A CASE STUDY OF A LOW POWER VAPOUR ADSORPTION REFRIGERATION SYSTEM

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Abstract
Industrial refrigeration is one of the most energy consuming sector. In conventional Vapor Compression refrigeration system, compressor is the major power consuming element. Vapor Adsorption refrigeration system is one of the best replacement for the Vapor Compression refrigeration system. Our main objective is to analyze, design and develop a Vapor Adsorption refrigeration system which is cost effective and environment friendly. A prototype model that is capable of producing a temperature drop in closed evaporator chamber was designed, fabricated and tested. Activated carbon/Methanol pair is chosen as Adsorbent/Refrigerant pair. The system is analyzed in ANSYS 14.5 using the inlet conditions obtained from the experimental setup. The performances and effectiveness of the unit was studied by determining Refrigeration Effect (RE), Coefficient of Performance (COP) and operational issues of the unit are explained. The results obtained from the analysis and experiments have marginal difference in COP i.e. with an error percentage of 5.94%. The overall COP obtained is 0.34 through experiments and from analysis the COP obtained is approximately 0.32.

Keywords
Adsorption refrigeration, Activated Carbon, Coefficient of Performance (COP)

1. INTRODUCTION
In order to meet the present day challenges an eco-friendly refrigeration system is required. Our objective is to design and develop a sustainable ecofriendly refrigeration system which can run throughout the year. Among alternative refrigeration systems, Adsorption [1] refrigeration system is the best choice because it is simple in process with less number of parts, eco friendly and has many more advantages [2, 3]. Among different Adsorbent/Refrigerant pairs Activated carbon/Methanol pair has advantages like its operating temperature range, easy availability and its environment friendliness. Many papers mentioned proper designing of the Adsorption refrigeration system is one of the major goals in obtaining better COP’s [4, 5]. Tchernev reported about zeolite based system and reported a less (0.109) net COP though the cycle COP was promising 0.8 [6]. In one of the papers on Absorption refrigeration system, using two drum shaped vessels, written by Iwasawa et al., it was mentioned that twin drum system has more advantages than single drum system [7]. Operating a single drum system is difficult because maintaining two different pressures in the single drum is extremely difficult.

Dhokane et al. (2014), reported design and development of intermittent solid adsorption refrigeration system running on solar energy [8].Their system consisted of one adsorption bed compared to the multi bed system. The adsorbent was activated carbon and methanol was refrigerant. It had four main components namely, a solid adsorbent bed, a condenser, an evaporator and an ice-box. They mentioned that activated carbon bed acts as compressor so as to drive refrigerant (methanol). They have stated the design parameters of adsorbent bed which is made of flat plate stainless steel box and other components. This entire setup is assembled...
and then it is vacuumed. Since the system had no valves, the cost of the system is reduced and absence of noisy components helps vapor adsorption refrigeration system to gain its importance in numerous applications [9, 10]. The refrigerant (methanol) used in this system is not harmful to the environment and also satisfies the Montreal Protocol [3]. Therefore, adsorption refrigeration is based on the evaporation and condensation of a refrigerant employing the vapor adsorption phenomena.

2. EXPERIMENTAL METHODS

There are four major parts in Twin drum vapor Adsorption refrigeration system, which are Generator, Condenser, Evaporator and Adsorber [11, 12]. Generator and Condenser are kept in one chamber with a partition plate separating them. Evaporator and Adsorber are kept in one more chamber having partition plate separating them. The Generator/Condenser drum (Drum 1) is a high pressure chamber (1 atm) and Evaporator/Adsorber drum (Drum 2) is a low pressure chamber (0.1 atm). One-fourth of the Generator is filled with Activated Carbon [13]. Initially Methanol is sprayed on the Adsorbent bed using aquarium pump (4 W). Later hot water is supplied through the Generator coil which is located across the Adsorbent bed (Fig. 1). Hot water is generated in a separate chamber with electric immersion coil and the Methanol vapor rise by taking the heat [14,15]. Methanol vapor move onto the Condenser (which is in the same chamber) and releases heat to the surroundings at given pressure. Now it moves to the expansion coil where pressure drops suddenly at constant temperature. Liquid refrigerant is sprayed over the Evaporator coil in the Evaporator section. The Evaporator coil is filled with water (secondary refrigerant). The low pressure, low temperature Methanol takes the heat out of secondary refrigerant. Taking this heat, methanol vapors are generated; this will be collected in the Adsorption chamber and pumped back to the Generator thus completing the cycle.

