Measurement of Ammonia Absorption in New Absorbent - Preliminary Results

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Abstract:
In absorption refrigeration system, absorber is considered as the most critical component, both in terms of influence on system performance and cost. Research and investigations related to the absorption characteristics have been carried out extensively, particularly in the interest of heat and mass transfer phenomena in order to improve the performance of the absorber and to reduce its size. However, information related to the absorption characteristics in the absorber with new working fluid pairs remains limited. In this paper, ammonia-ionic liquids are proposed as a novel working pairs for absorption refrigeration systems. The main objective of this paper is to develop a measurement setup to study the absorption capacity of the ammonia vapor in various ionic liquids in a pool type absorber. This investigation is necessary to find the most suitable ionic liquid as an absorbent for ammonia (refrigerant). Furthermore, it is also important to find the most suitable absorber configuration for the proposed ammonia/ionic liquid absorption systems. The selection of absorber type for ionic liquids as absorbents in the initial studies plays an important role as they are quite viscous. The details of the methodology and experimental setup of the measurement are explained in this paper as well as preliminary results of absorption capacity using ammonia/polyethylene glycol mixture.

Keywords:
Absorption, Ammonia, New absorbent, Refrigeration.

1. Introduction

Besides the conventional compression refrigeration cycle, the absorption refrigeration cycle is one of the most common refrigeration system used in the world. The absorption cycle contains non CFC and thus, environmentally friendly and becomes a competitive alternative to the conventional compression refrigeration cycle. On the other hand, the waste heat that can be utilised by absorption cycle to produce cold carries a primary energy saving, and thus emission reduction. These advantages have made the absorption refrigeration system to become viable alternative to vapour compression cycle. Similar to the compression cycle, absorption cycle is based on the cooling and heating process associated with phase changes of evaporation and condensation of refrigerant fluid at different temperatures and pressures. The working fluid consists of refrigerant and absorbent, so that the boiling temperature can be modified by changing the pressure or composition of the mixture.

One of the most common working fluid pair in absorption refrigeration cycle is ammonia/water. In this working pair, ammonia works as refrigerant and water works as absorbent. The ammonia/water absorption cycle is used mainly for refrigeration purpose, since it can produce cold below 0°C. Being natural fluids, both are emission free and ozone friendly resulting with zero global warming potential (GWP) and ozone depletion potential (ODP). However, the characteristic of ammonia is toxic, so it is necessary to be handled carefully. In addition, the characteristic of water is volatile, thus it is necessary to add an additional component, namely rectifier, to minimize the amount of water entering to the condenser.

Many researchers have been investigating to find working fluid pairs that can overcome the above limitations. One of the working fluid has been investigated for absorption refrigeration cycle is ammonia/ionic liquid. The use of ionic liquid (IL) as an alternative to water as absorbent in the absorption refrigeration cycle gives some advantages such as elimination of the rectification process in ammonia/water system. The use of IL as absorbent with ammonia as refrigerant in the absorption refrigeration cycle has been discussed by researchers [1–2]. According to them, one of the main advantages in comparison with a conventional ammonia/water absorption refrigeration cycle is that the ammonia/IL absorption refrigeration system may not require the costly rectifier unit needed for traditional ammonia/water system due to there being practically no vapour pressure for the absorbent.

Ionic liquids, or often referred as room temperature ionic liquids (RTIL), are defined as salts which have liquid phase at temperatures below 100ºC [1]. These liquids, which usually consist of organic cation and inorganic anion, have negligible vapour pressure and good thermal stability. In addition, the thermophysical properties of ionic liquids can be adjusted by combining the cation and anion pair. These unique characteristics make ionic liquids to be a potential candidate as a novel absorbent for absorption system eliminating the drawbacks of conventional working fluids.

Absorption refrigeration system has four main components namely absorber, generator, condenser, and evaporator. Among these, absorber is considered to be the most critical part in the system, both in terms of influence on system performance and cost [3]. Absorption system based on ammonia/ionic liquid is desirable for subzero temperature applications. Thus it is essential to investigate the absorption characteristic of the ammonia vapour into ionic liquid absorbent.

