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Continuous Flow Thermal Desorption of VOC's From Activated Carbon

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A countercurrent thermal VOC desorber apparatus with 0.43 to 0.67 lb/hr (0.195 to 0.304 kg/hr) activated carbon flow and 0.43 to 0.49 scfm (0.88 to 1.00 kg/hr) purge air flow provided 26.6 to 77.7% VOC desorption efficiency over the 62 to 199°F (16 to 92°C) operating range. The VOC concentration of the carbon was measured at the carbon inlet, outlet, and two intermediate points in the desorber by thermogravimetric analysis. Inlet adsorbent carbon VOC concentrations ranged from 0.23 to 0.44 grams VOC/gram carbon. The VOC concentration of the purge air was measured at the purge air outlet and two points within the desorber by GC-FID. The VOC concentration of the outlet purge air ranged from 14,627 to 44,209 ppm (0.023 to 0.070 grams VOC/gram air). The VOC concentrations measured in the activated carbon and in the purge air provided the oprating line data for plotting on an X-Y diagram and together with the equilibrium isotherms resulted in mass transfer coefficients $K_g a$ *in the 472 to 864 lb/ft^3 hr (7,561 to 13,840 kg/m^3 hr) range.*

INTRODUCTION

Research Objectives

The primary objective of this research was to relate the VOC desorption efficiency to the design and operating parameters of a continuous flow countercurrent VOC thermal desorber. A secondary objective was to measure the thermal desorption mass transfer coefficients.

Research Significance

Activated carbon is commonly used to remove VOCs from air or water. The VOC laden spent activated carbon is either replaced with fresh adsorbent or regenerated on site. A continuous flow countercurrent desorber could be used to regenerate the spent activated carbon which is produced by a number of environmental treatment processes (fixed bed, fluidized bed, moving bed, etc.). Also, a continuous flow desorber could be an integral component in a continuous flow moving bed VOC adsorption system. A continuous flow moving bed VOC adsorption system for control of low VOC concentration (10–100 ppm) high air volumetric flow rate VOC air pollution sources (such as commercial aircraft painting) was described by Larsen and Pilat [1]. In this system, the dilute VOCs are adsorbed from the high volumetric flow rate air emission stream by a cross-flow moving adsorbent bed. The VOC laden adsorbent then exits the adsorber section and flows into the desorber section where it is heated and the VOCs are removed by a countercurrent low volumetric flow rate purge gas stream. The regenerated carbon is then cooled and returned to the top of the adsorption section for reuse. The system concentrates the VOCs into the low volume purge gas stream from which they can be recovered or eliminated.

Research Approach

A countercurrent thermal VOC desorber research apparatus was designed and constructed with a nominal carbon throughput capacity of 0.1 to 1 lb/hr (0.045 to 0.45 kg/hr). The apparatus was used to measure the desorption of ethanol from granular activated carbon under conditions of variable heat input. The measurements were made of the activated carbon ethanol concentration, the purge air ethanol concentration, the temperature within the apparatus, and the activated carbon and purge air mass flow rates. These results were used to

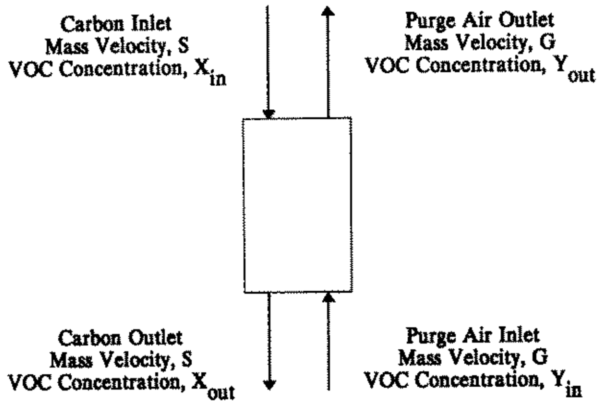

FIGURE 1. Desorber flow configuration.

construct operating lines, to calculate desorption efficiencies, and to calculate mass transfer coefficients.

LITERATURE REVIEW

Fixed Bed Desorption

A variety of approaches have been used to predict the desorption behavior of fixed beds of activated carbon. A non-isothermal, adiabatic equilibrium model was used by Basmadjian et al. [*2*]. Friday and LeVan [*3*] used a nonadiabatic model similar to Basmadjian. While these equilibrium models (which assume no heat or mass transfer resistance) are useful for predicting the breakthrough time of a fixed bed undergoing desorption, they are not able to accurately predict the shape of the mass transfer zone. Nonequilibrium models used by Zwiebel et al. [*4*] and Schork and Fair [*5*] predicted the shape of the mass transfer zone in reasonably good agreement with experimental results. The nonequilibrium models used by these authors correlated the mass transfer rate to the concentration gradient by defining a mass transfer coefficient.

