Journal of Energy in Southern Africa 18(2): 26–30
DOI: http://dx.doi.org/10.17159/2413-3051/2007/v18i2a3370

The cooling effect by an adsorption-desorption refrigeration cycle

G Halder

S C Sarkar
Centre for Rural and Cryogenic Research, Jadavpur University, Kolkata, India

Abstract
An experiment has been carried out utilizing the activated carbon granules as an adsorbent indigenously developed from coconut shell and carbon dioxide gas as an adsorbate in a small experimental chamber, specially designed for this purpose. Adsorption followed by removal of heat of adsorption and subsequent desorption produces refrigeration. After a few cycles in the chamber, temperatures drop from 304 K to 282.5 K. Therefore, continuous production of refrigeration could be achieved by a suitable mechanism. The paper describes the details of the design and fabrication of the experimental chamber, the experimental procedure and discusses the results obtained to assess its feasibility towards development of an alternative eco friendly refrigeration cycle for replacement of chlorofluorocarbons.

Keywords: adsorption-desorption, chlorofluorocarbons, refrigeration cycle, cooling effect

Introduction

Many of the conventional refrigeration systems use Chlorofluorocarbons (CFCs) as refrigerants, particularly in developing and under developed countries. The ozone layer, which protects life on earth from the sun's ultra-violet radiation, is getting depleted due to use of chlorine containing chemicals in conventional refrigeration systems (Mollina et al., 1974).

The Chlorine destroys nearly 100 000 ozone molecules per CFC molecule. Destruction of the ozone layer not only affects the plant and animal kingdom, but also threatens human life because of the increased amount of ultra-violet (UV) radiation (*Bulletin of International Institute of Refrigeration*, 1998).

As per Montreal Protocol (1987) and the Vienna Conference (1995), it was decided to phase out CFCs from all conventional refrigeration systems (Chan, 1981) and in this regard, the Pressure Swing Adsorption System using activated carbon and carbon dioxide having zero ozone depletion potential could be a unique solution.

Pressure Swing Adsorption (PSA) simply defines a cyclical process where the pressure is alternatively raised and lowered thereby forcing an adsorbent to adsorb a particular gas at its porous surface during pressurization and to release the gas during depressurisation. The adsorption process is exothermic which becomes endothermic during desorption. In a PSA system, the adsorbent is regenerated by reducing the gas pressure. The adsorption/desorption cycle is perfectly reversible and can be repeated for years without causing any degradation in the adsorbent. The PSA system has already revolutionized the gas separation industries over the last decade, and also finding increasing use in refrigeration industries as adiabatic de-sorption for a gas can, which produces a low enough cold temperature for replacement of CFCs from any refrigeration systems.

It is established that activated carbon developed from coconut shell has excellent gas adsorption properties, and heat of adsorption of carbon dioxide is higher than many so called permanent gases such as nitrogen ,oxygen etc. Thus, with a carbon dioxide gas-active carbon system working in a Pressure Swing Adsorption (PSA) cycle, this could be chosen as an alternative technique for producing a low temperature (Chan, 1981; Chen et al., 1997). With this consideration, an experiment has been carried out on possible cold production based on a gas-active carbon system, and it has been possible to produce effective refrigeration after running a few adsorption / de-sorption cycles.

Technical details

The adsorption/de-sorption chamber consisting of a sample holder and jacket has been designed to operate at maximum gauge pressure of 0.5MPa (5.0 Kg/cm^2). The adsorption material (activated carbon granules) has been prepared from matured coconut shell.

Fabrication of apparatus

The sample holder is fabricated from thermally non-conductive bakelite and is cylindrical in shape. Internal diameter (ID), height (h) and thickness (d) of the chamber are 58 mm, 100 mm and 8 mm respectively. It is jacketed by a stainless steel cylindrical cover (ID=74.0 mm, h=100.0 mm). The chamber is equipped with necessary valves, pipelines, cooling coils and bakelite lids as shown in Figure 1.

