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Techniques to Detect Failure in Carbon Adsorption Systems

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16. ABSTRACT

The study was originated to determine if simple techniques, or equipment inspection could determine that a given carbon adsorption system was operating at satisfactory adsorbtion efficiency.

The study determined that no visual inspection would be adequate, but that two other techniques are feasible. The first technique, utilizes portable, concentration-sensitive, continuous-measuring equipment which can detect break-through. Break-through is indication that a carbon adsorbtion system is not operating properly. This technique is suitable for field inspections.

Maintenance of overall solvent material balances, subject to inspection, is an alternate technique. A form for a material balance is presented.

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Techniques to Detect Failure in Carbon Adsorption Systems

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SECTION I

SUMMARY

For many industries the Control Technology Guidelines, published by OAQPS, define overall efficiencies for the affected facility. The documents also define control-device efficiencies which may be expected to achieve these required overall efficiencies. Enforcement of the guidelines will result in installation of many volatile organic compound (VOC) control devices in the near future.

Carbon-adsorption is the most widely-used technique for controlling VOC discharges which can show a return on investment. Therefore, it is reasonable to expect that many new carbon-adsorption installations will join the many existing installations. Techniques exist for determining the exact concentration of solvent in inlet and discharge gas streams. These techniques require high technology to perform, and are beyond the scope of what might be considered feasible for continued surveillance.

The purpose of this study was to determine if simple techniques were available for assuring that large carbon-bed solvent-vapor adsorption systems operated properly, and were maintaining the design adsorption efficiency. Large systems were defined as multi-bed (two- or more-bed) systems equipped with automatic-cycle control. In the process of investigating these issues, ES made telephone contacts and field visits to the following:

- Existing installations;
- Organizations which design and construct adsorption systems; and
- Trade associations.

The study determined that no visual inspection technique could reliably predict or define loss of adsorption efficiency. However, it did identify two techniques which could determine the loss in system efficiency. These were the measurement of solvent concentration in the discharge, and the preparation of a material balance.

Portable instruments are available for measuring low-level solvent concentrations in a gas stream. Although the instruments may not be calibrated for the gas stream being measured, they do indicate the increase in solvent adsorption system is not functioning properly. This technique is recommended for inspection of existing systems. Those jurisdictions which encompass several carbon adsorption systems should be equipped with a suitable solvent-concentration meter, and recorder, and have personnel trained in their use. Such training is not difficult. Alternatively, a consultant familiar with carbon-adsorption systems might be called in to make the tests when they are required.

Preparation of an overall solvent material balance can determine solvent recovery efficiency for an entire facility. Inasmuch as the Industry Guidelines define overall recovery as their primary goal, this might be the better technique. The overall material balance would not be difficult for a facility to maintain, or for an inspector to review. Many existing facilities are equipped to maintain the necessary records, and many others could be so equipped by the addition of one or more totalizing flow meters to measure recovered solvent flow.

Existing systems should be inspected periodically by either of the above-mentioned techniques. New systems should be equipped with instrumentation to continuously record discharge solvent concentrations, as well as with equipment to measure the quantity of solvents recovered. EPA may also require that each facility prepare monthly reports similar to those prepared for opacity-monitoring installations.

SECTION II

INTRODUCTION

This project was originated to determine if visual inspection could assure that large carbon-bed solvent vapor recovery systems retained the recovery efficiency for which they were originally designed. A large system is defined as a two- (or more) bed system which is regenerated by automatic control.

A list of typical failure modes was drawn up following discussions, and visits with trade organizations, design and construction corporations, and operating corporations. These are listed in Appendix A. The failure modes identified were:

