

Solar heat transformation alternatives

M. Felli*, F. Cotana** and C. Buratti***

SYNOPSIS

The utilization of solar energy in wintertime corresponds with the low temperature of the produced heat, which is often too low to directly feed heating plants. Heat transformation appears to be an attractive way of increasing the temperature of solar fluids, so that in the present paper some solutions are examined with different operating mixtures, i.e. $\text{H}_2\text{O-LiBr}$, $\text{CH}_3\text{OH-LiBr}$, $\text{CH}_3\text{OH-LiBr-ZnBr}_2$ (2:1, 3:1). The overall efficiencies of the mentioned systems are determined, as well as the heat rates and the exergetic efficiencies. The conclusions are positive, especially with low values of the solar radiant power W_i . For values of W_i less than 700 W/m^2 , which cover the majority of situations in temperate climates, it is remarkable that the introduction of an absorption heat transformer increases the overall efficiency; the advantage becomes very appropriate for low values of W_i , as it is usual in cold-temperate climates.

INTRODUCTION

The fluids heated by flat plate solar collectors usually do not reach a high enough temperature to directly feed conventional heating plants; although if those temperatures are reached, the efficiency may be very low. So heat transformers could be installed between the solar and the heating plants, in order to raise the temperature of the fluid heated by the solar plant. The heat transformation, however, implies a reduction of about 50% of the heat available at higher temperatures, so that evaluations have to be carried out to understand whether and in which conditions the proposed solution may be efficient.

In this paper a general layout of the plant is shown and the overall efficiency is calculated. Furthermore, a number of particular binary and ternary mixtures are examined, such as:

- Water-Lithium Bromide ($\text{H}_2\text{O-LiBr}$);
- Methanol-Lithium Bromide ($\text{CH}_3\text{OH-LiBr}$);
- Methanol-Lithium Bromide-Zinc Bromide ($\text{CH}_3\text{OH-LiBr-ZnBr}_2$) with molar ratio 2:1 between the salts (two moles of LiBr for one mole of ZnBr_2);
- Methanol-Lithium Bromide-Zinc Bromide ($\text{CH}_3\text{OH-LiBr-ZnBr}_2$) with molar ratio 3:1 between the salts.

The P-T-X used and the calorimetric data are taken from our laboratory [1] and from the literature [2, 3]. The different mixtures are compared in the $-10/+20^\circ\text{C}$ range of the environment temperature: heat rate, energetic and exergetic efficiencies are calculated supposing that the required temperature of the utilizer is 60°C .

* M. Felli, Università degli Studi di Perugia, Istituto di Energetica, Strada S. Lucia, Canetola, Perugia 06125, Italy.

** F. Cotana, Università degli Studi di Perugia, Istituto di Energetica, Strada S. Lucia, Canetola, Perugia 06125, Italy.

*** C. Buratti, Università degli Studi di Perugia, Istituto di Energetica, Strada S. Lucia, Canetola, Perugia 06125, Italy.

