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Heat reject recovery in solar air conditioning

P.Corrada[1], J.M.Bell[1], L.Guan[1], L.Molinaroli[2], N.Motta[1]
[1]School of Engineering Systems, Faculty of Built Environment and Engineering
Queensland University of Technology
Garden Point Campus, 2 George St, Brisbane QLD 4000 (Australia)
[2]Dipartimento di Energia
Politecnico di Milano
Via Lambruschini 4, 20156 Milano (MI) Italy
Paolo.corrada@qut.edu.au

ABSTRACT

This study demonstrates the possibility of using an absorption chiller to produce chilled water for air conditioning, and at the same time recover the rejected heat producing domestic hot water. The absorption chiller considered for this application has been sized to suit a standard household and uses a solution of ammonia and water running on hot water at a temperature ranging from 80 - 120°C produced by thermal solar panels.

The system consists of five main components: generator, rectifier, condenser, evaporator and absorber, and is divided in two sections at two different pressures. The section at higher pressure includes the generator, rectifier and condenser whereas the section at lower pressure includes the evaporator and the absorber.

Heat in this type of system is usually rejected to the environment from the condenser, rectifier and absorber through a cooling tower or air cooler exchanger. In this paper we describe how to recover this heat to create domestic hot water by providing a quantitative evaluation of the amount of energy recovered by the proposed system, if used in the Australian region.

Keywords: absorption chiller, heat recovery, solar air-conditioning, solar cooling, solar heat pump.

Introduction

There is a direct relation between the cooling demand and the intensity of solar radiation in each region of the earth. Therefore, a system that links the cooling output to the heating input is a sustainable alternative to current cooling systems which are electrically driven and whose consumption is responsible for seasonal peak loads.

Queensland residential electricity prices are forecast to increase by 32% in nominal terms between 2009/10 and 2012/13. One of the drivers of this price movement is the forecast increases in distribution costs, driven by increases in maximum demand and consumption, higher rates of return following the Global Financial Crisis, and increases in the cost of land and materials.(J.Pierce 2010)

Another reason for this price increase is the cost of upgrading networks in remote areas because of the long distances the network has to cover.

Solar air conditioning systems, including heat reject recovery, can be a key element to reduce the maximum demand on the network in remote areas, while at the same time providing an economical way to satisfy the need for cooling and domestic hot water for a standard household.

Compared to an ordinary cooling cycle, the absorption system aims to avoid the compression work by using a suitable working pair of fluids (Kalogirou 2007) reducing electric power and consequently greenhouse gas emissions.

In a solar cooling system the thermal energy from the sun is transformed in refrigeration energy as cold fluid. This is achieved using an absorption cycle, through a liquid absorber (Keil, Plura *et al.* 2008), which mixes with the refrigerant at a lower temperature and releases heat at a higher temperature. Chillers based on this principle are called absorption chillers and work by changing the state of the refrigerant used in the cycle. Absorption chillers are becoming popular in refrigeration and air-cooling, especially when the availability of electric power is limited, such as in remote areas. (Lazzarin, Gasparella *et al.* 1996; Byongjoo and Jongil 2007)

Absorption chillers have certain disadvantages, limiting them to a niche market:

- Solar cooling systems are expensive, as costly high-grade solar collectors are required to provide a generator temperature around 90°C. (Sumathy, Huang *et al.* 2002)
- Solar cooling systems cannot always operate at their nominal rating during periods of low solar radiation and high cooling water temperature. (Sumathy, Huang *et al.* 2002)
- The quantity of heat rejected by an absorption chiller is higher than the rejected heat from a vapour compression chiller. This means the system needs additional heat exchangers making the initial investment higher. (Lee 2007)

The last limitation can be overcome by using a heat-recovery system to lower the rejected heat, and turned into an advantage to produce domestic hot water.

The combination of air conditioning and domestic hot water production in an absorption chiller make this system very effective in remote areas, especially where there is little or no access to power from the grid, contributing as well to decrease the greenhouse footprint of the household, making such a system very attractive in this niche market.