Continuous Adsorption and Desorption

A continuous flow desorber was reported by Sakaguchi [*6*] as a part of an adsorption-desorption system for air pollution control using a special beaded activated carbon. The desorber section was a continuous flow VOC thermal desorber operating under fluidized bed conditions. Treybal [*7*] described a steady state countercurrent moving bed adsorber and developed mass transfer equations for isothermal conditions. Larsen and Pilat [*8, 9*] reported that low concentration (10–200 ppm) airborne VOCs were collected with a 10 to 100 cfm (17 to 170 m^3/hr) cross-flow activated carbon moving bed test apparatus. The collected VOCs were removed in a countercurrent thermal desorption section.

Mass Transfer Coefficients

Few measured values for mass transfer coefficients in carbon adsorption-desorption systems have been reported. Schork's Ph.D dissertation [*10*] research with a 3 inch (7.62 cm) diameter fixed bed of activated carbon 12 inch (30.48 cm) in length presented propane desorption mass transfer coefficients, fitted to experimental data, of 909 lb/ft^3 hr (14,561 kg/m^3 hr) for $K_g a$ and 675.4 lb/ft^3 hr (10,819 kg/m^3 hr) for $K_s a$. Larsen and Pilat [*1*] reported gas phase coefficients $K_g a$ between 530 and 2,600 lb/ft^3 hr (8,490 and 41,648 kg/m^3 hr) for adsorption of ethanol in a cross-flow moving bed adsorption test apparatus.

THEORY AND EQUATIONS

Mass Balance

Adsorbent media (containing a VOC concentration X_{in}) enters the desorber section from the top and moves downward with a mass velocity S, as shown in Figure 1. Purge air (with a VOC loading Y_{in}) enters the desorber from the bottom and moves upward with a mass velocity G. The mass balance of the VOC in the thermal desorber is given by:

$$\begin{array}{c}\text{Increase in gaseous} \\ \text{VOC in the purge gas}\end{array} = \begin{array}{c}\text{Decrease in adsorbed} \\ \text{VOC in the absorbent}\end{array} \tag{1}$$

$$G(Y_{out} - Y_{in}) = S(X_{in} - X_{out}) \tag{2}$$

Desorber Overall Efficiency

The desorber overall efficiency for removal of VOCs from the activated carbon is defined as:

$$\begin{array}{c}\text{Desorber} \\ \text{Efficiency}\end{array} = \left[\frac{\begin{array}{c}\text{VOC adsorbed} \\ \text{on inlet carbon}\end{array} - \begin{array}{c}\text{VOC adsorbed} \\ \text{on outlet carbon}\end{array}}{\text{VOC adsorbed on inlet carbon}}\right] \tag{3}$$

$$\begin{array}{c}\text{Desorber} \\ \text{Efficiency}\end{array} = \left[\frac{X_{in} - X_{out}}{X_{in}}\right] \tag{4}$$

Assuming that all of the VOC desorbed from the carbon is transferred into the gaseous stream, equation 2 can be used to substitute for $(X_{in} - X_{out})$ in equation 4 to give:

$$\begin{array}{c}\text{Desorber} \\ \text{Efficiency}\end{array} = \frac{G(Y_{out} - Y_{in})}{S \quad X_{in}} \tag{5}$$

Assuming that the purge air entering the desorber is free of VOCs (i.e. $Y_{in} = 0$), the equation for the desorber efficiency reduces to:

$$\begin{array}{c}\text{Desorber} \\ \text{Efficiency}\end{array} = \frac{G Y_{out}}{S X_{in}} \tag{6}$$

Mass Transfer

The rate at which VOCs adsorbed on the activated carbon are transferred to the gas phase is a function of the gas phase concentration gradient $(Y^* - Y)$ and the gas phase overall mass transfer coefficient $K_g a$ or the solid phase concentration gradient $(X - X^*)$ and the solid phase overall mass transfer coefficient $K_s a$. The term X^* is the VOC adsorbed concentration on the carbon in equilibrium with the actual VOC gas phase concentration Y and the term Y^* is the VOC gaseous concentration in equilibrium with the actual VOC adsorbed phase concentration X. The a is the outer surface area of the adsorbent particles. The change in the gaseous phase VOC mass flow with distance in the desorber is given by:

$$G dY = K_g a (Y^* - Y) dZ \tag{7}$$

and correspondingly the change in adsorbed phase VOC mass flow is given by:

$$S dX = K_s a (X - X^*) dZ \tag{8}$$

Rearranging equations (7) and (8) gives:

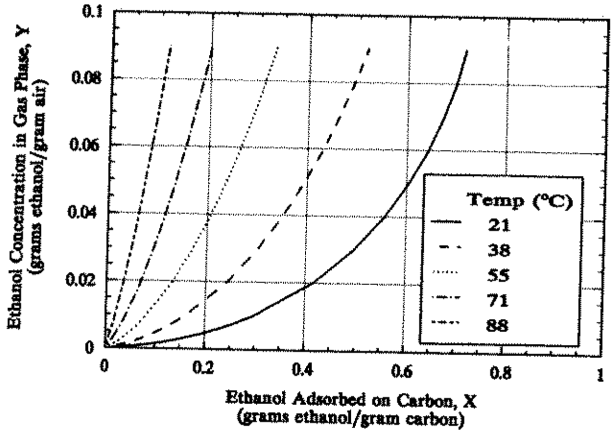

FIGURE 2. Equilibrium adsorption isotherms of Westvaco WV-B850 activated carbon.

