DATE: November 5, 1952

SUBJECT: DESIGN OF THE DISSOLVER OFF-GAS SYSTEM FOR THE IDAHO CHEMICAL PROCESSING PLANT

TO: F. L. Steahly

FROM: John M. Holmes, Foster Wheeler Corporation

AEC RESEARCH AND DEVELOPMENT REPORT

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TABLE OF CONTENTS

DESIGN OF THE DISSOLVER OFF-GAS SYSTEM FOR THE IDAHO CHEMICAL PROCESSING PLANT

1.0 Correlation of Adsorption Data 4
   1.1 Static Adsorption Data 4
   1.2 Dynamic Adsorption Data 4

2.0 WN System Adsorption Equipment 15
   2.1 Description of WN Adsorption Equipment 15
   2.2 Reference Drawings of WN Adsorption Equipment 17

3.0 Heat Transfer from Refrigerant to Tubes in WN 114 and 116 17
   3.1 Calculation Procedure 17
   3.2 Heat Transfer Calculations 18

4.0 Process Calculations on Adsorbers WN 114, 115, 116, 117 21
   4.1 Design Basis 21
   4.2 Determination of Time Bed will Operate Before "Break Through" 21
   4.3 Basis for Material Balance 27

5.0 Calculations for the Regeneration of Adsorption Beds, WN 114, 115, 116, and 117 28
   5.1 Regeneration Procedure 28
   5.2 Determination of the Heat Required for Regeneration 28
   5.3 Estimation of the Desorption vs. Temperature and Time Curves 36
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SUBJECT: DESIGN OF THE DISSOLVER OFF-GAS SYSTEM FOR THE IDAHO CHEMICAL PROCESSING PLANT

1.0 CORRELATION OF ADSORPTION DATA

The data used for designing the WN System adsorbers are divided into two groups: the static equilibrium data and the dynamic adsorption data involving mass transfer considerations.

1.1 Static Adsorption Data

These data are presented in figures #1, 2, 3, and 4. These data were determined experimentally by the Linde Air Products Laboratory and from other sources as listed in the bibliography.

In order to estimate the degree of desorption of the adsorbed gases during reactivation, it was necessary to extrapolate many of the curves to higher pressures. An examination of the experimental curves indicated that for low temperatures, krypton, xenon, carbon monoxide and nitrogen follow the Freundlich equation in the low pressure range and the Langmuir equation in the high pressure range. Since the extrapolations were done in the high pressure range, the Langmuir equation was used. It is believed that this method was sufficiently accurate for the reactivation calculations. Extrapolated data are shown as dashed lines on all curves.

Figure #4 for the adsorption of nitrogen on charcoal indicates discrepancies between the high and low pressure data, especially in the low temperature range. This is undoubtedly due to the differences in charcoal used by the various investigators and to experimental errors. However, again the data appear accurate enough for reactivation calculation.

1.2 Dynamic Adsorption Data

The dynamic adsorption data were obtained from two sources; the Linde Air Products Laboratory, (Linde C.F. No. 51-11-5), and Oak Ridge National Laboratory, (ORNL 52-3-151). The Linde data include runs made at -183°C, -170°C and -150°C on krypton-nitrogen mixtures and krypton-xenon-nitrogen mixtures. The Oak Ridge data were obtained at -170°C with krypton-xenon-nitrogen mixtures. A brief description of the apparatus used by each laboratory follows:
FIGURE 3
THE ADSORPTION OF CO ON CHARCOAL
FIGURE 4
THE ADSORPTION OF N₂ ON CHARCOAL
Linde Air Products Laboratory. The adsorption trap consisted of a Pyrex glass "U" trap 1.05 cm in diameter, with a bed of 10 gms. Columbia CXA activated carbon, 11.0 cm in depth. Flow rates and temperatures were varied. The rare gas concentrations of the effluent gas were measured with a mass spectrometer capable of detecting a concentration as low as 10 ppm krypton or xenon.

Oak Ridge National Laboratory. The adsorption trap consisted of a 35 gram bed of 4 to 6 mesh CXA Columbia carbon, 6 inches in length and 1.04 inches in diameter. Flow rates were varied at a constant temperature of -170°C. The krypton concentration of the effluent was determined by adding a small amount of radioactive krypton to the stable krypton and xenon mixture entering the bed and then counting the inlet and outlet gas streams. The ratio of the inlet and outlet counts per minute were then equal to the ratio of the inlet and outlet krypton concentrations.

The first data from the Linde Air Products Laboratory were correlated employing the equations of Hougen and Marshall, Chemical Engineering Progress 43, 197, 1947, and are presented in ORNL 51-5-193. Later data from the Linde laboratory and Oak Ridge National Laboratory are correlated in this report using a simplified solution to these equations presented by S. H. Jury, (ORNL C.F. 51-7-41.) The simplified equation became:

\[
2 \frac{Y}{Y_0} - 1 = \phi \left[ \sqrt{a x} - \sqrt{b \tau} \right]
\]

Where \(Y\) = concentration of rare gas in effluent

Where \(Y_0\) = concentration of rare gas in inlet stream

\(\phi\) = indicates the error function of the terms enclosed by brackets

\(a\) = \(1/Hog\)

\(Hog\) = Height of a transfer unit for gas adsorption, \(\rho m\)

\(x\) = length of bed, \(\rho m\)

\(b\) = \(CG.\)

\(c\) = equilibrium constant \(\frac{gms \text{ adsorbent}}{gms \text{ N}_2 \text{ gas}}\)

\(G_1\) = Mass flow rate, \(\frac{gms}{hr.cm^2 \text{ bed}}\)

\(\rho\) = density adsorbent \(gm/cc\) of bed

\(\tau\) = time bed has run, hrs.
Probability paper has been prepared by plotting $\phi (\xi)$ vs. $\xi$ on the ordinate and with a linear coordinate on the abscissa as $1/2$ suggested by Dr. Jury. Therefore, if $2 Y/Y_o - 1$ is plotted vs. $t$ a straight line should be obtained with $\sqrt{ax}$ as the intercept and $\sqrt{a}$ as its slope. A simple method for determining the intercept is to extrapolate the curves to $2 Y/Y_o - 1 = 0$. Then $\sqrt{ax} - \sqrt{bY}$ and $\sqrt{ax}$ can be determined from the slope $= \sqrt{a}$ and $\sqrt{b}$ when $2 Y/Y_o - 1 = 0$.