Description of water ammonia absorption cycle

The water ammonia absorption cycle uses a solution consisting of a refrigerant (ammonia-NH_3) and an absorber (water-H_2O). This system is shown schematically in Figure 1.

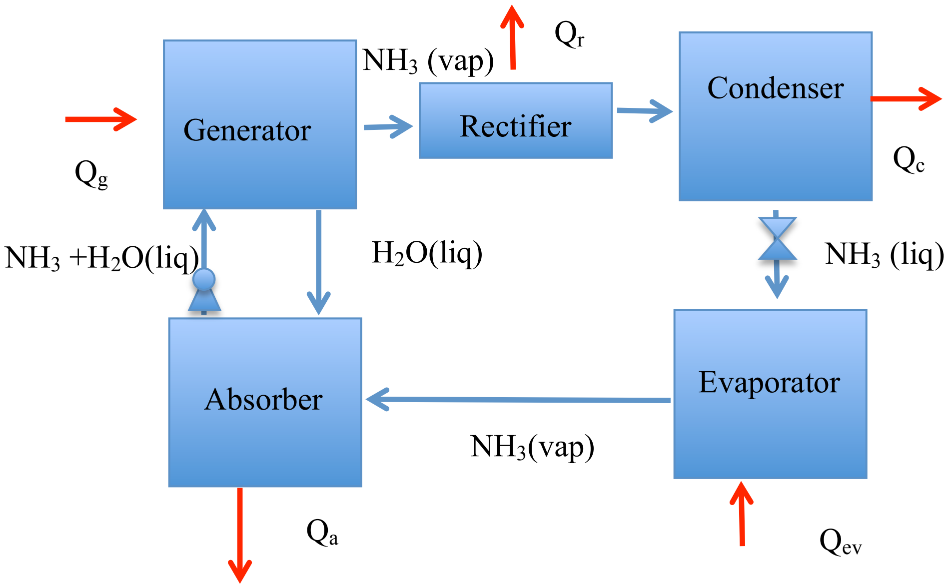

Figure 1 water ammonia absorption chiller

Thermal energy (Q_g) is used in the generator chamber to separate the low boiling refrigerant from the solution. The refrigerant then flows in a rectifying column to ensure no water vapour reaches the evaporator where it could freeze (Karno and Ajib 2008; Nunez 2010).

The process of water separation from the refrigerant in the rectifier involves heat rejection (Q_r). The strong solution (high concentration of absorbent H_2O in the solution) flows to the absorber.

The refrigerant then goes from the rectifier to the condenser where it rejects heat (Q_c) as in an ordinary cooling cycle. However, the condensed refrigerant is pressure reduced when it flows to a throttling valve before it reaches the evaporator. Here, the condensed refrigerant vaporizes by extracting the heat (Q_{ev}) from the chilled water loop, providing the cooling capacity of the system. The strong solution from the generator then absorbs the refrigerant vapour from the evaporator and becomes a weak solution which leaves the absorber.

Since the absorption process between the strong solution and refrigerant vapour is exothermic, heat (Q_a) needs to be rejected from the absorber. The weak solution is pumped to the generator at a high pressure with an ordinary liquid pump compressing the refrigerant vapour without the need for mechanical energy as demanded in vapour-compression air conditioning systems.

The NH_3-H_2O system requires generator temperatures ranging from 125 - 170°C when the absorber and condenser are air-cooled, and 80 - 120°C when water-cooling is used instead. The coefficient of performance (COP) of this class of air conditioners, which is defined as the ratio of the cooling effect to the heat input, is between 0.6 to 0.7 (Kalogirou 2007).

The above systems reject heat from the condenser, the rectifier and the absorber. The remainder of this paper investigates how to recover the heat from these components to produce domestic hot water, and to increase the total efficiency of the air conditioner.

