Effect of Zeolite NaA additive on the absorption refrigeration unit

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Abstract. Absorption refrigeration has a potential to become among the most effective refrigeration unit due to low power consumption and eco-friendly benefits. However, the problem of relatively lower performance compared to the compressor refrigeration unit has increased the efforts for improvements including working fluid modification and addition of special additive. The purpose of this study was to investigate the effects by adding Zeolite NaA as an additive in the ammonia/water solution in the bench-scale absorption refrigeration system. The additive contains of certain chemicals such as sodium hydroxide, sodium aluminate and sodium metacilicate. The additive was added with different concentrations in the range of 0.2 mM to 0.001 M. From the experiment, the highest COP was calculated to be 6.3 with 0.001 M of additive, while the lowest cooling box temperature was recorded to be 20°C with 0.6 mM additive and 1.5 of COP. The ratio of ammonia and water solution was 30/70% by volume for the obtained result which could be subjected to further research.

1. Introduction
A chiller or refrigerator is a machine that removes heat from a liquid via a vapour-compression or absorption refrigeration cycle. Chilled water is used to cool and dehumidify air in mid- to large-size commercial, industrial, and institutional facilities. In general, there are two types of refrigerators that are mainly used; i) compression refrigerator, and ii) gas absorption refrigerator. The compression refrigerator consists compressor, expansion device, condenser and evaporator. For absorption refrigerator, the compressor is replaced by an absorber, pump and generator, while the condenser, expansion device, and evaporator are the same. It utilizes a heat source to provide the energy needed to drive the cooling system rather than being dependent on electricity to run a compressor. Working fluids in the system contain a mixture of refrigerant and absorbent. The two most common mixtures for absorption refrigeration are water/lithium bromide and water/ammonia [1]. In the latter, water acts as absorbent and ammonia is a refrigerant.

The coefficient of performance (COP) which is the efficiency of a chiller, defined as the ratio of refrigeration effect (chiller load) against the net heat input or the amount of electrical energy consumption. There are situations that favour applications of refrigeration by absorption. Mainly, these refrigerators are popular where electricity is unreliable and costly for running the compressor for compression refrigeration, and the availability of low temperature heat sources [2, 3, 4, 5]. As stated
by [6], there are four categories of improvements which have been proposed and studied as to increase technological aspects of absorption refrigeration system; i) absorption system developments, ii) machine component developments, iii) working fluid modifications and additives, and iv) novel applications of absorption cooling systems.

As the performance of the chiller is critically depending on the chemical and thermodynamic properties of the working fluids (combination of refrigerant and absorbent), the selection criteria including margin of miscibility, the elevation of boiling temperature between pure refrigerant and its mixture should be high, non-toxic, non-toxic, chemically stable, non-corrosive, environmentally friendly and low-cost [7]. Magnetic field enhancement model in water-ammonia absorption refrigeration system was developed by [8] based on conservation equation and mass transport relationship. The magnetic field has affected and increased the COP of the system. Five ammonia and ionic liquids pair were studied by [9], which one pair has the highest increment of the COP. Simulation model for gas-fired ammonia-water absorption system was developed and validated against commercial absorption chiller [10]. Other works included working fluids comparisons for refrigeration temperature below 0°C [11], use of process steam for cooling and heating applications [12], and the possibility of using carbon dioxide and ionic liquids for absorption refrigeration [13]. As the past and current researches are still ongoing, this study focuses for the effect of adding different concentrations of additive to the lowest cooling box temperature and the overall COP.

2. Materials and method
The experimental study was conducted in a single-stage and bench-scale sized of absorption refrigeration unit. Preparation of the Zeolite NaA additive has involved de-ionized water, sodium hydroxide, sodium aluminate and sodium metacilicate. The water and sodium hydroxide was first mixed and allowed to dissolve completely. The mixture was then partly mixed with sodium aluminate and sodium metacilicate in separate containers, and eventually put together for homogenization. The prepared additive is white in colour and it is soluble in water. With this characteristic, it is easy to dissolve in the aqueous ammonia solution.

After that, 0.2 mM additive was added to the ammonia and water solution with 30/70% by volume in the bench-scale absorption refrigeration system. The absorption refrigeration unit was started and temperature of ambient, generator and cooling box were recorded during the experiment. Calculation of the absorption refrigeration’s COP was based on Equation 1. \( T_0 \) is the recorded ambient temperature when running the experiment, \( T_s \) is the generator’s temperature which should be allowed until 2 hours after start up for stable reading (positive value of COP), and \( T_L \) is the cooling box temperature.

\[
COP = \left(1 - \frac{T_L}{T_s}\right) \left(\frac{T_s}{T_s - T_L}\right)
\]  

(1)

The experiments were repeated with other concentration of Zeolite NaA additive (0.4 mM, 0.6 mM, 0.8 mM, and 0.001 M).