Dr. Jury in his report, "Design of Percolators," ORNL 51-7-41, suggests that an adsorption bed should be designed for each component separately. However, in correlating the Oak Ridge National Laboratory adsorption data, this would be impossible since the xenon concentrations throughout the bed are not known. Further, the lengths of bed for xenon and krypton adsorption at any one time vary, causing the intercept term $\sqrt{ax}$ to change. Therefore, it has been decided to correlate the data for xenon and krypton as one component. This may be done without introducing appreciable errors because the two terms which vary with the components, $c$, the equilibrium constant and $Hog$, the height of a transfer unit are of the same order of magnitude. The following calculation is included to prove this point:

1. Hog - The height of a transfer unit will vary as the $2/3$ power of the Schmidt number according to the correlation of Gamson, Thodos, and Hougen.

Therefore:

$$\frac{Hog(Xe)}{Hog(Kr)} = \left(\frac{\mu_{Xe}}{\mu_{Kr}}\right)^{2/3} \times \left(\frac{\rho_{Xe}}{\rho_{Kr}}\right)^{2/3} \times \left(\frac{D_v(Kr)}{D_v(Xe)}\right)^{2/3}$$

where:

$\mu$ = gas viscosity

$\rho$ = gas density

$D_v$ = diffusivity of vapor in carrier gas

Then from handbook data:

at approximately - 180°C

$$\left(\frac{\mu_{Xe}}{\mu_{Kr}}\right)^{2/3} = \left(\frac{210.7}{233.4}\right)^{2/3} = 0.932$$

$$\left(\frac{\rho_{Xe}}{\rho_{Kr}}\right)^{2/3} = \left(\frac{83.7}{131.3}\right)^{2/3} = 0.741 \text{ (the densities will vary as the molecular weights)}$$
CORRELATION OF DATA - ADSORPTION OF Xe & Kr ON COLUMBIA CXA CARBON AT -170°C

FIGURE 5
The diffusivities may be calculated from the equation given by Sherwood excluding the terms which are constant for each gas, (temperature, total pressure, and the constant.)

\[
\frac{D_v(Kr)}{D_v(Xe)} = \sqrt[3]{\frac{1/M_{Kr}}{V_{Kr}} + \frac{1/M_{N2}}{V_{N2}}} \quad \frac{1/M_{Xe}}{V_{Xe}} + \frac{1/M_{N2}}{V_{N2}}^{2}
\]

Where \( M \) = molecular weights

\( V \) = molecular volume at the normal boiling point. CC/gm mole.

From Perry:

\( V_{N2} = 31.2 \)

From Handbook data:

\( Kr = \frac{83.7 \text{ gm/mole}}{2.818 \text{ gm/cc}} = 29.7 \text{ cc/gm mole} \)

\( Xe = \frac{131.3 \text{ gm/mole}}{3.06 \text{ gm/cc}} = 43.0 \text{ cc/gm mole} \)

Therefore:

\[
\frac{D_v(Kr)}{D_v(Xe)} = 1.13 \quad \frac{D_v(Kr)^{2/3}}{D_v(Xe)} = 1.085
\]

Therefore:

\[
\frac{\text{Hog}(Xe)}{\text{Hog}(Kr)} = 0.932 \times 0.741 \times 1.085 = 0.748
\]

2. The Equilibrium constant.

The adsorption equations used for correlations assume a linear equilibrium curve through the origin such that \( y^* = CW \) where \( y^* \) = concentration of adsorbable vapor in equilibrium with the adsorbate in the carbon \( W \). This is not the case for rare gas adsorption, for the equilibrium equations are actually of the exponential type,
y* = CW^2. However, values for the equilibrium constant c have been calculated from the adsorption data and are plotted in Figure (6) as c versus the total concentration of rare gas in ppm. Further it has been determined that these values are of the same order of magnitude as the c values calculated by assuming a linear curve through the origin and the inlet concentration of rare gas, an example of which follows:

C for Krypton

\[
C = \frac{gm \text{ Kr/gm gas}}{gm \text{ Kr/gm carbon}} = \frac{\text{Mol fraction Kr} \times 83.7/28}{\text{cc Kr/gm carbon}} = \frac{800 \times \text{Mol Fraction Kr}}{\text{cc Kr/gm carbon}}
\]

Inlet Kr = 4000 ppm

partial pressure = \(4000 \times 10^{-6} \times 760 = 3.04 \text{ mm} \)

cc/gm from Figure (1) = 277 cc/gm

Therefore:

\[
C = \frac{800 \times 0.004}{277} = 0.0116
\]

C for Xenon

Inlet Xe = 4000 ppm. partial pressure = 3.04 mm

cc/gm from Figure (2) = 314 cc/gm

Therefore:

\[
C = \frac{800 \times 0.004}{314} = 0.0102
\]

Average C = 0.0109

C determined experimentally from Figure (6) = 0.0170.

The calculated values are reasonably close to the experimental and very close to each other.
FIGURE 6
EQUILIBRIUM C FOR ADSORPTION OF
XENON & KRYPTON ON COLUMBIA CXA
CARBON AT -170 C VS CONCENTRATION
OF XENON & KRYPTON IN INLET TO
ADSORBERS.

EQUILIBRIUM CONSTANT C

PPM. Xe + Kr

1000 10,000 100,000
The data for the five ORNL experimental runs and two Linde runs are plotted in Figure (5) according to the theory. For most runs, excellent straight lines were obtained for values of \( Y/Y_0 \) above 0.01.

The values for the height of a transfer unit, \( H_{og} \), and the equilibrium constant, \( C \), are given in the following figures. \( H_{og} \) values are plotted versus velocity in Figure (7). Contrary to the correlation by Gamson, Thodos, and Hougen, the value for the slope of the \( H_{og} \) versus velocity plot in Figure (7) is 0.61 instead of 0.51. Equilibrium data calculated from the experimental data are given in Figure (6) as \( C \) versus ppm of total rare gas concentration.

These data are used to determine the length of time the designed adsorption bed for the Arco, Idaho Plant will run before "break through" of radioactive krypton.

2.0 WN SYSTEM ADSORPTION EQUIPMENT

2.1 Description of WN Adsorption Equipment

Two complete and independent adsorption units are provided in order that one may be operated while the other is being regenerated. Each unit consists of an Insulation box (WN 131 or WN 132), Gas Pre-Cooler, (WN 324 or WN 326), Adsorption Unit, (WN 114 or WN 116) and an adsorption Clean-Up unit, (WN 115 or WN 117).