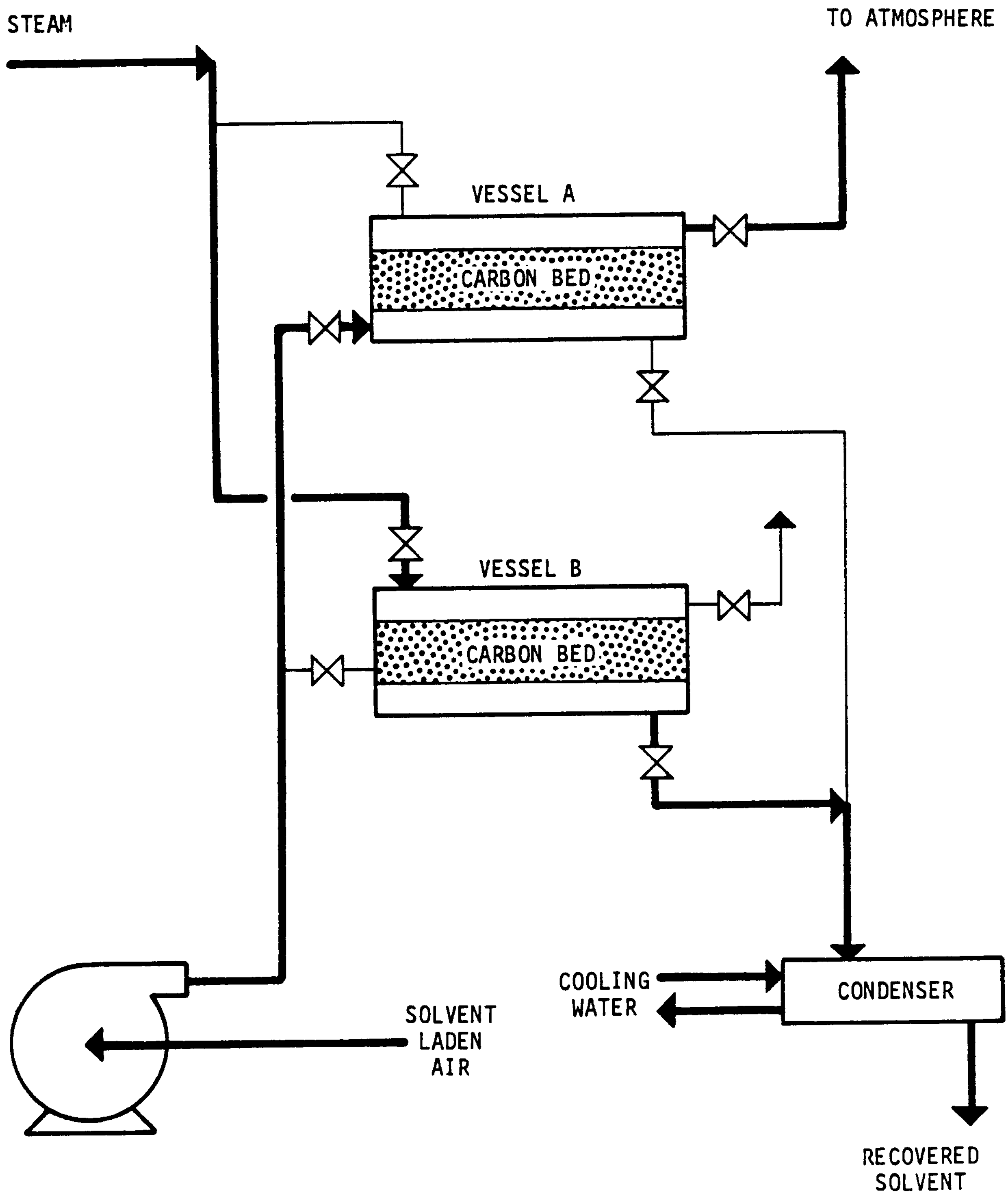
- Steam valves leak;
- Air discharge valves leak;
- Insufficient steam flow during regeneration;
- Insufficient time for steamout;
- Collapse of carbon bed;
- Loss of carbon activity;
- Bed blockage due to buildup of lint, dust, polymers, or other materials;
- Uneven bed distribution; and
- Improper setting of system controls.

Based on inspections at six plants, it was determined that an expert might detect several of these failures in some systems, but it would be impossible to detect most of the failure modes by physical inspection. Two alternate techniques were then identified for determining the effectiveness of operating carbon-adsorption systems. These were:

- Monitoring the discharge to determine if breakthrough occurs; and
- Preparation of a material balance to determine overall system efficiency.

A discussion of the operation of a carbon-bed adsorption system may provide an understanding of how these techniques may be applied. Figure II-1 is a simple operating flow diagram of a typical carbon-adsorption unit. Bed A is "on-stream". Solvent flows through the blower, up through carbon Bed A.

