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Moving Bed Adsorption System for Control of VOCs from an Aircraft Painting Facility

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An activated carbon moving bed system (10 to 100 acfm air flow) was tested for controlling VOC emissions from a commercial aircraft painting facility. The cross-flow moving adsorbent bed showed a VOC collection efficiency in the 77.1 to 99.6 percent range over a superficial gas velocity range of 27 to 185 ft/min (0.14–0.94 m/sec). The collection efficiencies were neither affected by a change in carbon flow rates from 5 to 8 lb/hr (2.3 to 3.6 kg/hr) nor by a change in the gas superficial velocity from 27 to 185 ft/min. The VOC concentration in the emission stream from the painting hangar was found to vary by at least a factor of 20 (from 0.18 to 15 ppm) both over the five month period (during which the 15 system tests of about three hours each were conducted) and within a single eight hour work shift.

The initial results of the EPA's 1988 Toxic Release Inventory reported that 4.57 billion pounds of toxic chemicals were released into the air, water, and land nationally. Of this, 53 percent (2.43 billion lbs) were emitted into the air.[1] Aircraft painting processes are point sources of air emissions which could be reduced using add-on exhaust gas control technologies. The aircraft painting hangar used as a test site in this study emits approximately 51 tons of VOCs per year (based on 1988 emissions estimates). This source represents about 7 percent of the total VOC emissions (on a mass basis) into the air from the plant where the hangar is located and is the second largest single VOC airborne emission source at the plant.

Control of VOC air pollutants at high concentrations (i.e., greater than 1000 ppm) encountered in continuous processes such as metal coil coating lines is readily accomplished with existing control technologies. At lower concentrations, such as the 1 to 20 ppm range measured at the aircraft painting hangar described in this study, the cost of installing existing control technologies discourages the use of existing, commercially available equipment to control VOC emissions. As the concentration of the emissions stream decreases and the volumetric flow rate of the emission source increases, the associated control cost increases.

Implications

A cross-flow moving activated carbon "thin" bed with low (0.5 to 3.0 inches water) pressure drop may have application for the control of volatile organic compounds, especially for the lower concentrations (1 to 1000 ppm). Such innovative new control technologies are needed for the reduction of VOC emissions, as required to meet the new air toxic regulations and the long-established ozone ambient air quality standards.

Research Objectives

The objective of this research project was to test a moving bed adsorption system at an operating VOC emissions source. In this research, a cross-flow moving adsorbent bed was constructed and tested. Development of a moving adsorbent bed VOC control system could help lead to reduced size VOC control systems. Reduction of the size of VOC control systems could be accomplished by developing a system which would allow superficial gas velocities higher than the 60 to 100 ft/min velocities present in current commercially available fixed bed adsorption systems. Reduction of the size of control devices may result in less costly control systems as the cost of an emission control device is in large part determined by the materials required to construct the system. The research approach was to:

1. Design and construct a cross-flow moving bed carbon adsorption system for controlling VOC emissions.
2. Incorporate a flow-through thermal desorption device in the system to continuously recover the adsorbed VOCs and allow for continuous recycling of the activated carbon adsorbent.
3. Evaluate the performance of the cross-flow moving adsorbent bed by installing and testing the system on a portion of the emission stream from an operating VOC source.

The design, construction, initial assembly, and testing of the adsorption apparatus was conducted at the University of Washington Department of Civil Engineering. The results of those tests have been previously reported.[2] This adsorption test apparatus was moved to an aircraft painting hangar in Renton, Washington for the system testing described in this paper.

Adsorption of VOCs on Activated Carbon

The adsorption of VOCs on activated carbon is dependent upon two factors. The first is the equilibrium relationship between the particular VOC, or mixture of VOCs, and the activated carbon adsorbent. The second is the rate of transfer of the VOC from the gas stream to the adsorption sites within the activated carbon. The equilibrium relationship between the gas and the carbon is a function of the VOC concentration, temperature, and total pressure. At a

Notation

a,b = equilibrium isotherm constants
G = gas flow rate, lb/ft^2 hr
K_yA = overall mass transfer coefficient, lb/ft^3 hr
S = adsorbent flow rate, lb/ft^2 hr
X = adsorbed phase concentration, lb voc/lb carbon
Y = gas phase concentration, lb voc/lb gas
Y* = equilibrium gas phase concentration, lb voc/lb gas
Z = distance in direction of gas flow, ft

given temperature, this equilibrium relationship can be described mathematically by an equation fitted to observed measurements. Examples of such relationships are the Freundlich isotherm:

$$Y^* = a X^b \tag{1}$$

and the Langmuir isotherm:

$$Y^* = \frac{aX}{(1 + bX)} \tag{2}$$

where X is the concentration of VOCs adsorbed on the carbon, Y* is the equilibrium gas phase concentration corresponding to the adsorbed phase concentration X, and a and b are empirical constants relating the two. Once the maximum adsorption capacity of the carbon has been reached, the carbon must be "regenerated" before additional adsorption can occur. Regeneration can be accomplished by raising the temperature of the carbon so that the equilibrium between the adsorbed and gas phases is changed, thus causing the adsorbed VOCs to be removed from the carbon.