$$G\frac{dY}{Y^{*}-Y}=K_{g}a\,dZ \tag{9}$$

$$S\frac{dX}{X-X^{*}}=K_{s}a\,dZ \tag{10}$$

Integrating equations 9 and 10 over the height of the desorber gives:

$$K_{g}a=\frac{G}{Z}\int_{Y_{in}}^{Y_{out}}\frac{dY}{(Y^{*}-Y)} \tag{11}$$

$$K_{s}a=\frac{S}{Z}\int_{X_{out}}^{X_{in}}\frac{dX}{(X-X^{*})} \tag{12}$$

Equations (11) and (12) can be used to obtain the mass transfer coefficients from the adsorption equilibrium isotherms, the VOC concentrations of the inlet and outlet adsorbent and purge gas, the desorber height, and the adsorbent and purge gas flow rates.

Equilibrium Adsorption Isotherms

The carbon equilibrium VOC adsorption capacity X^{*} was related to the gas phase VOC concentration Y and temperature by the Dubinin-Astakhov [*11*] equation. Equilibrium adsorption data for ethanol concentrations up to 10,000 ppm was supplied by the activated carbon manufacturer, Westvaco. Four additional data points in the 30,000 to 50,000 ppm range were measured using a gravimetric method. The equilibrium data was fitted to the Dubinin-Astakhov equation to allow prediction of the adsorption equilibrium at other temperatures and concentrations. The Dubinin-Astakhov equation relates the volume of VOC adsorbed per unit mass of adsorbent to the vapor pressure of the VOC in the gas phase.

$$W=W_{o}\exp-k\epsilon^{n} \tag{13}$$

Where the adsorption potential ϵ is defined as:

$$\epsilon=\mathrm{RT}\ln\left(\frac{P_{o}}{P}\right) \tag{14}$$

The value of the saturation vapor pressure P_{o} was calculated using the Antoine equation [12]:

$$\log_{10}(P_{o})=8.321-\frac{1718.10}{T\,(^{\circ}\mathrm{C})+237.52} \tag{15}$$

Substituting equation 14 into equation 13 gives:

$$W=W_{o}\exp-k\left[\mathrm{RT}\ln\left(\frac{P_{o}}{P}\right)\right]^{n} \tag{16}$$

Taking the $\log_{e}$ of both sides gives:

$$\ln W=\ln W_{o}-k\left[\mathrm{RT}\ln\left(\frac{P_{o}}{P}\right)\right]^{n} \tag{17}$$

The term W is defined as:

$$W\,(\mathrm{cm^{3}\ VOC/gram\ adsorbent})=\frac{X^{*}\ (\mathrm{gram\ VOC/gram\ adsorbent})}{\rho\ (\mathrm{gram\ VOC/cm^{3}\ volume\ of\ VOC})} \tag{18}$$

The VOC equilibrium partial pressure P is related to the total pressure P_{t} by:

$$P=\left(\frac{MW_{air}}{MW_{voc}}\right)Y\,P_{t} \tag{19}$$

Substituting equations (18) and (19) into equation (17) gives:

$$\ln\frac{X^{*}}{\rho}=\ln W_{o}-k\left[\mathrm{RT}\ln\left(\frac{P_{o}MW_{voc}}{YP_{t}MW_{air}}\right)\right]^{n} \tag{20}$$

The ethanol equilibrium adsorption data was fitted to equation (20) and the parameters giving the best fit were:

$k=7.75\times10^{-5}(\mathrm{cal/mole})^{-n}$
$W_{o}=0.918 \quad (\mathrm{cm^{3}/gram\ carbon})$
$n=1.3$

A plot of the calculated equilibrium adsorption isotherms at 21, 38, 55, 71, and 88°C obtained with equation 16 and the above parameters is presented in Figure 2.