The flow of gas through the vessels in WN 131, (flows through WN 132 are identical), are as follows: Gases enter the Gas Pre-Cooler, (WN 324), at room temperature, are cooled to -150°C by the gases leaving the Adsorption Clean-Up Unit, (WN 115), and during this cooling the remaining \( \text{N}_2\text{O} \) and \( \text{H}_2\text{O} \) are condensed out in WN 324. They are then sent to the Adsorption Unit, (WN 114), where they are cooled to -180°C and the rare gases adsorbed. The stream is then sampled for rare gas concentration, and passed through the Adsorption Clean-Up Unit, (WN 115), and Pre-Cooler, (WN 324). Gases leaving WN 324 are near room temperature, free of all radioactive material and are sent to the stack after being filtered in WN 116.

The WN Adsorption System is equipped with a pressure vessel, WN 130, which has sufficient volume to keep the pressure of the adsorption system below 300 psig. should a breakdown occur in the liquid nitrogen system. Therefore, the system could be isolated and the rare gases confined even if the temperature of the adsorption beds was at room temperature.
FIGURE 7
HOG FOR Xe & Kr Adsorption on Columbia CXA Carbon at -170 C. vs Velocity (S.T.P)

HEIGHT OF TRANSFER UNIT, HOG. cm.
2.2 Reference Drawings of WN Adsorption Equipment

Details of the WN System Adsorption equipment are given on the following Alloy Fabricators drawings:

- WN 114 & WN 116
  - A-1390-A-15
  - A-1390-A-17
- WN 115 & WN 117
  - A-1390-A-16
  - A-1390-A-17
- WN 324 & WN 326
  - A-1390-A-18
- WN 131 & WN 132
  - A-1390-A-10
  - A-1390-A-11
  - A-1390-A-12
  - A-1390-A-14
  - A-1390-A-21
- WN 130
  - A-1390-A-9

Details of the flow system are given on WN Flowsheet 542-41-P1341C and details of the Cold Box piping layout are given on 542-41-P1388 and 542-41-P1389.

3.0 HEAT TRANSFER FROM REFRIGERANT TO TUBES IN WN 114 & WN 116

3.1 Calculation Procedure

Calculations on WN 324 and WN 326 show that the temperature of the process gases entering WN 114 or WN 116 will be approximately -254°F. It will be necessary to cool these gases to -292°F, the operating temperature of the adsorber. The assumption is made that the greater part of this cooling will be done in the upper part of the adsorber tubes since the area for heat transfer from the refrigerant to the gas in the adsorber head is small. The level of liquid nitrogen will be maintained near or below the center line of the vessel so it is assumed that the heat will be transferred across two gas films - from the vaporized nitrogen to the tube and from the tube to the carbon granules and the flowing gases.

The heat transfer coefficient for the gas film outside the tube is taken from the chart on page 477, Perry's Chemical Engineer's Handbook, third edition. The mass velocity for the N₂ gas is so low that a free convection coefficient is used. The heat transfer coefficient for the gases flowing over the granular bed is calculated using the chart on page 165 in McAdams', "Heat Transmission," second edition for air inside tubes at low velocities. This coefficient is

3.2 Heat Transfer Calculations

A. Physical Dimensions

Tubes:

OD = 1 in
ID = 0.870 in
Wall = 0.065 in
Inside Area = 0.00413 ft² x 48 = 0.198 ft²

Area for Heat Transfer =
  Inside = 0.2277 ft²/ft
  Outside = 0.2618 ft²/ft

Charcoal:

Specific Heat = 0.242 Btu/lb°F
OD Dimensions = 3/16 in
  Length = 1/8 in to 3/8 in
  Average = 1/4 in
  Mesh Size = 4 to 6
Density = 30 lbs/ft³
Thermal Conductivity = 0.326 Btu in/hr ft² °F

Gases:

Composition = (neglect N₂O and rare gases)
  N₂ at -254°F (-159°C) to -292°F (-180°C)

Pressure = 8.05 psia.
Temperature (Average) = -273°F
Heat Capacity = 0.25
Density
\[ \frac{28 \times 8.05 \times 492}{359 \times 14.7 \times 187} = 0.112 \text{ lb/ft}^3 \]

Flow Rate
\[ = 3.69 \text{ SCFM} \]

Velocity (Standard Conditions)
\[ = \frac{3.69}{45 \times 0.00413} = 18.6 \text{ ft/min} \]

Velocity (Actual Conditions)
\[ = \frac{18.6 \times 0.078}{0.112} = 12.95 \text{ ft/min} \]

Viscosity
\[ = 0.0056 \text{ cp.} = 0.0136 \text{ lb/hr ft} \]

Mass Flow Rate
\[ = 28 \times 0.589 + 2 \times 0.0285 + 2 = 16.6 \text{ lbs/hr} \]

Thermal Conductivity
\[ = 0.0037 \text{ Btu/ft/hr ft}^2 \text{ OF} \]

B. Heat Transfer Coefficient Inside Tubes
(From Chart, Page 165 McAdams, Heat Transmission, Second Edition)

\[ h = 1.5 \text{ for } G \leq 800 \]

Corrected for Pressure
\[ h_1 = 1.5 \times \left[ \frac{0.55}{1.07} \right]^{2/3} = 0.97 \]

Diameter Carbon
\[ = 0.188 \]

Diameter Tube
\[ = 0.870 \]

\[ D_p/D_l = 0.216 \]

\[ h/u_l = 7.5 \] (From Colburn ICE 23, 910, 1931)

\[ h = 7.5 \times 0.97 = 7.3 \text{ Btu/hr ft}^2 \]

C. Heat Transfer Coefficient Outside Tubes

If Liquid N₂ Level is below the area for transfer, the gas film will control.

Area for flow
\[ = 0.785 \times \left[ \frac{10}{12} \right]^2 \times 0.785 \times \left[ \frac{1}{12} \right]^2 \]
\[ = 0.542 - 0.260 = 0.282 \text{ ft}^2 \]

Average Flow N₂
\[ = 20 \text{ lbs/hr} \]
Therefore:
\[ G = \frac{20}{0.282} = 71 \text{ lbs/hr ft}^2 \]
\[ G^1 = \frac{71}{3500} = 0.0197 \text{ lbs/sec ft}^2 \]


Temperature of \( N_2 \) gas = Saturation Temperature Liquid \( N_2 \)
at 62 psia = \(-294^\circ F(-181.0^\circ C)\)

Final temperature \( N_2 \) gas = \[ \frac{158}{20 \times 0.25} \] - 294 = \(-262.4^\circ F(-163.5^\circ C)\)

Average \( \Delta t = \frac{(-159 + 163.5)}{2} + \frac{(-180 + 181)}{2} = 2.75^\circ C \)

Absolute Pressure of \( N_2 \) = 62 psia = 4.22 atmospheres

\[ p^2 \Delta t_m = 17.7 \times 2.75 = 48.7 \]

\[ h = 2.7 \text{ Btu/hr ft}^2 \circ F \]