The rate at which gas phase VOC molecules are transported from the bulk gas phase to the adsorption sites within the carbon is the mass transfer rate of VOCs from the gas phase to the adsorbed phase. The mass transfer rate is dependent on the resistances to mass transfer from the gas to the adsorbent particle, from the adsorbent particle surface to the adsorption sites within the particle, and adsorption at the adsorption site. The resistance encountered at the adsorption site is generally considered negligible as the VOC molecule is assumed to be adsorbed instantaneously once the adsorption site has been reached. The contributions of the gas phase and intraparticle resistances can be combined into a single resistance, or represented by an overall mass transfer coefficient, K_yA.

Figure 1 shows a differential volumetric element of a gas-solid system for the adsorption of a single pollutant from a cross-flow gas stream. A mass balance for the pollutant around the element can be written as:

$$G\,(Y_{in} - Y_{out}) = S\,(X_{in} - X_{out}) \tag{3}$$

If the gas phase and adsorbed phase concentrations are small, as is generally the case in air pollution control devices, the total gas flow G and the total adsorbent solid flow S can be assumed to be constant throughout the adsorption bed. Over the length of the element in the direction of gas flow, the mass transfer rate from the gas to the adsorbent can be expressed as:

$$G\frac{dY}{dZ} = K_yA\,(Y - Y^*) \tag{4}$$

where K_yA is the overall gas phase mass transfer coefficient, Z is the direction of gas flow, and Y is the bulk gas phase pollutant concentration. The concentration gradient (Y − Y*) is the "driving force" for the pollutant mass transfer between the gas and the solid adsorbent. The equilibrium concentration Y* can be described with an equilibrium relationship such as Equations 1 or 2, or by measured data. By solving for dY in Equation 4, the change in gas phase pollutant concentration over the length of the adsorbent bed volume element can be given by:

$$dY = (Y_{in} - Y_{out}) = \frac{K_yA\,(Y - Y^*)\,dZ}{G} \tag{5}$$

The change in the adsorbed phase pollutant concentration can then be obtained from the mass balance around the element:

$$dX = (X_{in} - X_{out}) = \frac{G}{S}\,dY \tag{6}$$

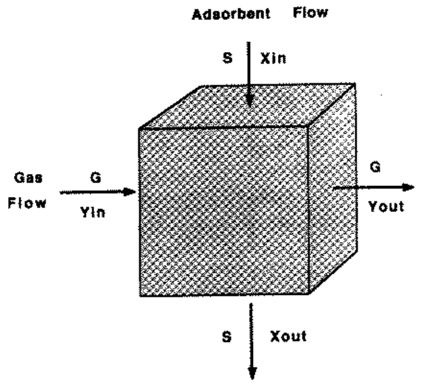

Figure 1. Element of a cross-flow adsorption system.

Literature Review

Fixed bed adsorption devices have been used in numerous applications for air pollutant control and reviews are available in other literature.[3,4] Fixed bed technology has also been used to control low concentration VOC air pollutant emissions sources, such as groundwater air strippers, and reviews of such processes have been reported.[5–7] However, there are very few reports about moving bed adsorption systems. Sakaguchi[8] described the development of a continuously flowing countercurrent design for recovery of organics from air using a special beaded activated carbon derived from oil pitch. This process was marketed in the United States by Union Carbide. Theodore and Buonocore[9] describe conceptually a moving bed process consisting of coaxial cylinders. A portion of an annular bed adsorbs VOCs while another portion is undergoing desorption. Slow rotation of the annular bed allows switching between adsorption and regeneration modes. Crompton[10] described a similarly constructed system where a slowly rotating wheel carbon adsorber was used to control VOC emissions from an automotive paint spray booth. Ritts[11] described the testing of a pilot plant employing the combination of a rotating carbon paper filter and a catalytic incinerator. The system was tested against emissions from a large paint spray booth measuring 50 ft long by 22 ft wide by 15 ft high. A portion (4000 cfm) of the 32,000 cfm exhausted from the paint spray booth was directed through the pilot plant. The inlet VOC concentration to the pilot plant ranged from 30 to 752 ppm. In Sweden, Nobel Chematur developed a system to control VOC emissions using a fluidized bed of polymer adsorbent particles.[12] This process has been applied to the recovery of styrene from a polyester manufacturing plant and to controlling emissions from spray painting. A simulated moving bed process, under the general name of Sorbex, has been used in liquid systems for the separation of hydrocarbons among other applications. The process employs a valve switching system to redirect flows to portions of a vertical fixed bed. Johnson[13] reviewed the Sorbex process and described applications using the simulated moving bed. Barker and Ganetsos[14] described the application of moving bed processes to continuous liquid chromatographic separations.