The gas inlet and outlet pipes are made of stainless steel (ID=3 mm) while the cooling coil is made of copper (ID=2 mm). There is provision for insertion of the thermocouple sensor (TC) in the sample holder for measuring the temperature of the adsorption bed. The sample holder could be connected with a carbon dioxide cylinder through the gas inlet pipe. The cooling copper coil (P_1P_2) is extended beyond the adsorption/de-sorption chamber at both of its ends by stainless steel tubes to cut-off the heat transfer rate.

Experimental procedure

The success of an adsorption/de-sorption refrigeration cycle depends much on the micro-pore volume of the adsorbent (Chen et al., 1997). The higher the micro-porosity, the higher is the mass of circulating gas and the higher is the co-efficient of performance (COP). The efficiency of an adsorption/de-sorption refrigeration system will also be influenced by the choice of the adsorbent- adsorbate pair (Follin, 1996).

The present investigations have been conducted utilizing the activated carbon namely, ACG-825-1.5 (granular grades), indigenously prepared from coconut shell as the adsorbent. The total pore volume and surface area have been determined by a nitrogen adsorption technique at liquid nitrogen temperature (77K) using a Quanta chrome autosorb automated gas adsorption system (ASORB 2 PC VERSION 1.05), which can access pores of around 9 A^0. Pore size distribution is given in Table 1.

