Experimental investigation of activated carbon – R723 pair for use in adsorption heat pump and refrigeration systems

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ABSTRACT

The physical behavior of the new refrigerant R723, an azeotropic mixture of 60% Ammonia and 40% Dimethyl Ether, was investigated for use in adsorption heat pumps and refrigeration systems. The potential use of this refrigerant blend in adsorption systems with components made of copper instead of stainless steel provides with a motive for experimental investigation. In this work the experimental results of an activated carbon – R723 pair generator are presented when operating with driving temperatures ranging from 100^{o}C up to 170^{o}C and condensing temperatures of 20^{o}C and 35^{o}C. By comparing the measured temperature of the refrigerant liquid in the receiver and the saturated temperature calculated from the measured pressure it is shown that the refrigerant R723 remains stable throughout the adsorption – desorption process even when operating at pressures as high as 16 bar.

1. INTRODUCTION

The key objective of this paper is the investigation of the use of refrigerant R723 in adsorption heat pumps and refrigeration systems. Activated carbon – Ammonia pairs have been investigated extensively by researchers (Tamainot-Telto *et al.* 2009c; Wang *et al.* 2006) for use in sorption cooling systems. Although significant advances have been made that improve the performance (Metcalf 2009; Tamainot-Telto *et al.* 2009b) these systems are entirely manufactured with stainless steel (due to the presence of ammonia) which is more expensive and heavier than copper or copper alloys (widely preferred and used in the conventional refrigeration and heat pump systems). The compatibility of R723 with refrigeration copper tube or its alloy CuNi10 when the moisture content within the sorption system does not exceed 400ppm is well established (OSCAR Final Report 2005; Palm 2008). As a blend refrigerant, the key concern remains the separation of his two components in course of adsorption or desorption process. Although the initial work (Tamainot-Telto *et al.* 2009a) has already demonstrated the potential of this refrigerant at restricted operated conditions in both pressure (0.9 to 8.5 bar) and temperatures (20^{o}C to 70^{o}C), the current work has widen the operating conditions within the full range of adsorption heat pump and refrigeration systems: 1 to 16 bar for the pressures and 20^{o}C to 170^{o}C for temperatures. The sketch of the experimental set-up used to cycle the reactor containing activated carbon-R723 pair is shown in Figure 1. This work consists of looking into both the adsorption and desorption process in order to identify possible changes in the refrigerant's physical behaviour.

2. EXPERIMENTAL SETUP

The experimental set-up is illustrated in Figure 1. It consists primarily of two vessels, the receiver which contains the refrigerant (marked with number 1 in Fig 1) and the generator which contains the activated carbon (marked with number 2 in Fig 1). They are connected with ½" OD stainless tube (0.71 mm thickness) and three ball valves. The receiver is immersed in a constant temperature water bath. Two pressure transducers are placed in line to monitor the pressure changes of the system. Each pressure transducer's rating range is 0 to 17 bar. Three type-K thermocouples shielded with stainless steel are used to monitor the temperature of the constant temperature water bath, the saturated temperature of the refrigerant inside the receiver (with its measuring junction close to the bottom of the vessel to ensure that it stays always wet) and the temperature of the generator at the centre. A silicone rubber heating tape is wrapped around the generator with time percentage dial control for regulating the heat input and therefore keeping the driving temperature constant during desorption. All the system components exposed to the refrigerant were made of stainless steel. A data acquisition system is used for acquiring the signals from the thermocouples and pressure transducers connected to a PC which runs a data logging software.