D. Overall Coefficient

\[ \frac{1}{U_o A} = \frac{1}{7.3 \times 48 \times 0.2277 \text{ ft}^2/\text{ft}^2} + \frac{1}{2.7 \times 48 \times 0.2618 \text{ ft}^2/\text{ft}^2} \]

\[ U_o A = 23.8 \text{ Btu/hr ft}^2 \circ F \]

E. Log Mean Temperature Difference:

\[ = 1.8 \times 4.5 - 1 \]

\[ = \frac{1}{\ln 4.5/1} = 4.2^\circ F \]

\[ Q = 16.6 \times 0.25 \times 38 = 158 \text{ Btu/hr} \]

F. Length of Tubes Necessary for Heat Transfer

\[ Q = UAL \Delta t_m \]

\[ L = \frac{q}{U A \Delta t_m} = \frac{158}{23.8 \times 4.2} = 1.6 \text{ ft} \]

Therefore it will take 1.6 ft to cool the gases from \(-254^\circ F\) to \(-292^\circ F\).
4.0 PROCESS CALCULATIONS ON ADSORBERS WN 114, WN 115, WN 116 AND WN 117

4.1 Design Basis

The basis for design will be the material balance streams from the preliminary heat exchangers, WN 324 or WN 326 for MTR processing:

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>LB MOLES PER HOUR</th>
<th>MOL %</th>
<th>SCFM (32°F &amp; 1 atm)</th>
<th>PP at TOTAL PRESS = 415 mm</th>
<th>CONDENSATION TEMPERATURE °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>N₂ + A</td>
<td>0.5875</td>
<td>95.11</td>
<td>3.5152</td>
<td>395</td>
<td>-203</td>
</tr>
<tr>
<td>H₂</td>
<td>0.0285</td>
<td>4.61</td>
<td>0.1705</td>
<td>19.1</td>
<td>-261</td>
</tr>
<tr>
<td>CO</td>
<td>0.0012</td>
<td>0.194</td>
<td>0.0072</td>
<td>0.806</td>
<td>-222</td>
</tr>
<tr>
<td>N₂O</td>
<td>8.1 x 10⁻⁵</td>
<td>1.31 x 10⁻²</td>
<td>-</td>
<td>0.0544</td>
<td>-159</td>
</tr>
<tr>
<td>Kr</td>
<td>69.92 x 10⁻⁶</td>
<td>1.13 x 10⁻²</td>
<td>-</td>
<td>0.0470</td>
<td>-210</td>
</tr>
<tr>
<td>Xe</td>
<td>406.2 x 10⁻⁶</td>
<td>6.59 x 10⁻²</td>
<td>-</td>
<td>0.2738</td>
<td>-174</td>
</tr>
<tr>
<td>TOTAL</td>
<td>0.6177</td>
<td></td>
<td>3.6929</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

These data show that N₂O and Xe will enter the -180°C adsorption bed with condensation temperatures higher than the bed temperature. However, ORNL and Linde data show that Xenon was adsorbed without condensation on a bed which has a temperature of -170°C while the condensation temperature of the Xenon was greater than -170°C.

4.2 Determination of Length of Time Bed Will Operate Before "Break Through"

4.21 Method of Calculation

A. Assume a period of 300 hrs or two months MTR operation.
B. Determine quantity of charcoal used up by N₂O gas in first adsorption band of bed.
C. Determine the length of time the bed will run by two methods:
   1. Using data from the adsorption bed experiments conducted by the Linde Air Products Laboratory
2. Using a factor determined from the above data for the bed loading at equal contact times, and using equilibrium data, determine the amount of rare gases the bed will hold before "break through."

4.22 Quantity of Charcoal Used by N\textsubscript{2}O Adsorption

Data are not available for N\textsubscript{2}O adsorption at \(-180^\circ\)C. Instead one may use the volume of solid N\textsubscript{2}O and the pore volume of charcoal as determined from adsorption of N\textsubscript{2}gas.

Total pressure of system = 415 mm.

Volume of liquid N\textsubscript{2} at \(90^\circ\)K = 37.5 cc/gm mole

Formula for capacity of charcoal for N\textsubscript{2} - National Bureau of Standards

Paper R.P. 1496 page 191, 1942

\[ \frac{p}{v} = 0.00251 \times P + 0.15 \]

where \( p \) = partial pressure mm
\( v \) = capacity cc/gm S.T.P.

\[ \frac{415}{v} = 0.00251 \times 415 + 0.15 \]

\[ v = 348 \text{ cc/gm} \]

Therefore:

Liquid volume = \( \frac{348 \times 37.5 \text{ cc lig}}{22,400 \text{ gm mole}} \) = 0.583 cc/gm

Solid volume N\textsubscript{2}O = 1.226 gm/cc

Therefore:

Capacity for N\textsubscript{2}O = 1.226 gm/cc \times 0.583 cc/gm

= 0.714 lb N\textsubscript{2}O

1 lb charcoal
\[ \text{N}_2\text{O accumulated after 300 hrs} = 8.1 \times 10^{-5} \times 300 \times 44 \text{ lb/mol} = 1.07 \text{ lb} \]

Charcoal used = \( \frac{1.07}{0.714} \) = 1.50 lb charcoal

Length of Bed = \( \frac{1.50}{30} \times \frac{1}{0.198} \) = 0.25 ft

Use a safety factor of 3.25, therefore length = 0.25 x 3.25 = 0.82. Therefore \( \text{N}_2\text{O} \) will take up 0.82 ft which is less than the 1.6 ft necessary to cool the bed down to the temperature of the liquid nitrogen. The remainder of the bed will be approximately \(-170^\circ\text{C}\) to \(-180^\circ\text{C}\), nearly the saturation temperature of the refrigerant. The data used for Xenon adsorption are for \(-170^\circ\text{C}\) so the calculation will be on the conservative side.

4.23 Time Bed Will Operate Before "Break Through" of Krypton

A. Length of Bed Available to Krypton and Xenon
   Pack bottom of bed with quartz to a height of 1 1/2 in and the remainder with CCA carbon. Length = 7 ft - 0.125 - 0.82 = 6.055 ft.