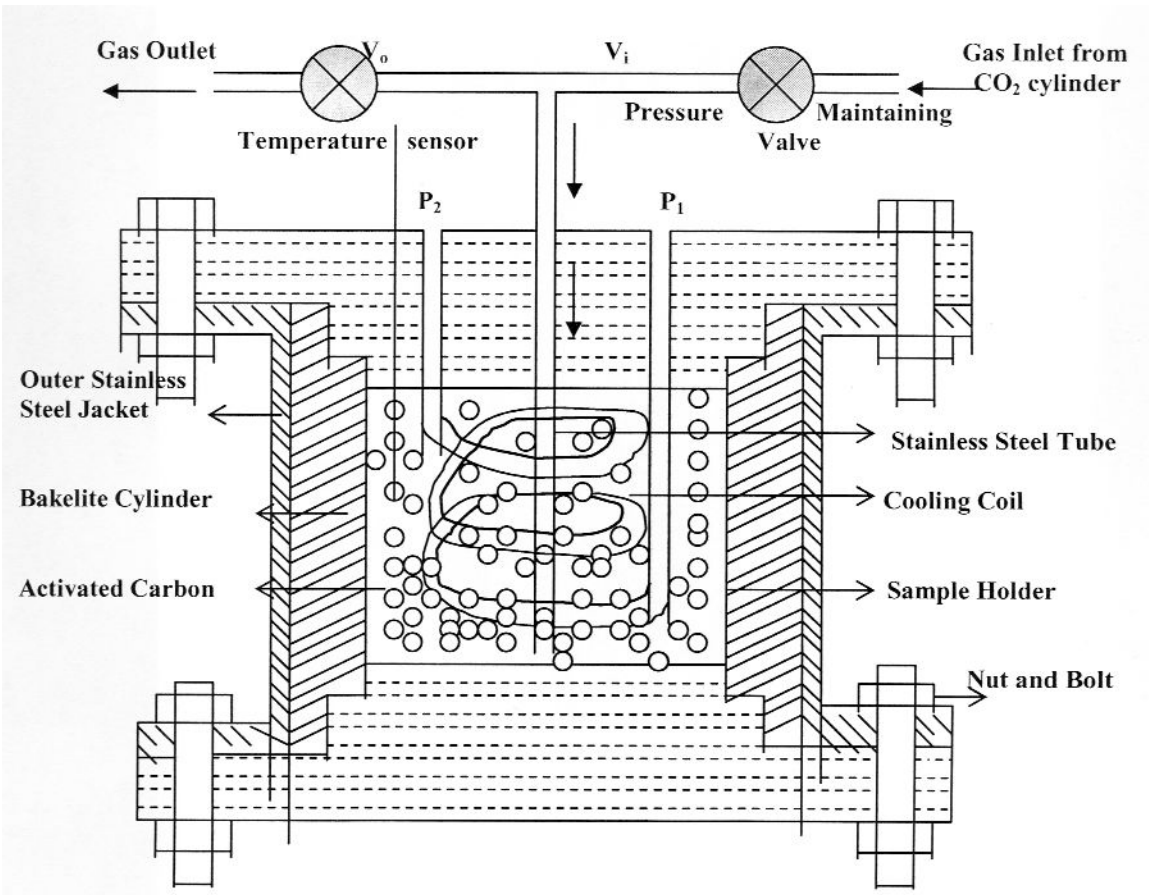

Figure 1: Adsorption-desorption refrigeration chamber

Table 1: Adsorption pore size distribution of activated carbon granules

Gas type: Nitrogen
Sample weight: 0.3352 gram
Analysis time: 299.3 minutes
Out gas time: 2.0 hours
Out gas temperature: 200°C

Radius A °	*Pore volume (c/g)*	*Pore surface area (m^2/g)*
9.07	7.631E-02	1.683E+02
11.69	1.140E-01	2.328E+02
14.49	1.358E-01	2.629E+02
18.05	1.528E-01	2.817E+02
23.01	1.645E-01	2.918E+02
30.81	1.742E-01	2.981E+02
45.03	1.822E-01	3.017E+02
78.43	1.903E-01	3.038E+02
760.58	2.027E-01	3.041E+02

The activated carbon has a total micro pore volume 0.4324 cm^3/gm, a total pore volume for pores less than 1418.6 A^0 at p/p_0 = 0.9932 is equal to 0.5719 cm^3/gm surface area of 1000.0 m^2/gm. The carbon dioxide is chosen as the adsorbate as it has very high heat of adsorption, less global warming impact and zero ozone depletion potential (*Bulletin of International Institute of Refrigeration*, 2000). The present experiments show a high rise in temperature during adsorption indicating high heat of adsorption for carbon dioxide.

The sample holder (adsorption/de-sorption chamber) is first filled with 80 gm activated carbon granules. The carbon dioxide gas is passed through the pipeline to the chamber at a gauge pressure of 0.5MPa (5.0 kg/cm^2), when valve V_i remains open and valve V_o remaining closed. The gas is adsorbed by the activated carbon in the chamber. Heat is evolved during adsorption as indicated by rise in temperature.

After completion of adsorption, indicated by no further rise in temperature, the heat of adsorption is removed by circulating air through the pipeline P_1P_2 in a separate circuit when valve V_o remains closed and V_i still remaining open. The adsorption is carried out at different initial temperature but at a fixed pressure of 0.5MPa (5.0 Kg/cm^2). The temperature of the sample chamber is brought back to ambient temperature in each case before de-sorption commences by circulating ambient air. The pressure is then released into the air at an atmospheric pressure by opening the valve V_o while V_i remains closed. The temperature is reduced due to de-sorption of gas as indicated by a drop in temperature. Adequate refrigeration could be produced after a few successive cycles. The adsorption process has been conducted at varying initial temperatures and results are tabulated in Table 2.

Results and discussion

The experimental results of the feasibility of low temperature generation by the adsorption/de-sorption technique are represented in Table 3.

The adsorption is carried out at 0.5MPa (5.0 Kg/cm^2) gauge pressure as the optimum pressure of adsorption, and then heat of adsorption is removed by keeping the valves Vi and Vo in an open and a

Table 2: Adsorption-desorption data

Initial ambient temperature, T_{amb}: 304.3 K
T_{ab}: Initial adsorption temperature which is the minimum temperature reached in the previous cycle
Operating pressure: 0.5MPa (5.0 Kg/cm^2)
Techniques applied: adsorption-desorption