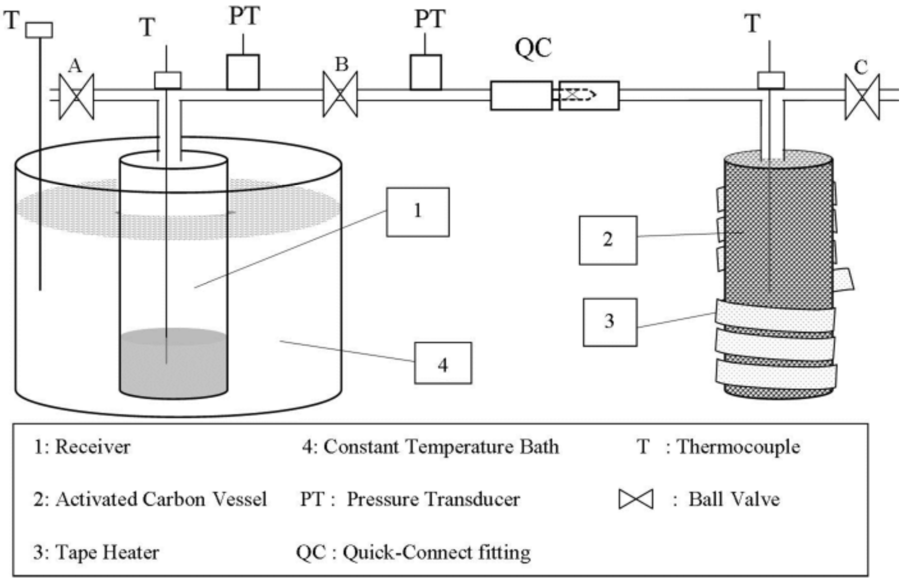

Figure 1: Sketch of the experimental rig.

3. EXPERIMENTAL PROCEDURE AND RESULTS

The generator is a cylindrical vessel (0.35 l capacity) filled up with dried activated granular carbon 208C (Chemviron) weighed approximately 162 g (M_c). The generator is under vacuum; it was heated up to 110^{o}C and vacuumed with a vacuum pump connected through valve C in order to remove moisture and air. The receiver is a cylindrical vessel (0.13 l capacity) that was loaded with R723 refrigerant (about 4/5 of the total volume) through valve A. Valve B remained closed throughout the charging process. When both the receiver and the generator are in thermal equilibrium (ambient temperature) valve B is opened slowly, the refrigerant gas flows in the generator (bed) and adsorption takes place. This is the initial loading of the generator. In Figure 2 the temperature of the bed T_{bed} and saturation temperature $T_{sat,rec}$ as measured in the receiver are illustrated against time during the initial loading and cooling of the generator. The maximum concentration of R723 adsorbed by the carbon was calculated from the mass difference of the saturated carbon (after the initial loading) divided by the mass of the dried carbon (kg of R723 / kg of carbon):

$$X_0 = \frac{\Delta m}{M_c} = 0.3624 \tag{1}$$

The experiments carried out after the initial adsorption take place in two stages:

Stage 1. Desorption takes place when the generator is heated up at desired driving temperature (regulated with the tape heater control); valve B is open therefore the refrigerant condenses in the receiver which is kept cool with the aid of the constant temperature bath. The process ends after heating up for approximately 30-40 min at the desired driving temperature when the system reaches steady state. Then we close valve B and the pressure of the generator drops as the system is left to cool down to ambient temperature.

Stage 2. Valve B is opened slowly and then R723 gas flows from the receiver to the generator where is adsorbed by the activated carbon. This is the adsorption stage, in the beginning the generator's temperature is rising because of the adsorption, reaches a maximum and then is left to cool down to the ambient temperature (end).

Table 1 summarises the experimental conditions. The experimental results of experiment 1a (see Table 1) are illustrated in figures 3 and 4. Figure 3 shows the measured pressures of the generator (P_{gen}) and the receiver ($P_{sat,rec}$) compared to the predicted saturation pressure Psat(T_{rec}) as predicted based on the temperature measurements of the receiver and saturation pressure Psat(T_{bed}) as predicted based on the temperature measurements of the bed during stages 1 and 2. Figure 4 shows the measured temperatures of the generator (T_{bed}) and the receiver ($T_{sat,rec}$) during stages 1 and 2.

Similar temperature and pressure profiles were obtained from the other experiments when carried out at higher temperatures and pressures. By comparing the measured temperature (T1) of the refrigerant liquid in the receiver (C) and the saturated temperature calculated from the measured pressure (PT1) (BOC Gases 2012), we are able to conclude whether there is component separation or change in component ratio; in fact the temperature differences in all the experiments carried out were between 1 – 2.5 ^{o}C. Even when operating under the experimental conditions of 4b (see Table 1) the pressure difference between the saturation measured pressure $P_{sat,rec}$ and predicted pressure $P_{sat,pred}$ after cooling was less than 0.5 bar (see Figure 5). Similarly the pressure differences $P_{sat,rec}$ - $P_{sat,pred}$ observed in the rest of the experiments ranged between 0.4 and 0.5 bar.

