SIMULATION OF A LiBr ABSORPTION SOLAR COOLING SYSTEM AND GLOBAL WARMING IMPACT ESTIMATION

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ABSTRACT

The objective of this paper is to present the modelling of a complete lithium bromide (LiBr)-water absorption system and perform a global warming impact assessment. The system is modelled with the TRNSYS simulation program and the typical meteorological year file containing the weather parameters for a hot climate (Nicosia, Cyprus). Initially the LiBr cooler is modelled in order to derive the polynomial equations to be used in the TRNSYS deck file. These equations relate the unit capacity with the solution heat exchanger exit temperature, the coefficient of performance and the generator heat. The system considered employs a compound parabolic type collector 15 m^2 in area, sloped at 30° and a storage tank size of 600 lt. Subsequently the global warming impact of the system is evaluated by estimating the total equivalent warming impact (TEWI) of the system in comparison to a system utilising a conventional R-22 air conditioner. The TEWI of the solar assisted system is about 107,200 kg CO_2 and is lower than that of a conventional R-22 air conditioner system, which is 132,800 kg of CO_2.

INTRODUCTION

Solar energy is in abundance in Cyprus. In summer, the mean monthly temperature for Nicosia at 14.00 hours in July is 35.4°C with the temperature sometimes reaching 43°C [1]. Therefore, there is a need to lower the indoor temperature considerably in order to be able to provide comfort. Solar cooling of buildings seems to be one of the most attractive solutions and its effectiveness needs to be investigated. This is an application in which the demand for cooling energy closely matches the availability of solar energy, not only to the seasonal but also to the daily variation.

Many researchers have developed solar assisted absorption refrigeration systems. Most of these systems have been produced experimentally and computer codes were written to simulate them [2,3,4,5,6].

The objective of this paper is to model a complete system, consisting of a solar collector, storage tank, boiler and a LiBr-water absorption refrigerator unit. Such units though, are not yet readily available in small residential-sizes. Therefore, the design of an 11 kW unit required for the cooling needs of a typical Cypriot house was based on data collected for an experimental 1 kW unit [7].

The typical Cypriot house considered has a floor area of 196 m^2 and details of the house are presented in [8]. An insulated roof, insulated walls, double-glazed windows, internal shading and mechanically controlled ventilation (3 ach) in summer, were considered in order to minimise the house load. The double-walls are made of 0.10 m hollow brick and 0.02 m plaster on each side and a layer of 0.05 m insulation in between. The

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roof is constructed from fair-faced 0.15 m heavy concrete, 0.05 m polystyrene insulation, 0.07 m screed and 0.004 m asphalt, covered with aluminum paint of 0.55 solar absorptivity.

The TRNSYS program is used to model the complete system (house load estimation with solar powered heating and absorption cooling) run for a typical meteorological year (Nicosia, Cyprus). The solar powered system consists of an array of solar collectors, boiler, storage tank, an 11 kW absorption cooling unit, pumps and thermostats. The simulations showed that the above construction requires an annual cooling load at 25°C of 17,600 kWh with a peak load of 10.3 kW and an annual heating load at 21°C of 3,530 kWh with a peak load of 5.5 kW.

CHARACTERISTICS OF THE 11 KW WATER-LiBr ABSORPTION CHILLER

The characteristics of the 11 kW unit required to cover the cooling needs of the typical house are shown in Table 1.

TABLE 1
DESIGN PARAMETERS FOR THE SINGLE-EFFECT WATER-LITHIUM BROMIDE ABSORPTION COOLER

Parameter	Value
Evaporator heat (capacity)	11 kW
Heat input to generator	14.9 kW
Evaporator temperature	6°C
Generator solution exit temperature (T1)	75°C
Solution heat exchanger exit temperature (T2)	55°C
Generator (desorber) vapour exit temperature	70°C
Weak solution mass fraction	55 % LiBr
Strong solution mass fraction	60 % LiBr
Generator-Condenser pressure	4.82 kPa
Evaporator-Absorber pressure	0.935 kPa