.	. *Adsorption phase*					*Desorption phase*			
Obs. No.	*Temp, T_{ab} (before adsorption) in K*	*Temp, T_{aa} (after adsorption) in K*	*Time taken in min for adsorption*	*Rise in temp, K (T_{ab}– T_{aa})*	*Temp. after heat removal by air*	*Temp, T_{da} (after desorption) in K*	*Time taken in min for desorption*	*T_{total} total cycle time in min*	*Temp drop below ambient T_{diff} in K ($T_{amb} - T_{da}$) = ΔT*
1	304.3	327.5	2.24	23.2	304.3	288.2	3.05	5.29	16.1
2	288.2	313.0	3.12	24.8	304.3	284.0	3.24	6.36	20.3
3	284.0	309.4	3.53	25.4	304.3	283.4	3.07	7.00	20.9
4	283.4	308.6	4.31	25.2	304.3	283.1	2.02	6.33	21.2
5	283.1	308.6	3.32	25.5	304.3	282.8	2.44	6.16	21.5
6	282.8	308.1	3.25	25.3	304.3	282.5	3.05	6.30	21.8
7	282.5	308.1	3.57	25.1	304.3	282.5	3.08	7.05	21.8
8	282.5	308.1	3.57	25.1	304.3	282.5	3.08	7.05	21.8

Table 3: Cooling capacity of different cycles

Obs. No.	*Temperature drop, ΔT in K*	*Cooling produced in Joules, H = 282.60 ΔT*	*T_{total}, total cycle time in seconds*	*Cooling in Watts (H_w) = H/cycle time in seconds*	*Cooling in Watts per gram of activated carbon(h_w) = H_w/80*
1	16.1	4549.86	329.0	14.33	0.181
2	20.3	5736.78	396.0	15.03	0.188
3	20.9	5906.34	420.0	14.06	0.175
4	21.2	5991.12	393.0	15.77	0.197
5	21.5	6075.90	376.0	16.44	0.205
6	21.8	6160.68	390.0	16.22	0.202
7	21.8	6160.68	425.0	14.56	0.182
8	21.8	6160.68	425.0	14.56	0.182

closed position respectively. After the heat of adsorption is removed, the valve Vi is closed and Vo is made open so that initial de-sorption pressure is 0.5 MPa.

From the tabular results, it is seen that the temperature drop increases as the initial adsorption temperature of the adsorbent bed is decreased at a fixed pressure. This observation is corroborated with the fact that the extent of adsorption increases with the decrease in temperature and increase of pressure of the adsorbent bed i.e., with the state of the adsorbent.

In this experiment, the heat of adsorption is removed by circulating ambient air in the separate circuit, and hence, it has not been possible to remove the entire heat of adsorption e. g ; in observation number-2, adsorption has been initiated at 288.2K and after adsorption the temperature has reached 313K. The heat removal is not sufficient to bring down the temperature back to 288.2K before commencement of desorption, and as a result, the initial desorption temperature is 304.3K. It is possible to bring down the temperature to the initial temperature at which actual adsorption has begun in each case by complete removal of heat of adsorption by circulating cooled desorbed gas, and then it would have been possible for the temperature to go down gradually a few degrees below 273K after a few cycles.

Therefore, for operation of the system continuously i.e., continuous production of cold temperatures, two adsorber beds filled with activated carbon and another chamber (refrigeration chamber) are required. When the first adsorber is in adsorption phase, the second adsorber is in desorption phase and the desorbed cold gas is passed through the refrigeration chamber and imparts its cold to the fluid/material to be cooled and come back to the compressor via heat exchanger. Again, when the second adsorber is in the adsorption phase, the first one is in a regeneration step i.e., desorption phase and desorbed cold gas passes through the refrigeration chamber and the heat exchanger, and finally returns to compressor.

Cooling effect

The cooling produced in watts for different observations has been computed by making a heat balance around the chamber.