Table 1: The experimental conditions

Experiments	1a	1b	2a	2b	3a	3b	4a	4b
T_{driv} (^{o}C)	100	100	125	125	150	150	170	170
T_{cond} (^{o}C)	18.4	16.3	16.9	18.9	19.3	17.7	16.9	35

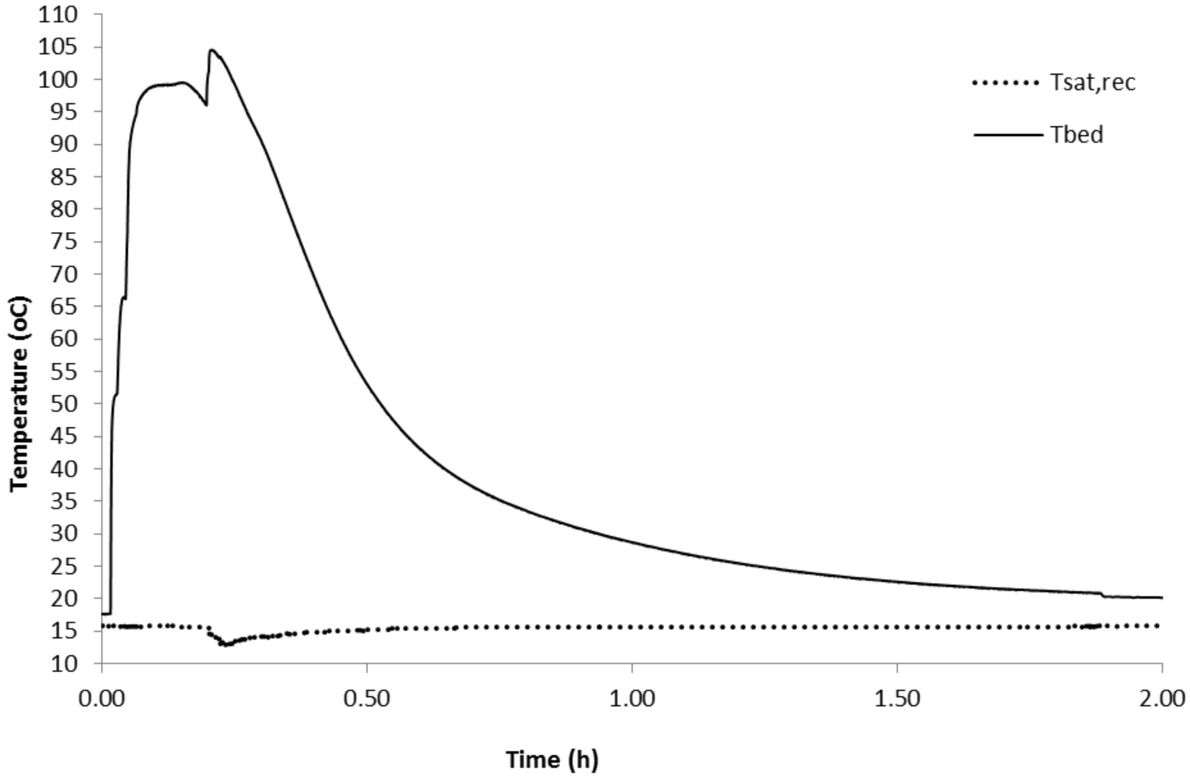

Figure 2: Temperature profiles of the receiver $T_{sat,rec}$ (saturation temperature) and generator T_{bed} during the initial loading of the generator.