In the TRNSYS deck file the generator load, the mass flow of the heating water to the generator heat exchanger and its input and output temperatures are required. Since the heat exchangers of an actual 11 kW unit are sized for maximum capacity, the unit has oversized heat exchangers when it delivers a smaller capacity. The operation of the heat exchangers of the generator, condenser, evaporator and absorber can be controlled externally by adjusting the valves of the cooling or heating source water. In this way the cycle temperatures are kept at their preset values and no problems are faced during delivery of a smaller capacity. The efficiency of the cycle though, will be affected by the operation of the solution heat exchanger, since for less capacity, the mass flows will be smaller but the heat exchanger area will be the same. The calculated area of the solution heat exchanger, for the 11 kW unit, is 0.343 m^2. Using a computer program, the characteristics of the LiBr absorption unit can be estimated. Appropriate equations and procedure needed for this program are presented in [7]. The temperatures at the output of the solution heat exchanger (T2) for smaller mass flows, and the coefficient of performance when the unit operates at a smaller capacity can therefore be estimated and the results are presented in Figure 1. The same computer program was also used for the evaluation of the variation of the generator input heat with reduced unit capacity, and the results are shown in Figure 2.

The temperature of the generator inlet heating water affects the amount of heat delivered to the generator. Since the pressure in the generator is set to 4.82 kPa and the mass fraction of the LiBr-water solution to 60% (this is done by checking the solution levels in the generator and absorber), the generator water evaporates from the solution always at the same temperature (T1, 75°C), which depends on the working fluid properties.

When experimenting with the generator heat exchanger, the results indicated that the overall heat transfer coefficient was around 2300 W/m^2K [7], changing slightly with inlet heating water temperature, i.e., the temperatures used for the input heating water can be between 85°C and 92°C without any significant variation in the operation of the heat exchanger. Therefore, the generator load can be calculated directly from Figure 2.

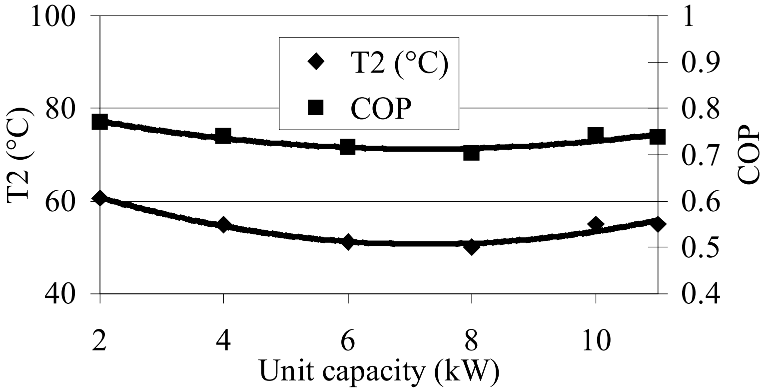

Figure 1: Coefficient of performance (COP, %) and variation of temperature at the exit of the solution heat exchanger (T2, °C) with unit capacity (kW).

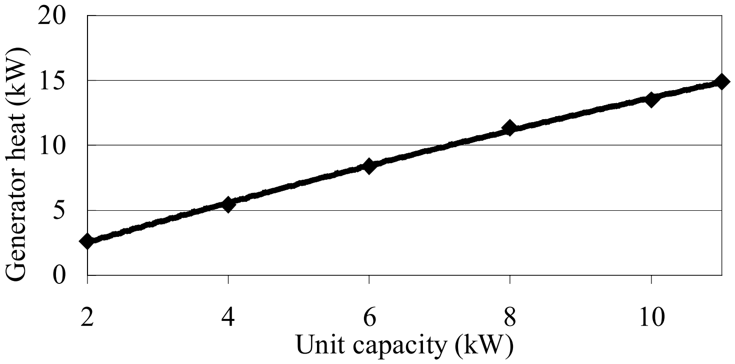

Figure 2: Variation of generator input heat with unit capacity.