Neglecting heat transfer through bakelite, a very poor conductor of heat, and through the lid, the cooling produced is expressed as follows:

Total cooling produced = Refrigeration load for activated carbon + Refrigeration load for cooling copper coil + Refrigeration load for stainless steel tube

i.e. $H_c = m_{ac}.\ s_{ac}.\ \Delta T + m_c.\ s_c.\ \Delta T + m_{ss}.\ s_{ss}.\ \Delta T$

$$= (m_{ac}.\ s_{ac} + m_c.\ s_c. + m_{ss}.\ s_{ss})\ \Delta T \qquad (1)$$

where

m_{ac} = mass of activated carbon = 80 gm

s_{ac} = standard specific heat of well-character ized activated carbon = 1.05 Joule/gm/K

ΔT = temperature drop which is different for different observations

m_c = mass of copper tube inside the sample chamber = 50 gm

s_c = specific heat of copper coil = 3.78 Joule/gm/K

m_{ss} = mass of stainless steel = 19 gm

s_{ss} = specific heat of stainless steel = 0.504 Joule/gm/K

Therefore putting the above values in equation number - 1, the total cooling produced,

$$H = 282.60\ \Delta T \qquad (2)$$

Actual cooling produced will be slightly higher than what is predicted by equation (2), if heat is leaked into the system, is taken into account.

For different observations i.e. for different ΔT cooling loads are evaluated and are tabulated in Table 2.

Conclusions

The present experiment has demonstrated that it is feasible to produce a low temperature by an eco friendly mechanism using an activated carbon bed for adsorption/desorption of carbon dioxide, which has zero ozone depletion potential and less global warming impact as compared to CFCs and other refrigerants. The temperature drops from 304 K to 282.5 K easily.

The refrigeration thus produced could be utilized for cooling water required for different domestic and industrial purposes. The mechanism, if extended, can produce a further low temperature as enumerated in the outlook i.e., scope for future work.

Outlook

The objective of this work is to establish an alternative eco friendly refrigeration cycle for producing a temperature usually encountered in a conventional refrigerator. The cooling capacity is always high with carbon dioxide than any other gases but for reaching a cryogenic temperature, an active carbon–nitrogen system may be the choice, as nitrogen can be handled as gas even at 80 K whereas carbon dioxide became solid at 195K.

An activated carbon-nitrogen adsorption-desorption system operated with solar energy coupled with a Joule-Thomson expansion device needs the greatest attention in view of production of cooling required down to 100K in a space shuttle for detector cooling .

A prototype refrigerator consisting of two adsorbers, a refrigeration chamber, a compressor, four solenoid valves connected with suitable pipelines has been developed at the Centre for Rural & Cryogenic Research, for continuous production of low temperature application and a further paper on this is being prepared for publication shortly.

Acknowledgements

The authors are thankful to Sri N. R. Chakrabarty, CRCT, Kolkata, for his effective help in fabricating the experimental set-up. Thanks are also due to other technical staff viz. Sri Arun Sarkar, Atanu Mukherjee, Sujit Das and Bimal Ghosh for their help during the experimental work. Dr. S.C.Sarkar as the Principal Investigator acknowledges his gratefulness to the Ministry of Science and Technology, Government of India, for their financial assistance for the project titled: *Feasibility Studies on the Development of a Refrigeration cycle based on an activated carbon-carbon dioxide pair.*

References

15th Informatory Notes on Refrigerant : Carbon dioxide (CO_2) as a Refrigerant, Bulletin of International Institute of Refrigeration, 2000, 3, 21-25.

Chan, C. K. Cryogenic Refrigeration using a Low Temperature Heat Source. Cryogenics, 1981, 7, 391-399.

Chen, H. J; Wong, D. S. H; Tan, C. S., Adsorption and Desorption of Carbon dioxide onto and from Activated carbon at high pressures, Industrial & Engineering Chemistry Research, 1997, 36, 2808-2815.

Follin, S., Influence of Microporous Characteristics of Activated carbon on the performance of an adsorption cycle for refrigeration. Industrial & Engineering Chemistry Research, 1996, 35, 2632-2639.

Kyoto-Global Warming, Bulletin of International Institute of Refrigeration, 1998, 2, VII-XI.

Lorentzen, G. Refrigeration, Energy and the Environment. IIR, Progress in the Science and Technology of Refrigeration in Food Eng., 1990, 4, 31.

Mollina, M. J; Rowland, F. S., Stratospheric Sink for Chlorofluoro Methane : Chlorine Atom Catalysed Destruction of Ozone. Nature, 1974, 248, 810-812.

Received 2 January 2007; revised 17 April 2007