B. Height of Transfer Unit \( \text{Hog} \)
   Velocity at standard temperature but corrected for pressure:
   Flow rate = 3.69 SCFM
   \[ \text{Velocity} = \frac{3.69}{48 \times 0.00413 \times \frac{14.7}{8.05}} = 34 \text{ ft/min} = 1037 \text{ cm/min} \]
   Use Figure 7 for the value of \( \text{Hog} \)
   \[ \text{Hog} = 2.70 \text{ cm} \]
   Therefore \( \text{Hog} = 0.0885 \text{ ft} \)

C. Equilibrium Constant - c
   Total ppm of rare gas = 113 + 659 = 772
   partial pressure = 772 x \(10^{-6}\)
   Therefore \( c = \frac{800 \times 0.000772}{245} = 0.00252 \)
   \( c \) from Figure 6 = 0.0072
D. Calculation of \( b \)
\[
B = \frac{G_1}{\rho \cdot \text{Hog}}
\]
Where:
- \( G_1 \) = Mass Flow rate \( \text{lb/hr ft}^2 \)
- \( \rho \) = Density of CXA Charcoal \( \text{lb/ft}^3 \)

Mass Flow rate = 16.6 \( \text{lb/hr} \)

\[
G_1 = \frac{16.6}{48 \times 0.00413} = 83.7 \text{ lb/hr ft}^2
\]

\( \rho = 30 \text{ lb/ft}^3 \)

Hog = 0.0885 \( \text{ft} \)

Therefore \( b = \frac{0.0072 \times 83.7}{30 \times 0.0885} = 0.227 \)

E. Calculation of \( ax \)
\[
x = 6.055 \text{ ft}
\]
Therefore \( ax = 68.5 \)

Where:
- \( a = 1/\text{Hog} \)
- \( x = \text{Length of Bed} \)

F. Calculation of \( Y/Y_0 \)
\[
Y \text{ allowable} = 20 \text{ ppm}
\]

\[
Y/Y_0 = \frac{20}{772} = 0.026
\]

Where:
- \( Y \) = concentration rare gas leaving bed.
- \( Y_0 \) = concentration rare gas entering bed.

G. Time Bed Will Run For:

\[
Y/Y_0 = 0.026, \ ax = 68.5 \text{ from chart Page 882 in Perry's Chemical Engineers' Handbook, Third Edition}.
\]

\( b\gamma = 48 \)

\[
\gamma = \frac{48}{0.227} = 212 \text{ hrs.}
\]

Where:
- \( \gamma \) = time bed has operated.
4.24 Calculation of Bed from Equilibrium Data and Contact Time

A. Contact time for bed = \( \frac{6.055}{34} \times 60 = 10.7 \text{ sec.} \)

B. Experiment No. 5 from ORNL 52-3-151 would correspond to this time. The contact time for this run was:

\[
\frac{6 \times 2.54 \times 60}{97.5} = 9.4 \text{ sec}
\]

This bed containing 35 gms of CXA charcoal ran 20 hours before "break through" i.e., before effluent rose to 20 ppm.

C. Material balance from Experiment No. 5 ORNL Data

Flow rate = 533 cc/min  
Inlet Kr = 2500 ppm  
Inlet Xe = 2000 ppm

Krypton = \( 533 \times 60 \times 20 \text{ hrs} \times 2500 \times 10^{-6} = 1600 \text{ cc} \)

Xenon = \( 533 \times 60 \times 20 \times 2000 \times 10^{-6} = 1280 \text{ cc} \)

TOTAL = 2880 cc

Bed loading = \( \frac{2880}{35} = 82.4 \text{ cc/gm} \)

Bed loading from equilibrium data:

Krypton pp = 0.0025 \times 760 = 1.9 mm

Equilibrium conc. from Figure = 265 cc/gm

Xenon pp = 0.002 \times 760 = 1.52 mm

Equilibrium concentration from Figure = 260 cc/gm

Weighted loading = \( \frac{25}{45} \times 265 + \frac{20}{45} \times 260 = 263 \text{ cc/gm} \)

% of equilibrium loading = \( \frac{82.4}{263} \times 100 = 31.4 \)

D. Total weight of charcoal available to Xe and Kr adsorption = \( 6.055 \text{ ft} \times 0.198 \text{ ft}^2 \times 30 \text{ lbs/ft}^3 = 36.0 \text{ lbs} \).
Lex \( X \) = hours bed will run. Then total lbs. \( Kr \) accumulated =

\[
(69.92 \times 10^{-6}) \times (83.7 \text{ lb/mole}) \times X = (58.4 \times 10^{-4}) X
\]

Total lbs \( Xe \) = \( (406.2 \times 10^{-6}) \times (131.3 \text{ lb/mole}) \times X = (534 \times 10^{-4}) X \)

Partial Pressure \( Kr \) = \( 1.13 \times 10^{-4} \times 415 = 0.0469 \text{ mm} \)

Equilibrium concentration \( Kr \) = 160 cc/gm

Partial Pressure \( Xe \) = \( 6.59 \times 10^{-4} \times 415 = 0.274 \text{ mm} \)

Equilibrium concentration \( Xe \) = 242 cc/gm

Charcoal that \( Kr \) will use for equilibrium adsorption =

\[
\frac{58.4 \times 10^{-4} X}{160 \times \frac{83.7}{22400}} \text{ gm/gm} = 0.00975 X
\]

Charcoal \( Xe \) will use = \( \frac{534 \times 10^{-4} X}{242 \times \frac{131.3}{22400}} \) = 0.0376 X

Total Charcoal available = 36.0 \times 0.314 = 11.3 \text{ lbs}

Time bed will run = \( \frac{11.3}{0.0376 X + 0.00975 X} \) = 239 hours

4.25 Additional Time Bed Will Run After "Break Through" in Main Adsorber

(\text{WN 114 or WN 116})

Using Hougan and Marshall Method

\begin{align*}
\text{Hog} &= 0.0885 \text{ ft} \\
X &= 6.055 + 2 - 0.125 = 7.93 \\
aX &= 7.93/0.0885 = 89.6 \\
by &= 66 \\
\tau &= 66/0.227 = 291 \text{ hours total}
\end{align*}

Therefore additional time = 291 - 212 = 79 hours
Using equilibrium loading method

\[
\text{Time} = 239 \times 7.93/6.055 = 312 \text{ hours total}
\]

Additional time = 312 - 239 = 73 hours

4.3 Basis for Material Balance

The material balance will be figured on a basis of 300 hours of MTR operation. Therefore the amount of gases adsorbed will be as follows:

Total length bed = 9 - 2 \times 0.125 = 8.75 \text{ ft}

Pounds charcoal = 8.75 \times 0.198 \times 30 = 52.0 \text{ lbs}

Calculation of \( N_2 + A \) and CO:

Assume that \( N_2 + A \) and CO are adsorbed in quantities proportional to their inlet concentrations. Total charcoal available to \( N_2 + A \) and CO = 52.0 - 1.50 - 2.94 - 11.30 = 36.26 lbs.

