GENERAL ATOMIC
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JOHN JAY HOPKINS LABORATORY FOR PURE AND APPLIED SCIENCE

P.O. BOX 608, SAN DIEGO, CALIFORNIA 92112

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**LOW-TEMPERATURE ADSORPTION STUDIES
FOR THE PSC REACTOR**

by

R. D. Burnette and D. R. Lofing

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ABSTRACT

Laboratory experimental work on adsorption at liquid-nitrogen temperature for the PSC reactor project is described.

Data on the dynamic and equilibrium adsorption of H_2 , tritium, and CO on activated carbon at $-196^\circ C$ are given. In addition, experiments on the effect of high CO impurity levels on the adsorption of Kr are reported.

The results indicate that the Langmuir isotherm model is an excellent representation of pure and mixed gas adsorption on activated carbon.

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INTRODUCTION

The coolant cleanup system of the Public Service Company of Colorado (PSC) reactor features a liquid-nitrogen-cooled, activated carbon bed for the removal of such gaseous impurities as Xe, Kr, N₂, CH₄, and CO. Tritium and H₂ also will be adsorbed to a significant extent on the carbon bed; however, an additional unit (hot titanium gettering) is required for the cleanup of these species.

The concentration of gaseous impurities in the PSC reactor coolant helium will be extremely low during normal operation of the plant; indeed, the total impurity level could fall below 1 ppm. During transient periods, however, some of these species may be higher than normal. Table 1 lists expected gaseous impurity concentrations for both normal and transient conditions.

Thus, knowledge of the adsorption characteristics of all the impurities for the three conditions listed in Table 1 is necessary for design and operation of the PSC low-temperature sorber unit.

Considerable work at General Atomic and elsewhere had already elucidated much of the needed information. Data on the equilibrium adsorption of all of the species except tritium were at hand. Moreover, experimental work on the dynamic adsorption behavior of Kr and Xe was more than adequate for the design of the sorber unit.

Experimental data were needed, however, on the adsorption behavior of CO and H₂ at the high partial pressures (~ 1 atm) that might occur following a major steam leak. More important, information was needed on the effect of high partial pressures of CO on Kr and Xe adsorption. These data were necessary to ascertain whether premature elution of radioactive Kr as a result of displacement by CO would be a problem. Thus, experimental work was required in three distinct areas:

1. Determination of H₂ and tritium adsorption behavior for both dynamic and equilibrium conditions.
2. Measurement of dynamic and equilibrium adsorption behavior of high partial pressures of CO.

3. Determination of the effect of high CO pressures on the dynamic adsorption of Kr.

TABLE 1
EXPECTED IMPURITY CONTENT OF PSC REACTOR COOLANT
(In ppm)

Species(a)	Normal Reactor Operation(b)	Maximum Allowable for Continuous Operation(c)	Transient Conditions(d)
Tritium	8.5×10^{-5}	--	---
Xe	3.19×10^{-3}	--	---
Kr	3.76×10^{-3}	--	---
N ₂	< 1	10	10 - 10 ³
CH ₄	< 1	1	1 - 100
CO	< 1	10	10 - 2 × 10 ⁴
H ₂	< 1	10	10 - 2 × 10 ⁴

(a) CO₂ and H₂O are also expected impurities but are of no concern here because they are removed by a molecular sieve unit upstream of the low temperature sorber bed.

(b) Normal reactor operation is the condition that exists after the core has been completely outgassed and no steam ingress is occurring.

(c) Small undetected steam leaks could lead to CO and H₂ levels up to 10 ppm for long periods. The indicated limits are imposed to minimize carbon deposition and core oxidation.

(d) Transient conditions such as initial startup and core outgassing will result in high levels of N₂, CH₄, CO, and H₂. Steam ingress could raise CO and H₂ levels for short periods.

EXPERIMENTAL

A high-pressure helium loop system was used for both equilibrium and dynamic studies. The apparatus, shown in Fig. 1, consisted of a test trap, a cleanup trap, a circulator, an in-line ionization chamber, and the usual valves, rotameters, and other fittings. The test and cleanup traps were stainless steel U-tubes, filled with the desired adsorbent and chilled by immersion in a liquid-nitrogen-filled dewar.

Fig. 1. High pressure adsorption apparatus

Each trap was provided with a tube-in-tube regenerative exchanger and a precooler to reduce liquid nitrogen usage and to ensure that the inlet gas was adjusted to -196°C . For long runs, an automatic liquid nitrogen filler device maintained the liquid level above the top of the test trap.