Experimental Measurements

Apparatus

A cross-flow carbon adsorption bed was constructed and tested for controlling VOC emissions from cleaning and painting of commercial passenger aircraft. The control device tested consisted of a small (gas flow rate 10 to 100 ft^3/min) research test apparatus. VOC containing air was delivered to a four inch deep adsorption bed containing Westvaco BX-7540 activated carbon pellets via a six inch diameter duct connected to the outlet side of one of the hangar exhaust ducts. The properties of the activated carbon adsorbent (provided by the manufacturer) are presented in Table I. As shown in Figure 2, a fan located on the outlet side of the adsorbent bed provided air flow through the adsorption bed. The activated carbon flowed between support screens slowly downward through a cross-flow of the VOC containing air. The downward velocity of the activated carbon pellets was about 6 inches/hour. After passing through the adsorption bed section of the device, the carbon continued downward through a thermal desorption section and then was recycled to the top of the adsorption bed. Both the activated carbon and the air flow continuously in the system. The overall height of the test apparatus was 7 ft. A detailed schematic of the adsorbent bed portion of the apparatus is shown in Figure 3.

The activated carbon was continuously regenerated by passing the carbon through a moving-bed thermal desorber before being recycled to the top of the adsorbent bed. The desorption section consisted of a narrow (1 inch wide) continuously heated metal section which heated the activated carbon from about 70°F to 180°F as it passed through. The VOCs desorbed from the heated carbon were removed by countercurrent air flow through the heated section. The apparatus operating conditions for the 15 tests conducted at the field test site varied and can be summarized as follows:

1. The superficial gas velocities into the test apparatus adsorption section ranged from 27 to 185 ft/min.
2. The gas volumetric flow rates through the adsorption section ranged from 5.3 to 36 cfm.
3. The activated carbon flow rates used in the tests conducted were 5 and 8 lb/hr.
4. The heated desorption section was operated at an average temperature of 180°F.

Aircraft Painting Hangar

The test site for the research apparatus was an aircraft painting hangar in Renton, Washington. Aircraft are cleaned and painted in this hangar, which measures approximately 160 ft. long by 120 ft. wide by 70 ft. high. Air enters the hangar from above the aircraft and is exhausted through grated ventilation trenches beneath the fuselage and wings. The building ventilation control system is such that temperature conditioned air is forced into the hangar via ceiling diffuser outlets. Fourteen fans exhaust a total of 231,470 cfm through the ventilation trenches and out of the painting hangar. The test apparatus was installed such that a small portion (10–100 cfm) of the exhaust from one of the 14 ducts was drawn through the cross-flow adsorbent bed. The treated air from the adsorbent bed was returned to the building exhaust.

Table I. Properties of Westvaco BX-7540 Carbon.

Pellet diameter	4.4 mm
Apparent density (ASTM D2854)	0.33-0.38 g/mL
Hardness (ASTM D3802)	95
Ignition temperature (ASTM D3466)	450°C
Surface area (Nitrogen BET method)	1100-1300 m^2/g

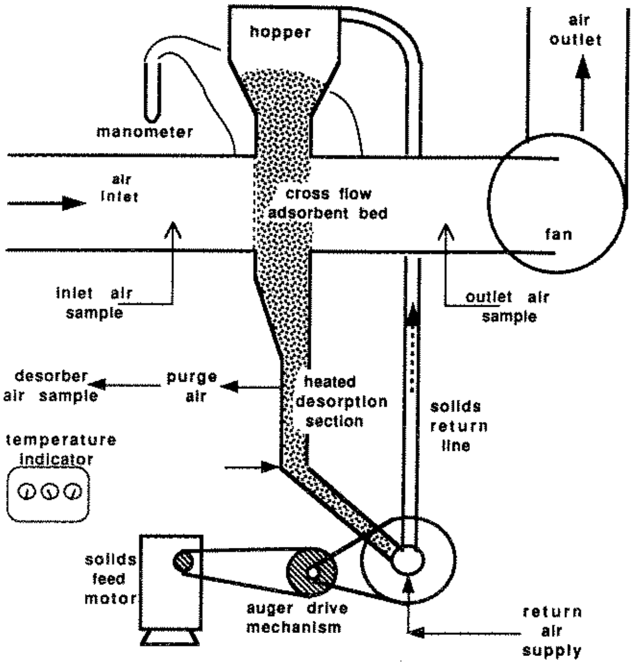

Figure 2. Control system schematic.