EXPERIMENTAL APPARATUS

Desorber Apparatus

Tests were conducted using a thermal desorber apparatus shown schematically in Figure 3. VOC loaded adsorbent was contained in a closed cylindrical reservoir of 0.49 ft³ (0.0139 m³) volume at the top of the apparatus. From the reservoir the adsorbent flowed downward through the 2 inch (5.08 cm) diameter tubular test section. The adsorbent flow rate was regulated by rotary airlock feeder valves at the top and bottom of the test section. The airlock feeders (which prevented uncontrolled escape of the purge air as well as controlling the adsorbent flow rate) were constructed by coupling diverter ball valves to variable speed DC gearmotors. The airlock feeders had a capacity of approximately 0.00028 ft³ (7.9 cm³) per revolution and were driven at approximately 2 revolutions per

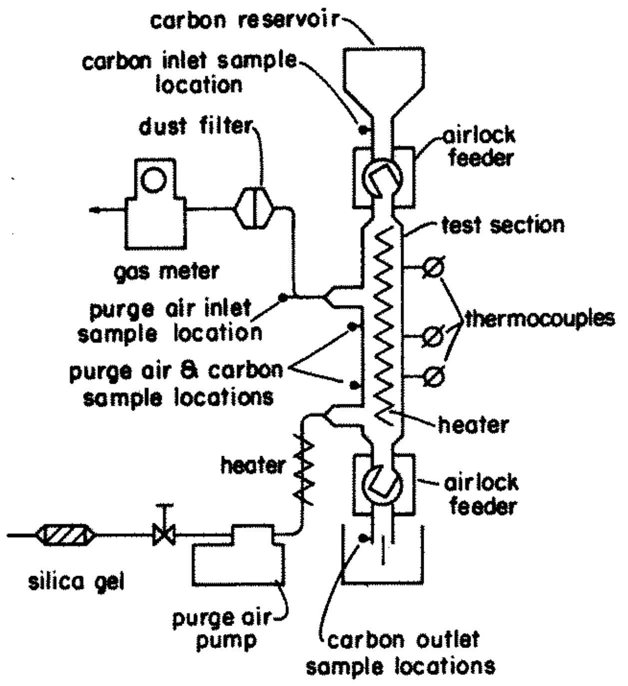

FIGURE 3. Thermal desorber test apparatus schematic.

minute which corresponds to a volumetric flowrate of 0.00056 ft^3/min. (15.8 cm^3/min.).

Test Section

The cylindrical test section of the thermal desorber was constructed from 2 inch schedule 40 steel pipe and fittings having an inside diameter of 2.067 inch (5.25 cm) and a wall thickness of 0.154 inch (0.391 cm). The test section was 36 inches (91.4 cm) in height measured from center to center of the airlock feeders. The pieces of the test section were connected using two piece grooved couplings with silicone gaskets. This type of fitting provides flush connections on the inside of the pipe to allow the adsorbent to move freely. The purge air connections were 2 inch × 2 inch × 2 inch tee fittings with the inlet near near the bottom and the outlet near the midpoint of the test section. The distance between the center of the purge air inlet and outlet fittings was 18 inches (45.7 cm) as shown in Figure 4. A cylindrical section of 30 mesh stainless steel screening with 0.033 inch (0.083 cm) openings was fitted inside the inlet and outlet purge air fittings to separate the air and carbon streams. The carbon was preheated without purge in the upper 18 inches (45.7 cm) of the test section. The cylindrical test section of the desorber was heated by a 1 inch (2.54 cm) wide by 72 inch (183 cm) long electrical resistance heating tape with a rated capacity of 627 watts and insulated with four inches (10.2 cm) of fiberglass insulation. Supply voltage to the heating tape was regulated by a 15 amp variable transformer.

Purge Air Supply

Dry heated purge air at a flow rate of about 0.47 ft^3/min. (13.3 liter/min.) was applied to the apparatus by a diaphragm pump. The air was dried before entering the desorber by passing through two 3 inch (7.62 cm) diameter glass impingers filled 10 inches (25.4 cm) deep with silica gel. The air was heated by passage thorough a 0.5 inch (1.27 cm) outside diameter 48 inch (122 cm) long copper tube which was heated by a 1 inch (2.54 cm) wide by 72 inch (183 cm) long 627 watt electrical resistance heating tape wrapped around the outside. Supply voltage to the heating tape was regulated by a 15 amp variable transformer. The heater air entered the test section through the lower purge air connection, flowed upward through the desorber and exited through the upper purge air connection. After exiting the test section the, purge air flowed through a dust filter and into a Rockwell model 175-S dry gas meter.

Purge Air and Adsorbent Sampling Locations

Samples of the purge air and adsorbent were taken from several points within the apparatus. The purge air was sampled at three points and analyzed immediately by GC-FID. Two of the purge air sample ports were located 3 inches (7.62 cm) above and below the midpoint of the test section as shown in Figure 4. The 0.25 inch (0.635 cm) outside diameter sample tubes were inserted through these purge air sampling ports so as to extend 0.5 inch (1.27 cm) into the carbon stream. A third fitting was located in the purge air exit pipe and allowed sampling of the purge air at the outlet of the test section (as shown in Figure 3). The inlet purge air was assumed to have a negligible VOC content. Each purge air sample fitting was connected to a midget impinger to prevent carbon dust from entering the purge air analysis instrumentation.