The main objective of this investigation is to develop a measurement set up to study the absorption capacity of the ammonia vapour in ionic liquids in a pool type absorber. This investigation is necessary to find the most suitable ionic liquid as an absorbent for ammonia refrigerant. Furthermore, it is also important to find the most suitable absorber configuration for the proposed ammonia/ionic liquids absorption system.

The preliminary experimental studies are done with ammonia-polyethylene glycol working pair. It is prudent to use polyethylene glycol in preliminary studies before dealing with ionic liquids due to the reasons such as it has similar characteristic as ionic liquids in terms of its solubility with ammonia [4], and is less expensive and easily available in commercial market, apart from being harmless as similar to ionic liquids.

2. Research methodology

2.1. Absorber type selection

Absorber is the most critical part in the absorption refrigeration system. Thus as a consequence the selection of absorber type for new working fluid pairs for the initial studies becomes an important step in the starting point before building a complete absorption refrigeration machine.

The most common types of absorber for industrial applications are falling film and bubble plate. The former has been recommended to enhance heat and mass transfer during the absorption process. Thin falling film heat transfer mode provides a high heat transfer coefficient and is stable during operation. However, it has a wettability problem that deteriorates the absorption performance.

Bubble type absorber provides better heat and mass transfer coefficients, and also has good wettability and mixing between the liquid and the vapour [5]. Bubble absorption is in general more efficient than falling-film absorption, especially for low solution flow rates. This fact is explained by the low wetted area in falling film flow under such regimes. These low solution flow rates are more characteristic of low capacity absorber, therefore, the bubble flow is more suitable in such applications [6].

Lee [7] carried out experimental studies on absorption heat and mass transfer performance in ammonia/water adding nanofluids into the system. In their experiment, they measured the effect of nanoparticles on heat and mass transfer aspects of ammonia vapour absorption in ammonia/water solution in a pool type absorber. The equipment test consists of an absorber test section equipped with a vapour distributor, a coolant refrigerator, an ammonia cylinder with pressure regulator, a solution outlet line with a balance and a data acquisition system. All pipelines as well as the absorber test rig are made of stainless steel to avoid corrosion problems caused by ammonia. The test section unit has dimensions of 300 mm width, 300 mm length, and 150 mm height.

The absorption processes on a very small bubble type absorber was studied experimentally by Kim et al. [8] in order to find the optimal conditions to design compact absorber for ammonia/water absorption system. In this study, they considered mechanical treatment method and nanotechnology application to enhance the heat and mass transfer. They choose bubble absorption type as the absorption method for mechanical treatment and add the nanoparticles into the working fluids for improvement in performance. Their experimental equipment consists of an absorber test unit, a vapour orifice, an ammonia gas cylinder and a bubble behaviour visualization apparatus. The test section unit has dimensions of 20 mm width, 20 mm length, and 200 mm height. The vapour orifice is 2 mm in diameter.

In addition to the above two types of absorber configuration, there are some other configurations which are investigated for the absorption characteristic of a refrigerant into an absorbent at relatively small flow rates. A novel design and configuration of wiped-film evaporator has been proposed for high viscosity working fluids [9-10]. Since the basic principle of evaporation process is a reverse process of absorption, this configuration may be applied and be adjusted for the application of absorption process. For instance, Mc Kenna [9] proposed a design model of a wiped-film evaporator for the devolatilisation of polymer solutions. He reported that wiped film evaporators (WFE) can be used in chemical process operations where heat and/or mass transfer steps are rate limited since they can be adapted to treat liquids with a wide range of viscosities while maintaining short residence times. Both Heimgartner [11] and Biesenberger [12] indicated in their reviews on the applications of such devices that they can operate at liquid viscosities ranging from 1 poise up to 105 poise.

In this study, the pool type absorber configuration is selected to examine the absorption rate of ammonia refrigerant into ionic liquid absorbent as this configuration is suitable for the measurement of absorption capacity in liquid static conditions. In addition, this configuration is suitable to handle high viscosity fluid like ionic liquids. However, as mentioned above, the preliminary experimental studies are done with ammonia-polyethylene glycol working pair for the reasons that the glycol has similar characteristic as the ionic liquids in terms of its solubility with ammonia.

2.2. Experimental apparatus and measurements

The main components of the experimental set-up (Fig. 1) for absorption measurement are liquid cell, temperature and pressure sensor, data logger, thermal bath, magnetic stirrer, ammonia tank and vacuum pump.