© Ambient Press Limited 1994

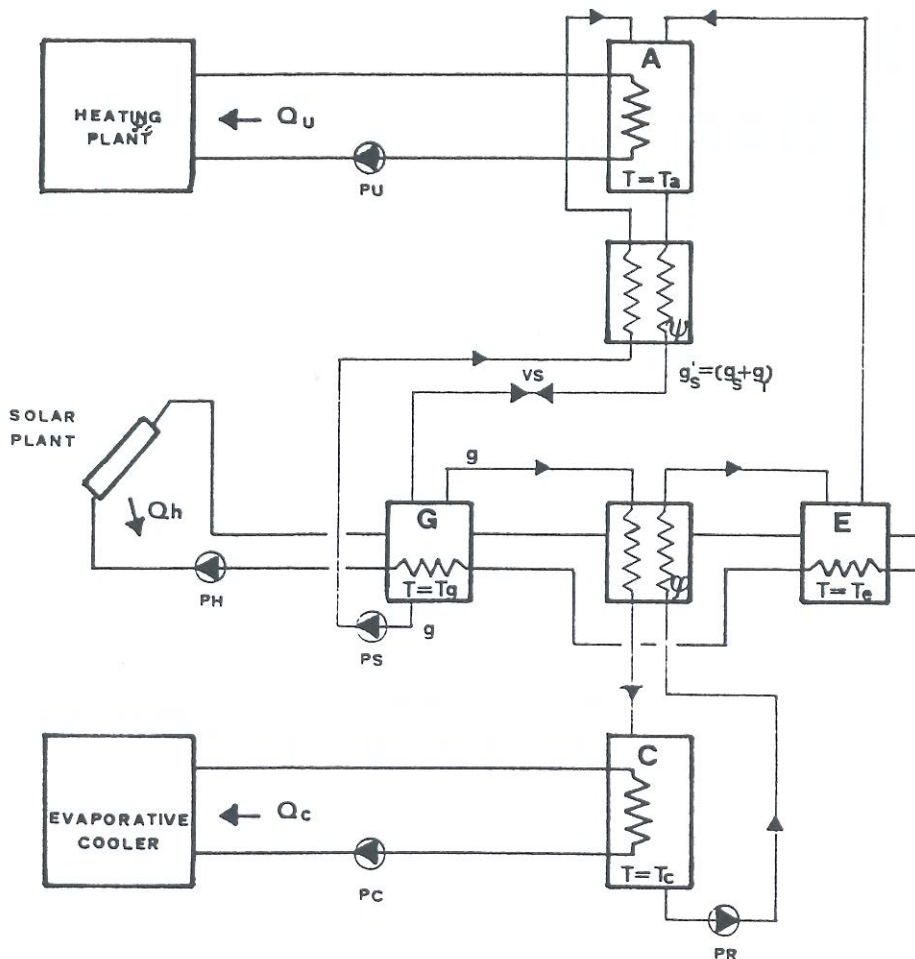


Figure 1
General layout of the proposed system.

GENERAL LAYOUT OF THE PROPOSED SYSTEM

A general layout of the system is sketched in Figure 1. A solar plant feeds the generator G and the evaporator E of the heat transformer, at a temperature some degrees higher than the arithmetic mean of the utilizer and the environment temperatures. The solar plant supplies the heat Q_h to the generator G; consequently, 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 released into the environment. The refrigerant flow g_r is pumped from C into E by PR: the solar plant supplies therefore the evaporation of g_r from E; g_r is finally absorbed by the solution in A, releasing the heat Q_u to the utilizer. The circulation of solution between G and A completes the cycle that is accomplished as follows: the pump PS takes the flow rate g_s from G into A and the flow rate $g_s' = g_s + g_r$ is expanded from A into G through the valve VS. Two heat exchangers, ψ and ϕ , are located on the circuits in order to partially recover sensible heat and to improve the performances of the machine.

The total efficiency of the described system may be defined as follows:

$$\epsilon = \frac{Q_u}{W_i} \tag{1}$$

ϵ depends both on the efficiency of the solar plant, defined as:

$$\eta = \frac{Q_h}{W_i} \tag{2}$$

and on the Coefficient of Performance of the absorption heat transformer, defined as:

$$C.O.P. = \frac{Q_u}{Q_h} \tag{3}$$

Combining the equations (1), (2) and (3), it may be stated that:

$$\epsilon = \eta \cdot C.O.P. \tag{4}$$

The efficiency of flat plate solar collectors may be considered as a linear function of the temperature difference $(T_h - T_o)$; besides it rises with the increase of the radiant power W_i incident on the collector (see Figure 2).