The cleaning and painting process typically extends over three days. The process involves an aircraft being brought into the building, washed and stripped of protective coatings, cleaned, and painted. Residues from the cleaning process are removed by wiping the aircraft by hand with cloths dampened with methyl ethyl ketone (MEK). Organic solvent compounds in the paints used vary somewhat depending on the paint manufacturer and the aircraft customer specifications. After the aircraft has received a

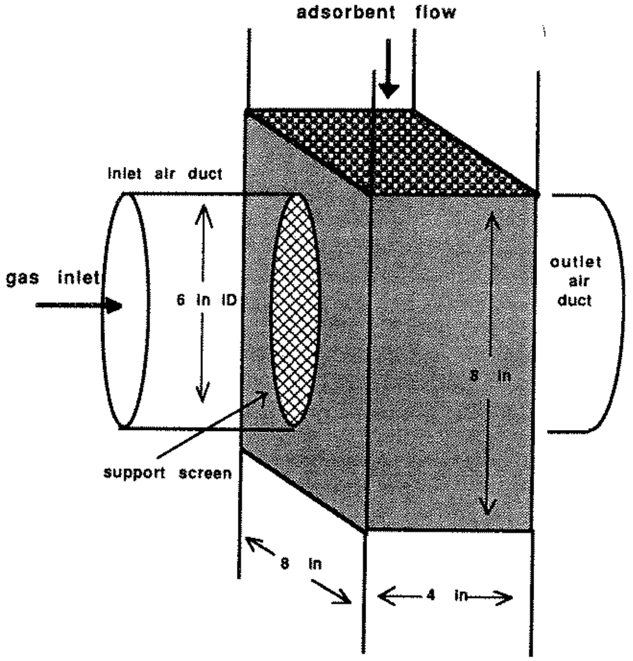

Figure 3. Cross-flow adsorbent bed detail.

new coat of paint, the paint is allowed to cure. During this period, a combination of infrared lamps and heated building makeup air are used to assist in the curing process.

Measurement Methods

The inlet and outlet VOC concentrations to the test apparatus adsorption section were measured by collecting air samples from the inlet and outlet air ducts on SKC charcoal adsorbent tubes. VOC samples were also collected from purge air outlet fittings on the desorber. The carbon flow rate was measured by weighing the carbon discharged from the auger feeder located below the desorber section over a recorded time period. Once the adsorbent flow rate was obtained as a function of the rotation speed of the auger feed mechanism, the carbon flow rate during any given test could be obtained by noting the rotation speed of the feed mechanism. The air flow rate through the moving bed of pellets versus air pressure drop across the bed was obtained from velocity traverses measured upstream of the adsorbent bed with an Alnor Model 8565 thermoanemometer. The pressure drop across the four inch adsorbent bed was measured with a water-filled u-tube manometer.

Air Sampling

The adsorbent tubes used for VOC air sampling were small (100 mg front section, 50 mg backup section) coconut-based charcoal tubes (SKC No. 226-01, Lot 120). Low-flow sampling pumps (SKC Model 222) were used to draw air samples through the adsorbent tubes. The flow rate of the low flow sampling pumps was 0.05 to 0.20 mL/min. The adsorbent tubes and sampling pumps were obtained from SKC Inc., Fullerton, California. The sampling and analytical method used corresponded closely to that described in NIOSH Method 1300.[15] The air volume sampled by the sampling pumps was obtained by recording the initial and final counts on the sampling pump counters and calculating the sample volume from the known count rate (ie., mL/count) of the sampling pump. The count rate was measured by calibration of the pumps using a 50 mL burette and soap solution. The sampling rate of each pump was obtained from the number of counts required for a soap bubble to travel 50 mL in the burette. The adsorbent tubes were placed inside the inlet and outlet air ducts to the adsorbent bed through sampling ports that had previously been used for air velocity traverses on the inlet side and for a sampling port on the outlet side when testing was conducted at the UW. The adsorbent tubes were connected to the sampling pumps using tygon tubing. At the end of the test run, the adsorbent tubes were capped, labeled, and taken to the UW laboratory for analysis.

Sample Analysis

To analyze the adsorbent tubes, the front and back sections were placed in separate vials and desorbed with 1.0 mL of liquid carbon disulfide. The vials were capped, agitated, and allowed to stand for at least 30 minutes in the sealed vials. The desorbate was then analyzed by gas chromatography with a flame ionization detector (GC/FID). The chromatograph used was a Hewlett-Packard 5880A GC fitted with an Altech 15 m × 0.53 mm × 1.2 micron film Carbowax capillary column. The injection volume was 2.0 microliters with a split ratio of 10:1. For the samples from the last five tests, a Hewlett-Packard 7672A automatic liquid sampler and an injection volume of 1.0 microliter was used. The injector and detector temperatures were set to 250°C. The GC oven was programmed to hold at 50°C for 1 minute, then heat at 10°C/minute to 150°C and hold for 0.5 minutes.

In this study, only MEK concentrations were quantified. The response of the FID to other volatile organic compounds was assumed to be attributable to MEK. For our research objective of measuring the VOC collection efficiency of the moving adsorbent bed test apparatus, inlet and outlet VOC concentrations were needed. The total hydrocarbon concentrations measured are reported in units of "MEK equivalents." This approach was assumed to provide VOC concentrations similar to those obtained with EPA Method 25A.[16] Method 25A is used to measure VOC concentrations as determined from the total response of a flame ionization detector without speciation of the components in the sample.