The liquid cell is a cylinder and is made up of stainless steel to avoid corrosion problem due to ammonia contact. It has inner volume of about 14 ml, with wall thickness of 2 mm. The liquid cell has a temperature sensor (PT-100) and pressure sensor (Wika S-20 pressure transmitter). The temperature and the pressure sensors are connected to the data logger (DataTaker DT80) to record the temperature and pressure in a certain interval of time. The cell is immersed in a thermal bath to maintain the temperature, and is placed over a magnetic stirrer to agitate the liquid absorbent inside the cell in order to ensure that the ionic liquid/ammonia solution is in homogenous condition and the liquid surface is less than equilibrium condition so that the absorption process can occur until the solution reaches the equilibrium condition with the refrigerant vapour. The detailed schematic diagram of the measurement setup is shown in Figure 1.

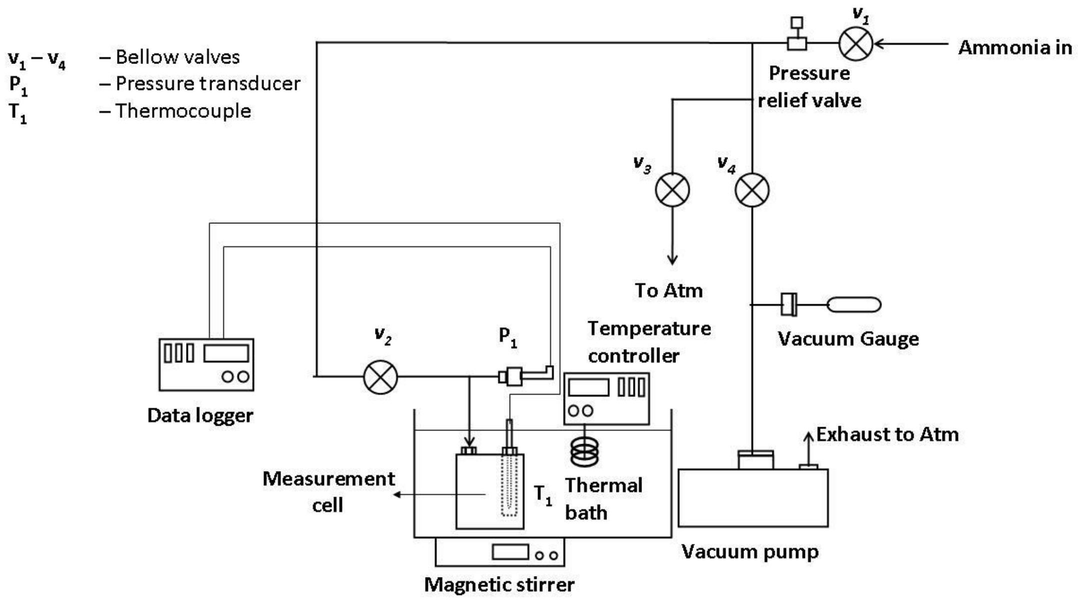

Fig. 1. Schematic diagram of the experimental measurement setup

The main ammonia line is connected to the ammonia tank which has a valve, a pressure regulator, and a relief valve. In addition, the ammonia line has a connection to the vacuum pump to remove non-absorbable gas inside the liquid cell.

An amount of about 10 ml of absorbent is taken using a syringe and weighted on a mass balance, and then is injected carefully into the cell via injection line. After all liquid is inserted into the cell, the syringe is weighted again on a mass balance in order to get the exact mass of the absobent inserted into the cell. The total mass of the liquid inserted into the cell can be calculated using simple formula as follows

$$m_{liq} = m_{ini} - m_{fin} \quad (1)$$

where m_{liq} is the mass of the liquid inserted into the cell, m_{ini} is the mass of syringe with liquid before the liquid is inserted into the cell, and m_{fin} is the mass of the syringe after the liquid is inserted into the cell.

