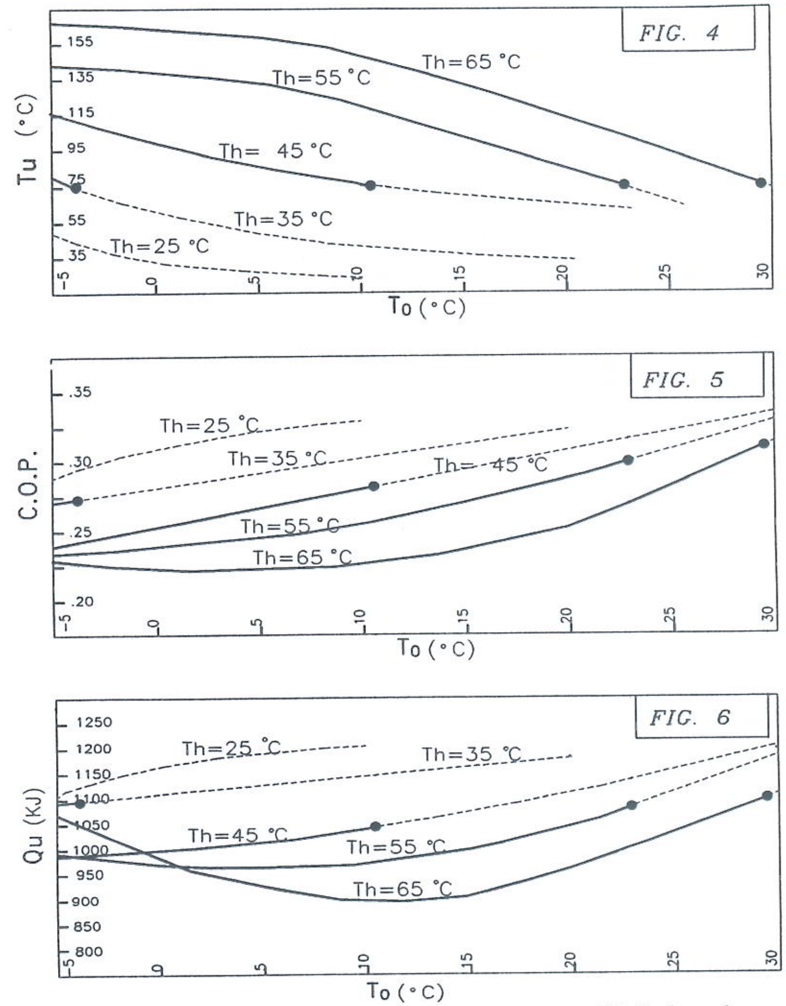

Fig. 4, 5, 6 - Performances of the machine: utilizer temperatures, C.O.P., thermal rates.

6. RESULTS AND DISCUSSION

On the figures 4, 5, 6 are sketched the graphics of T_u, C.O.P. and Q_u vs. T_o, for different values of T_h. A flow-rates ratio $m = g_s/g_r = 10$ has been considered, as it is in

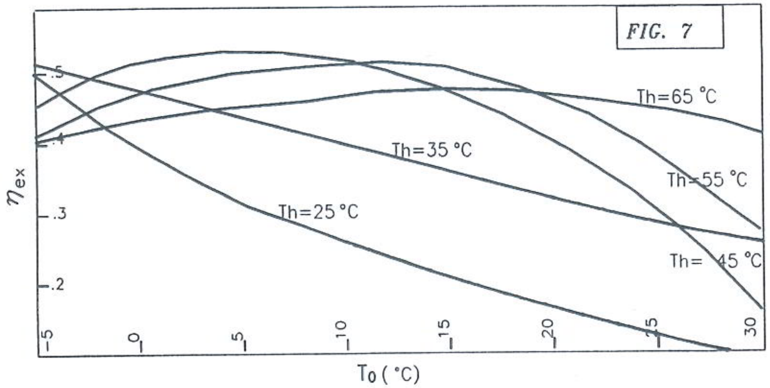

Fig. 7 - Performances of the machine: exergetic efficiency.

the commercial Water-Lithium Bromide machines. Utilizer temperatures higher than 75 °C have been put into evidence, because that field is good for applications to conventional residential heating [5].

Temperatures of the heating fluid higher than 45 °C are enough to reach the desired utilizer temperatures in a wide interval of the environment temperature; however the heat rates and the C.O.P. exhibit quite low values.