CARBON BED ADSORPTION SYSTEM
SIMPLIFIED FLOW DIAGRAM



Solvent is adsorbed by the carbon, and the purified air flows to atmosphere. Bed B is being regenerated. Steam flows down through the bed, heating the carbon, driving off previously-adsorbed solvents, and carrying them to the condenser. Condensed water and solvent flow from the condenser to whatever treatment is required to make the solvent reusable. Steam flow rate, and steam-out time are adjusted to provide adequate regeneration of Bed B before Bed A is loaded. Usually, Bed B is placed on stream when regeneration is completed, and Bed A is regenerated. In a properly operating system, the bed being regenerated is placed onstream before the other bed is fully loaded with solvent.

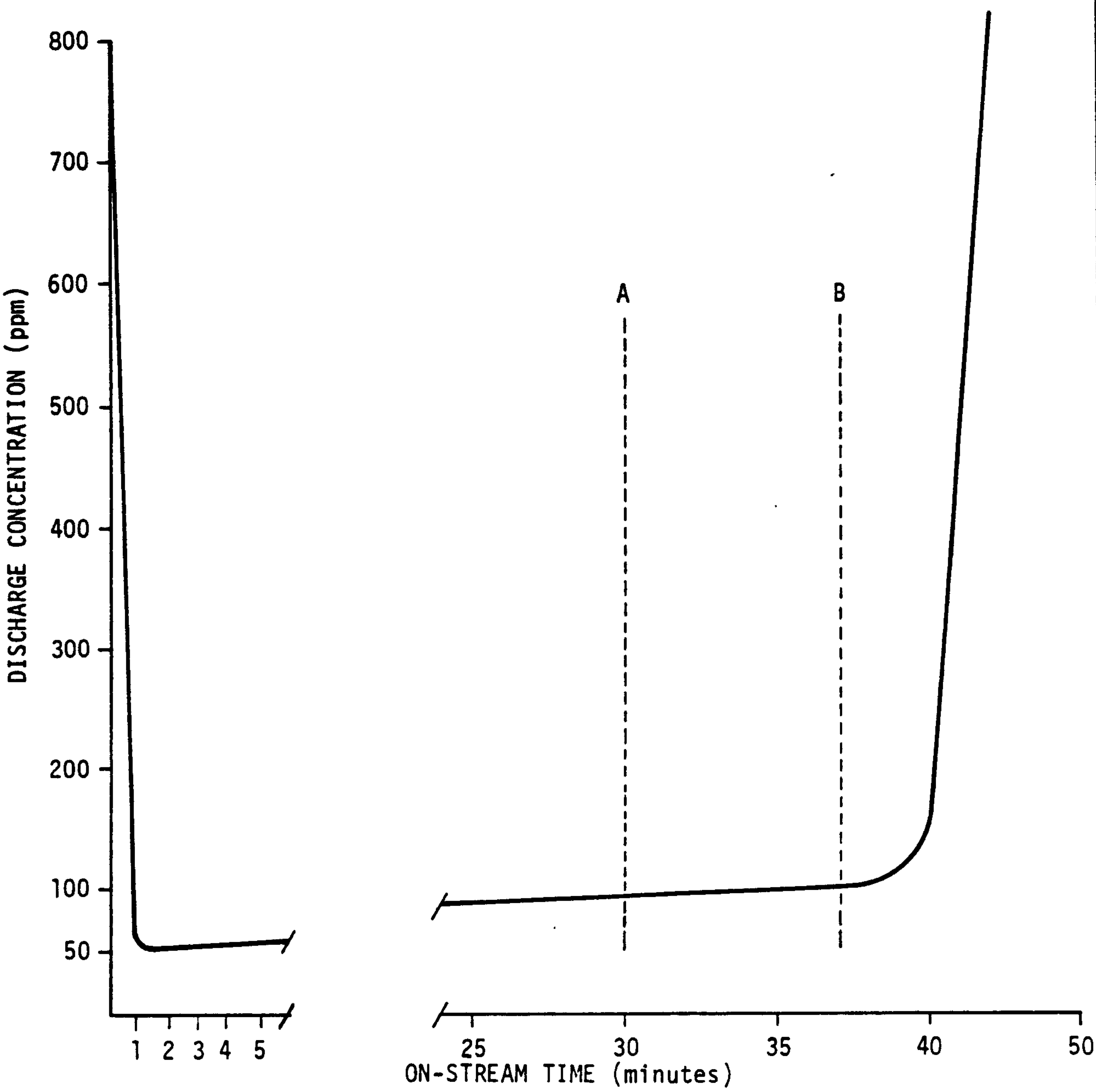
MONITORING TECHNIQUES

Continuous discharge monitoring can demonstrate that breakthrough does, or does not ccur. Although not an exact test, it is probable that a system which goes through several cycles of full-load operation, without reaching breakthrough, is operating at adsorption efficiencies approaching the original adsorption efficiency for the VOC inlet loads during the test. Instruments suitable for these tests are discussed in Section III. Figure II-2 presents typical discharge solvent concentration plotted against time. The diagram is a representative example example of the general shape of such a curve. Actual time, and discharge concentration will vary from system to system. Initially, discharge concentration will be high because the bed remains hot from regeneration, and because the vessel is full of steam and solvent vapor. The bed cools rapidly, due to the evaporation of water which condenses on the carbon, and the discharge solvent concentration falls rapidly (1 to 2 minutes) to low levels (50 to 250 ppm). Discharge concentration then rises slowly. The beds are usually switched at the point marked "A" on graph. If a bed is kept on stream, the discharge concentration continues to rise slowly until it reaches point "B", where it begins to rise rapidly. This point is known as breakthrough. It can occur because bed changeover is delayed, because bed capacity is reduced, or because steamout is incomplete so that the time to breakthrough is reduced to less than the cycle time.

A measure of total solvent capacity can be determined by interrupting the normal operating cycle and delaying regeneration until breakthrough has occurred. This can be express as:

$$\frac{\text{Time to Breakthrough}}{\text{Normal On-Stream Time}} \times \text{Solvent Loading at Time of Test} = \text{Actual Capacity}$$

TYPICAL DISCHARGE CONCENTRATION VS. TIME