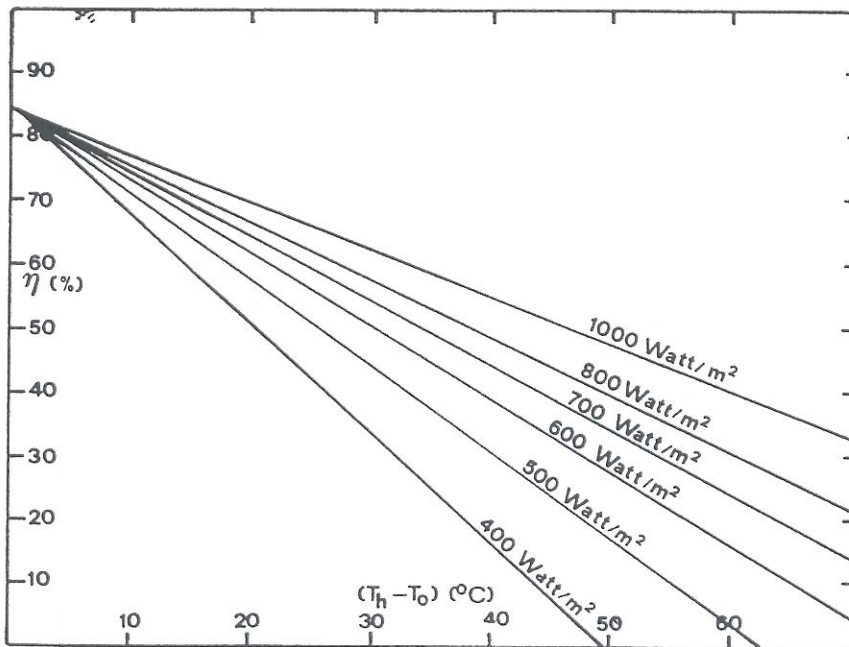


Figure 2
Efficiency of flat plate solar collectors vs. the difference $(T_h - T_o)$, for different values of the radiant power [5].

The C.O.P. of an absorption heat transformer is given by [4]:

$$\text{C.O.P.} = \frac{Q_a}{Q_g + Q_e + L_{pr} + L_{ps}} \quad (5)$$

where [4]:

$$Q_a = r(T_a) + s(X_a, T_a) - \gamma_s(T_a - T_g) [m - \alpha_\psi(m + 1)] - \gamma_{r,v}(T_a - T_e)$$

$$Q_g = r(T_g) + s(X_g, T_g) - (1 - \alpha_\psi)(m + 1) \gamma_s(T_a - T_g) \quad (6)$$

$$Q_e = r(T_e) + \gamma_{r,l}(T_e - T_c) - \gamma_{r,v}\alpha_\psi(T_g - T_c)$$

$$L_{pr} = v_r(P_e - P_c)/\eta_{pr}$$

$$L_{ps} = mv_s(P_a - P_g)/\eta_{ps}$$

COMPARISON OF DIFFERENT FLUIDS

A computer program has been developed, which allows the calculation of the total efficiency of the proposed system by means of the Equations 1–6 and the diagrams shown in Figure 2; the block diagram of the mentioned program is sketched in Figure 3. The utilization temperature is fixed equal to 60°C, while the environment temperature is assumed to be variable in the $-10/+20^\circ\text{C}$ range. The heat exchange requires temperature differences between fluids, so that it may be assumed that:

$$\begin{aligned} T_u &= T_a - 5^\circ\text{C} \\ T_h &= T_e + 5^\circ\text{C} = T_g + 5^\circ\text{C} \\ T_o &= T_c - 5^\circ\text{C} \end{aligned} \quad (7)$$

All mixtures having Methanol as a refrigerant show about the same C.O.P., which is in the 0.52–0.56 range, and also about the same η_{ex} , which is in the 0.65–0.70 range; the C.O.P. of $\text{H}_2\text{O-LiBr}$ mixture is in the 0.47–0.48 range, while the exergetic efficiency is in the 0.50–0.55 range. On the contrary, the thermal rate per unit weight of refrigerant is much higher for Water (2300–2350 kJ/kg) than for Methyl Alcohol (1200–1400 kJ/kg).

Figures 4a, 4b, 4c and 4d show that all the parameters concerning the solar heat transformers are slightly variable with the operating conditions; this is very good for solar operation in wintertime, because a smaller and more convenient volume of accumulation is better achieved. This behaviour is emphasized in Figures 5a, 5b, 5c and 5d, where the overall efficiency of the solar-heat transformer system is reported vs. the environment temperature (continuous lines); in the same Figures, the efficiency of a simple solar system is reported vs. the environment temperature (dashed lines). If very high radiant powers were available ($>700 \text{ W/m}^2$), the simple solar system is preferable to the integrated solar-heat transformer system. But, in the majority of situations, when the radiant powers are less than 700 W/m^2 , the integrated system exhibits higher mean efficiency values; besides, if the radiant power is less than 400 W/m^2 , the simple solar system is not able to operate, while the integrated system can.