Adsorbent samples (5 mL) were taken at four locations and stored in 5 mL glass vials until TGA analysis. Two of the adsorbent sample ports were located 3 inches (7.62 cm) above and below the midpoint of the test section (as shown in Figure 4). Adsorbent samples were removed at these points by inserting an open ended piece of 0.375 inch (0.953 cm) outside

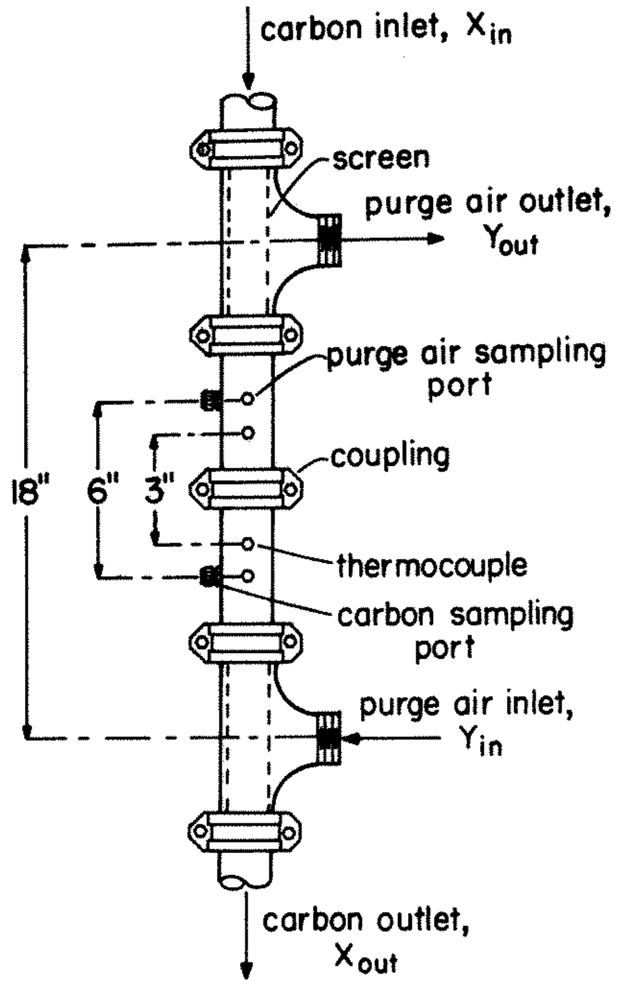

FIGURE 4. Details of desorber test section.

diameter copper tubing and withdrawing the tubing with the sample inside. Inlet adsorbent samples were collected (at room temperature) from the prepared adsorbent as it was being loaded into the reservoir. Outlet adsorbent samples were collected from the adsorbent exit stream by placing the container below the lower airlock feeder exit pipe (see Figure 3).

Temperature Sensors

The carbon temperature within the desorber was measured by two 1/8 inch (0.318 cm) diameter sheathed type J thermocouples that were inserted into the desorption section. The thermocouples were located 1.5 inches (3.81 cm) above and below the midpoint of the desorption section (as shown in Figure 4) and their tips were inserted to the centerline of the 2.067 inch (5.25 cm) inside diameter test section. Temperatures were measured by connecting a digital temperature indicator to the thermocouples.

Fixed Bed VOC Adsorber Apparatus

The VOC was loaded onto the adsorbent in a fixed bed adsorption system. The adsorbent was contained during loading in a vertical PVC cylinder 6 inches (15.24 cm) in diameter and 48 inches (122 cm) tall. The carbon was supported by a fixed stainless steel 30 mesh screen with 0.033 inch (0.083 cm) openings at the bottom of the cylinder. A VOC and air mixture was drawn downward through the adsorbent at a flow rate of 1 cfm (28.3 liter/min.) by a diaphragm pump. The air was first dried by passing it through a 3 inch (7.62 cm) diameter impinger filled 10 inches (25.4 cm) deep with silica gel and then the VOC was added by bubbling about 0.25 cfm (7.08 liter/min.) of the air through an impinger containing the liquid VOC at room temperature.

Analytical Instrumentation

The ethanol concentration in the purge air was measured with a SRI model 8610 gas chromatograph with a flame ionization detector (FID). Because a single VOC was involved in this research, no separation of other VOC peaks was required. To allow more frequent gas sampling, the instrument was modified to function as a total hydrocarbon analyzer by replacing the capillary chromatographic column with an 18 inch (45.7 cm) length of uncoated fused silica tubing. Sampling of the purge air was accomplished by installing tubing between a sample port on the test section with a tee fitting at the GC inlet. Purge air from the positive pressure test section flowed through a tubing and exited through a rotometer connected to the third leg of the tee fitting at a rate of 0.01 cfm (283 cm^3/min.). The SRI GC internal vacuum pump periodically transported a gas sample of approximately 0.02 cubic inch (0.33 cm^3) from the stream flowing through the tee fitting into an internal sample loop. An internal switching valve then directed the nitrogen carrier gas through the sample loop carrying the sample to the detector. The detector response was recorded on an IBM compatible personal computer (286), operating with SRI Peaksimple II software, through an SRI analog to a digital interface board. The software integrated the detector response (0.0 to 100 millivolt) and controlled the timing of the sampling valve and sampling vacuum pump. The integrated detector response was calibrated to known concentration ethanol-air mixtures prepared in 0.71 ft^3 (20 liter) glass vessels.