FOR A CARBON-BED VAPOR ADSORPTION SYSTEM



NOTE: This curve is an example. Actual time will vary for each application.

This is not an exact measure of adsorption system capacity, but it can indicate significant deterioration.

MATERIAL BALANCE

An overall system material balance is the best technique for determining the overall system efficiency addressed in the OAQPS Guideline Series. Data to prepare a material balance could be assembled in many existing facilities. Other facilities could be modified simply by addition of totalizing flow meters to the recovered solvent lines. This is discussed in more detail in Section IV.

SECTION III

MONITORING TECHNIQUES

Determination of time to breakthrough requires that solvent concentrations in the 50-500 ppm range be continuously measured. Several types of instruments are available for measuring solvents at these low levels.

- o Catalytic oxidation;
- o Chromatography;
- o Diffusion sensor;
- o Flame ionization;
- o Instantaneous sampling;
- o Nondispersive infrared; and
- o Ultra-violet ionization.

These systems each have some advantages and disadvantages. They require calibration for the solvent being measured if exact measurements are required, but can also be used without calibration to indicate relative concentration levels. If the output of a suitable detector is connected to a recorder, the adsorber-discharge concentration could be monitored over several cycles to demonstrate the absence of breakthrough. For a facility operating at normal production rates, the absence of breakthrough may be taken as evidence that the adsorption system is operating satisfactorily. A brief description of each of the available instruments follows. Costs for VOC instruments are contained in a report "Summary of Available Portable VOC Detection Instruments" prepared by PEDCO Environmental, Inc. under Task No. 120 of EPA Contract 68-01-4147. It would not be difficult to train inspectors in use of the instrumentation, and in their application to carbon-adsorption systems.

CATALYTIC OXIDATION SYSTEMS

Catalytic oxidation systems measure the heat evolved when the organic vapors in a gas stream are oxidized by a platinum-black catalyst. These units are light, and easy to use. System response varies with the heat of combustion of the organic vapor, but most hydrocarbons, including most chlorinated hydrocarbons can be detected. At low vapor concentrations, catalytic oxidation units must be zeroed every few minutes. They are not suitable for continuous low-level measurement.

CHROMATOGRAPHY SYSTEMS

Chromatography systems require considerable operator training if reliable results are desired. They are not suitable for this service.