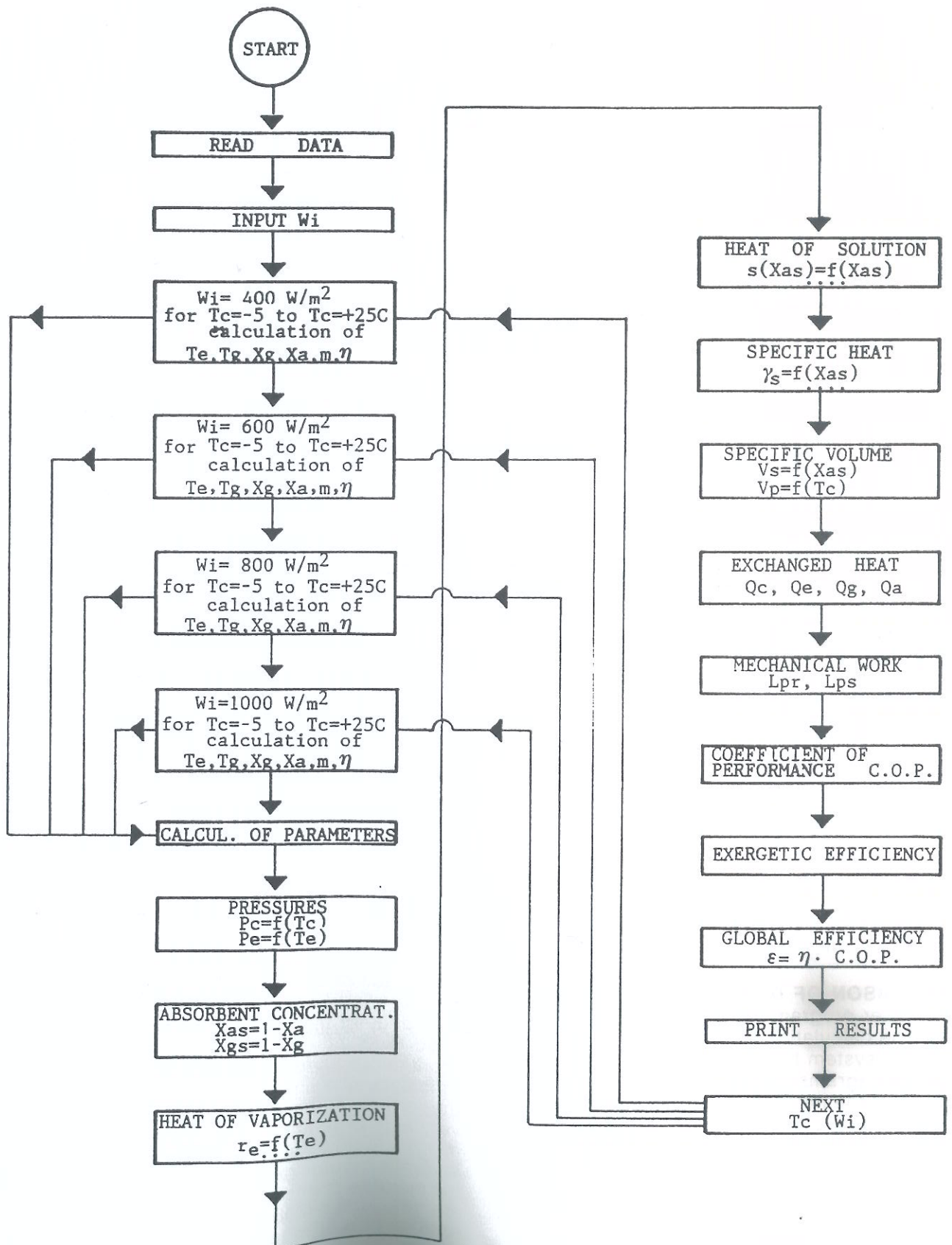


Figure 3 Block diagram of the computer program.

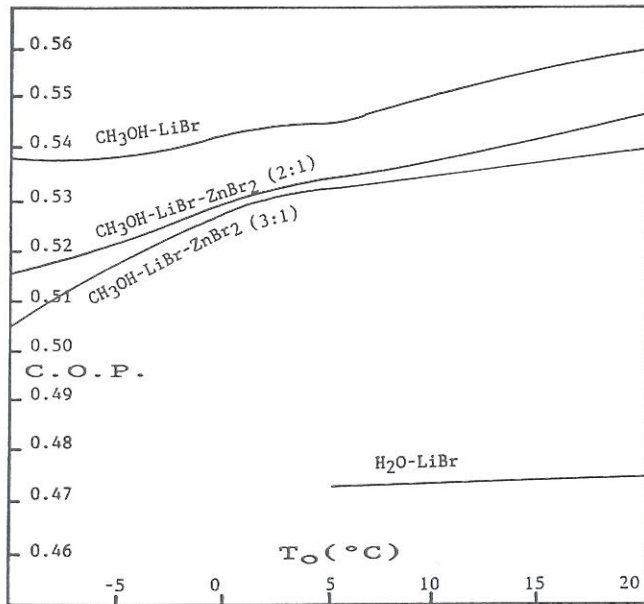


Figure 4a C.O.P.