Let \( X = \text{lb moles } N_2 + A \) adsorbed

Let \( Y = \text{lb moles } CO \) adsorbed

\[
\frac{X}{Y} = \frac{0.5875}{0.0012} = 490
\]

\[
\frac{28X \times 22,400}{335 \times 28} + \frac{28Y \times 22,400}{6.5 \times 28} = 36.26
\]

\[
X = 0.491 \text{ lb moles}
\]

\[
Y = 0.0010 \text{ lb moles}
\]

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>LB MOLES</th>
<th>LBS</th>
<th>MOL. PERCENT</th>
<th>EQUILIBRIUM CONCENTRATION</th>
<th>LBS OF ADSORBENT USED</th>
</tr>
</thead>
<tbody>
<tr>
<td>( N_2 + A )</td>
<td>0.4910</td>
<td>13.73</td>
<td>74.5</td>
<td>335 \text{ cc/gm}</td>
<td>32.77</td>
</tr>
<tr>
<td>( N_2O )</td>
<td>0.0243</td>
<td>1.070</td>
<td>3.6</td>
<td>363 \text{ cc/gm}</td>
<td>1.50</td>
</tr>
<tr>
<td>CO</td>
<td>0.0010</td>
<td>0.028</td>
<td>0.2</td>
<td>6.5 \text{ cc/gm}</td>
<td>3.49</td>
</tr>
<tr>
<td>Kr</td>
<td>0.0210</td>
<td>1.757</td>
<td>3.2</td>
<td>160 \text{ cc/gm}</td>
<td>2.94</td>
</tr>
<tr>
<td>( Xe )</td>
<td>0.1218</td>
<td>16.01</td>
<td>18.5</td>
<td>242 \text{ cc/gm}</td>
<td>11.30</td>
</tr>
<tr>
<td>TOTAL</td>
<td>0.6591</td>
<td>100.0</td>
<td></td>
<td></td>
<td>52.00</td>
</tr>
</tbody>
</table>
5.0 CALCULATIONS FOR THE REGENERATION OF ADSORPTION BEDS
(WN 114, WN 115, WN 116, WN 117)

5.1 Regeneration Procedure

Linde Air Products Laboratory recommended heating the adsorption beds to 100°C while pulling a vacuum in order to completely remove all adsorbed gases. Xenon and NO are the most difficult gases to remove, and therefore will come off at the higher temperatures, while the others will be desorbed almost immediately on heating.

The procedure for regenerating the WN adsorption beds will involve the heating of the beds from the shell side of the adsorbers using warm dry air supplied by blower WN 211, air drier WN 134, and heater WN 315. The dry air will be available at a temperature of between room temperature and 300°F and a flow of 60 SCFM. Desorbed gases from the beds will flow to the cold traps WN 118 or WN 119. These traps will be cooled by liquid nitrogen under vacuum, which in turn will cool the condensing vapors to a temperature low enough that a vacuum will be created on the beds. The desorbed gases from the beds will be condensed in the inner vessels of WN 118 or WN 119. After regeneration is complete, the valves to WN 118 or WN 119 will be closed and the vessels allowed to warm up to room temperature, thus vaporizing the desorbed gases and raising the pressure to nearly 1400 psig. WN 118 or WN 119 will then be connected to storage cylinders where the gases will be stored by progressively opening and closing cylinder valves until the pressure in the cold trap is down below 100 psig. Each cylinder will then be removed from the manifold when its pressure has reached the highest pressure obtainable on warming up WN 118 or WN 119.

5.2 Determination of the Heat Required for Regeneration

5.21 Calculation Procedures

The procedure for calculating the heat required for regenerating the adsorption beds in Cold Boxes WN 131 and WN 132 follows. The time for regeneration is arbitrarily set at 10 hours. Flows and temperatures have been specified to meet this condition.

The total quantity of heat required to raise the adsorber temperatures to 212°F from -292°F, is calculated. An approximation is necessary in order to determine the heat that the insulation will absorb during regeneration. This involves calculating the space mean temperatures of the insulation around the adsorbers for different thicknesses until a temperature is reached where the heat load drops off rapidly. The resulting thickness is 6 inches of insulation. An approximate figure is also included to account for the heat conducted through the 6 inches of insulation.
during the 10 hour period.

The time to heat WN 131 or WN 132 is calculated from the heat load and the heat transfer rate employing a graphical integration method. The total heat transferred for an average vessel temperature of T, is plotted versus the reciprocal of the heat transfer rate at T, in Figure 8. The area under the curve is therefore equal to the time. Figure 9 gives the time versus temperature curve for WN 131 or WN 132.

5.22 Conditions

A. Original Temperature = -180°C (-292°F)
B. Final Temperature = 100°C (+212°F)
C. Total Weights of Material
   Steel = 2430 lbs
   Carbon = 52 lbs
D. Time to Regenerate = 10 hours

5.23 Heat Necessary for Regeneration

Steel = 2430 x 0.12 x (212 + 292) = 147,000 Btu
Carbon = 52 x 0.15 x 504 = 3930 Btu

Insulation:
To calculate an approximate heat load for insulation, assume that temperature at start = -292°F and determine space mean temperatures at different depths until a temperature is reached where the heat load drops off rapidly.

Variables:
\[ x = \frac{Kt}{Pct^2} \]

Therefore:
\[ x = \frac{0.0192 \times 10}{14.5 \times 0.26t^2} \]
\[ x = \frac{0.0509}{t^2} \]

Where:
\[ K = \text{Conductivity} \]
\[ \theta = 10 \text{ hours} \]
\[ C = 0.26 \text{ Btu/lb°F} \]
\[ P = 14.5 \text{ lb/ft}^3 \]

\[ Y = \frac{t^2 - ta}{t^2 - tb} \]
\[ 212 - ta \]
\[ 212 + 292 \]