A comparison has been carried on between the one and two stages engines: the results are shown in the figures 8, 9, 10. The two stages machine allows to get a larger increase of the utilizer temperature , but, in the meantime, it presents a reduction of the heat rate and of the C.O.P..

The graphic of η_{ex} vs. T_o, for different values of T_h, is sketched on figure 7. We may conclude that a two stages heat transformer may be proposed for conventional residential heating only if there are large amounts of heat, at temperatures in the field 40 - 50 °C, disposable and free of charge during wintertime.

7. LIST OF SYMBOLS

C.O.P.	=	Coefficient of Performance
g	=	Flow Rate (Kg/sec)
H	=	External source of Heat
L	=	Mechanical Work (KJ)
P	=	Pressure (KPa)
PR	=	Pump of the Refrigerant
PS	=	Pump of the Solution

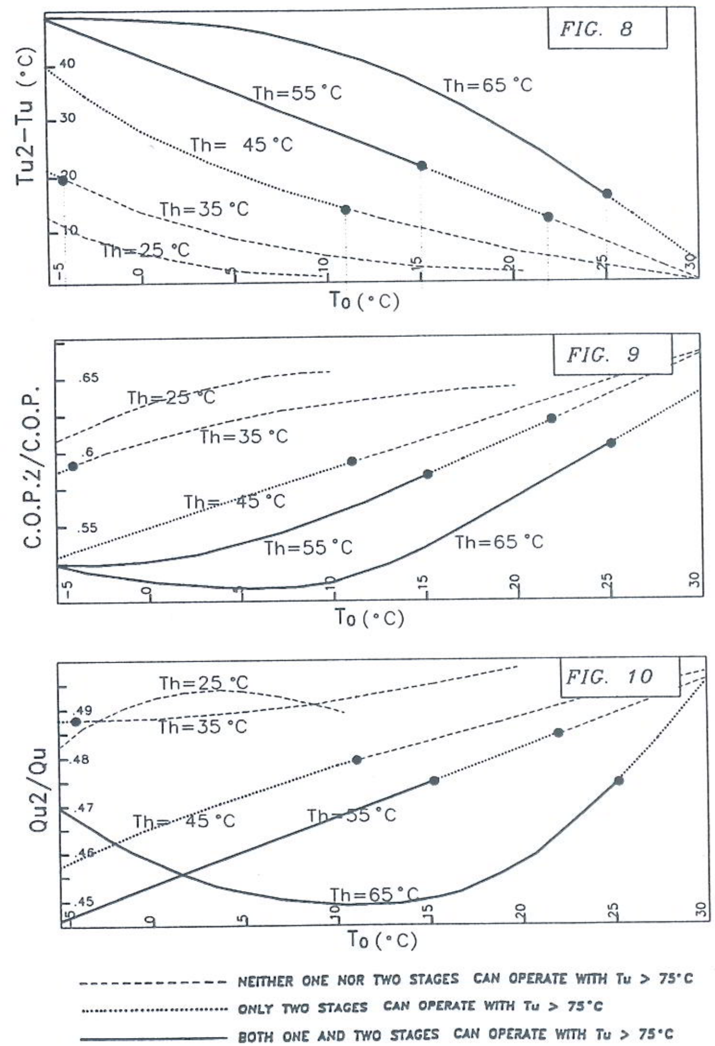

Fig. 8, 9, 10 - Comparison between one and two stages heat transformers: operating temperatures, C.O.P., thermal rates.

Q = Quantity of Heat (KJ)
T = Temperature (K, ^oC)
v = Speficic Volume (m^3/Kg)
X = Concentration of Refrigerant (% by weight)

Greek Letters.

α = Efficiency of Heat Exchangers
γ = Specific Heat (KJ/Kg K)
η = Efficiency

Subscripts.

a = absorber
c = condenser
e = evaporator
ex = exergetic
g = generator
h = heat supply
l = liquid
o = environment
p = pump
r = refrigerant
R = recovered
s = solution
u = utilizer
v = vapour

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DESSIN ET PERFORMANCES D'UN PARTICULIER TRANSFORMATEUR DE CHALEUR A DEUX ETAGES

Résumé: Un particulier dessin d'un transformateur de chaleur à Eau-Bromide de Lithium a été étudié pour atteindre de temperatures d'utilisation plus élevées. La machine est composée par trois appareils qui travaillent à trois differents valeurs de pression: les performances de la machine sont calculées pour differentes conditions operationelles et comparées avec celles de la machine à un étage.