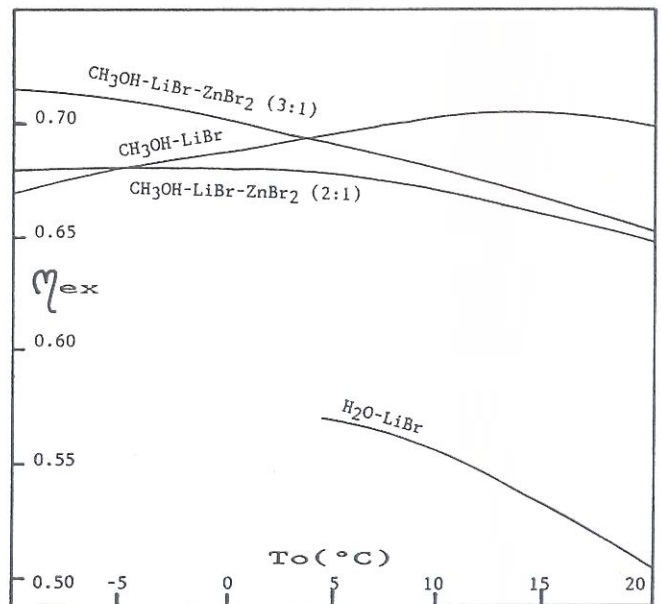


Figure 4b η_{ex} .

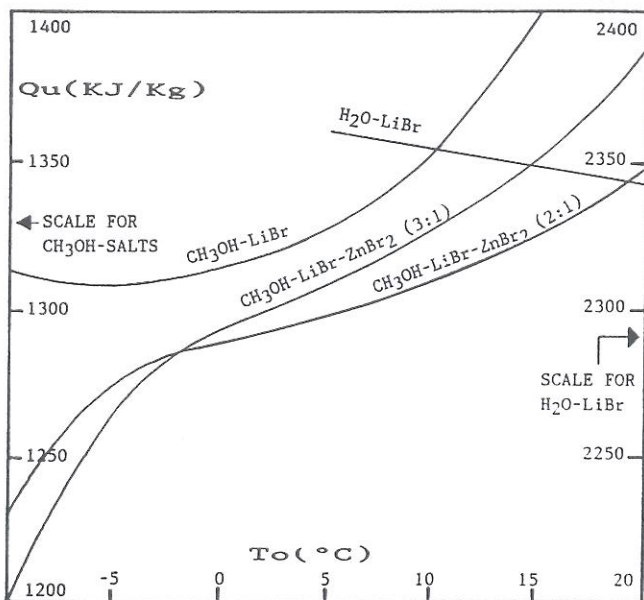


Figure 4c Q_u .

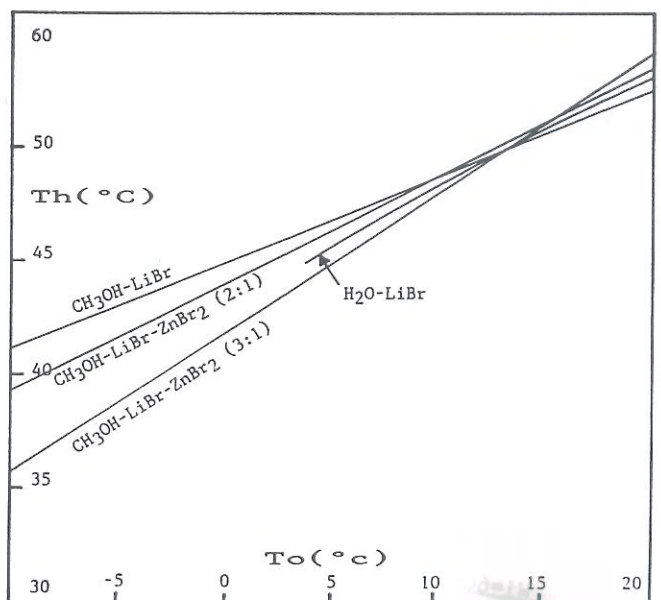


Figure 4d T_h .

