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Absorption Cooling Devices with LiBr/H_2O as Working Media

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A short historical review of absorption cooling devices, starting from the first experiments revealing that some liquids are capable to absorb aqueous vapour and some other gases, all through the mass produced devices that have become forerunners of modern absorption systems, is given in the paper. The aim of the study was to develop the mathematical model of an absorption cooling process in MATLAB and to test this model by calculating thermodynamic properties of binary mixture LiBr/H_2O using the constant coefficients given by Dong – Seon Kim and Infante Ferreira. The derived model was then used for calculation of absorption cooling process in the working conditions of the installed solar cooling plant in Dubrovnik, Croatia. The technical parameters of the system which are used for the verification of the model are collected by using the long distance measurement system.

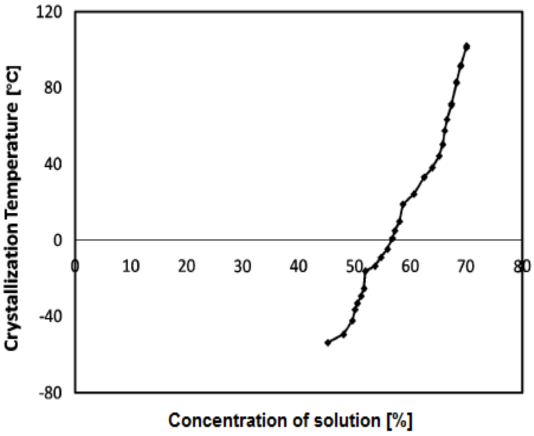
1. Introduction

Nowadays, cooling demand is rapidly increasing in many parts of the world, especially in Mediterranean and moderate climates. Electrically driven compression chillers usually used for the refrigeration and space cooling purposes consume large amount of electric energy. This causes some problems in energy systems especially in peak–load periods during the summer. On the other hand, the absorption cooling devices are driven mostly by thermal energy and only a small part of electric energy is used for their operation (Eicker, Pietruschka, 2009). As the electric energy is mainly obtained from fossil fuels and thermal energy can be obtained from waste heat or even from renewable energy sources such as solar energy, absorption cooling is more environmentally friendly solution.

Although the absorption cooling is not so well known and widely spread as the compression systems, it has a long history of development. The first absorption refrigerator was developed by the French inventor Edmond Carré in 1850 and that original design used sulphuric acid and water as working media. Due to the high corrosivity of this binary mixture, Edmond's brother Ferdinand Carré made some modifications and he demonstrated his absorption cooling device using NH_3/H_2O solution as working media in 1862. Significant contribution in the field of absorption cooling was given by Carl G. Munters and Baltazar von Platen in 1922. They enhanced the principle with a three-fluid configuration while they still were students at the Royal Institute of Technology in Stockholm, Sweden. Their invention achieved successful commercialization started in 1923 by the newly formed company AB Arctic, which was bought by Electrolux in 1925. This production enabled that absorption refrigerator become an infallible part of every American household. Albert Einstein and his former student Leó Szilárd proposed an alternative design of absorption refrigerators in 1926. Their invention known as Einstein's refrigerator was the subject of many subsequent studies (Thévenot, 1979). From 1930's upward absorption refrigerators were suppressed by compression refrigeration systems, but nowadays, there is increasing interest for absorption refrigeration systems and they again become attractive because they can be driven by low-temperature heat sources and provide an excellent way for converting solar energy or waste heat into useful refrigeration. Therefore some solar absorption systems were erected in the Mediterranean area in the frame of an international project ADRIA COLD (Tehnokom, 2014). One of those installations is also chosen as a case study in this paper and its measured data are used for the verification of the derived model.

2. The absorption cooling system with $LiBr/H_2O$ as working media

The $LiBr/H_2O$ solution is widely used as working media in absorption cooling systems because of its non-toxicity and being environmentally friendly by not contributing to ozone depletion. Low cost and easy handling are the advantages of using water as refrigerant, but its high freezing point is a disadvantage. On the other hand, low crystallization temperature (Figure 1), high absorption capacity and low viscosity are the advantages of LiBr as absorbent. The basic single-effect $LiBr/H_2O$ absorption system is illustrated in Figure 2.