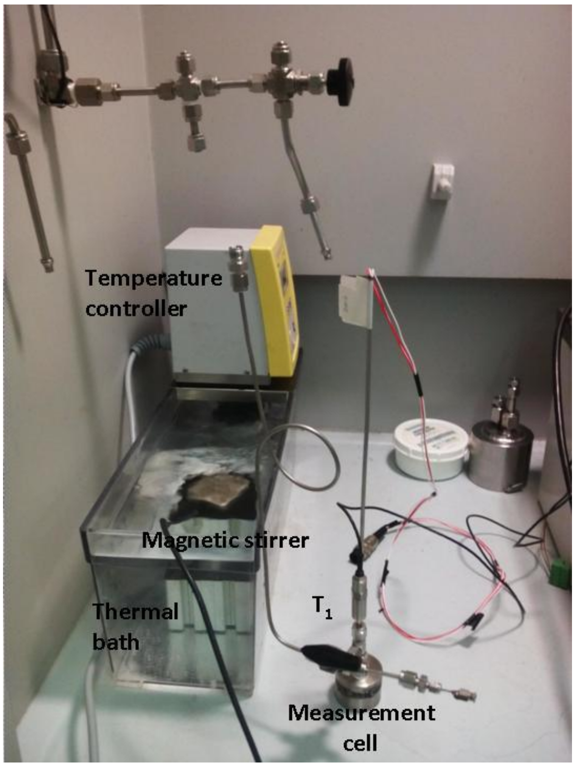

Fig. 2. Photograph of the measurement setup

After the liquid is inserted into the cell, all the lines are connected properly. Before starting the measurement, it is important to remove the non-absorbable gas trapped both in the line and the cell. To remove the non-absorbable gas, vacuum is applied to the whole gas pipeline and the cell, in order to remove the air inside them. The vacuum pressure is monitored with the digital Pirani gauge meter, until that segment reaches vacuum (around 0.01 mbar). After removing the non-absorbable all valves are closed. The temperature and pressure sensors are connected to the data logger. The cell is then immersed into the thermal bath placed over the magnetic stirrer.

The final step before starting the measurement is to set the ammonia pressure regulator to the desired pressure. The first step to set the ammonia pressure is to ensure that the ammonia tank valve and the pressure regulator are closed, and then to reduce the pressure by opening the release valve. The second step is to open the ammonia tank valve and then carefully open the pressure regulator until reach the desired pressure.

To start the measurement, the ammonia valve V_2 is opened. The pressure and the temperature are recorded every 3 seconds until these parameters become invariant and then the measurements and experiment are stopped.

The maximum temperature change during the absorption process can be roughly predicted from the iteration heat balance calculation

$$Q = m_{NH3}(h_{NH3} - h_{NH3sat}) \quad (2)$$

$$Q = (T_{fin} - T_{ini})(m_{cell} \cdot Cp_{cell} + m_{sol} \cdot Cp_{sol}) \quad (3)$$

Where, Q is the heat released or absorbed during the absorption process. m_{NH3}, m_{cell}, and m_{sol} represent the mass of absorbed ammonia vapour into the absorbent, the mass of liquid cell, and the mass of liquid solution respectively. m_{NH3sat} is the ammonia mass at saturated liquid condition correspondind to the pressure and temperature. T_{ini} and T_{fin} are the initial and final temperatures respectively. Cp_{cell} and Cp_{sol} are the heat capacity at constant pressure of liquid cell and solution respectively. The concentration of the ammonia mixture at saturated condition can be obtained from the literature [1-2, 14] and then the T_{fin} can be calculated. Assuming T_{fin} and T_{ini} for the next calculation, the iteration is continued until the T_{fin} becomes equal to T_{ini}. The final T_{fin} represents the predicted maximum temperature of the solution during the absorption process.

3. Preliminary results and Discussions

As preliminary experiments, the experimental studies are done using ammonia/polyethylene glycol working pair. It is interesting to use polyethylene glycol for preliminary studies before starting with ionic liquids because it has similar solubility with ammonia [4] and is less expensive and easily available in commercial market.

In this preliminary study, the measurement is carried out at initial temperature of 30ºC and initial pressure of 3.5 bars. The present experimental results for the absorption capacity of ammonia/polyethylene glycol are shown in figure 3 and figure 4.