Description of the water ammonia absorption cycle with heat recovery

Theoretically, the energy balance across the absorber, evaporator, condenser, rectifier and generator is zero (Kong, Liu *et al.* 2009). In practice there are heat losses and then the sum of the heat rejected from the absorber (Q_a), heat rejected from the condenser (Q_c) and heat rejected from the rectifier (Q_r) is lower than the heat supplied to the system through the generator (Q_g) and the evaporator (Q_{ev}) (Dingfeng, Jianhua *et al.* 2010). Heat losses were estimated to be 6-7% compared to $Q_g + Q_{ev}$ (Syed, Izquierdo *et al.* 2005). The proposed system under development has a cooling capacity of approximately 10kW (Q_{ev} = 10kW) which is the average cooling requirement of a standard household. The coefficient of performance (COP) of such a system is variable as it is a function of the evaporator and generator temperature, and directly dependent on the environment temperature (Grossman 2002; Kalogirou 2007; Pospisil, BALAS *et al.* 2008; Wang, Ge *et al.* 2009; Al-Alili, Islam *et al.* 2011).

The COP of such a system, defined as the ratio of the cooling effect to the heat input, is between 0.6 and 0.7. (Florides, Kalogirou *et al.* 2002). Assume that our proposed system has a COP = 0.70, as

$$COP = Q_{ev}/Q_g \qquad (1)$$

then the solar panels need to provide:

$$Q_g = Q_{ev}/COP = 14.3\text{kW} \qquad (2)$$

to the generator, excluding any heat loss in the pipeline from the solar collector to the generator. By assuming a solar panel efficiency of 60% (Hang, Qu *et al.* 2011) and a solar radiation field of 1000W/m^2 (Marc, Praene *et al.* 2011) the solar panel area required is approximately 24 m^2 (Li and Sumathy 2001). The maximum amount of heat Q_{max} that can theoretically be recovered (Ziegler, Kahn *et al.* 1993; Dingfeng, Jianhua *et al.* 2010; Koroneos, Nanaki *et al.* 2010) is:

$$Q_{max} = Q_c+Q_a+Q_r = Q_{ev}+Q_g = 24.3\text{ kW} \qquad (3)$$

then,

$$Q_c+Q_a+Q_r = (Q_g+Q_{ev})\text{-}7\% \qquad (4)$$

which means the maximum heat available for recovery Q_{rec} can be calculated as

$$Q_{rec}=(Q_g+Q_{ev})*0.93 = 22.6\text{ kW} \qquad (5)$$

This heat can be recovered for two needs, hot water (when operating in cooling mode in summer) or for heating and domestic hot water production in winter (when the system works as a heat pump), enabling the system to be used all year round.

Saman and Sa’id proposed (Saman and Sa'id 1996) that the convenient temperature in the absorber for the cooling operation is 30˚C and the temperature in the condenser depends on the temperature of the generator, which in turn is related to the temperature of the water from the solar panels. The proposed system aims to use hot water at 90°C as produced by evacuated tube panels (Li and Sumathy 2001; Florides, Kalogirou *et al.* 2002; D.S. Kim 2007; Venegas, RodrÌguez-Hidalgo *et al.* 2011). Figure 2 details the solar air conditioner where an additional stage of heat recovery is added to the system represented in Figure 1:

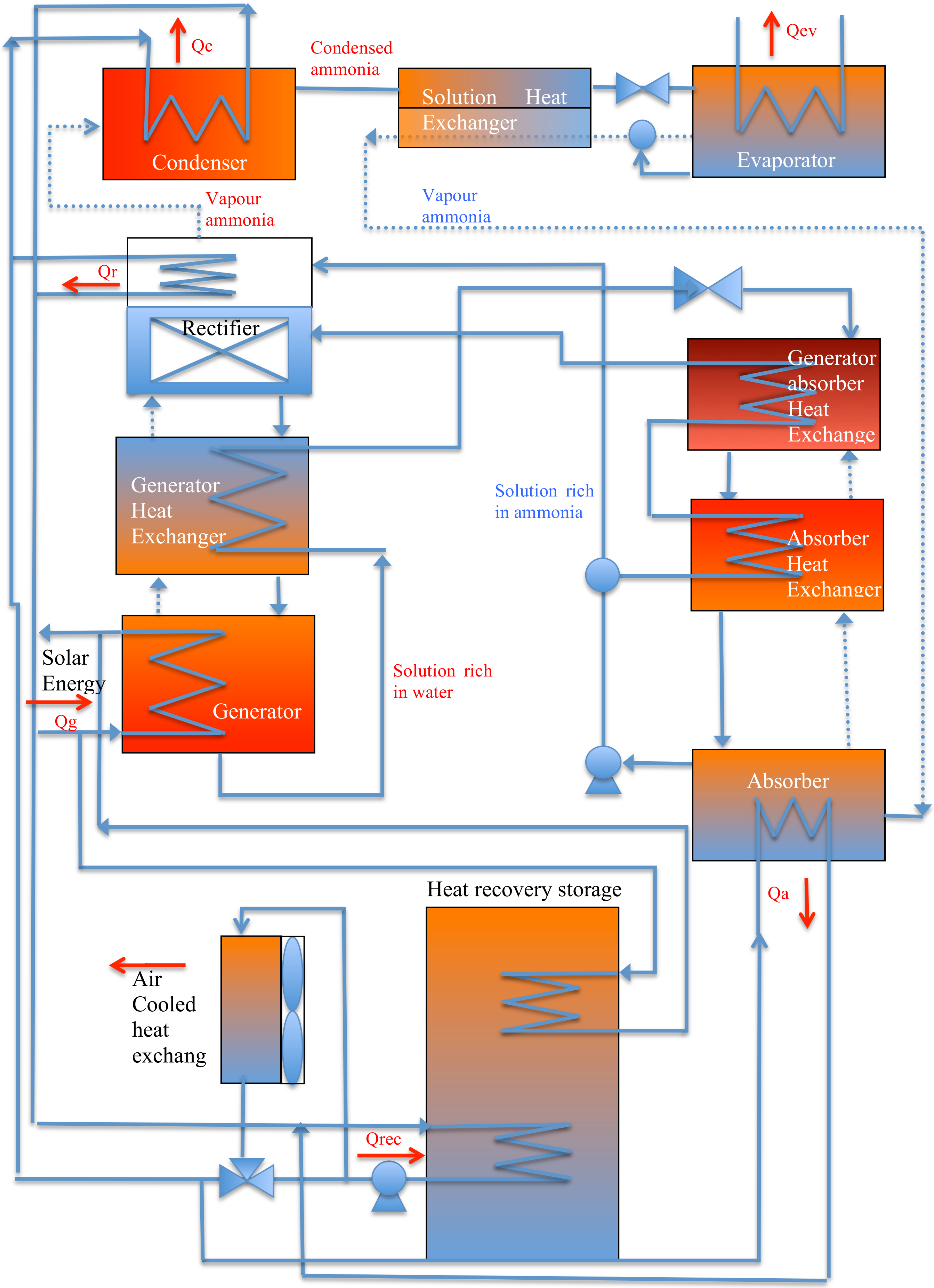

Figure 2 water ammonia absorption chiller with heat recovery

After the condenser, the refrigerant flows to the solution heat exchanger, which recovers heat from the higher temperature refrigerant stream to the lower temperature one. The heat exchanger serves to increase the efficiency of the system.

A generator/absorber heat exchange (GAX) using rich and weak absorption working fluids is used to increase the efficiency of the system while reducing the heat needed in the generator and the heat rejection requirement from the absorber.

The waste heat is recovered by using a heat recovery system which includes a heat exchanger in the condenser, rectifier, and absorber, as well as a storage tank and circulating pump. Water will be pumped through the exchangers transferring the heat to the circulating water that delivers it to the storage tank.

Health regulations in terms of water sanitization demand that water temperature in a storage must be kept higher than 60°C. To this purpose, a small amount of water from the solar field has to be diverted into the hot water storage. If this is over the required maximum temperature (80°C) then excess heat can be rejected through an air-cooled exchanger.

