1990

Experimental Investigation on an Adsorption System for Producing Chill Water

R. Zhu
Xi'an Jiaotong University

B. Han
Xi'an Jiaotong University

M. Lin
Xi'an Jiaotong University

Y. Yu
Xi'an Jiaotong University

EXPERIMENTAL INVESTIGATION ON AN ADSORPTION SYSTEM FOR PRODUCING CHILL WATER

Ruiqi Zhu, Baoqi Han, Meizhen Lin* and Yongzhang Yu

Department of Power Machinery Engineering,
Xi'an Jiaotong University, Xi'an, China
*Minjing Aquatic Refrigeration Equipment Factory,
Fuzhou, China

ABSTRACT

This paper provides a zeolite-water adsorption refrigeration system for producing chill water, in which zeolite 13X - H_2O is used as a working pair and the exhaust gas from diesel engine is utilized as a heat source.The system is to be used on a fishing boat for preserving aquatic products. The design of the system is given. The adsorption unit consist of many adsorption elements. The dynamic curve of the element is measured in a laboratory. A medium-type sample of the adsorption chiller has been made out, and its preliminary operating performance, associated with a diesel engine, is given. Now further testing of its application is underway, test results are expected and will be reported at the end of 1990.

NOMENCLATURE

A	constant in Equation (1)
Γ	amount adsorbed, kg/kg
Γ_o	monolayer capacity, kg/kg
p	pressure, kPa
p_s	saturation pressure, kPa
T_z	temperature of zeolite, °C
T_w	wall temperature of lower section of adsorption tube °C
T_c	temperature of cooling water, °C
T_d	temperature of cooled water, °C
T_{gin}	temperature of exhaust gas at the inlet of generator °C
$T_{g\ out}$	temperature of exhaust gas at the outlet of generator, °C
m	mass of cooled water, kg
τ	time, minute

INTRODUCTION

The Montreal Protocol on protecting stratospheric ozone layer restricts CFC' refrigerants and has a strong impact on refrigeration industry. Besides researching alternatives to CFCs used in the vapor compression system, development of various refrigeration methods other than the vapor compression's is significant. Moreover, in view of energy comprehensive utilization, using waste heat to produce cold is an important field too.

Adsorption refrigeration as a refrigeration method has certain advantages of energy saving and environmental protection because of using a heat source as power and no CFC'S substance taken as refrigerant. Three known adsorption systems have been investigated:

1. Zeolite-water system Having a good adsorption behaviour and requiring a high temperature (above 150 °C) to achieve a regeneration process, such a system has a satisfactory refrigeration ability and is suitable for use in the case of a high temperature heat soure.
2. Silica gel-water system Such a system can operate at a lower temperature

(70 - 80 °C). It is suitable for utilization of low potential heat source, but its refrigeration ability is lower than zeolite's, the result being a requirement for about three times as much as an adsorbent bed.

3. Activated carbon- mathanol system Methanol has a high boiling point (64.7 °C) and a low solidifying point (-98 °C). An adsorption system with methanol as adsorbate can produce a low temperature below 0 °C, but methanol's evaporating latent heat is only a half of water's.

In view of the fact that on the fishing boat, the high temperature heat of exhaust gas from the diesel engine can be utilized directly (its temperature is up to 400 °C and the available temperature is up to 200 - 300 °C), the zeolite - water system is chosen to produce cold for preserving aquatic products [1]. Since the best preserving condition for aquatic products is to put them in chill sea water at about 5 °C, the system is aimed at producing chill water.

ADSORPTION ISOTHERMS OF ZEOLITE 13X - H_2O

The adsorbent used was synthetic zeolite 13X. It has a surface area of over 700 m^2/g and a pore size of 10 Å. The average particle diameter is 2 - 3 mm. The charge density is 0.66 g/cm^3. The adsorbate is ion-free water (pure water used in a laboratory).

The adsorption isotherms for water adsorption in zeolite 13X were measured at various temperatures [2]. The equilibrium data were correlated with the model of Langmuir as below:

$$\frac{\Gamma}{\Gamma_0} = \frac{A\, p/p_s}{1+A\, p/p_s} \qquad (1)$$

The results are shown in Figure 1.

