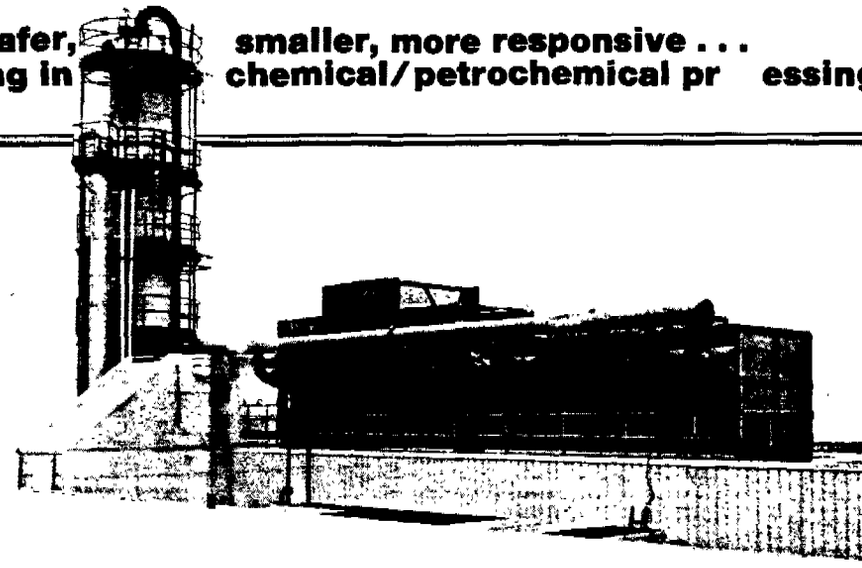
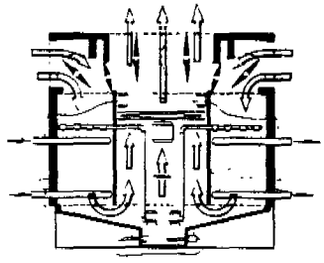
NIAGARA WET-SURFACE AIR COOLERS

More economical, safer, smaller, more responsive . . . for cooling/condensing in chemical/petrochemical pr essing



The Principle . . . Cooling With Air

The process liquid, gas or vapor flows through smooth-wall tubes whose exterior is continually drenched with a cascade of water which is collected and revolved. Downdraft air mingles with the water, cooling it as it descends. Air flow reverses and is discharged upwards, with all water left behind and falling back into the collecting basin.



Applications Throughout the Chemical Industries

Niagara Wet-Surface Air Coolers are applicable wherever chemical or petrochemical processes call for cooling of liquids or gases, condensation of steam or other vapors at a relatively low temperature level. With today's incentives to conserve energy, Wet-Surface Air Coolers are regularly replacing conventional cooling towers which work in conjunction with surface heat exchangers, or misapplied dry-surface air coolers, with appreciable long-term benefits.

The Advantages

Saves Capital — With lower initial cost, smaller plot area and relatively simple installation and supports, the cost of putting these essentially "package" units on-stream is comparatively small.

Saves Operating Cash — Because of minimal water consumption and the fact that the pumps used to deluge the tube bundles operate against low heads over a short distance, power consumption for the Wet-Surface Air Cooler is exceptionally low.

Low Maintenance — Massive and continuous drenching of tubes prevents scaling and corrosion, keeping maintenance problems at a minimum, while the basic design makes on-stream inspection of air/water side surfaces practical.

Environmentally acceptable — Wet-Surface Air Coolers installed on overhead beams, propel a quickly dissipating plume of moist air skywards, visible only in cold weather.

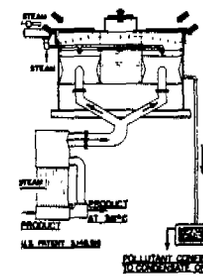
Safety — With only atmospheric pressure on the coolant side, there is no danger of contaminating the process stream, and any accidental outward leakage of the process fluid is readily detectable.

Simple Temperature Control — Thermostatic control simply adjusts the positions of a damper train to divert the coolant air, which is either discharged to the atmosphere, or partially or wholly recirculated to control the process temperature.

Air — Another big saving! The cooling medium is readily available and free.

Flexibility of Installation — Because of the "package" nature of Wet-Surface Air Coolers, they can be quickly and compactly installed above ground on structural supports or at ground level, but always at optimum proximity to the process. Supports are simple, with no need for expensive foundations.