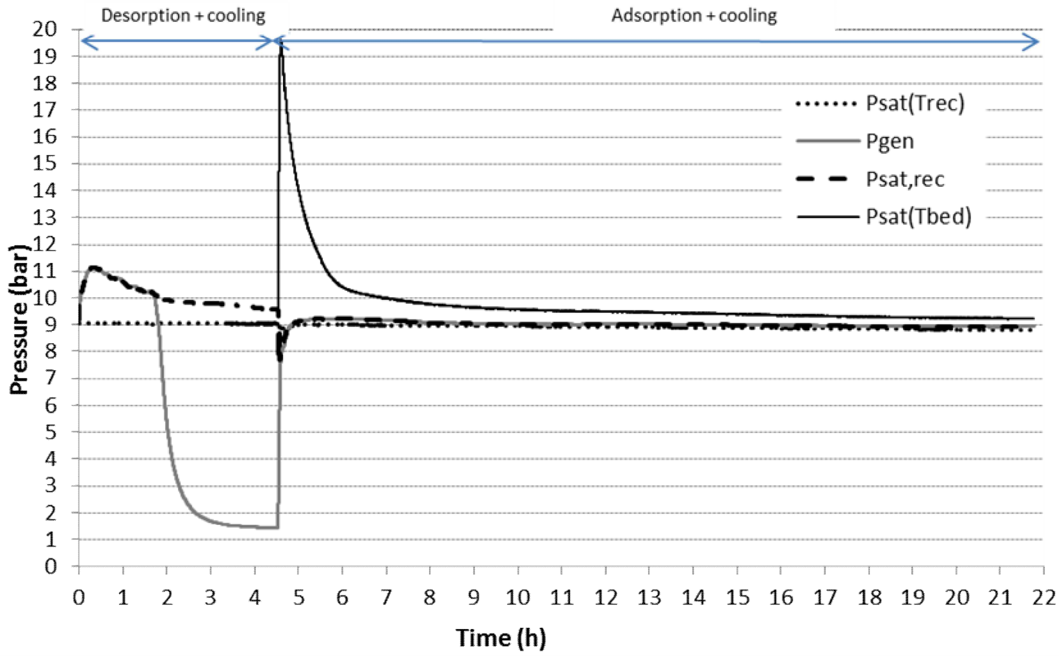

Figure 3: Pressure profiles of the generator (P_{gen}), the receiver ($P_{sat,rec}$) compared to the saturation pressure $Psat(T_{rec})$ as predicted based on the temperature measurements of the receiver and saturation pressure $P_{sat}(T_{bed})$ as predicted based on the temperature measurements of the bed during desorption at 100°C (condensing temperature 18.4°C) and adsorption.

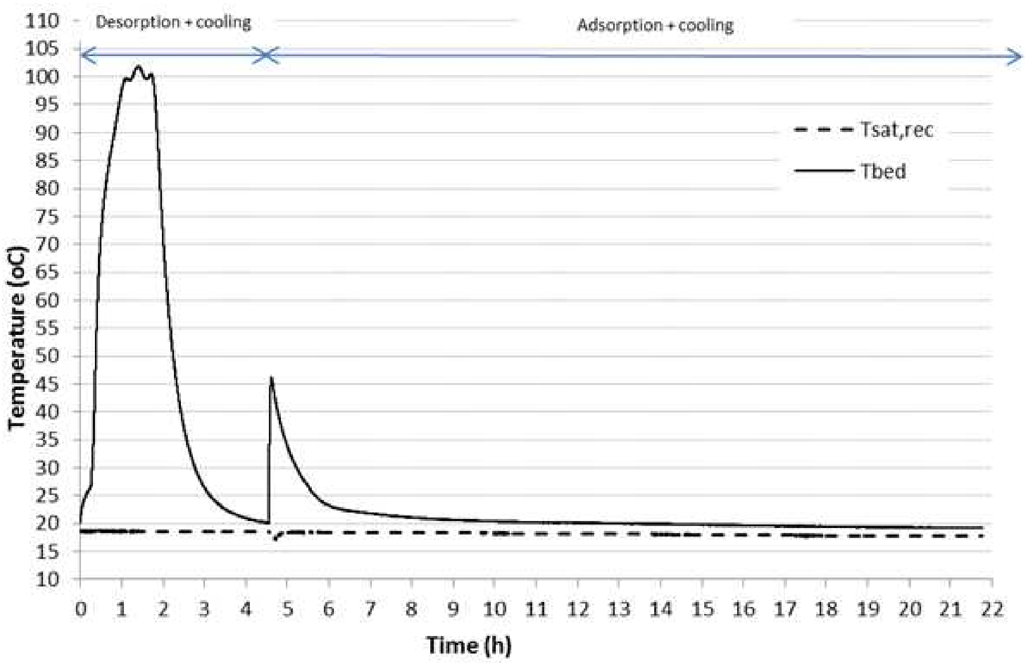

Figure 4: Temperature profiles of the generator (Tbed) and the receiver (Tsat,rec) during desorption at 100°C (condensing temperature 18.4°C) and adsorption.