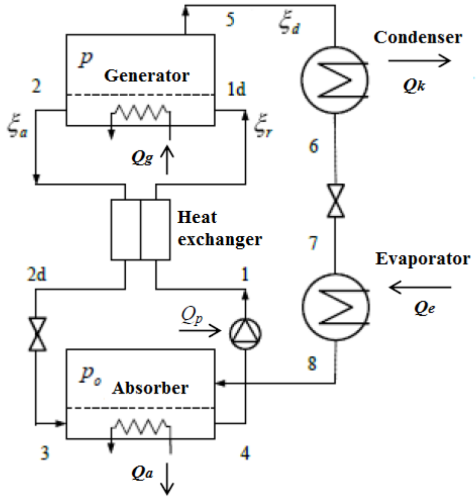


Figure 1: Solubility of pure LiBr in water (Boryta, 1970)

Figure 2: Schematic of an absorption cooling device

The absorber / pump / heat exchanger / generator assembly essentially replaces the compressor of a vapour-compression refrigeration system. This assembly is sometimes referred to as a thermal compressor. A weak solution (concentration ξ_r) of LiBr in water is pumped (4-1) from the absorber to the generator. The heat exchanger preheats the weak solution (1-1d) before entering the generator. Thermal energy (Q_g) is used for heating the solution in the generator and to evaporate the water from the solution. The water vapour then flows to the condenser where it is condensed (5-6) and the heat (Q_k) is rejected from the system by cooling water. The condensed water flows through an expansion device (6-7), where the pressure is reduced from (p) to (p_0). The low temperature heat (the desired cooling effect, Q_e) is supplied to the evaporator and is used for evaporating the condensate (7-8) and the water vapour then returns to the absorber. When the water is evaporated out of the weak solution in the generator, the remaining solution becomes strong solution (concentration ξ_a) (1d-2). This solution is precooled in heat exchanger (2-2d), and returns to the absorber flowing through a pressure restriction valve (2d-3) where its pressure is reduced from (p) to (p_0). In the absorber the water vapour returning from the evaporator is absorbed in the strong solution giving the weak solution again. During this process the thermal energy (Q_a) has to be rejected from the system by cooling water. The entire cycle operates at two pressure levels below the atmospheric pressure (Hatraf et al., 2014).

2.1 Calculation of absorption cooling process – heat balance

An absorption refrigerator uses a heat source (solar energy, waste heat from factories or district heating system) which provides the energy needed to drive the cooling process. The heat (Q_g) required for starting the absorption cycle can be calculated by the following equation:

$$Q_g = D_2 \cdot h_2 + D_5 \cdot h_5 - D_1 \cdot h_{1d} \tag{1}$$

where D_i (kg s^{-1}) represents the corresponding mass flow rate and h_i (kJ kg^{-1}) is the corresponding specific enthalpy of working media in characteristic point of absorption process.
Cooling capacity (Q_e) can be calculated from Eq(2):

$$Q_e = D_8 \cdot h_8 - D_7 \cdot h_7 \tag{2}$$

The absorption refrigerator device units that have to be cooled are condenser and absorber. Heat rejected from condenser (Q_c) can be calculated by Eq(3):

$$Q_c = D_5 \cdot h_5 - D_6 \cdot h_6 \tag{3}$$

Since the absorption of LiBr in water is an exothermic process, heat rejected from the absorber (Q_a) can be calculated from Eq(4):

$$Q_a = D_3 \cdot h_3 + D_8 \cdot h_8 - D_4 \cdot h_4 \quad (4)$$

The heat exchanged between hot strong solution from generator and cold weak solution from absorber (Q_{he}) can be calculated by Eq(5):

$$Q_{he} = D_1 \cdot (h_{1d} - h_1) = D_2 \cdot (h_2 - h_{2d}) \quad (5)$$

2.2 Mathematical model

The mathematical model of absorption cooling process is derived in MATLAB in order to predict and simulate the real process behaviour. It can be also used for an optimization of the solar cooling plant. In the model there are used basic heat balance equations which are given in chapter 2.1 and empirical correlations representing the dependence of working pressure, specific enthalpy and heat capacity as a functions of temperature and concentration of LiBr/H_2O. These dependences are calculated here using the coefficients given by Kim and Ferreira (2006) and are shown in Figures 3, 4 and 5. The model respects the fact that crystallization of LiBr occurs when the solution is more concentrated and cooled, especially if the concentration rises to 70 %. The optimal concentrations of strong (ξ_a) and weak solution (ξ_r) were chosen based on solubility diagrams given by Boryta (1970). Input data which is needed to start the calculation also include pressures in generator/condenser (p) and in evaporator/absorber (p_0) which can be chosen according to Figure 3 in dependence on available temperature of heat source ($t_{g(input)}$). Enthalpies and specific heat capacities of LiBr/H_2O solution as calculated in the model are shown in Figures 4 and 5.