Calibration

The response of the gas chromatograph was calibrated by analyzing standards containing known amounts of reagent grade MEK in carbon disulfide. Three standard solutions were analyzed along with each of the sets of samples collected during each system test. Standards were prepared by adding measured amounts of MEK to a 100 mL volumetric flask from a 1 mL pipet. CS_2 was added to the flask to the dilution mark. The lower concentration standards were prepared by taking an amount from the next highest concentration standard and adding it to a 100 mL volumetric flask with a pipet and then diluting with CS_2 to the mark. For the samples from test numbers 7 through 17, standards containing 0.1329, 0.3329, and 0.6442 mg/mL were used. For the samples from tests 18 through 21, standards containing 0.1007, 2.014, and 40.27 mg/mL were used. For each set of samples analyzed, FID response curves relating the detected concentration (mg MEK/mL solution) to the peak area response of the gas chromatograph were prepared by drawing a response curve which consisted of three straight line segments. The first line segment of the response curves extended from the origin to the mean response of the lowest concentration standard. The second and third line segments were obtained from a least squares fit of the responses obtained from the lowest and mid-range concentration standards, and the mid-range and highest concentration standards.

The desorption efficiency for MEK in the analysis procedure was measured by spiking adsorbent tubes with 0.5, 1.0, and 5.0 microliters of MEK (0.4 to 4.0 mg). The measured desorption efficiencies corresponding to these spiked amounts were 85.8, 88.8, and 74.2 percent, respectively. The average value of 82.9 percent was used to calculate the concentrations in the air sampled. Similar desorption efficiencies have been reported[17] after spiking large (400 mg) charcoal tubes with doses of 0.252, 1.258, and 2.516 mg of MEK (desorption efficiencies of 75, 82, and 96 percent, respectively).

Limit of Detection

The limit of detection (LOD) was obtained from replicate analyses of the lowest concentration standard. The LOD is defined as the lowest concentration level that can be determined to be statistically different from a blank. A value of three times the standard deviation of the FID response (peak area) to the lowest concentration standard was used as the estimate of the minimum peak area that could be considered statistically different from a blank. A value of three times the standard deviation of the instrument response to the lowest concentration standard has been recommended by the American Chemical Society as a value to use as the estimate of the analytical LOD.[18] The concentration corresponding to the minimum detectable peak area was determined by multiplying the minimum detectable peak area by the response factor for the portion of the GC/FID response curve extending from the origin to the average response to the lowest concentration standard.

The analytical detection limit averaged 19 micrograms of MEK per sample. For a three-hour sample period with an air sampling rate of 0.15 L/min (typical value) this corresponds to an MEK concentration of 0.24 ppm. When the amount of VOC analyte detected in the adsorber outlet air samples was less than the LOD, a value of ½ the LOD was substituted for use in subsequent calculation of VOC collection efficiency. The substitution of LOD/2 for "none detected" values assumes a uniform distribution of data below the LOD.[19,20]

Measured Results

Gas Pressure Drop

The pressure drop through the moving adsorbent bed ranged from 0.5 to 3 inches of water and is shown in Figure 4 as a function of gas velocity (40–180 ft/min) across the bed. The line on Figure 4 is a least squares best-fit with the line forced through the origin. During each system test, the pressure drop across the adsorbent bed was measured every 10 minutes. The average air velocity over the test was obtained from the velocities corresponding to the pressure drop measurements.

Adsorbent Attrition

The attrition of the activated carbon pellets being circulated through the system was assessed by periodically withdrawing samples of the carbon from the test system. These carbon samples were separated with sieve screens into greater than and less than 30 mesh fractions. The weight fraction less than thirty mesh (595 micron diameter) was selected as an indicator of attrition, because with the test apparatus particles less than 595 microns diameter would need to be controlled as 'dust' downstream of the adsorbent bed. Figure 5 shows the measured attrition of the activated carbon after it had circulated through the system for 20 minutes, 6.6 hours, 26 hours, and 46 hours. At the field test site, approximately 20 lbs of activated carbon were initially loaded into the system at the beginning of the testing program and were used throughout the tests. The 46 hours system operating time shown in Figure 5 is the total time the adsorbent was circulated through the system. The initial wear of the carbon is due to the initial passing of the carbon through the auger feeding mechanism. After the first pass of the carbon through the auger feeding mechanism, the attrition rate slowed as the activated carbon in the system became somewhat "sized" for the feeding mechanism.