Figure 4 Performances of the solar heat transformer vs. the environment temperature, for different solute-solvent pairs ($T_u = \text{constant} = 60^\circ\text{C}$).

CONCLUSIONS

It may be concluded that the solar transformation appears to be a good way of utilizing solar energy in wintertime. The different alternatives here examined exhibit about the same values of the overall C.O.P.; the H₂O-LiBr system shows a higher value of the thermal rate, while the CH₃OH

systems can operate even if the environmental temperature is lower than 0°C.

Until now, heat transformers have come into practical application only at more elevated temperatures. The feasibility of heat transformation in the range of temperatures useful for solar heat utilization has not yet been

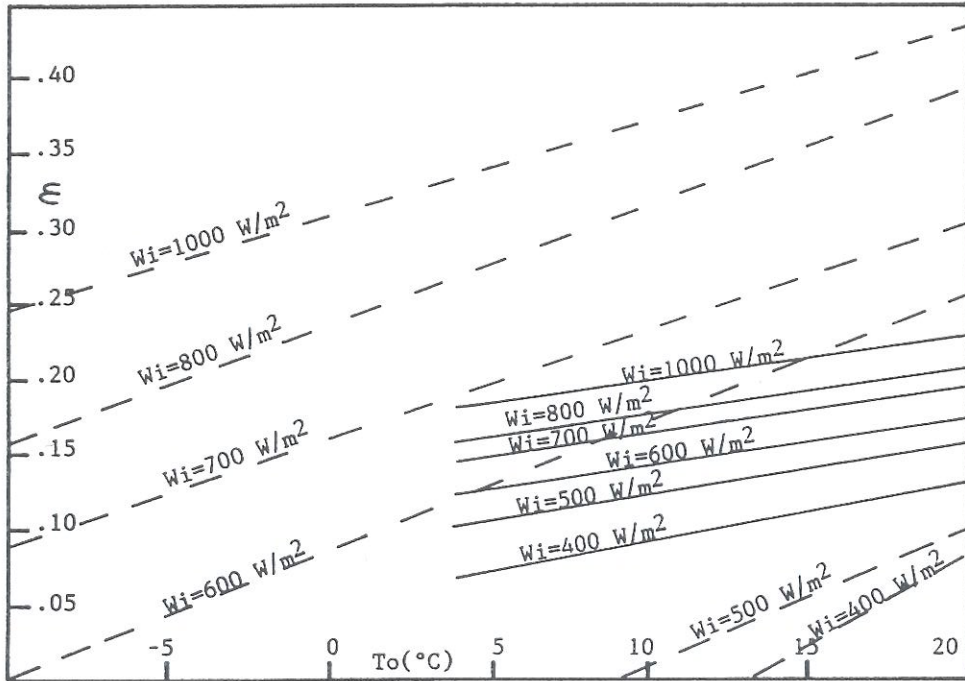


Figure 5a $\text{H}_2\text{O-LiBr}$.