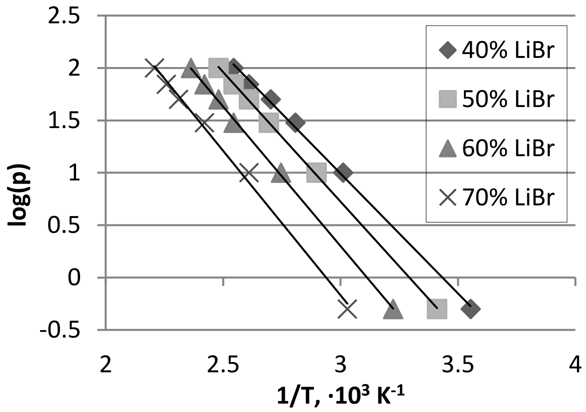


Figure 3: Pressure dependence on temperature for LiBr/H_2O

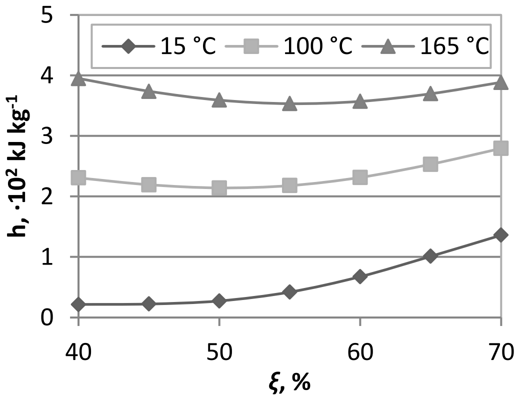


Figure 4: Specific enthalpy of LiBr/H_2O solution

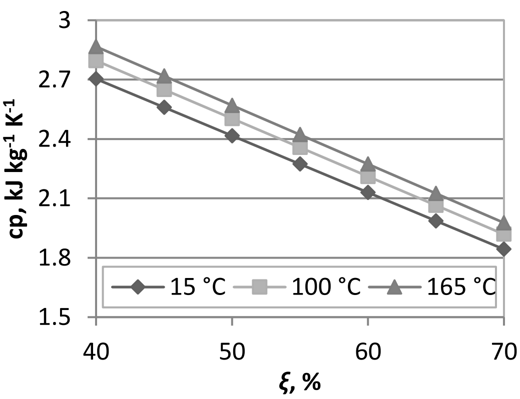


Figure 5: Specific heat capacity of LiBr/H_2O solution

3. Solar absorption cooling system in Dubrovnik

The application of solar cooling has become the most discussed application of the absorption cooling technology. The reason for this is the use of solar radiation as a free and renewable energy source for driving the process. Therefore this technology acquires the status of ‘Green energy’. Another good circumstance of this technology is the simultaneous cooling demand and available solar radiation (cooling during the day in summer). As a case study for this article the solar cooling system installed for the cooling purposes of the business building of “Vodovod Dubrovnik” in Dubrovnik, Croatia is chosen. The central part of this system (Figure 6) is the device Yazaki-Maya WFC-SC5 (Tehnokom, 2014).