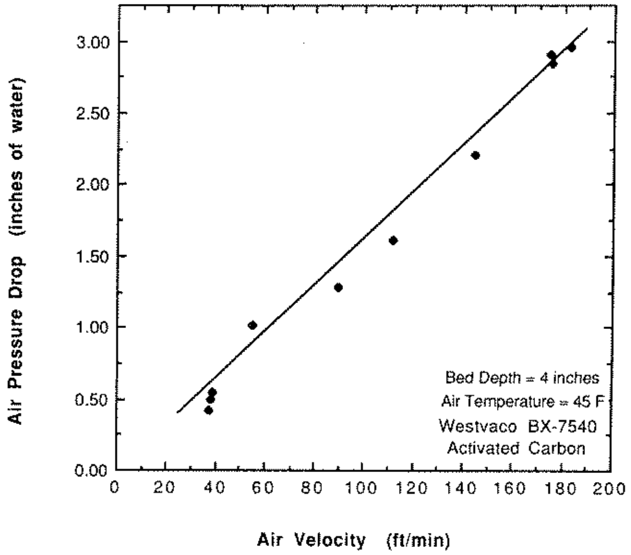

Figure 4. Pressure drop versus air velocity through the adsorption bed.

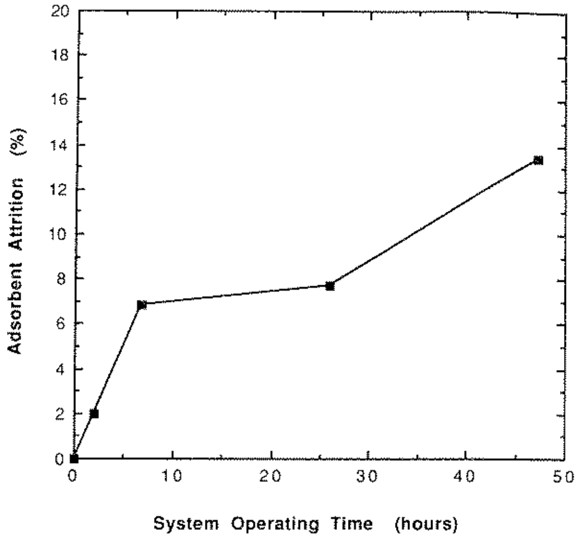

Figure 5. Attrition of activated carbon adsorbent in cross-flow system.

VOC Collection Efficiency

The VOC collection efficiencies were obtained from the inlet and outlet total hydrocarbon concentration measurements. The collection efficiency versus superficial gas velocity through the moving bed is shown in Figure 6. The carbon flow rates used in these tests were 5 and 8 lb/hr. The VOC collection efficiency for the moving adsorbent bed was not significantly influenced by the gas velocities ranging from 20 to 185 ft/min.

The effect of inlet concentration on the VOC collection efficiency of the moving adsorbent bed is shown in Figure 7. The inlet concentration shown is the average over the test as measured from the adsorbent tube samples collected at the inlet to the bed. The collection efficiency was not affected by VOC concentrations over the range of about 0.2 to 16 ppm as MEK.

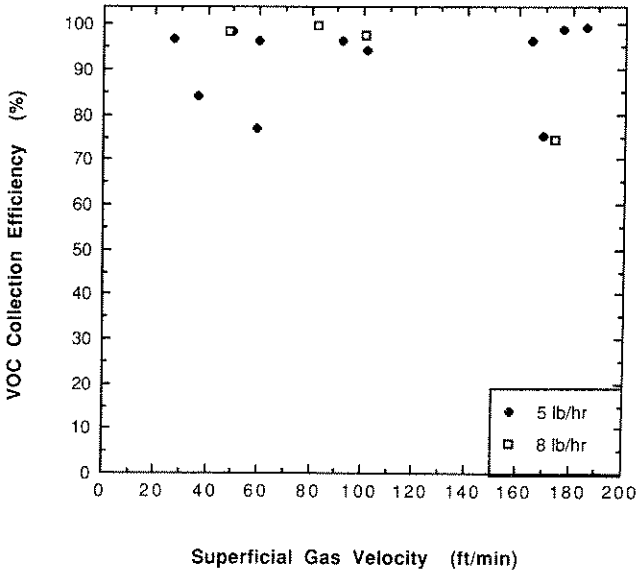

Figure 6. Effect of gas velocity on moving adsorbent bed VOC collection efficiency.

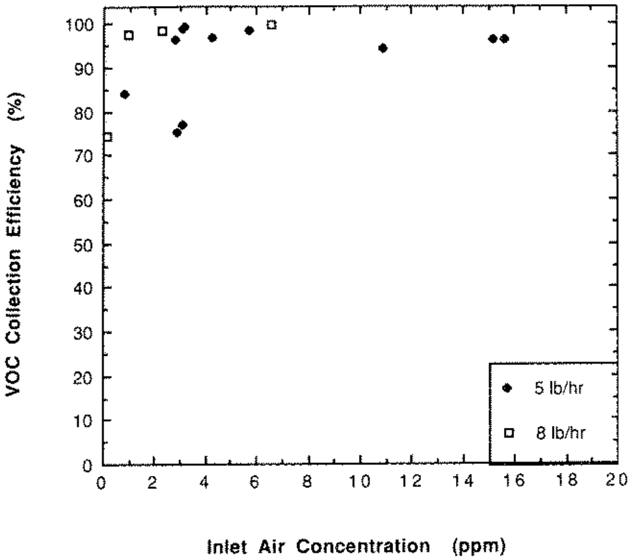

Figure 7. Effect of inlet VOC concentration on moving adsorbent bed collection efficiency.