930 - 029
FIGURE 8

\( \frac{1}{B} \) VS HEAT CONTENT OF SYSTEM

BEING REACTIVATED

BTU HEAT TRANSFERRED \( \times 10^3 \)
<table>
<thead>
<tr>
<th>Depth</th>
<th>Inches</th>
<th>Feet</th>
<th>t^2</th>
<th>X</th>
<th>Y</th>
<th>504 Y</th>
<th>ta 212 - 504 Y</th>
<th>Mean Area for Heat Transfer A_m</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/4</td>
<td>0.0208</td>
<td>0.01</td>
<td>0.000433</td>
<td>117.2</td>
<td>0.01</td>
<td>----</td>
<td>207 space mean temp.</td>
<td>----</td>
</tr>
<tr>
<td>1</td>
<td>0.0833</td>
<td>0.07</td>
<td>0.00691</td>
<td>7.36</td>
<td>0.01</td>
<td>----</td>
<td>207 space mean temp.</td>
<td>----</td>
</tr>
<tr>
<td>3</td>
<td>0.25</td>
<td>0.21</td>
<td>0.0625</td>
<td>0.814</td>
<td>0.110</td>
<td>55.4</td>
<td>156.6 space mean temp.</td>
<td>10.4 space mean temp.</td>
</tr>
<tr>
<td>5</td>
<td>0.417</td>
<td>0.35</td>
<td>0.174</td>
<td>0.292</td>
<td>0.40</td>
<td>201.6</td>
<td>10.4 space mean temp.</td>
<td>156.6 space mean temp.</td>
</tr>
<tr>
<td>6</td>
<td>0.50</td>
<td>0.42</td>
<td>0.250</td>
<td>0.204</td>
<td>0.49</td>
<td>246.4</td>
<td>-34.4 space mean temp.</td>
<td>10.4 space mean temp.</td>
</tr>
<tr>
<td>6</td>
<td>0.50</td>
<td>0.42</td>
<td>0.250</td>
<td>0.204</td>
<td>0.74</td>
<td>373.2</td>
<td>-160.2 (temp at t = 6&quot;)</td>
<td>156.6 space mean temp.</td>
</tr>
</tbody>
</table>

Therefore Heat Being Transferred

\[
q = \frac{0.23 A_m (212 + 160.7)}{6} = 143 A_m
\]

Mean Area for Heat Transfer \(A_m\)

Inside: \(11.9 \times \pi \times 10.75/12 + \frac{4}{4} \times \pi \left(\frac{10.75}{12}\right)^2 = 35.9\)

Outside: \(11.9 \times \pi \times 22.75/12 + \frac{4}{4} \times \pi \left(\frac{10.75}{12}\right)^2 = 73.4\)

Average: \(\frac{73.4 + 35.9}{2} = 54.7 = A_m\)

\[
q = 14.3 \times 54.7 = 783 \text{ Btu/hr}
\]

Volume of Insulation

\[
= 11.9 \times \frac{\pi}{4} \left(\frac{22.75}{12}\right) - 11.9 \times \pi \left(\frac{10.75}{12}\right)^2 + 4 \times \frac{1}{2} \times \frac{10.75^2}{12}\]

\[
= 27.4
\]

Heat Load

\[
= 27.4 \times 7 \times 0.26 \times (-34.4 + 292) = 12,830 \text{ Btu}
\]

Therefore total load = 147,000 + 3930 + 12,830 + 783 \text{ Btu/hr x 10 hrs = 171,590 Btu}
5.25 Time to Heat WN 131 or WN 132 from -292°F to +212°F

Calculate heat transfer rate and then calculate time by a graphical integration. (Figure 6.)

\[
\text{Time} = \frac{\text{Heat Content per Temp. rise}}{q(\text{Btu/hr})}
\]

a. Heat Load Per°F = 171,590
Heat per F = \frac{171,590}{212 + 292} = 341 \text{ Btu/°F}

b. Determination of Area for Heat Transfer
Area Adsorber Tubes = 48 \times 0.262 \text{ ft}^2/\text{ft} \times (7 + 2*) = 113.0 \text{ ft}^2

* Secondary Adsorber

Area of Shells
9.0 ft \times 2.55 \text{ ft}^2/\text{ft} = 23.0 \text{ ft}^2

Area Heads
\[
4 \times \frac{\pi}{4} \left(\frac{10}{12}\right)^2 - 4 \times 48 \times \frac{\pi}{4} \left(\frac{1}{12}\right)^2 = 0.28 \text{ ft}^2
\]

There is no area inside the low temperature heat exchangers available for warming operation.

Therefore: Total Area = 113.0
23.0
0.3
\frac{136.3}{\text{ft}^2}

5.25 Heat Transfer Coefficient for Warming Gases in Adsorber Shell


Cross-sectional Area of Adsorbers:
\[
\frac{\pi}{4} \left(\frac{10}{12}\right)^2 - 48 \times \frac{\pi}{4} \left(\frac{1}{12}\right)^2 = 0.544 - 0.261 = 0.283 \text{ ft}^2
\]
Flow = 60 SCFM = 270 lbs/hr

\[ G = \frac{270}{0.283} \times 3600 = 0.265 \text{ lb/Sec. ft}^2 \]

d0 = 1 inch

\[ \text{Cp for N}_2 \text{ at approximately } 300^\circ F = 0.245 \]

\[ \frac{h}{\text{Cp}} = 4.7 \quad h = 4.7 \times 0.245 = 1.15 \text{ Btu/hr ft}^2 \text{ F} \]

q = UADT

\[ U = 1.15 \text{ Btu/hr ft}^2 \text{ F} \]

A = 136.3 ft²

T = gas entering temperature

\[ T_2 = \text{gas exit temperature} = T - q/(270 \times 0.24) = T - q/64.8 \]

\[ T_1 = \text{Average Temperature of vessel} \]

\[ q = 1.15 \times 136.3 \Delta t = 156.745 \Delta t \]

\[ \Delta t = \frac{(T-T_1) - (T_2-T_1)}{\ln \frac{T - T_1}{T_2 - T_1}} = \frac{q/64.8}{\ln \frac{T - T_1}{T - q - T_1}} \]

\[ \Delta t = \frac{q/64.8}{\ln \frac{T - T_1}{T - q - T_1}} \]

\[ q = 156.8 \quad \frac{q/64.8}{\ln \frac{T - T_1}{T - T_1 - q/64.8}} = 2.42 \]

\[ \frac{\ln \frac{T - T_1}{T - T_1 - q/64.8}}{\ln \frac{T - T_1}{T - T_1 - q/64.8}} = 11.20 \]

930 - 059

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5.26 Calculation of Heat Transferred to WN 131 During Reactivation

\[
\frac{T - T_1}{T - T_1 - q/64.8} = 11.2
\]

\[
\frac{T - T_1}{11.2} = T - T_1 - q/64.8
\]