The ethanol concentration in the carbon samples was measured by thermally desorbing the ethanol with a Perkin Elmer model TGA 7 thermogravimetric analyzer. A 20–40 mg portion of each carbon sample was loaded into a platinum pan 0.32 inch (0.81 cm) in diameter and 0.16 inch (0.41 cm) deep. The sample was heated in a nitrogen atmosphere at a rate of 18°F (10°C) per minute to 392°F (200°C) and maintained there for 15 minutes. The carbon sample weight M was continuously recorded during the heating cycle (to an accuracy of 0.01 mg) by the dedicated computer of the Perkin Elmer model TGA 7. The amount of VOC adsorbed on the carbon, X (lb ethanol/lb carbon), was obtained using equation 21 and the initial and final sample weights.

$$X = \left[\frac{M_{\text{initial}} - M_{\text{final}}}{M_{\text{final}}}\right] \tag{21}$$

EXPERIMENTAL PROCEDURE

Materials

The tests were conducted using ethanol as the VOC and activated carbon as the adsorbent. Ethanol was used as the VOC because of it's low toxicity and lack of objectionable odor. The ethanol used was reagent grade 200 proof from Midwest Grain Products. Activated carbon was selected as the adsorbent because it is widely used for VOC adsorption. Westvaco nuchar WV-B850 10 × 25 mesh granular activated carbon, lot #11561, was used for the tests. It is a wood based product and the particles are irregular in shape with their largest dimension ranging from approximately 0.04 inch (0.102 cm) to 0.1 inch (0.254 cm). It has a bulk density of 16 lb/ft^3 (256 kg/m^3) and an ash content of less than 5%.

VOC Loading

Prior to the VOC loading, the carbon was stored in the sealed shipping containers. Sufficient carbon for one desorber test, approximately 0.3 ft^3 (8.4 liters), was baked overnight in 2 inch (5.08 cm) deep pans at 300°F (149°C) to remove volatiles and then allowed to cool in a closed container. This procedure was used because the TGA analysis of the carbon as received showed 4 to 6% volatiles by weight. After this treatment the TGA analysis showed less than 1% weight change in the carbon. The carbon was loaded with between 0.23 and 0.44 grams of ethanol/gram of carbon in the fixed bed adsorber apparatus by passing ethanol laden air through it. The ethanol concentrations in the air stream at the inlet and outlet of the fixed carbon bed were measured using an SRI model 8610 gas chromatograph equipped with a flame ionization detector. When the air outlet concentration was within 10% of the inlet concentration the carbon was assumed to be saturated and the loading process was ended. The carbon was then removed from the adsorber apparatus, placed in an airtight container, and mixed by manually agitating the container for five minutes.

VOC Desorption

The desorption measurement test was started with an apparatus preheat period of 4 to 6 hours. The experimental test procedure included recording the desorber temperature, heater input voltage, and dry gas meter reading every 15 minutes. The sample tubing leading to the gas chromatograph was manually moved sequentially between the two purge air sampling ports in the desorption section and the purge air outlet sampling port. Three to five samples on three minutes intervals were taken at each port. Therefore, the gas was sampled from each of the 3 sampling locations every 27 to 45 minutes. Every hour a sample of activated carbon was taken from the two adsorbent sampling ports and the accumulated carbon from the desorber outlet was weighed.

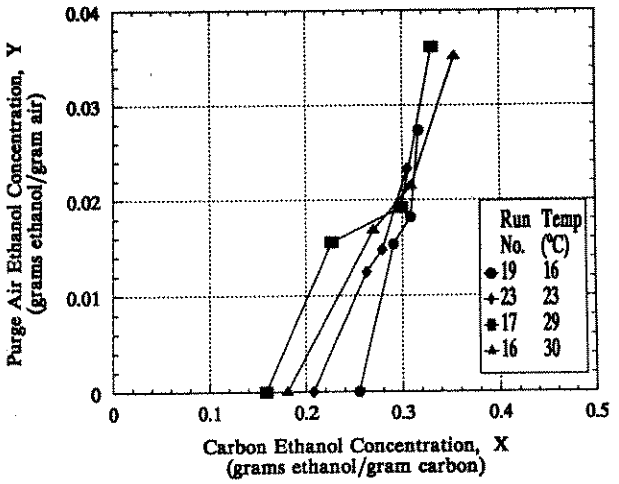

FIGURE 5. Desorber operating lines for 16 to 30°C tests.

RESULTS

VOC Concentrations in Air and Carbon

The ethanol concentration data from the purge air and carbon measurements was used to construct operating lines for each test run. The operating lines are shown in Figures 5 and 6. The end points of each line represent the measurements at the inlet and outlet of the apparatus. The intermediate points represent the measurements at the two gas and adsorbent sampling locations, about 6 inches (15.24 cm) apart, within the test section. Figure 5 presents data obtained at the 16 to 30°C temperature range and Figure 6 for the 38 to 93°C temperature range.