Ecological Benefits — Cooling with air prevents thermal pollution of water resources, while transfer of process fluids in a closed loop prevents objectionable volatiles from escaping to the atmosphere.



Aircooler condenses steam at 38° C. and 50 mm Hg, Abs.

Engineering Assistance . . . As Near As Your Ph ne

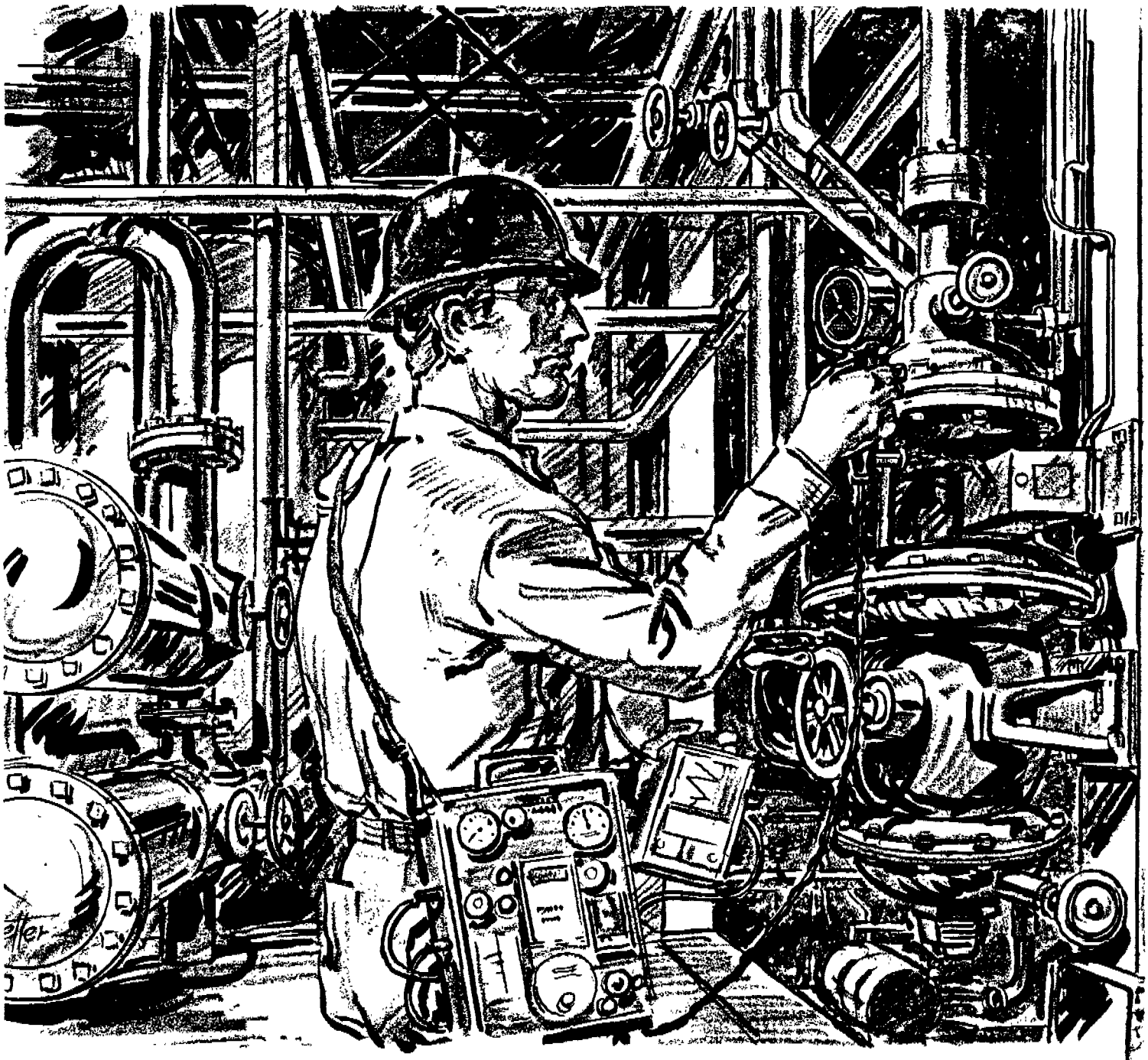
For additional descriptive and illustrative literature or for prompt engineering assistance in appraising the applicability of Wet-Surface Air Coolers for your particular operation, just contact Niagara Blower's executive offices or your nearby Niagara District Engineer. The answer to your problems is only a phone call away.