One kilogram of Activated carbon is used in the generator as Adsorbent bed [13] and Methanol (NICE Chemicals, Cochin) is used as refrigerant. Activated Carbon is prepared using coconut shells. Two immersion coils of 50 W are used to heat the water which is given as input to the generator coil.

![Fig. 1: Vapor Adsorption Refrigeration Cycle](image)

3. CFD ANALYSIS

During CFD analysis heat input to activated carbon, pressure drop in expansion coil, heat removed (in evaporator), temperature distribution in drum 1 and temperature distribution in drum 2 are considered as the major parameters to be computed. CFD Analysis is done using ANSYS 14.5 [16]. The geometric model of generator coil, evaporator coil and expansion coil were done using CATIA V5 (Dassault Systemes) with same dimensions as working model and imported the same into the ANSYS 14.5 platform [16]. Coarse mesh was given to these three models and for the remaining Drum1 and Drum2 models fine mesh is given [17, 18]. Viscosity is considered as per k-ε model and radiation is considered as discrete ordinates for all the five models [19]. All simulations are done using density based approach. Boundary conditions are given in Table 1 and Turbulence intensity for Generator, Condenser and Expansion coil is 5%.
Table 1: Boundary conditions for various components

| **Generator coil:** | **Condenser:** | **Expansion coil:** |
|---------------------|----------------|-------------------|
| Wall material       | Wall material  | Aluminum           |
| Inlet Fluid         | Inlet fluid    | Methanol           |
| **Mass flow rate**  | **Inlet methanol** | **Inlet gauge** |
| $32.97 \times 10^{-3}$ kg/s | $343$ K       | Pressure           |
| **Inlet Temperature** | **Wall 1: Free Convection temperature** | **Inlet Temperature** |
| $363$ K             | $303$ K        | **Convection heat transfer coefficient** |
| **Inlet gauge Pressure** | **Convection heat transfer coefficient** | **Natural convection temperature** |
| $12753$ Pa          | $1 \text{ W/m}^2\text{K}$ | $303$ K |
| **Surrounding Temperature** | **Inlet Temperature** | **Temperature** |
| $303$ K             | $363$ K        | |

| **Adsorber:** | **Evaporator:** |
|----------------|----------------|
| Wall material  | Wall material  |
| Inlet Fluid    | Inlet Fluid    |
| Inlet Temperature | Mass flow rate |
| $293$ K        | $35 \times 10^{-4}$ kg/s |
| **Wall 1: Temperature** | **Inlet gauge Pressure** |
| $303$ K        | $1410$ Pa      |
| **Wall 3: Temperature** | |
| $303$ K        | |

4. RESULTS AND DISCUSSION
4.1. Result from the analysis:
4.1.1. Generator
Due to heat transfer from the generator coil to adsorbent bed there is a significant temperature drop i.e., $363$ K to $327$ K. Outlet temperature of the generator coil ranges from $327$ K to $324$ K and outlet gauge pressure is $100.76$ Pa. The heat released by the generator coil is absorbed by adsorbent bed [1]. The temperature contour and pressure contour are shown in the Fig. 2 and Fig. 3 respectively.

4.1.2. Drum 1 and Drum 2
The temperature distribution is computed for 2-D models. However the temperature distribution for 3D models can be generated by integration of corresponding 2D model. The temperature distribution might be similar throughout the drum because of similar conditions throughout the drum. The minimum temperature obtained in the drum 1 is $339$ K. As Methanol...
vapor rise from the adsorbent bed by taking the generator coil heat, it gets condensed in the condenser chamber. The temperature of distribution inside is shown in Fig. 4. In drum 2 the methanol which is sprinkled on the evaporator coil takes the heat out of evaporator coil and gets evaporated and moves to the next chamber. The temperature distribution of drum 2 is as shown in the Fig. 5.

![Fig. 4. Temperature distribution in Drum 1](image1)

![Fig. 5. Temperature distribution in Drum 2](image2)

### 4.1.3. Expansion coil

In expansion coil methanol vapor gets expanded at constant temperature. An outlet temperature of 313.64 K and outlet gauge pressure of -2.36 Pa is observed from the analysis. From the results we can say that there is a significant pressure drop with negligible change in temperature as shown in the Fig. 6 and Fig. 7.