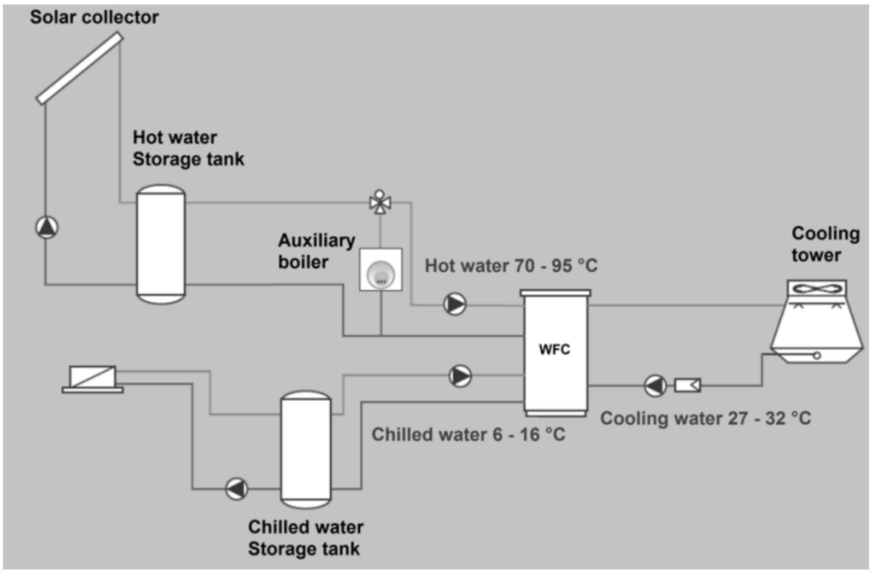


Figure 6: Process flow diagram of solar cooling system in Dubrovnik

According to the system data, the optimum hot water temperature is 88 °C, and chilled water temperature is 6/12 °C. Installed electric power of the device is 0.05 kW and nominal cooling capacity is 17.6 kW. As the heat source, the system uses a solar field of vacuum-tube’s collectors with a total absorption area of 60 m^2 (Figure 7). The received solar thermal energy is stored in the hot water storage tank of the volume of 3 m^3 and on the cold side there is an integrated chilled water storage tank of the volume of 1 m^3. The wet cooling tower is installed for the rejection of the waste heat from absorber and condenser. Described cooling system has been working since May 2014 and it is in continuous operation for over 5 months during the summer period each year. Existing boiler and heat pump are left in the system for the safety reasons. As it can be seen in Figure 6 the boiler gives operates as additional thermal energy source when there is not enough solar radiation heat.

Figure 7: Installed solar collectors’ field in Dubrovnik

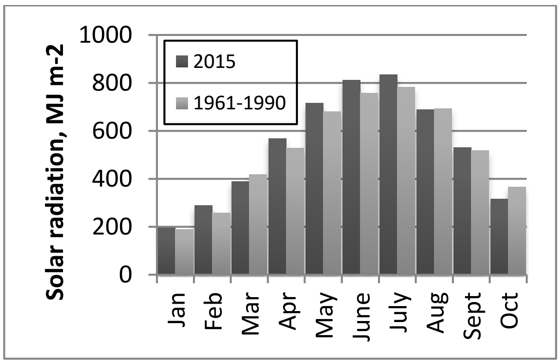


Figure 8: Measured solar radiation in Dubrovnik

Figure 8 shows the comparison between measured mean solar radiation data at the location of solar cooling system in Dubrovnik from January to October of the year 2015 and the average values of measured solar radiation in Dubrovnik for the period from 1961 to 1990 (Zaninović, 2008). It could be seen that cooling demand during the period from April to July of 2015 was increased comparing to the averaged one for the same period from 1961 to 1990. According to Figure 8 the maximum of solar radiation is achieved in July so this is the reason that data measured on the 21st July 2015 are used here for further calculation and analysis. Measured distribution of cooling capacity of the system depending on instantaneous solar radiation during the day from 9 am to 6 pm is shown in Figure 9. The absence of direct dependence of cooling capacity on the solar radiation is due to the hot and cold water storage tanks in the system, the thermal inertia of the building and other thermal parameters of the system.

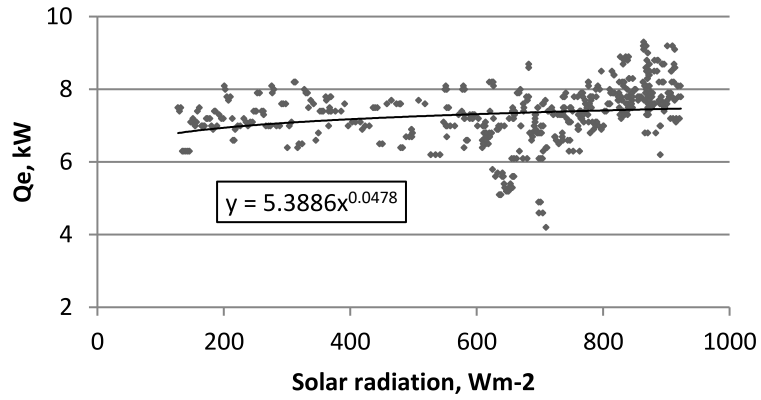


Figure 9: Measured cooling capacity depending on solar radiation on the 21st July 2015 from 9 am to 7 pm