Figures 6 and 7 include the measurements taken at carbon flow rates of both 5 and 8 lb/hr. No particular change in collection efficiency was apparent due to the change in carbon rates. The uncertainty in the measurement of both carbon flow rate and VOC concentration could mask any differences due to a slight change in carbon flow rate.

Inlet Concentration Variability

The inlet VOC concentrations measured during the tests conducted at the painting hangar are shown in Figure 8. The VOC sampling time of each test was approximately three hours. The sampling time ranged from 148 to 231 minutes. The inlet concentration varied from 0.18 ppm to 15.6 ppm for the 15 tests conducted between 1/29/90 and 5/11/90.

For the tests conducted on May 11, 1990, an HNU Model 311 portable gas chromatograph equipped with a photoionization detector was also used to measure the inlet VOC concentration. The portable gas chromatograph continuously drew sample air through an internal sample loop. The sample loop was flushed into the chromatographic column for analysis about every six minutes (about 1 second grab sample every 6 minutes). Equivalent MEK concentrations were calculated from the total PID response by measuring the response of the PID to a constant MEK concentration vapor source constructed in the laboratory. The concentration emanating from the MEK vapor source was measured by sampling with charcoal adsorbent tubes with analysis by GC/FID. The variation in the inlet air concentration measured with the PID is shown in Figure 9. The rather large fluctuations in the inlet concentration are because of the painting operation variability. As painting of one section of the aircraft is completed, the personnel move to another section. The VOCs emitted from painting another aircraft section are then exhausted through a different duct among the 14 exhausting air from the hangar.

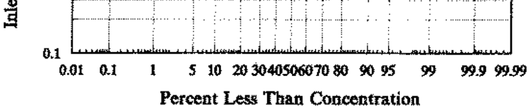

Figure 8. Variation in inlet concentration.

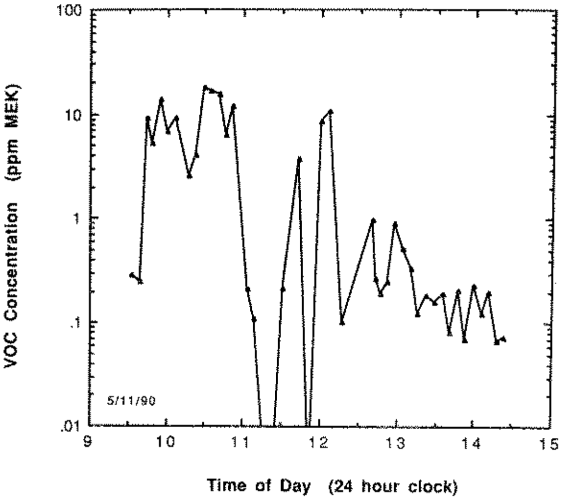

Figure 9. Variation in inlet concentration over several hours.

Desorber Performance

Only about 0.04 percent of the VOCs collected by the carbon over the 46 hours of operation were removed from the carbon by the thermal desorber. However, this is in approximate agreement with the MEK equilibrium isotherms shown in Figure 10 for Westvaco BX-7540 carbon. The 70°F data were measured by Westvaco and the 185°F points were calculated by Westvaco from measurements at 70°F and 100°F. A total of 2.3×10^{-5} lbs of VOCs (obtained from measured VOC concentrations in the desorber purge air) were desorbed from the carbon by the thermal desorber (average temperature 180°F) during the 46 hours of operation. This 2.3×10^{-5} lbs of VOCs desorbed is about 0.04 percent of the total 0.054 lbs VOC (based on the VOC airborne concentrations at the adsorber inlet and outlet, the air flow rate, and the time of operation) collected by the

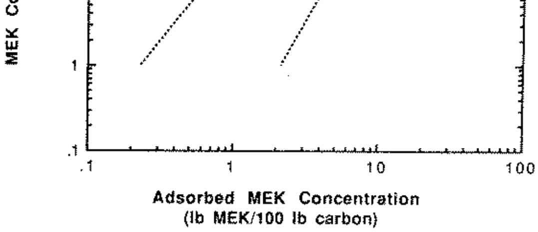

Figure 10. Adsorption isotherm for MEK on Westvaco BX-7540 carbon (data provided by Westvaco Carbon).