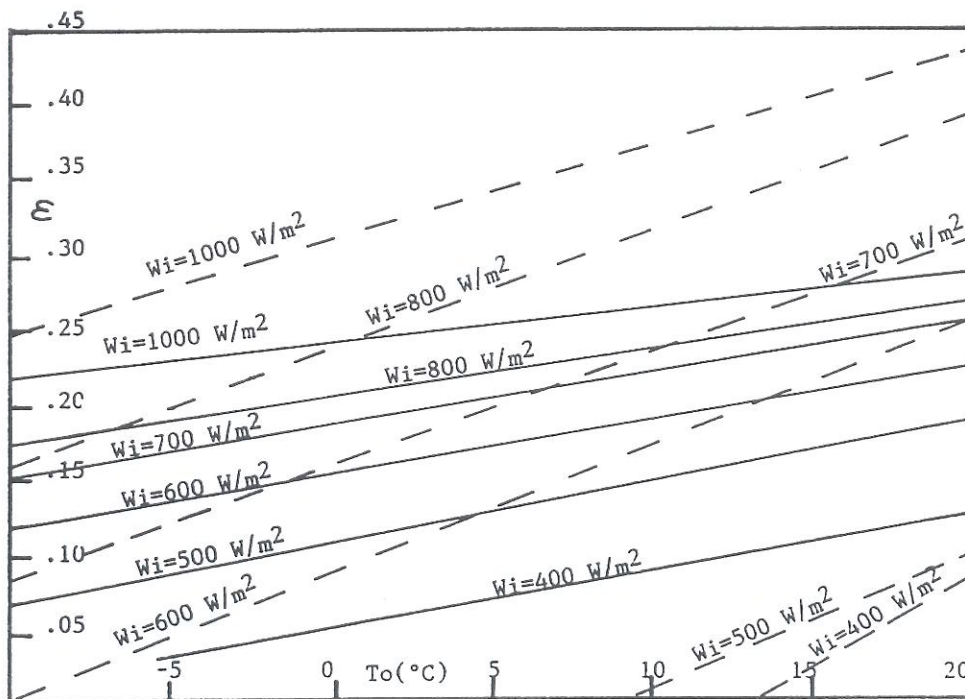


Figure 5b $\text{CH}_3\text{OH-LiBr}$.

Figure 5 Performances of different types of solar systems: solar heat transformers, continuous lines; simple solar plant, dashed lines. Total efficiency of the system vs. the environment temperature, for different values of the radiant power ($T_u = \text{constant} = 60^{\circ}\text{C}$).

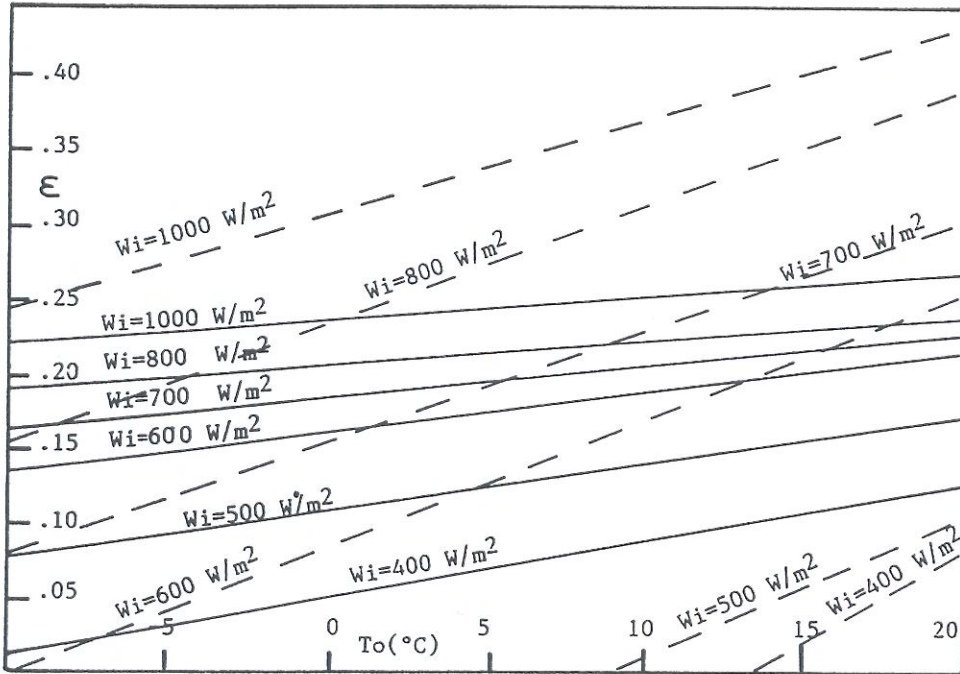


Figure 5c $\text{CH}_3\text{OH-LiBr-ZnBr}_2$ (2:1).