Using the experimental results obtained from the 1 kW unit, a total mass flow of heating water to the generator of 1.26 kg/s was estimated in order to deliver the maximum heat needed in the generator, which is about 15 kW (Table 1). The output temperature of the generator heating water can therefore be calculated according to the delivered load, from equation:

$$\dot{Q}_g = 1.26 * C_p * (T_{in} - T_{out}) \qquad (1)$$

where: $\dot{Q}_g$ = generator load (kW), C_p=specific heat of water (kJ/kg-K), T_{in}=inlet source water temperature (°C) and T_{out}=outlet source water temperature (°C)

SYSTEM LONG-TERM PERFORMANCE AND ECONOMIC ANALYSIS

The specifications of the final system obtained from the optimisation study are: CPC type collector 15 m^2 in area, sloped at 30° and a storage tank size of 600 lt. The magnitude of these parameters is decided by an optimisation analysis of the system, which is presented in a separate paper of this conference and shows also the complete modelled system. The energy flows of the system as obtained by the simulation are shown in Figure 3. The cooling load of the building reaches a maximum monthly value of 4200 kWh (in July), whereas the maximum monthly heating load occurs during January and is equal to 1250 kWh. The heat required from the conventional boiler is also shown in Figure 3. The maximum monthly load supplied by the solar system is 1300 kWh and as can be seen from the difference of the curves for the cooling load and boiler heat, nearly all collector heat can be utilised for cooling or heating purposes.

The annual cooling load of 17,600 kWh is covered with a total supply of 15,220 kWh of boiler heat, supplemented by 8500 kWh of solar heat, offered by the solar system. The annual heating load of 3530 kWh is covered with a total supply of 2880 kWh of boiler heat and 1300 kWh of solar heat.

The total cost of the LiBr-water cooler, based on the production of the prototype 1 kW unit, is estimated to be € 8300. It is found that in order to be economically viable the price of such a system together with its accessories must not be higher than € 3450. It is believed that a mass-produced unit will be cheaper.

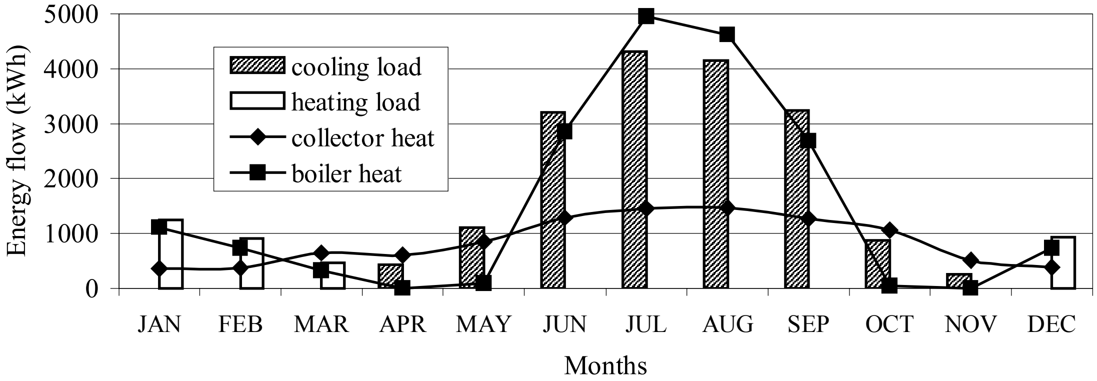

Figure 3: System energy flows.

GLOBAL WARMING IMPACT

Sun energy, passing through the atmosphere, heats the earth's surface and in turn, the earth radiates energy back into space. Atmospheric greenhouse gases such as water vapour and carbon dioxide, trap some of the outgoing energy, retaining heat in a way similar to the glass panels of a greenhouse. The chemical composition of the atmosphere is changing due to human activities, which are adding greenhouse gases to the atmosphere at a faster rate than at any time over the past several thousand years. Although uncertainty exists about how earth's climate responds to these gases, the heat-trapping property of the gases is undisputed. If emissions continue undiminished, global temperature and consequently the planet's climate may change causing problems to humanity. Some greenhouse gases occur naturally in the atmosphere, while others result from human activities. Naturally occurring greenhouse gases include water vapour, carbon dioxide, methane, nitrous oxide, and ozone.Very powerful greenhouse gases that are not naturally occurring include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6) and can affect the radiative balance of the earth by affecting atmospheric processes or producing chemical transformations.