Flow rates were measured with a high-pressure rotameter previously calibrated at the system pressure. Concentrations of radioactive gases, such as tritium and Kr, were monitored using an in-line high-pressure ionization chamber with strip chart readout. Thus, changes in gas phase content were automatically recorded.

Measurement of nonradioactive species, such as CO and H_2 , was accomplished with a gas chromatograph. The analysis of CO and H_2 at low levels was performed using a sample concentration technique. (The sensitivity for CO and H_2 was 0.1 and 1 ppm, respectively.)

The adsorbate gases CO and H_2 were added to the system directly from lecture bottles. Tritium was added from a pressurized tank containing a tritium-He mixture, purchased from the Matheson Company. The concentration of the tritium makeup tank was $17.9 \mu\text{c}/\text{cm}^3 \text{He}$, or 7.0 ppm.

EXPERIMENTAL PROCEDURE

EQUILIBRIUM MEASUREMENTS

For equilibrium measurements, the adsorbent is initially thoroughly degassed by evacuation and then purged with clean He at 600°F . The rest of the loop is evacuated and backfilled with helium. A final cleanup step for the entire system prior to each run involves circulation of the loop gas through the liquid-nitrogen-cooled cleanup trap while the test trap is warmed to 600°F .

The test trap is cooled by immersion in liquid nitrogen, pressurized to 450 psia, and valved out. The loop is then bled down to one atmosphere, while the test trap and cleanup trap are bypassed. The adsorbate-He mixture is slowly admitted until the desired adsorbate pressure is attained. The loop is then backfilled with purified He to 450 psia, and the circulator is turned on until complete mixing is achieved, as evidenced by either a steady ion current recording or gas chromatograph readings. The test trap is then valved in and the gas phase sorbate level is observed to decrease steadily, indicating adsorption, until equilibrium is attained.

The amount of gas adsorbed is calculated by multiplying the change in gas phase concentration by the system volume, or

$$V_a \cong \frac{(I_o - I)}{I_o} \frac{V_s P_o}{M} \quad (1)$$

and

$$P_e = \frac{I}{I_o} P_o, \quad (2)$$

where V_a = volume adsorbed (cm^3 (STP)/g),

I_o = initial gas phase sorbate concentration (relative units),

I = final gas phase concentration (equilibrium),

V_s = system volume (cm^3),

P_o = initial sorbate partial pressure (atm),

M = weight of adsorbent (g), and

P_e = equilibrium sorbate pressure (atm).

The utility of this technique is seen in its extreme sensitivity and in the simple and straightforward manner in which experimental observations are transformed into useful data.

At the end of each run, the test trap is heated to 600°F , thereby permitting the adsorbed radioactive gases to rapidly reenter the gas phase and causing the ion current to return to the initial value, thus effecting a material balance.

DYNAMIC MEASUREMENTS

For dynamic measurements, a pulse of adsorbate is injected into the test trap inlet after pressure, flow, and temperature are established. The time for the adsorbate pulse to traverse the bed is measured by monitoring the effluent purge stream. From these data, the dynamic adsorption coefficient is calculated using the relation

$$t = K \frac{M}{V}, \quad (3)$$

where t = time for the pulse to traverse the test trap (min),

M = mass of adsorbent (g),

V = volumetric flow rate (cm^3/min), and

K = dynamic adsorption coefficient (cm^3/g).

Alternatively, dynamic tests may be performed by continuously adding adsorbate at a constant level to the test trap inlet stream. Using this method, H , the height of the mass transfer unit, can be determined by the relation

$$R = \frac{V}{H} (C - a/k) , \quad (4)$$

where R = rate of adsorption per unit length of sorber bed (moles/sec-cm),

V = volume flow of gas (cm^3/sec),

C = concentration of sorbate in gas stream inlet (moles/cm^3),

a = amount of sorbate adsorbed per unit mass sorbent (moles/g), and

k = slope of initial (linear) portion of adsorption isotherm, also the dynamic adsorption coefficient (cm^3/g).

H can be regarded as a rate constant for the adsorption process; it determines the amount of broadening that occurs while a pulse or steady concentration of sorbate traverses a particular sorbent bed. H is determined from the slope of the effluent sorbate breakthrough front using an analytical treatment described first by Hougen and Marshall⁽¹⁾ and developed later at General Atomic to define the behavior of short-lived radioactive species during dynamic adsorption.⁽²⁾

It is stressed that the transfer unit analytical treatment assumes that the rate of adsorption is controlled by the rate of transfer of sorbate atoms to the sorbent surface. This is true for the entire range of sorbate pressure, but H is a constant only for the initial or linear portion of the adsorption isotherm, where the sorbate concentration is very low and the adsorption coefficient K is a constant.