Using the irradiation data from the Bureau of Meteorology (BOM) provided for the Brisbane area and using the formulas (3) (4) and (5), the average daily cooling and heat recovery available during the month of January have been evaluated in Table 1 as evidence of the effectiveness of the proposed system.

Table 1 Energy output from solar panels, Cooling from absorption chiller and reject heat available for recovering

Hour	Ambient Temperature (˚C)	Hourly Energy Output (kWh) from Evacuated Tubes	Hourly Cooling Output (kWh) from Absorption chiller	Hourly Heat reject available for recovery (kWh) from the proposed system
12:30 AM	23.3	0.00	0.00	0.00
1:30 AM	22.9	0.00	0.00	0.00
2:30 AM	22.4	0.00	0.00	0.00
3:30 AM	22.0	0.00	0.00	0.00
4:30 AM	21.9	0.00	0.00	0.00
5:30 AM	21.7	0.00	0.00	0.00
6:30 AM	22.3	0.95	0.66	1.50
7:30 AM	23.8	4.29	3.00	6.78
8:30 AM	25.3	7.77	5.44	12.29
9:30 AM	26.1	10.93	7.65	17.29
10:30 AM	26.9	13.37	9.36	21.13

11:30 AM	27.7	14.71	10.29	23.25
12:30 PM	28.0	14.73	10.31	23.28
1:30 PM	28.1	13.44	9.40	21.24
2:30 PM	27.9	11.04	7.73	17.46
3:30 PM	27.4	7.90	5.53	12.49
4:30 PM	26.8	4.47	3.13	7.07
5:30 PM	26.2	1.19	0.83	1.88
6:30 PM	25.6	0.00	0.00	0.00
7:30 PM	25.1	0.00	0.00	0.00
8:30 PM	24.7	0.00	0.00	0.00
9:30 PM	24.4	0.00	0.00	0.00
10:30 PM	24.0	0.00	0.00	0.00
11:30 PM	23.6	0.00	0.00	0.00
Total daily		104.79	73.35	165.67

From the above result it is evident that the system has some limitations that need to be addressed for a practical application of this technology. A storage tank is required to make the domestic hot water available around the clock. Also, the availability of cooling power does not match with the cooling request; after 6.30 pm and during the night, the demand for cooling could be still relevant because of the temperature and/or the humidity.

These limitations can be easily overcome installing storages, but the cost of such a system will be increased; to reduce the cost, a reduction of the cooling capacity could be considered if compensated by increasing the insulation of the walls, roofs and windows of the standard household.

Also, the heat available for recovery by the system is much higher than the required energy for domestic hot water production (Strategies 2008) and part of the heat available for recovery is rejected to the environment trough the air exchanger as shown in Figure 2. The reduction of the cooling size will decrease also the amount of the heat rejected to the environment avoiding waste of energy.

A second option to recover the heat is to produce instantaneous hot water only when needed without storage. This option would avoid the installation of a storage tank but it will limit the amount of heat recovered, limiting its usage only during the activity of the absorption chiller.

Conclusion

Implementing a heat recovery circuit in a solar air conditioning system is possible for small household applications. Heat reject recovery is an useful improvement to a standard solar air conditioning system, providing both air cooling and domestic hot water, leading to a substantial reduction in peak demand of the electric network in remote areas.

This paper analyzed the efficiency of a 10 KW air conditioner equipped with heat recovery, and demonstrated that the rejected heat can provide more than the sufficient amount of domestic hot water to satisfy the need of a standard household in remote areas. The addition of a solar booster by simply adding extra surface to the solar hot water collectors would ensure the availability of domestic hot water in all seasons and maintain temperature at acceptable safety levels.

Further investigation of the minimum water temperature required to operate an NH_3-H_2O absorption chiller with heat recovery is underway, and will be the subject of a future paper (Corrada, Bell *et al.* to be published).

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