![Fig. 6. Pressure contour for Expansion coil](image3)

![Fig. 7. Temperature contour for Expansion coil](image4)

### 4.1.4. Evaporator

Evaporator coil releases the heat to the evaporator chamber (methanol inside the tube). There will be a temperature drop in the evaporator coil as shown in the Fig.8. The outlet temperature is 301.79 K and the outlet Gauge Pressure is -0.02302 Pa. The change in pressure is also shown in the Fig. 9. Overall COP obtained from simulations = 0.3198 which is slightly higher than that of a carbon-ammonia system as reported by Critoph [20].

![Fig. 8. Temperature contour for Evaporator coil](image5)
4.2. Experimental Results:

We have performed some design modifications after few trials like adding a valve between evaporator and expansion coil, adding a closed collection chamber with small valve after adsorption chamber and conducted experiment in room temperature and obtained encouraging results. The maximum temperature drop in the evaporator is 8°C. Component wise calculation is as follows:

4.2.1. Generator

The mass flow rate of water in the generator coil is obtained by using the formula \( m = \rho \times V \).

Therefore, \( m = 1000 \times \left( \frac{\pi \times 5 \times 5 \times 11}{26.2} \right) = 32.97 \times 10^{-6} \) kg/s.

Since height of water chamber from the ground level ~120 cm and the water level in the chamber ~10 cm; so the effective height \( h = 130 \) cm, density \( \rho = 1000 \) kg/m\(^3\) and \( g \) is taken as 9.81 m/s\(^2\). Length of the generator coil used is 130 cm.

Therefore, Pressure inlet = \( P_{atm} + \rho gh = 101325 \) Pa + \( 12853 \) Pa = 114078 Pa.

Inlet temperature variation as recorded is as shown in the Fig. 10 whereas outlet temperature variation is given in figure 11. The maximum surface temperature for the generator coil inlet is 82°C. Heat supplied to the generator can be calculated as \( Q = m \times C_p \times \Delta T \); \( C_p \) is specific heat =4187 J/kg and \( \Delta T \) is temperature difference.

Therefore, \( Q = 32.97 \times 10^{-3} \times 4187 \times (73.33 - 67.67) = 781.34 \) W.

4.2.2. Expansion valve:

An expansion coil of length 180 cm is used in this system which experiences a pressure drop of ~0.903 bar.

4.2.3. Evaporator:

Mass flow rate of the water (secondary refrigerant) in the evaporator coil is obtained from the formula \( m_w = \rho \times V \).

Therefore, \( m_w = 1000 \times \left( \frac{\pi \times 5 \times 5 \times 11}{42.8} \right) = 20.18 \times 10^{-3} \) kg/s.
The inlet pressure is calculated here similar to the generator coil. Here \( h = 15 \text{ cm} \). Therefore, Inlet Pressure = 1410 Pa. The Maximum Temperature drop obtained is 10°C. Inlet temperature variation of the evaporator is as shown in the Fig. 12 whereas Outlet temperature variation is given in Fig. 13. Similarly, Refrigeration effect can be calculated as \( Q_L = m \times C_p \times \Delta T \). Therefore, \( Q_L = 20.18 \times 10^{-3} \times 4187 \times (29.33 - 23) = 534.84 \text{ W} \).

**4.2.4. Coefficient of Performance:**

COP can be calculated as ratio of heat absorbed to heat input in the generator \( \text{COP} = \frac{T_e \times T_c}{T_a \times T_g} \).

The COP is calculated for different trials i.e., with and without using a hot water flow. The COP obtained experimentally by all trials with hot water flow and without hot water flow is averaged (Fig. 11). COP obtained with hot water flow is 0.3567 and without hot water flow is 0.3281. So the Overall Average COP of the system is 0.34. The results obtained from the analysis and experiments are almost same. The overall COP obtained experimentally is 0.34 and from analysis the COP obtained is 0.3198 marginally less than as reported by Pons and Guilleminot [21, 22]. The error percentage of the COP is 5.94%.

**5. CONCLUSION**

We have successfully designed and studied a sustainable eco friendly refrigeration system. This vapor adsorption system is simple and has less number of parts and requires less number of parts. We have performed some design modifications like adding a valve between evaporator and expansion coil, adding a closed collection chamber with small valve after adsorption chamber and conducted experiment in room temperature and achieved cooling. The maximum temperature drop obtained is 8°C.

Simulation of individual components converged within expected no. of iterations. The results obtained from the analysis and experiments are comparable with a margin of error. The overall COP obtained is 0.34. Keeping a pressure control valve in the evaporator drum provides
safe operation and makes the system more flexible. Continuous circulation of hot fluid in the generator coil increased the temperature of the adsorbent bed and also increased the rate of desorption of the methanol.

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