Thus, H has been measured in previous studies for tracer quantities of Xe and Kr⁽²⁾ and in the present work for tritium.*

*For more information on the height of the mass transfer unit, H , see Refs. 1 and 2.

EXPERIMENTAL RESULTS

HYDROGEN-TRITIUM EQUILIBRIUM MEASUREMENTS

Adsorption isotherms for tritium and tritium plus hydrogen at liquid nitrogen temperature (-196°C) are shown in Fig. 2. The adsorbents tested are Type BC-107 activated carbon (6 to 10 mesh) and Types 5A and 4A molecular sieve material (1/16-in. pellets).

The results in Fig. 2 show that the Type 5A molecular sieve material possesses about a factor of 2 higher adsorption capacity for tritium and hydrogen than does BC-107 carbon. The 4A molecular sieve (not shown in Fig. 2), however, was observed to possess about the same capacity for H_2 as BC-107 carbon.

The present experiments using pure tritium as the adsorbate, or as a tracer for hydrogen, are in very good agreement with a hydrogen-carbon isotherm determined independently using a gas chromatographic technique. It is interesting that the H_2 isotherm is quite linear in the range 10^{-6} to 10^{-1} mm Hg.

The data for activated carbon in Fig. 2 fit the following linear relation for H_2 pressures below 10^{-1} mm Hg:

$$V_a = 1.3 \times 10^{-5} p, \quad (5)$$

where V_a = volume H_2 adsorbed (cm^3 (STP)/g), and
 p = equilibrium H_2 pressure (mm Hg).

In 1914 Claude,⁽³⁾ and more recently Huthsteiner (as cited in Ref. 4), measured the H_2 -carbon isotherm at -196°C . Their data are described by

$$V_a = 1.6 \times 10^{-5} p \quad \text{for } p < 0.25 \text{ mm (Huthsteiner)}, \quad (6)$$

and

$$V_a = 2 \times 10^{-5} p \quad \text{for } p < 0.1 \text{ mm (Claude)}. \quad (7)$$

The isotherm for the present study (Eq. (5)) is predictably lower than that reported by the earlier investigations, perhaps because of the inhibiting effect of the high-pressure He. Ordinarily, He adsorption is quite negligible; however, at high He pressure, the competition for adsorption sites becomes significant.

Fig. 2. Hydrogen-tritium adsorption isotherms at 77°K

Using the Langmuir mixed adsorbate isotherm, one obtains

$$Q = \frac{k_1 P_{H_2}}{1 + k_1 k_2 P_{H_2} + k_1 k_2 P_{He}}, \quad (8)$$

where Q = moles H_2 /g,

$$k_1(H_2) = 8.9 \times 10^{-4} \text{ (Claude), } (3)$$

$$k_1(He) = 1.8 \times 10^{-7} \text{ (Antill et al.), } (5) \text{ and}$$

$$k_2 = 200.$$

One can predict that at low hydrogen pressures (where the isotherm is linear), the competition for active sites by 30 atm He will reduce the hydrogen adsorbed by about a factor of two. The present data show a reduction of around 1.5. This "agreement" is felt to be rather good (or fortuitous) in view of the obvious differences in activated carbon used.

HYDROGEN-TRITIUM DYNAMIC MEASUREMENTS

In the experiments on the dynamic adsorption of hydrogen and tritium on activated carbon, effluent breakthrough fronts were measured. Figure 3 shows breakthrough fronts for relatively high H_2 concentrations. (At 30 atm He pressure, 10^3 ppm $H_2 = 23$ mm Hg.) The effluent profiles are steep, indicating that adsorption equilibrium is rapidly attained. Moreover, at these high H_2 pressures, where the equilibrium isotherm is nonlinear (which is the case for H_2 pressures above ~ 0.1 mm Hg (see Fig. 2)), the rate of saturation of adsorbent, and therefore the breakthrough time, is dependent on the inlet concentration of the sorbate. It appears that for high H_2 partial pressures, breakthrough times are inversely proportional to the H_2 pressure. Thus, H_2 delay can be adequately predicted from a knowledge of the equilibrium isotherm (see Fig. 2) and the rate of mass flow of H_2 to the bed inlet.