carbon during its operation. The other 99.96 percent of the collected VOCs remained adsorbed on the carbon, probably because the desorber temperature was too cool to remove the low concentration of adsorbed VOCs. Looking at the equilibrium isotherms at 185°F will help to explain the low purge air outlet VOC concentrations measured. With about 20 lbs of carbon in the test system, the VOC concentration in the carbon was about 0.054 lbs VOC per 20 lbs carbon or 0.27 lbs VOC/100 lbs carbon. Figure 10 shows that the gas phase VOC (MEK) concentration in equilibrium at 185°F with 0.27 lbs VOC/100 lbs carbon is about 1 ppm. For the 27 VOC samples taken from the desorber purge air during the 15 tests, the average measured purge air outlet VOC concentration was 0.30 ppm. With a purge air flow rate of 0.14 cfm, the VOC purge air concentration of about 0.3 ppm VOC should be less than this equilibrium 1 ppm concentration. Therefore, the measured 0.30 ppm desorber outlet purge air concentration is consistent with the 1.0 ppm MEK gas phase concentration in equilibrium with the 0.27 lbs MEK/100 lbs carbon at 185°F.

Example Full Scale System

A schematic diagram of a full-scale cross-flow adsorption system is presented in Figure 11. The full-scale 15,000 cfm example system is intended for the control of an emission stream containing 20 ppm of toluene. The superficial velocity through the adsorbent bed is 150 ft/min. The adsorbent bed depth is about four inches and the activated carbon flow rate is about 35 lb/hr. The adsorbent flow rate through the system would be controlled by the rotary valves located above and below the desorption section. The adsorbent would be recycled through the system by pneumatically conveying the regenerated adsorbent to the top of the adsorbent bed. A heated air purge flow of 60 scfm through the desorption section would transport the desorbed VOCs through the countercurrent desorber to a thermal incinerator. In the example application, the 60 cfm thermal desorber emission stream to be incinerated would be only about 4 percent of the total 15,000 cfm emission stream.

Additional testing of such a cross-flow adsorbent system will be necessary in order to allow full scale development. Long term (ie., weeks to months) operation may be necessary to allow complete evaluation of the reliability of mechanical components used in moving adsorbent systems. More precise measurement of the VOC concentrations and adsorbent flow rates should be conducted to enable better quantification of the VOC mass balance and the performance of a cross-flow adsorbent bed. Additional research and development is needed on a continuous carbon regeneration device that will operate effectively when the VOC loading (the amount of VOC adsorbed on the carbon) is very low (less than about 0.5 lb VOC per 100 lb of carbon).

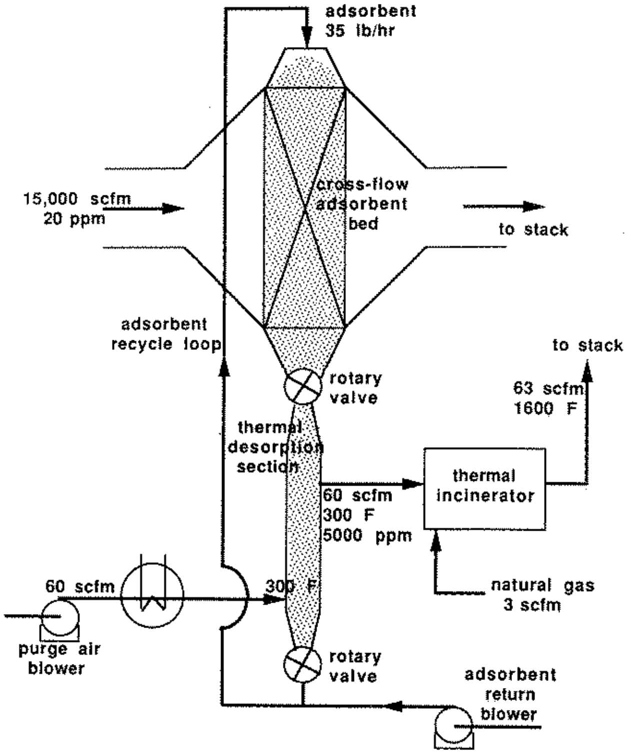

Figure 11. Schematic diagram of full-scale cross-flow adsorption system.

Conclusions

A cross-flow moving adsorption bed was found to have a VOC collection efficiency in the 77.1 to 99.6 percent range over a superficial gas velocity range of 27 to 185 ft/min. The collection efficiency was neither affected by a change in the carbon flow rate from 5 to 8 lb/hr nor by changes in the superficial gas velocity over the range of 27 to 185 ft/min. Adsorbent bed inlet VOC concentrations (averaged over the two to four hour test periods) ranged from 0.18 to 15.6 ppm as MEK. Outlet VOC concentrations ranged from less than the detection limit to 0.71 ppm as MEK. The adsorbent bed outlet VOC concentration was below the limit of detection in 11 of 15 tests. The VOC concentration in the air exhausting from the painting hangar varied from about 0.1 to 15 ppm as MEK (two to four hour air samples) over the five month period during which 15 tests were conducted. The VOC concentration in the air exhausting from the painting hangar (as measured with approximately one second grab samples taken every six minutes) was also found to vary by about the same magnitude during a single eight hour day. Additional research and development is needed for the design of full-scale systems.

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