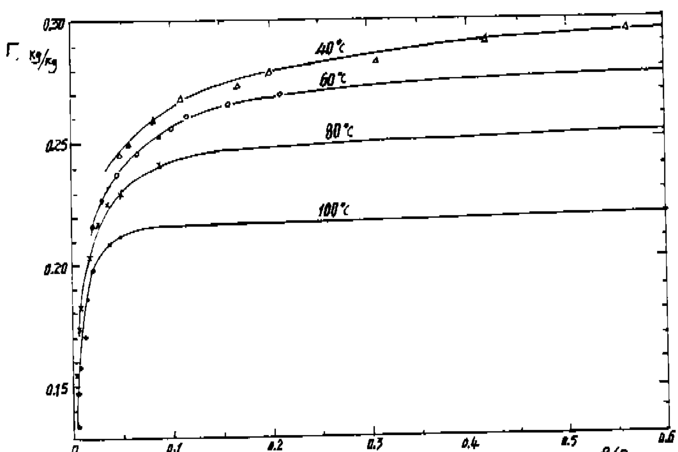

Figure 1 Water adsorption isotherms on zeolite 13X

SYSTEM DESCRIPTION

Figure 2 illustrates a scheme of the adsorption chill water system.Because of the intermitten process, two zeolite adsorption units 4a and 4b are arranged in the system. Each unit consist of a generator, a condenser/evaporator and a water tank. The configuration of the generator is similar to a shell-and-tube heat-exchanger. Zeolite molecular sieve is filled in the shell. Some tubes are extended into the shell-plates which are welded to the shell at each end. The tubes provides an area for zeolite to transfer heat over the nest of the tubes. The condenser/evaporator, which is finger-shaped, is connected to the shell with a vapor line and immersed in the tank. The tank, the shell and the vapor line are covered with insulating material.

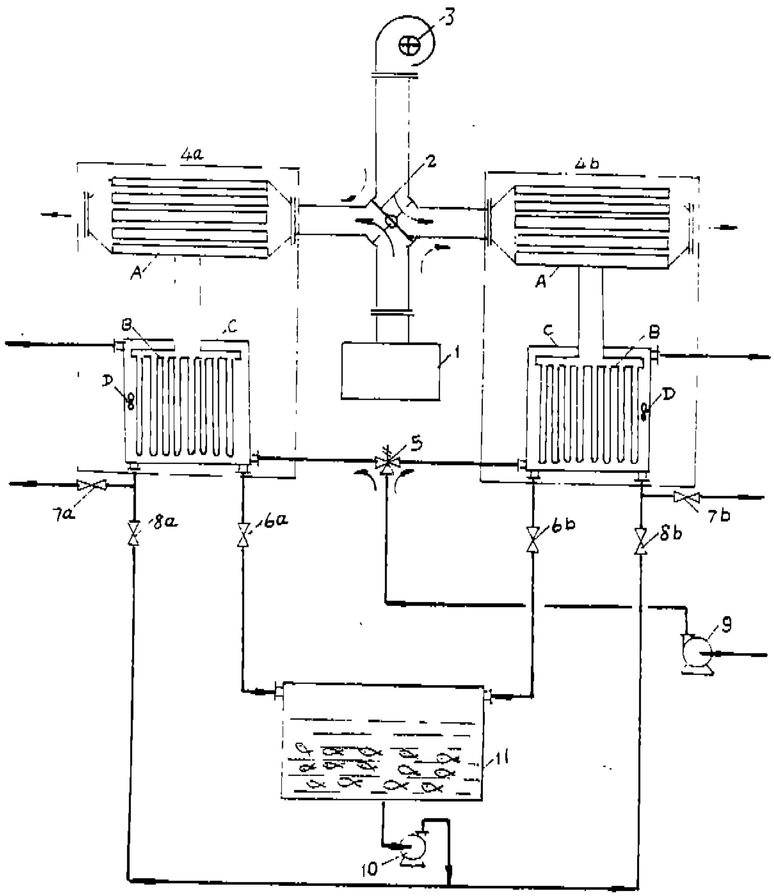

Figure 2 Scheme of the adsorption chill water system

1-diesel engine, 2-exchange-valve, 3-blower, 4a,4b-zeolite adsorption unit (A generator, B condenser/evaporator, C tank, D stirrer), 5-magnetic three-way valve, 6a,6b,7a,7b.8a,8b - valve, 9,10-pump, 11-fish storage