4. Results and discussion

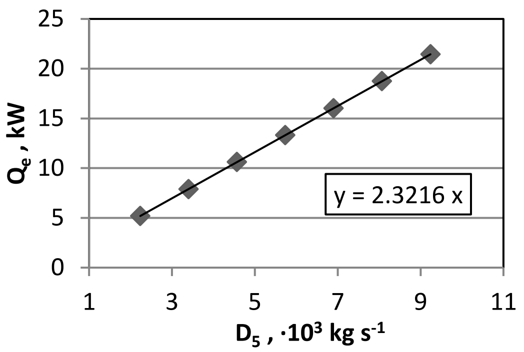
As it was already mentioned, the aim of this study was to get insights into the process and to calculate characteristic parameters of the process using the experimental data. This calculation was implemented in MATLAB and mathematical model is described in chapter 2.2. Table 1 contains the required input data for the calculation (p, p_0, ξ_r, ξ_a) and experimentally obtained data (Q_g, Q_e, $t_{g,inlet}$, $t_{g,outlet}$). Completed results of the calculation are given in Table 2.

Table 1: The input data for the MATLAB programme (data collected on 21st July 2015 at 12:36 pm)

p, kPa	p_0, kPa	ξ_r, %	ξ_a, %	Q_g, kW	Q_e, kW	$t_{g,inlet}$, °C	$t_{g,outlet}$, °C	COP
8.0	0.9	57	60	15.8	8.0	88.49	80.31	0.51

Table 2: The calculation results

System point	ξ, %	t, °C	p, kPa	D, kg·s^{-1}	h, kJ·kg^{-1}
1	57	40	8.0	0.3292	101.38
1d	57	80	8.0	0.3292	181.68
2	60	86	8.0	0.3258	204.24
2d	60	46	8.0	0.3258	126.34
3	60	46	0.9	0.3258	126.34
4	57	40	0.9	0.3292	101.38
5	0	86	8.0	0.0034	2652.41
6	0	41	8.0	0.0034	170.80
7	0	5	0.9	0.0034	170.80
8	0	5	0.9	0.0034	2510



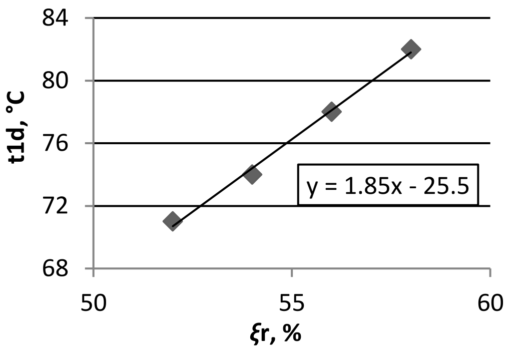


Figure 10: Cooling capacity depending on the mass flow rate of evaporated pure water

Figure 11: Temperature at the generator input depending on the concentration of weak solution

Figure 10 shows a linear dependence of cooling capacity of absorption cooling device on the mass flow rate of evaporated pure water. Since the water is used as refrigerant in cooling process, it is obvious that higher mass flow rate of water will contribute to the higher cooling capacity. On the other hand, it is necessary to bring more heating energy into the generator to achieve stronger evaporation (larger mass flow rate of the water). The COP value will just slightly change according to the manufacturer data. The dependence of temperature at the generator input on the concentration of weak solution is given in Figure 11. If the concentration of strong solution is fixed at 60 % just as chosen in this case, the temperature of the weak solution at the generator input will rise with the concentration as shown in figure. The dependences shown in Figures 10 and 11 are valid for the chosen pressures of generator/condenser 8.0 kPa and pressure of evaporator/absorber 0.9 kPa. Due to the lack of information obtained by the device supplier, the working pressures are chosen based on Figure 3 taking into account available temperatures of the heat source.

5. Conclusions

In this paper is explained how the mathematical model of absorption cooling process can be used to describe the thermodynamic state of LiBr/H_2O solution in different steps of the absorption cycle without having to use data or diagram tables. It is also shown that experimentally collected data from a real solar absorption installation can be used for the verification of the derived mathematical model of the working media LiBr/H_2O. The model has to be verified for more different working conditions and then can be used for the optimization of the absorption cooling system with the aim to improve it’s coefficient of performance or to obtain higher cooling capacity as well as to optimize the area of solar field which has to be used as the heat source.

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