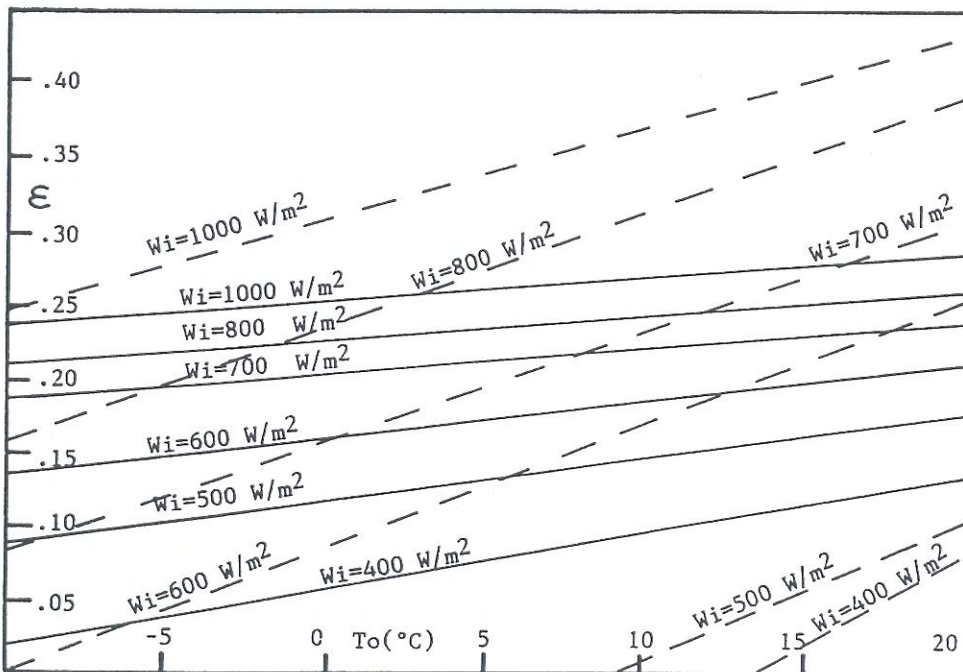


Figure 5d $\text{CH}_3\text{OH-LiBr-ZnBr}_2$ (3:1).

Figure 5 Performances of different types of solar systems: solar heat transformers, continuous lines; simple solar plant, dashed lines. Total efficiency of the system vs. the environment temperature, for different values of the radiant power ($T_u = \text{constant} = 60^{\circ}\text{C}$).

experimentally proved; it is possible that Alcohol-Salt mixtures, due to their strong chemical affinity, might be successful candidates.

NOMENCLATURE

C.O.P.	Coefficient of performance.
g	Flow rate (kg/s).
L	Mechanical work (kJ/kg).
m	g_s/g_r .
P	Pressure (kPa).
Q	Quantity of heat (kJ/kg).
r	Heat of vaporization of the refrigerant (kJ/kg).
s	Differential heat of solution (kJ/kg).
T	Temperature (K, °C).
v	Specific volume (m^3/kg).
X	Mass concentration of refrigerant (%).
W	Solar irradiation (W/m^2).
α	Efficiency of the heat exchangers.
γ	Specific heat (kJ/kg K).
ε	Total efficiency of the system.
η	Efficiency.
ϕ	Solution heat exchanger.
ψ	Refrigerant heat exchanger.

Subscripts

a	absorber
e	evaporator
ex	exergetic
g	generator
h	heating
i	incident
l	liquid
o	environment
P	pump
r	refrigerant
s	solution
u	utilizer
v	vapour

ACKNOWLEDGEMENTS

This work has been performed with the contribution of C. N. R. Progetto Finalizzato Edilizia; the authors are indebted to Professor Claudio Cerruti and Dr Arch Roberto Vinci.

REFERENCES

1. Felli, M., Cotana, F. and Buratti, C. "Fluids for Absorption Machines: Experimental Data and Working Performances". 18th International Congress of Refrigeration, Montreal, 1991.
2. McNeely, L. A. "Thermodynamic Properties of Aqueous Solutions of Lithium Bromide". ASHRAE Transactions, No. 3, 1979, pp. 413-434.
3. Iedema, P. D. "The Absorption Heat Pump with Lithium Bromide-Zinc Bromide-Methanol". Delft University of Technology, 1984.
4. Felli, M. "Lezioni di Fisica Tecnica". Ed. ESA - Masson, Milano, 1990.
5. Moncada lo Giudice, G. *et al.* "Nuovi fluidi per trasformatori di calore". C. N. R. Progetto Finalizzato Energetica RF - 87.02729.59, Roma, 1990.
6. Aker, J. E., Squires, R. G. and Albright, L. F. "An evaluation of Alcohol-Salt Mixtures as Absorption Refrigeration Solutions". ASHRAE Journal, May, 1965, pp. 90-92.
7. Hainsworth, W. R. "Refrigerant and Absorbents". Refrigeration Engineering, Vol. 48, 1944, p. 97.
8. Felli, M. "Proprietà termodinamiche di sistemi bifase a due componenti utilizzabili in macchine frigorifere ad assorbimento". Il Freddo, Vol. 33, 1979.
9. Felli, M., Cotana, F. and Asdrubali, F. "Design and Performances of a Two Stages Heat Transformer". 18th International Congress of Refrigeration, Montreal, 1991.