DIFFUSION SENSORS

Diffusion sensors have been used for several years in carbon adsorption systems. According to the manufacturer, detection of gases is accomplished by embedding a heater and collector in a metal oxide silica type material. At operating temperature, a very high resistance exists between the sensor elements. Upon sensing gas, this resistance changes significantly producing several volts output in relation to the gas concentration. These instruments, available in portable sizes, can be set up to indicate concentration as low as 50 ppm full scale, or up to several thousand ppm full scale. One type of instrument could, therefore, be used to monitor both inlet and discharge solvent concentrations. An instrument of this type would be an excellent tool to detect breakthrough in working carbon-adsorption systems.

FLAME-IONIZATION SYSTEMS

Flame-ionization units are among the oldest of the low-level solvent-detection systems. A sample of the gas flows continuously through a pure-hydrogen flame, and the resulting ions induce current flow to an electrode placed adjacent to the flame. Current flow is proportional to solvent concentration. Essentially, all hydrocarbons may be detected. These units are suitable for the application.

INSTANTANEOUS SAMPLING

There are several techniques which might be used to withdraw samples from the gas stream, and analyze them. The analysis may be rapid enough to be considered instantaneous, but the time between samples is usually several minutes. These techniques may be suitable for the application, but are usually not as convenient to use as continuous measuring techniques, and they cannot provide a continuous record.

NONDISPERSIVE INFRARED SYSTEMS

Nondispersive infrared systems require that the system be set for each hydrocarbon to be measured and that the measured sample be free from water. Operation of these systems is relatively complex. The maximum absorption frequency for each measured hydrocarbon must be known, and the instrument must be set for that frequency. Less complex systems are available to detect breakthrough, so the system is not considered desirable for this service.

ULTRA-VIOLET IONIZATION SYSTEMS

Ultra-villet ionization is a relatively new technique for detecting the presence of organic-carbon molecules. High-energy ultra-violet light ionizes the molecules, which induce current flow between two elecrodes. System response varies with light-source energy, and with sensitivity of the organic compound, but most commercial hydrocarbons, including chlorinated hydrocarbons, can be detected. Commercially-available units are light, safe, easy to use, and suitable for this application.

SECTION IV

MATERIAL BALANCES

Material balances, taken over a reasonable time period (usually more than one week) can provide demonstration that the entire facility is maintaining the collection efficiency required by the facilities' operating permit. To be effective, the operating plant must maintain accurate records of solvent-containing materials entering the process, and of the recovered solvent. Recovered solvent returned to the process is considered as part of the solvent entering the system. The solvent concentration of all materials entering the process must be known. A form for a material balance is presented in Appendix B.

Most of the information can be assembled by the source from shipping data, and from component data available from raw-material suppliers. The only data which must be generated directly by the source is the quantity of recovered solvent. This can be determined by use of totalizing flow meters measuring solvent from the recovery systems. These meters are similar to residential water meters. Many installations have such flow meters installed. It would not be difficult to install them in existing systems. All new systems should be so equipped.

APPENDIX A

ORGANIZATIONS CONTACTED OR VISITED

TRADE ASSOCIATIONS

Flexible Packaging Association

Gravure Research Institute

Graphic Arts Technical Foundation

OPERATING FACILITIES

Meredith-Burda Corporation - Rotogravure

Technicolor Laboratories, Inc. - Film Processing

Adhesives Research, Inc. - Pressure Sensitive Tape

Kecoughtan Laundry - Central Dry Cleaning

SCM Corporation - Pressure Sensitive Tape

Wabash Tape Corporation - Magnetic Tape

Alco-Gravure Corporation - Rotogravure

ADSORPTION SYSTEM MANUFACTURING ORGANIZATIONS

NuCon Corporation

Oxy-Catalyst Division of Research-Cottrell Corporation

Vara International, Inc.

SENSOR MANUFACTURING CORPORATIONS

HNU Systems, Inc.

International Sensor Technology, Inc.

Bacharach Instrument Company

Mine Safety Appliance Corporation

Analytical Instrument Development Company

APPENDIX B

MATERIAL BALANCE FOR DETERMINING OVERALL SOLVENT RECOVERY EFFICIENCY

United States
Environmental Protection
Agency

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