3. Results and discussion
Table 1 till table 5 show the data of absorption process with additive at the concentrations of 0.2 mM, 0.4 mM, 0.6 mM, 0.8 mM, and 0.001 M, respectively, after 8 hours of experiments. The first experiment with 0.2 mM of Zeolite NaA was added to the 30% ammonia and 70% water solution. After 5 to 8 hours operation of the absorption refrigeration, the temperature decreased until the final temperature of 24°C. The corresponding graph for table 1 is shown by figure 1.
Table 1. Absorption refrigeration process with 0.2 mM additive

| Time (Hour) | Generator Temperature, $T_S$ ($^\circ$C) | Cooling Box Temperature, $T_L$ ($^\circ$C) | Ambient Temperature, $T_0$ ($^\circ$C) | $1-(T_0/T_S)$ | $T_L/(T_0-T_L)$ | COP  |
|-------------|----------------------------------------|------------------------------------------|---------------------------------------|---------------|----------------|-------|
| 1           | 25                                     | 25                                       | 30                                    | -0.2000       | 5.000          | -1.000|
| 2           | 85                                     | 27                                       | 30                                    | 0.647         | 9.000          | 5.824 |
| 3           | 86                                     | 26                                       | 30                                    | 0.651         | 6.500          | 4.233 |
| 4           | 90                                     | 26                                       | 30                                    | 0.667         | 6.500          | 4.333 |
| 5           | 95                                     | 25                                       | 30                                    | 0.684         | 5.000          | 3.421 |
| 6           | 110                                    | 24                                       | 30                                    | 0.727         | 4.000          | 2.909 |
| 7           | 115                                    | 24                                       | 30                                    | 0.739         | 4.000          | 2.957 |
| 8           | 117                                    | 24                                       | 30                                    | 0.744         | 4.000          | 2.974 |

Figure 1. Calculated COP with 0.2 mM additive

Same goes to the next experiment which the additive was added at 0.4 mM, as shown by table 2. The different was the final temperature that the unit has achieved after 8 hours was lower than the first experiment. Corresponding graph is shown by figure 2. Then, after adding 0.6 mM of Zeolite NaA, the cooling box temperature has achieve 20$^\circ$C after 7 hours of operation. The details are shown in table 3 with corresponding graph by figure 3. Next, the experiments have proceed by adding the other two concentrations of additive that were 0.8 mM and 0.001 M. Both tables 4 and 5 show the details with figures 4 and 5, respectively.
Table 2. Absorption refrigeration process with additive 0.4 mM.

| Time (Hour) | Generator Temperature, $T_S$ (°C) | Cooling Box Temperature, $T_L$ (°C) | Ambient Temperature, $T_0$ (°C) | $1-(T_0/T_S)$ | $T_L/(T_0-T_L)$ | COP       |
|-------------|----------------------------------|------------------------------------|-------------------------------|-------------|----------------|----------|
| 1           | 25                               | 25                                 | 30                            | -0.200      | 5.000          | -1.000   |
| 2           | 85                               | 27                                 | 30                            | 0.647       | 9.000          | 5.824    |
| 3           | 87                               | 26                                 | 30                            | 0.655       | 6.500          | 4.259    |
| 4           | 90                               | 26                                 | 30                            | 0.667       | 6.500          | 4.333    |
| 5           | 99                               | 25                                 | 30                            | 0.697       | 5.000          | 3.485    |
| 6           | 100                              | 23                                 | 30                            | 0.700       | 3.286          | 2.300    |
| 7           | 115                              | 22                                 | 30                            | 0.739       | 2.750          | 2.033    |
| 8           | 120                              | 22                                 | 30                            | 0.750       | 2.750          | 2.063    |

Figure 2. Calculated COP with 0.4 mM additive.
Table 3. Absorption refrigeration process with 0.6 mM additive.

| Time (Hour) | Generator Temperature, $T_S$ ($^\circ$C) | Cooling Box Temperature, $T_L$ ($^\circ$C) | Ambient Temperature, $T_0$ ($^\circ$C) | $1-(T_0/T_S)$ | $T_L/(T_0-T_L)$ | COP |
|-------------|-----------------------------------------|-------------------------------------------|--------------------------------------|---------------|-----------------|-----|
| 1           | 25                                      | 27                                        | 30                                   | -0.200        | 9.000           | -1.800 |
| 2           | 85                                      | 25                                        | 30                                   | 0.647         | 5.000           | 3.235 |
| 3           | 87                                      | 26                                        | 30                                   | 0.655         | 6.500           | 4.259 |
| 4           | 90                                      | 24                                        | 30                                   | 0.667         | 4.000           | 2.667 |
| 5           | 99                                      | 23                                        | 30                                   | 0.697         | 3.286           | 2.290 |
| 6           | 100                                     | 21                                        | 30                                   | 0.700         | 2.333           | 1.633 |
| 7           | 115                                     | 20                                        | 30                                   | 0.739         | 2.000           | 1.478 |
| 8           | 120                                     | 20                                        | 30                                   | 0.750         | 2.000           | 1.500 |