Comparison of VOC Air and Carbon Mass Flow Rates

The rate of ethanol loss from the carbon is in relatively good agreement with the rate of ethanol gain in the purge air, as shown in Figure 7. The rate of ethanol loss from the carbon was obtained from the carbon mass flow rate and the difference between the inlet and outlet VOC concentration of the carbon. The rate of ethanol gain in the purge air was obtained from the air mass flow rate and the ethanol concentration in the purge air exit.

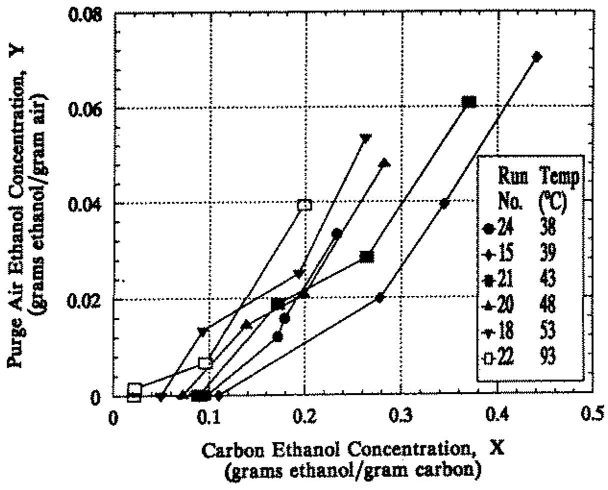

FIGURE 6. Desorber operating lines for 38 to 93°C tests.

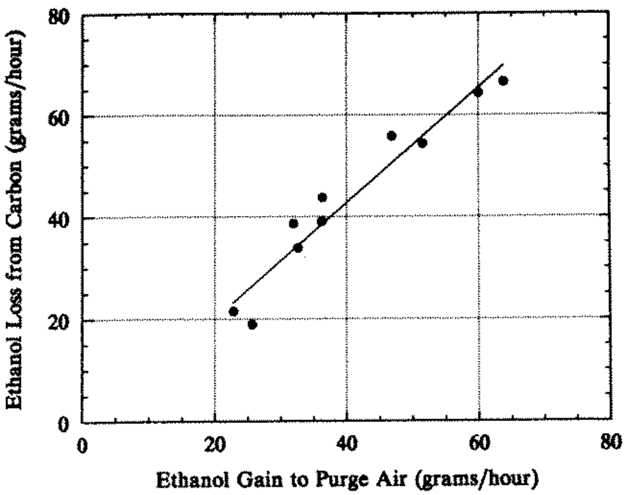

FIGURE 7. Comparison of carbon ethanol loss with purge air ethanol gain.

Desorber Overall Efficiency

The desorption efficiency was calculated for each test run using equation (3). The values for S, G, Y, and X used in the equation were averages of the measurements taken during the test run (the test run duration was typically 1-3 hours). The desorber efficiency ranged from 26.6 to 77.7% and increased with desorber temperature as is shown in Figure 8. This desorber temperature was the average temperature measured by the two thermocouples in the test section and averaged over the test duration (4-12 temperature readings were recorded per run). The desorber efficiency appears to be linearly related to the desorber heater input voltage, as is shown in Figure 9.

Mass Transfer Coefficients

For desorption of ethanol from a countercurrent moving bed, the overall gas phase mass transfer coefficient K_ga and the overall solid phase mass transfer coefficient K_sa were calculated using the equations (11) and (12). The equations were applied to the 6 inch (15.24 cm) segment of the test section between the two gas and adsorbent sampling locations. The integral terms in the equations were evaluated assuming straight equilibrium and operating lines (i.e. constant temperature of both the gas and solid streams and no heat effects). K_ga ranged

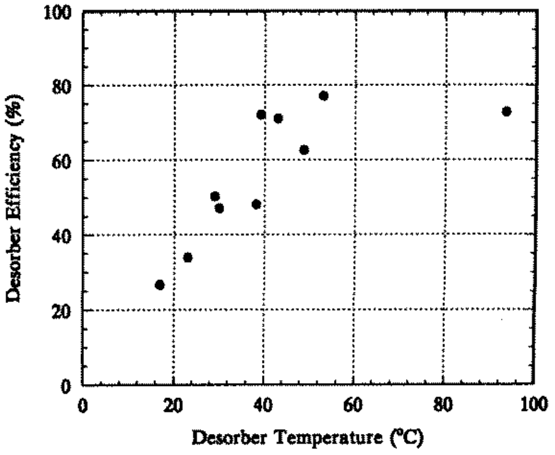

FIGURE 8. Desorber efficiency as a function of temperature.