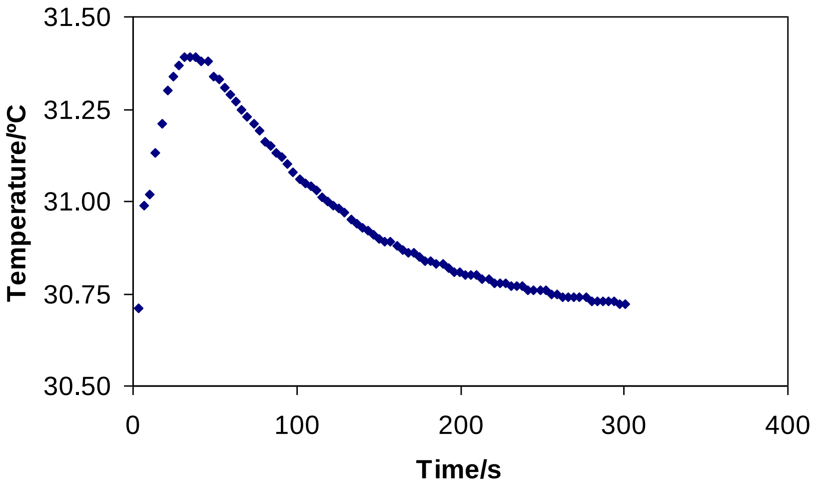

Fig. 3. Temperature variation during the absorption process of ammonia in polyethylene glycol

From figure 3 it can be seen that the pool type absorber with small volume can give relatively significant rise in temperature considering the small amount of absorbent inside the measurement cell. From the figure it also can be seen that the temperature increases significantly in the beginning of the measurement as at this time the absorption rate is the highest and the heat released to the system is also correspondingly maximum. The temperature then decreases as the absorption rate decrease until the solution reaches equilibrium. The temperature reached a maximum after 50 seconds and after 300 seconds the temperature almost reached to its initial condition as the absorption process decayed gradually.

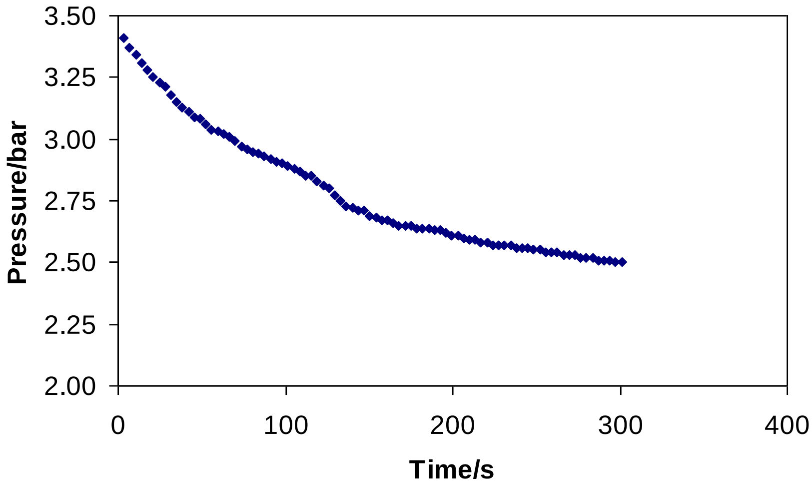

Fig.4. Pressure variation inside the cell during the absorption process of ammonia in polyethylene glycol

Figure 4 shows the pressure variation inside the cell during the measurement. As the absorption occurs, the pressure decreases during the process. The pressure decreases rapidly in the beginning of the measurement due to the fact that the absorption is in its highest rate.

4. Conclusions and future works

Ammonia is absorbed in polyethylene glycol in a small pool type absorber. From this experimental investigation it can be concluded that such a small pool type absorber can be used to measure the absorption capacity of a liquid mixture which has relatively low solubility. From our preliminary study, it can be seen that the temperature increases significantly in the beginning of the absorption process as in this time the absorption is in its highest rate releasing the corresponding exothermic heat of absorption. The temperature then gradually decreases as the absorption rate decreases to zero when the solution reaches equilibrium.

In addition, based on this preliminary study, it can be concluded that the measurement set up is able to measure the absorption capacity of ammonia refrigerant into new absorbent.

The investigation will be continued to measure the absorption capacity of ammonia into some selected ionic liquids to find the most suitable ionic liquid as an absorbent for ammonia refrigerant and to find the most suitable absorber configuration for the proposed ammonia/ionic liquid absorption system.

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