<table>
<thead>
<tr>
<th>(T_1)</th>
<th>(T)</th>
<th>(T-T_1)</th>
<th>(q/64.8)</th>
<th>(q)</th>
<th>(\frac{1}{q} \times 10^{-5})</th>
<th>Total q</th>
<th>Traps at</th>
<th>Total q</th>
<th>(T_1^\circ C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-292</td>
<td>+150</td>
<td>442</td>
<td>39.4</td>
<td>402.6</td>
<td>26,100</td>
<td>3.83</td>
<td>0</td>
<td>-180</td>
<td></td>
</tr>
<tr>
<td>-250</td>
<td>+175</td>
<td>425</td>
<td>38.9</td>
<td>386.1</td>
<td>25,000</td>
<td>4.00</td>
<td>14,300</td>
<td>-157</td>
<td></td>
</tr>
<tr>
<td>-200</td>
<td>+200</td>
<td>400</td>
<td>35.7</td>
<td>364.3</td>
<td>23,600</td>
<td>4.24</td>
<td>31,400</td>
<td>-129</td>
<td></td>
</tr>
<tr>
<td>-150</td>
<td>+250</td>
<td>400</td>
<td>35.7</td>
<td>364.3</td>
<td>23,600</td>
<td>4.24</td>
<td>48,400</td>
<td>-101</td>
<td></td>
</tr>
<tr>
<td>-100</td>
<td>+300</td>
<td>400</td>
<td>35.7</td>
<td>364.3</td>
<td>23,600</td>
<td>4.24</td>
<td>65,400</td>
<td>-73.3</td>
<td></td>
</tr>
<tr>
<td>-50</td>
<td>+300</td>
<td>350</td>
<td>31.3</td>
<td>318.7</td>
<td>20,600</td>
<td>4.86</td>
<td>82,900</td>
<td>-45.6</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>+300</td>
<td>300</td>
<td>26.8</td>
<td>273.2</td>
<td>17,700</td>
<td>5.65</td>
<td>100,000</td>
<td>-17.8</td>
<td></td>
</tr>
<tr>
<td>+50</td>
<td>+325</td>
<td>275</td>
<td>24.6</td>
<td>250.4</td>
<td>16,200</td>
<td>6.17</td>
<td>117,000</td>
<td>-10.0</td>
<td></td>
</tr>
<tr>
<td>+100</td>
<td>+350</td>
<td>250</td>
<td>22.3</td>
<td>227.7</td>
<td>14,720</td>
<td>6.79</td>
<td>134,000</td>
<td>37.8</td>
<td></td>
</tr>
<tr>
<td>+150</td>
<td>+350</td>
<td>200</td>
<td>17.9</td>
<td>182.1</td>
<td>11,800</td>
<td>8.55</td>
<td>151,000</td>
<td>66</td>
<td></td>
</tr>
<tr>
<td>+212</td>
<td>+350</td>
<td>138</td>
<td>12.3</td>
<td>125.7</td>
<td>8,150</td>
<td>12.28</td>
<td>171,500</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

Heat Transfer Increment x 10 + 3 | Average \(-5\) \(1/q \times 10^{-5}\) | Time Hours | Total Hours |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0-30</td>
<td>4.00</td>
<td>1.20</td>
<td>1.20</td>
</tr>
<tr>
<td>30-60</td>
<td>4.24</td>
<td>1.27</td>
<td>2.47</td>
</tr>
<tr>
<td>60-100</td>
<td>4.80</td>
<td>1.92</td>
<td>4.39</td>
</tr>
<tr>
<td>100-120</td>
<td>6.20</td>
<td>1.24</td>
<td>5.63</td>
</tr>
<tr>
<td>120-140</td>
<td>6.60</td>
<td>1.32</td>
<td>6.95</td>
</tr>
<tr>
<td>140-160</td>
<td>8.30</td>
<td>1.66</td>
<td>8.61</td>
</tr>
<tr>
<td>160-171</td>
<td>10.90</td>
<td>1.20</td>
<td>9.81</td>
</tr>
</tbody>
</table>

\( \text{Total} = 9.81 \)
5.3 Estimation of the Desorption vs. Temperature and Time Curves

An attempt is made using the equilibrium curves to estimate the desorption of the gases from the beds at bed temperatures during re-activation. The vapor pressure of the gases condensing in cold traps WN 188 or nitrogen at the cold trap temperature. The other rare gas components will not have appreciable vapor pressures at this temperature. The calculation method is a trial and error procedure over small increments of temperature for which data are available. Bed compositions are assumed for the higher temperatures, a material balance then gives the mole fractions of the components in the desorbed gases and the H. C. mole fractions are compared with the partial pressures of the components left in the bed. This procedure would be exact if very small increments of temperature were used, but data are not available for the calculation.

Figure (10) gives the results of the desorption calculation and Figure (11) gives the total quantity of desorbed gas vs. time curve. The calculations show that for a final temperature of 100°C and 178 mm Hg. total pressure, only a negligible percent of the nitrogen, less than 2.2% of the Krypton, a negligible percent of the CO, 5.2% of the Xenon and 0.1% of the N₂O will remain. The concentration of the Xenon and N₂O remaining should not affect the subsequent operation of the bed.

John M. Holmes
FOSTER WHEELER CORPORATION

amh
FIGURE 10.
PERCENT OF COMPONENT ADSORBED VS TEMPERATURE

TEMPERATURE °C

PERCENT OF COMPONENT ADSORBED

N₂  KR  XE  N₂O
### Calculation of the Desorption Chart

#### Temperature vs. Partial Pressure

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Partial Pressure (mm Hg)</th>
<th>Final Partial Pressure (mm Hg)</th>
<th>Moles of Desorbed Empirical</th>
<th>Partial Pressure (mm Hg)</th>
<th>Moles of Desorbed Empirical</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.0198</td>
<td>0.6099</td>
<td>Neg.</td>
<td>0.0252</td>
<td>Neg.</td>
</tr>
<tr>
<td>5</td>
<td>0.0211</td>
<td>0.6250</td>
<td>2.1</td>
<td>0.0211</td>
<td>2.1</td>
</tr>
<tr>
<td>10</td>
<td>0.0234</td>
<td>0.6400</td>
<td>4.2</td>
<td>0.0234</td>
<td>4.2</td>
</tr>
<tr>
<td>15</td>
<td>0.0257</td>
<td>0.6550</td>
<td>6.2</td>
<td>0.0257</td>
<td>6.2</td>
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#### Assumed Composition

- N₂ + A = Xe
- N₂ + A = Kr
- N₂ + A = Ne

#### Average Moles of Desorbed

- N₂ = 80
- A = 43
- Ne = 52

#### Calculated Moles of Desorbed

- N₂ = 70
- A = 90
- Ne = 90
## Calculation of the Desorption Vs. Temperature Chart (Cont'd)

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<th>pp T</th>
<th>Assumed Final pp cc/gm</th>
<th># moles desorbed</th>
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BIBLIOGRAPHY

4. C.R.C., Rare Gas Extraction. National Research of Canada, 297.