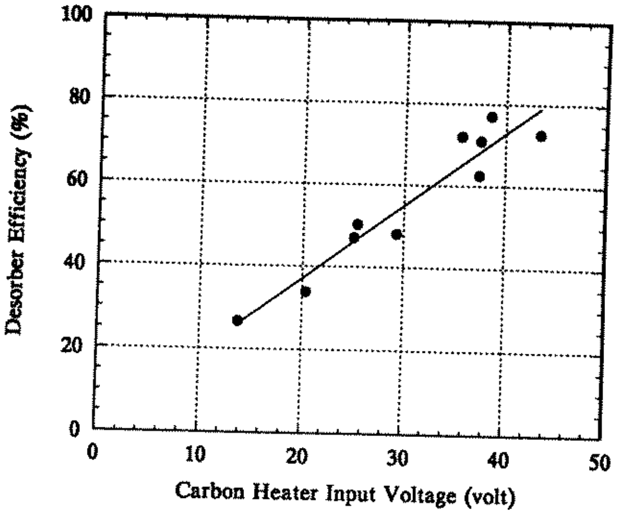

FIGURE 9. Desorber efficiency as a function of desorber heater input voltage.

from 472 to 864 lb/ft³ hr (7,561 to 13,840 kg/m³ hr) and K_sa ranged from 121 to 244 lb/ft³ hr (1,938 to 3,909 kg/m³ hr). The values for K_ga and K_sa were undefined for some of the tests because the equilibrium line, calculated using the fitted Dubinin-Astakhov equation, was on the wrong side of the operating line. This displacement of the equilibrium isotherm is believed to have been caused by problems with the measurement of the adsorbent temperature. Because heat was supplied from the walls of the test section it would be expected that the temperature would vary as a function of radial position. The tip of the thermocouple, located at the centerline of the test section, would therefore indicate a temperature lower than the average temperature. This offset in the desorber temperature could displace the calculated adsorption equilibrium isotherm away from the Y axis, potentially to the wrong side of the desorber operating line.

CONCLUSION

A continuous countercurrent air-solid adsorbent thermal desorber was tested for the removal of VOCs from a continuous flowing stream of activated carbon. Efficiencies of approximately 80% were achieved with a temperature of 53°C, a purge air flow of 91.41 lb/ft² hr or 22.5 ft/min. (446.3 kg/m² hr or 6.86 m/min), and a carbon flow of 24.13 lb/ft² hr or 0.025 ft/min. (117.8 kg/m² hr or 0.00762 m/min.) The desorption efficiency increased with increasing desorber temperature. Mass transfer coefficients ranged from 472 to 864 lb/ft³ hr (7,561 to 13,840 kg/m³ hr) for the gas phase (K_ga) and 121 to 244 lb/ft³ hr (1,938 to 3,909 kg/m³ hr) for the solid phase (K_sa). The use of a countercurrent thermal desorber apparatus to obtain mass transfer coefficients was demonstrated.

ACKNOWLEDGMENTS

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NOTATION

a = adsorbent surface area/unit volume, ft²/ft³ (m²/m³)
ϵ = adsorption potential, cal/mole
G = purge gas mass flow rate, $\text{lb}_{\text{purge gas}}/\text{ft}^2\text{hr}$
k = constant in Dubinin-Astakhov equation, $(\text{cal/mole})^{-n}$
K_g = gas phase mass transfer coefficient, $\text{lb}_{\text{VOC}}/\text{ft}^2\text{hr}$
K_ga = overall gas phase mass transfer coefficient, lb/ft³ hr
K_s = solid phase mass transfer coefficient, $\text{lb}_{\text{VOC}}/\text{ft}^2\text{hr}$
K_sa = overall solid phase mass transfer coefficient, lb/ft³ hr
M = weight of carbon sample, milligrams
MW = molecular weight, moles/gram
n = exponent in Dubinin-Astakhov equation
ρ = VOC liquid density, gram/cm³
P = equilibrium vapor pressure of VOC, mm Hg
P_o = saturation vapor pressure of VOC, mm Hg
P_t = total pressure, mm Hg
R = gas constant, cal/mole °K
S = adsorbent mass flow rate, $\text{lb}_{\text{adsorbent}}/\text{ft}^2\text{hr}$
T = absolute temperature, °K
X^* = equilibrium adsorption capacity, $\text{lb}_{\text{VOC}}/\text{lb}_{\text{adsorbent}}$
X = VOC adsorbed concentration, $\text{lb}_{\text{VOC}}/\text{lb}_{\text{adsorbent}}$
Y^* = gas phase equilibrium concentration, $\text{lb}_{\text{VOC}}/\text{lb}_{\text{purge gas}}$
Y = VOC gaseous concentration, $\text{lb}_{\text{VOC}}/\text{lb}_{\text{purge gas}}$
Z = height of desorption section, ft (m)
W = VOC volume/unit mass of adsorbent, cm³ VOC/gram adsorbent
W_o = adsorption volume/adsorbent mass, cm³/gram adsorbent

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