With exhange-valve 2, the two units can intermittently alternate their
functions each other. As shown in Figure 2, when valve 2 is in the place as
the real line shows, unit 4a is in desorption-condensing operation; its zeolite
bed is heated by the exhaust gas from diesel engine 1, and the hot vapor driven
out from the bed will condensate in the condenser, the condensing heat is re-
moved by the cooling water, which is pumped from the sea, goes through the tank
and backs into the sea. Meanwhile, unit 4b is in adsorption-evaporating opera-
tion: its zeolite bed is cooled by air from blower 3 and will regain its ad-
sorption ability, and the refrigerant water in the evaporator will evaporate
and the water in the tank will be cooled. When valve 2 is changed in the place
as the dotted line shows, unit 4a is in adsorption-evaporating operation and
4b is in desorption-condensing operation.

For each unit, when the desorption process is over, the cooling water is cut off by magnetic three-way valve 5, open valve 7 to empty the cooling water in the tank, then fill the tank with water from storage 11 (in which the water is at some lower temperature). In the adsorption process the water in the tank is neither in nor out, and is stirred by a stirrer to enhance the heat transfer; while its temperature reduces to a required value (2 - 5 °C), open valve 6 and let the chill water go down to the storage in which aquatic products are preserved.

A PERFORMANCE MEASUREMENT OF THE ADSORPTION ELEMENTS

The adsorption unit can be considered as a constitution of many adsorption refrigeration elements. Each elements is simply an adsorption tube, as shown in Figure 3. The tubes are made of red copper. Each tube has two sections: the upper section being the adsorbent bed in which zeolite is charged, the lower section being the condenser/evaporator which contains the refrigerant water. Each tube is charged with 400 g zeolite 13X and 120 g pure water. The thickness of the zeolite bed is 12 mm. The tubes are carefully sealed and free from any uncondensable gas.

In order to provide a reliable basis of design for a medium experiment of the above-mentioned system, a performance measurement of the elements is carried out. The schematic diagram of the apparatus for determining the dynamic performance of the adsorption elements is shown in Figure 4. The following parameters are measured: zeolite temperature T_z; wall temperature of the condention /evaporation section (the lower section of the tube) T_w ; cooling water temperature T_c in the desorption process; cooled water temperature T_d and mass m in the adsorption process.

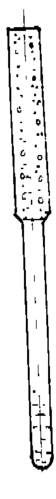

Figure 3 The adsorption element

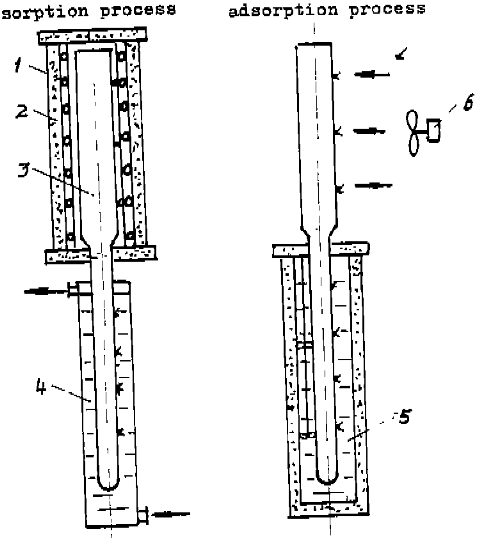

Figure 4 The performance measurement of the adsorption elements

1-electric heater, 2-insulating cover,
3-adsorption tube, 4-cooling water,
5-cooled water, 6-fan
↙ temperature measuring point

The experimental results are shown in Figure 5. From it we can see: the cycle period is taken as 3 hours (the desorption time and adsorption time in a cycle is 1.5 hours respectively), the zeolite is heated up to about 200 °C (the available temperature of exhaust gas from the diesel engine) and it is