At low partial pressures of H_2 (below 0.1 mm Hg), the isotherm is quite linear or pressure dependent. The breakthrough time is dependent on the slope of the isotherm, or the dynamic adsorption coefficient. Moreover, in this pressure range the height of the mass transfer unit, H , is a constant and can be determined from the slope of the effluent concentration profile.

Figure 4 shows the effluent concentration profile for tritium on activated carbon at -196°C . From this experiment and others, H was computed

Fig. 3. Hydrogen and tritium dynamic breakthrough profiles. Tritium concentration is plotted in arbitrary units; actual tritium concentration is in ppb range

Fig. 4. Tritium breakthrough profile

for widely divergent conditions of pressure, temperature, and flow rate. In sorbent bed studies, flow rate is often expressed in terms of particle Reynolds number, defined as $D_p G / \mu$, where D_p is the particle diameter, G is the mass velocity ($\text{lb/ft}^2\text{-hr}$) of gas, and μ is the viscosity of the carrier gas. Figure 5 is a plot of the height of the mass transfer unit, H , vs particle Reynolds number for both the present experiments using tritium and previous experiments using krypton. (2)

The fact that H increases with particle Reynolds number (flow rate) indicates that the rate of tritium adsorption is controlled by mass transfer of adsorbate to the adsorbent surface. The present work shows that calculational methods previously described in Refs. 1 and 2 and applied to krypton and xenon should be satisfactory for predicting tritium breakthrough profiles.

An experiment was conducted using a mixture of hydrogen and tritium as the adsorbate, with the concentration of tritium in the ppb range. The results are included in Fig. 3. The H_2 value was measured independently using the gas chromatograph, whereas the tritium was monitored with the ion chamber. It is seen that both species were eluted from the activated carbon bed in essentially the same time.

CO ADSORPTION STUDIES

Dynamic and Equilibrium Measurements

Dynamic adsorption experiments for CO on Type BC-107 activated carbon (6 to 10 mesh) at -196°C were performed using CO partial pressures of 9×10^{-3} to 0.39 atm at a total helium pressure of 30 atm. Figure 6 shows some typical CO elution curves for a 14-g activated carbon trap. The breakthrough fronts are steep, indicating rapid equilibration. As expected, the breakthrough times are dependent on the CO saturation level, or inlet concentration. This behavior is similar to the high H_2 pressure runs described above. Figure 7 shows the CO isotherm for this system as determined by an equilibrium adsorption measurement. Figure 8 is a plot of reciprocal breakthrough time (nominally the time for the effluent CO concentration to reach one-half of the inlet level) vs CO inlet partial pressure. A plot of predicted breakthrough times, calculated from the equilibrium isotherm of Fig. 7, is also shown in Fig. 8. These data clearly indicate that CO elution times can be calculated from the adsorption isotherm data.

Effect of CO Adsorption on Kr Delay

Impurities in the He purge gas, such as CO, N_2 , and CH_4 are expected to reduce the Kr dynamic adsorption coefficient and therefore the delay time,

Fig. 5. Height of the mass transfer unit, H, vs particle Reynolds number determined using activated carbon BC-107 (6 to 10 mesh) as the adsorbent

Fig. 6. Carbon monoxide elution curves (breakthrough fronts) for activated carbon trap

Fig. 7. Equilibrium adsorption isotherm for CO on activated carbon at -196°C

Fig. 8. Reciprocal CO breakthrough times as a function of CO concentration. The curve represents predicted breakthrough times calculated from CO adsorption isotherm (Fig 7)

by competition for adsorption sites. The adsorption coefficient K_{Kr} for a mixed adsorbate system at -196°C is well represented by the following equations:(3)

$$K_{Kr} = \frac{Q_{Kr} \times 22400 \times 760 \times 77}{P_{Kr} \times 273} \quad (9)$$

and

$$Q_{Kr} = \frac{k_1 P_{Kr}}{1 + k_1 k_2 P_{Kr} + k_{i1} k_{i2} P_i} \quad (10)$$

where Q_{Kr} = Kr adsorbed at equilibrium (moles/g C),

P_{Kr} = Kr partial pressure in coolant (1.35×10^{-4} mm Hg),

k_1, k_2 = adsorption constants for Kr,

P_i = impurity partial pressure (mm Hg), and

k_{i1}, k_{i2} = adsorption constants for impurity gas.