Figure 3. Calculated COP with 0.6 mM additive.
Table 4. Absorption refrigeration process with 0.8 mM additive.

| Time (Hour) | Generator Temperature, $T_S$ ($^\circ$C) | Cooling Box Temperature, $T_L$ ($^\circ$C) | Ambient Temperature, $T_0$ ($^\circ$C) | $1-(T_0/T_S)$ | $T_L/(T_0-T_L)$ | COP |
|-------------|------------------------------------------|---------------------------------------------|---------------------------------------|---------------|-----------------|-----|
| 1           | 25                                       | 25                                          | 30                                    | -0.200        | 5.000           | -1.000 |
| 2           | 80                                       | 26                                          | 30                                    | 0.625         | 6.500           | 4.063 |
| 3           | 85                                       | 27                                          | 30                                    | 0.647         | 9.000           | 5.824 |
| 4           | 87                                       | 24                                          | 30                                    | 0.655         | 4.000           | 2.621 |
| 5           | 95                                       | 24                                          | 30                                    | 0.684         | 4.000           | 2.737 |
| 6           | 100                                      | 25                                          | 30                                    | 0.700         | 5.000           | 3.500 |
| 7           | 120                                      | 25                                          | 30                                    | 0.750         | 5.000           | 3.750 |
| 8           | 122                                      | 25                                          | 30                                    | 0.754         | 5.000           | 3.770 |

Figure 4. Calculated COP with 0.8 mM additive.

From the experimental results that were shown above, the highest calculated COP was 6.3 at additive concentration of 0.001 M. Translating to physical meaning of this achievement, at 0.001 M, refrigeration duty can be supplied 6.3 times per single unit of energy input. The lowest cooling box temperature of 20$^\circ$C happened with 0.6 mM additive. The trends show that adding more zeolite NaA beyond 0.6 mM has opposite effects which temperatures of cooling box have increased. Table 6 summarizes the relationship between additive concentration and the lowest cooling box temperature. Figure 6 shows the overall relationship between COP and the additive concentration. Beyond 0.001M, COP should be expected to increase at the expense of higher cooling temperature.
Table 5. Absorption refrigeration process with 0.001 M additive.

| Time (Hour) | Generator Temperature, $T_S$ (°C) | Cooling Box Temperature, $T_L$ (°C) | Ambient Temperature, $T_0$ (°C) | $1-(T_0/T_S)$ | $T_L/(T_0-T_L)$ | COP  |
|-------------|-----------------------------------|------------------------------------|--------------------------------|--------------|-----------------|------|
| 1           | 25                                | 25                                 | 30                             | -0.200       | 5.000           | -1.000 |
| 2           | 50                                | 28                                 | 30                             | 0.400        | 14.000          | 5.600 |
| 3           | 55                                | 27                                 | 30                             | 0.455        | 9.000           | 4.091 |
| 4           | 98                                | 25                                 | 30                             | 0.694        | 5.000           | 3.469 |
| 5           | 99                                | 25                                 | 30                             | 0.697        | 5.000           | 3.485 |
| 6           | 99                                | 26                                 | 30                             | 0.697        | 6.500           | 4.530 |
| 7           | 100                               | 27                                 | 30                             | 0.700        | 9.000           | 6.300 |
| 8           | 100                               | 27                                 | 30                             | 0.700        | 9.000           | 6.300 |

Figure 5. Calculated COP with 0.001 M additive.

Table 6. Relationship between additive concentration and supplied cooling temperature.

| Additive Concentration (Molar) | Cooling Temperature (°C) |
|--------------------------------|-------------------------|
| 0.0002                         | 24                      |
| 0.0004                         | 22                      |
| 0.0006                         | 20                      |
| 0.0008                         | 25                      |
| 0.0010                         | 27                      |
4. Conclusion
Absorption refrigeration unit has the potentials to be a commercial chiller that can be used widely in the industrial and residential sectors especially when electricity is unreliable and costly for running the compressor for compression refrigeration, and the low temperature heat sources are readily available. From the experimental results, the best concentration of additive was 0.6 mM of Zeolite NaA, which has gained the lowest cooling temperature of 20°C. Theoretically, the cooling temperature can be achieved below 20°C, provided the optimum ratio of ammonia and water is applied. More portion of ammonia as a refrigerant was hindered because of the safety requirements in operating the unit. The calculated COP showed at highest value of 6.3 at the 0.001 M of additive.

Acknowledgment
The authors would like to acknowledge the financial support provided by the Universiti Malaysia Pahang (UMP Research Grant Scheme, RDU1703317).

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