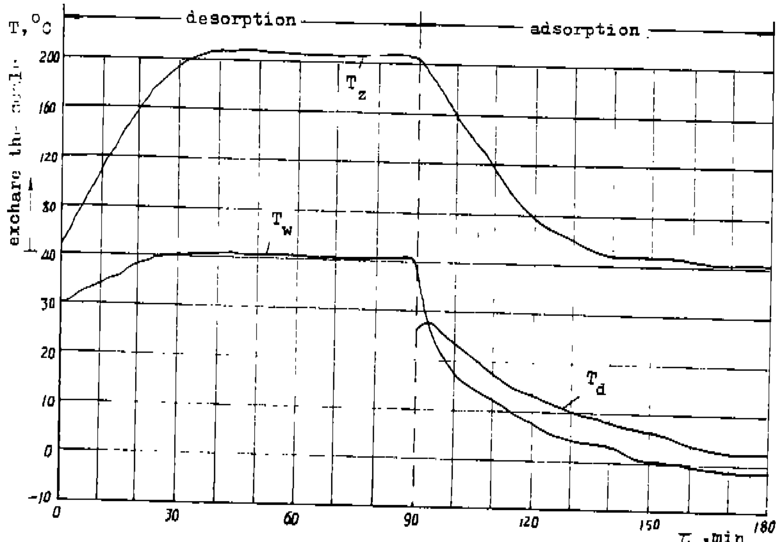

Figure 5 The dynamic performance of the adsorption elements

cooled at ambient temperature, a single adsorption element can cool 1 kg water from 24 °C to 2 °C. The net refrigeration capacity of it is 92 kJ per cycle under the conditions mentioned.

OPERATING PERFORMANCE OF THE MEDIUM-TYPE SAMPLE UNIT

Based on the experimental result of the elements, a medium-type sample unit

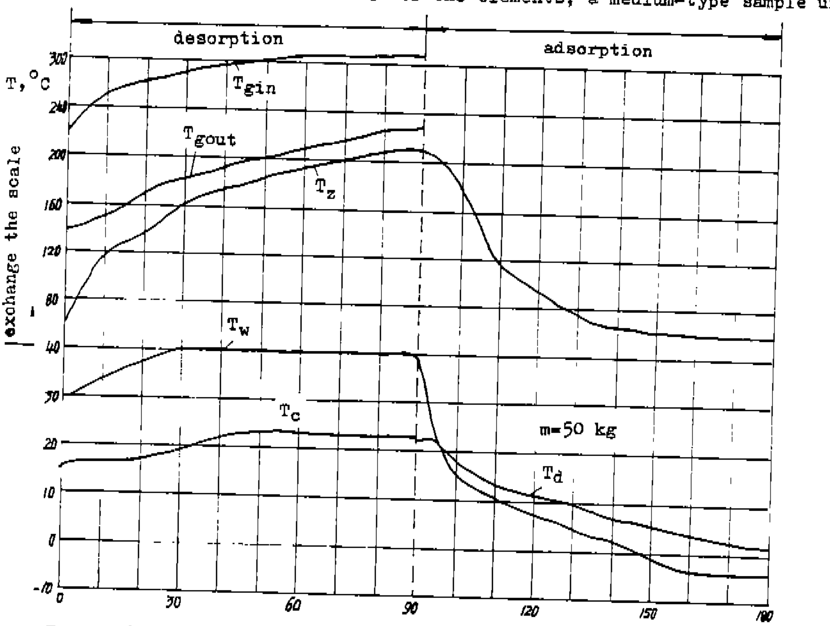

Figure 6 The operating performance of the medium-type sample

for chill water has been designed and made out. Its capacity is designed as 3500 kJ per cycle. The unit has the same mass ratio of zeolite to refrigerant water and the same thickness of adsorbent bed as that of the element. The sample unit testing is carried out under a real operating condition (i.e. the sample is connected to the diesel engine and heated by its exhaust gas). A preliminary operating performance of the unit is obtained as shown in Figure 6. It well accords with the dynamic performance of the elements. Besides, the testing operating shows: when the exhaust temperature becomes higher as a result of the increase of the engine's load, the capacity of the unit will increase or the period of cycle will be shortened.

Such a system will be equipped on a fishing boat. Its application investigation for preserving aquatic products and a test of long-time operation will go on, and further information will be reported at the end of 1990.

REFERENCES

[1] Baoqi Han, Ruiqi Zhu and Yujin Wu: A study on zeolite molecular sieve adsorption refrigeration using exhaust heat from diesel engine. Proceedings of International Conference on Energy Saving in Refrigeration, Sep. 17-19, 1986.

[2] Wu Jian, Analytical and experimental study of a zeolite molecular sieve refrigeration cycle, Journal of Engineering Thermophysics, 1985 No.4.