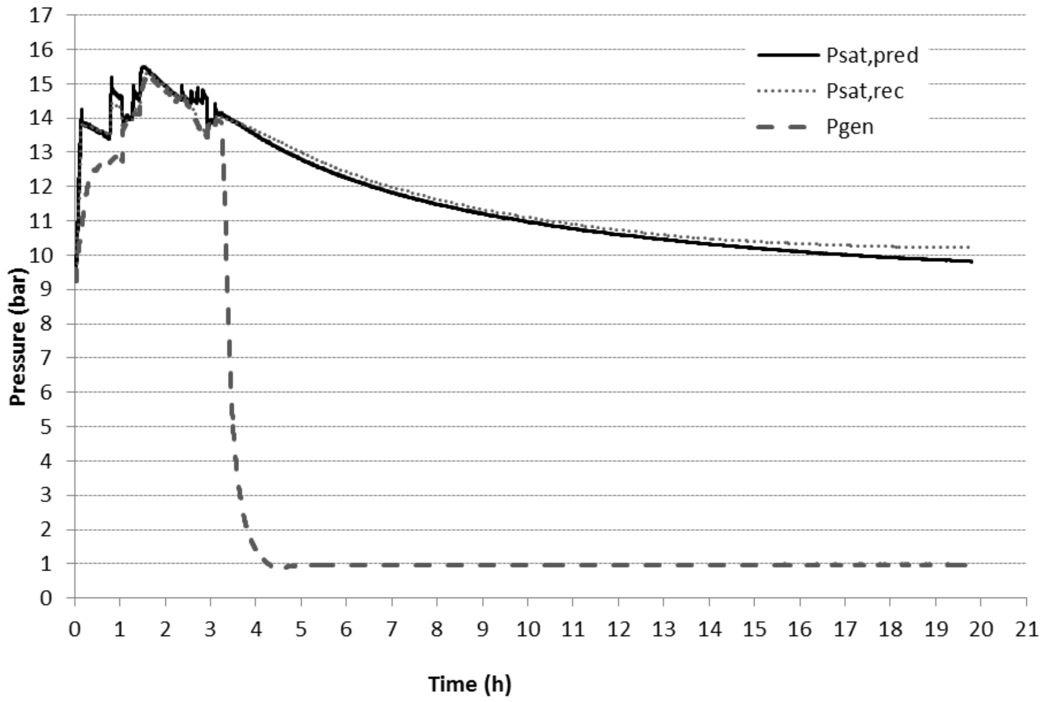

Figure 5: Pressure profiles of the generator (P_{gen}), the receiver ($P_{sat,rec}$) compared to the saturation pressure ($P_{sat,pred}$) as predicted based on the temperature measurements of the receiver during desorption at 170^{o}C (condensing temperature 35^{o}C) and cooling.

4. CONCLUSIONS

There was no unusual gas behavior observed throughout the whole series of experiments, i.e. there were not any anomalies in pressure or temperature profiles that would justify gas separation and dissociation. With a temperature difference of less than 3K between the measured temperature of the refrigerant liquid in the receiver and the saturated temperature calculated from the measured pressure, the refrigerant is considered unchanged therefore balanced. All test carried out were satisfactory within a large range of operating conditions. Even at driving temperatures as high as 170^{o}C and condensing temperature of 35^{o}C (which results in pressures of 15 – 16 bar during desorption) the saturation pressure measurements when compared to predicted ones showed differences within the measurement error. In fact the pressure differences were in the order of 0.5 bar when in thermal equilibrium. If there was gas separation (therefore altering significantly the ratio of ammonia - dimethyl ether initial mixture) the physical behavior of the refrigerant would have deviated significantly from the R723 standard one reported in the literature.

5. FUTURE WORK

The future work will be focused on porosity measurements of the activated granular carbon 208C – R723 pair under a wide range of temperatures (20 – 200^{o}C) and pressures (2 – 200 bar). This is mainly aimed to establish the concentration of R723 within the carbon as function of both temperature and pressure.

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