TABLE 2
ADSORPTION CONSTANTS FOR ACTIVATED
CARBON AT -196°C
(From Antill et al., Ref. 5)

Gas	$K(\text{cm}^3/\text{g})$	k_1 or k_{i1}	k_2 or k_{i2}
He	1.72	1.8×10^{-7}	200
H_2	2×10^4	2×10^{-3}	200
N_2	10^8	20	200
CO	10^9	200	200
CH_4	10^{11}	2×10^4	200
Kr	10^{11}	2×10^4	200
CO_2	10^{14}	2×10^7	200
Xe	10^{16}	2×10^9	200

In Table 2 the dynamic adsorption coefficients K are for low partial pressures of sorbate (i. e., for the linear or pressure-dependent portion of

the isotherm). Using Eqs. (9) and (10) new coefficients can be calculated for conditions of interest.

The following table lists calculated Kr dynamic adsorption coefficients for the three conditions of impurity contamination listed in Table 1.

CO is considered the most serious malefactor in this regard because of the high levels of CO that can occur as a result of accidental steam ingress. Methane may also be of concern, because even at the expected low partial pressures, the high adsorption constant k_1 (see Table 2) makes CH_4 an important competitor for sorption sites in the carbon bed.

TABLE 3
KRYPTON MIXED SORBATE DYNAMIC ADSORPTION
COEFFICIENTS AT 77°K

Gas	ppm	Hg (mm)	K_{Kr} (cm^3/g)	Krypton Delay Time(a) (days)
Kr	3.76×10^{-3}	1.35×10^{-4}	3.7×10^8	4×10^4
CO	10	3.57×10^{-1}	1.3×10^7	1.4×10^3
CO	10^4 (b)	3.57×10^2	1.3×10^4	1.4
CH_4	1	3.57×10^{-2}	1.3×10^6	1.4×10^2
CH_4	100	3.57	1.3×10^4	1.4

(a) Calculated from Eq. (3) for 1000 lb carbon at 77°K and 935 lb He/hr at 48 atm pressure.

(b) This partial pressure is near the condensation pressure for CO at 77°K (400 mm).

It is of interest that Xe, because of its high k_1 , would completely poison the adsorbent if the entire carbon bed were at saturation with respect to Xe. The high adsorption coefficient K , however, precludes saturation of the bed with Xe. Indeed, for normal operating conditions, Xe breakthrough is calculated to be 2×10^6 years for a 1000-lb carbon bed. Thus, Xe contamination will involve only a minor fraction of the total sorbent bed.

Experimental work using the high-pressure loop system included measurement of the delay time for a krypton pulse traversing a fixed bed

of BC-107 activated carbon while the gas phase CO contaminant was maintained at prescribed levels. Figure 9 is a plot of K_{Kr} vs $1/T$ ($^{\circ}K$) for several CO pressures. The solid points are calculated from Eqs. (9) and (10), for the conditions of the experiment. The experimental data are represented by the open points. It is seen that the test data agree quite well with the calculated data.

CONCLUSIONS

These data show quite conclusively that the Langmuir mixed sorbate equation (10) is an accurate model for gases adsorbed on activated carbon. Thus, it appears that elution times for various gaseous species can be adequately predicted for practically any condition of interest using equilibrium data presently available.

Pulse broadening, or the shape of the effluent breakthrough front, is a function of the number of mass transfer units in the sorbent bed of interest. Dynamic performance for any gaseous species can therefore be calculated from a knowledge of geometry and flow parameters and the height of the mass transfer unit, H , using analytical methods previously described. (1, 2)

REFERENCES

1. Hougen, O. A., and W. R. Marshall, Jr., "Adsorption from a Fluid Stream Flowing Through a Stationary Granular Bed," Chem. Eng. Progr. 43, 197 (1947).
2. Burnette, R. D., W. W. Graham III, and D. C. Morse, "The Removal of Radioactive Krypton and Xenon from a Flowing Helium Stream by Fixed-Bed Adsorption," in Reactor Kinetics and Control, USAEC Report TID-7622, 1964.
3. Claude, G., Compt. Rend. 158, 861 (1914).
4. Dushman, S., and J. M. Lafferty, Scientific Foundations of Vacuum Technique, 2d ed., John Wiley and Sons, New York, 1962, p. 453.
5. Antill, J. E., D. Bradley, R. H. Flowers, and N. Hodge, "Purification of Helium in High Temperature Reactors," in Progress in Nuclear Energy, Ser. IV, v. 4, C. M. Nichols (ed.), Pergamon Press, New York, 1961, p. 63-101.

Fig. 9. Krypton dynamic adsorption coefficients as a function of reciprocal temperature at several CO impurity levels. The open points are experimental data; the closed points are calculated from Eqs. (9) and (10)