Examination of the global warming impact of equipment releasing greenhouse gasses requires consideration of both direct and indirect effects. The direct component relates to release of refrigerants like HFCs, and the indirect one to carbon dioxide production in powering the equipment. Total equivalent warming impact (TEWI) is an estimating method for the combined effects where the direct effect is expressed in relation to the global warming potential (GWP) of a gas. The concept of GWP has been developed to compare the ability of a greenhouse gas to trap heat in the atmosphere relative to the effect of carbon dioxide (CO_2) and varies depending on the time frame considered (usually a 100-year period). Therefore the direct component can be expressed as:

$$\text{Direct effect of equipment (kg } CO_2) = (\text{make-up rate} * \text{service life} + \text{end-of-life loss}) * \text{charge} * \text{GWP} \qquad (2)$$

where: charge = initial charge of refrigerant in the system (kg)
make-up rate = percent refrigerant charge lost per year (averaged over the entire equipment life)
service life = total number of years that the system is in operation (yrs)
GWP = global warming potential of gas

The indirect effect, caused by the emission of CO_2 for producing the electrical power needed to run the equipment, is:

$$\text{Indirect effect (kg } CO_2) = \text{operation power} * \text{service life} * \text{emitted } CO_2 \qquad (3)$$

where: operation power = the power required by the system per year (kWh/yr)
emitted CO_2 = amount of CO_2 (kg) emitted from the power plan per kWh received by the system

In the case of the present study it is of interest to compare the TEWI of the absorption solar system to a conventional system utilising a vapour compression cooler without solar collectors, for a service life of 20 years. For this comparison, the variables and results are shown in Table 2.

TABLE 2
COMPARISON OF ABSORPTION SOLAR SYSTEM AND CONVENTIONAL R-22 SYSTEM (WITHOUT SOLAR COLLECTORS)

Absorption solar system	Conventional R-22 air conditioner and conventional boiler (no solar)
Annual cooling load = 17,600 kWh	Charge of R-22 for11KW capacity = 3.5 kg
Annual cooling load with solar = 15,220 kWh	COP = 2
Annual heating load = 3,530 kWh	Make-up rate = 4%
Annual heating load with solar = 2,880 kWh	End-of-life loss = 15%
Boiler efficiency = 85%	GWP for R-22 for a 100 year period = 1900 [9]
Calorific value of fuel= 42,900 kJ/kg	CO_2 release from power stations = 0.6 kg/kWh [9]
1 kg of fuel produces about 3 kg of CO_2	Direct effect of R22 unit = 6,300 kg CO_2
Boiler emissions for cooling = 90,150 kg of CO_2	Indirect effect for cooling = 105,600 kg of CO_2
Boiler emissions for heating = 17,050 kg of CO_2	Emissions for heating = 20,900 kg of CO_2
TEWI =107,200 kg of CO_2	**TEWI = 132,800 kg of CO_2**

CONCLUSIONS

The annual load of the typical house can be met by using about 28,100 kWh of boiler heat, when the efficiencies of the boiler and absorption cooler are considered. The present price of diesel, which is 0.296 €/lt indicates that it is economical to replace about 9,800 kWh with solar energy collected with 15 m^2 of CPC. An estimated price for the absorption unit together with its accessories is € 8300. In order to be economically viable the price of the absorption unit together with its accessories must not be higher than € 3450. This may be possible only when absorption units are mass-produced.

The TEWI of a conventional R-22 air conditioner and boiler, without solar collectors, is about 132,800 kg of CO_2 and exceeds that of the absorption solar cooling system by about 26,000 kg of CO_2. This factor is in favour of the absorption solar cooling system and should not be underestimated in the analysis and selection of the appropriate equipment since the environmental impact has become a major aspect during the last years. It should be noted that conventional HFC air conditioners, with higher coefficients of performance than the one considered here, are available, therefore the TEWI of the proposed system should always be carried out in order to test the benefit. The COP break-even point for a conventional R-22 air conditioner is 2.64.

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