Niagara Blower Company

405 Lexington Avenue, New York NY 10017
Phone: (212) 697-6151

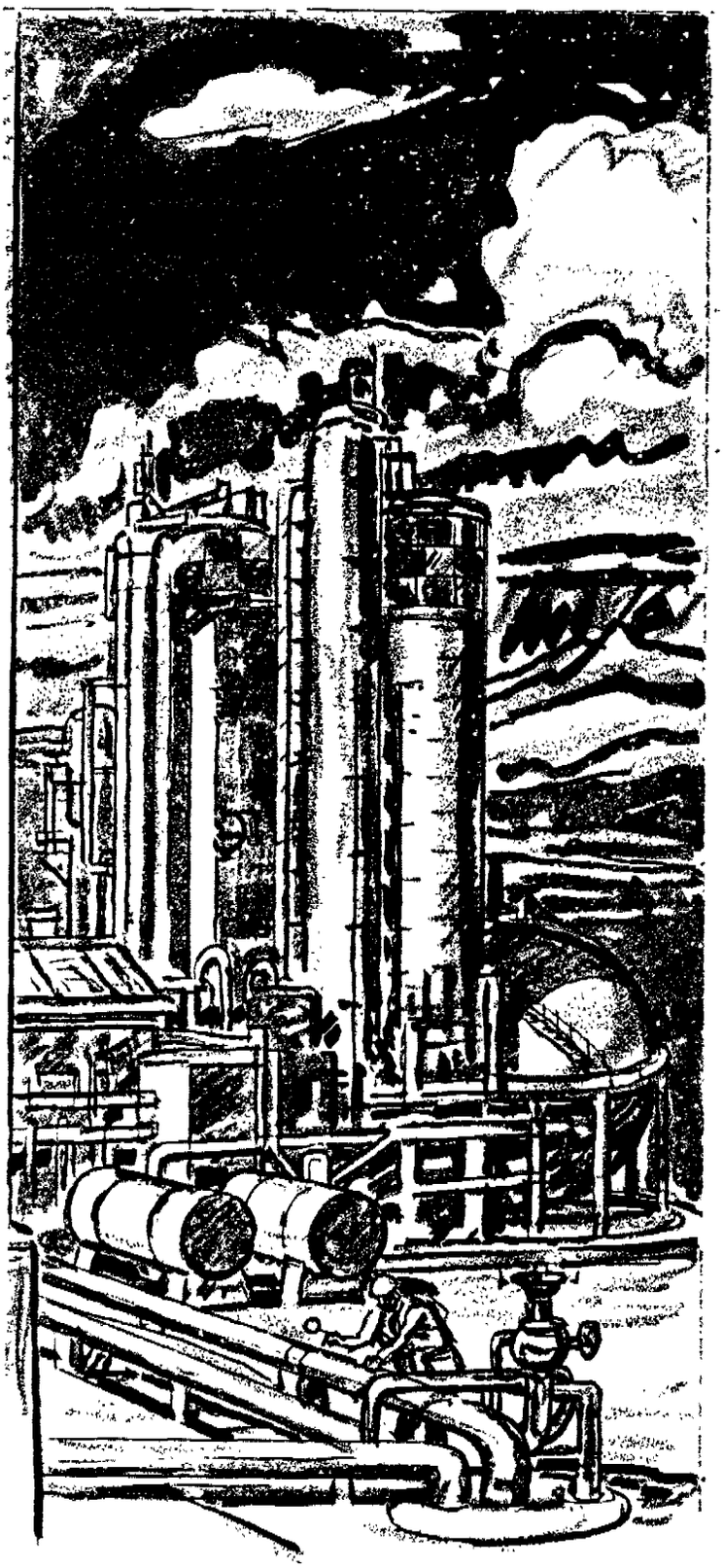
Circle 413 on Reader Service Card

Controlling fugitive



EPA is now in the process of developing standards for the control of these emissions. Here is a summary of the agency's draft standards, along with some alternative methods proposed by industry. These standards include air-quality rules, as well as a control program monitoring, reporting and maintenance.

emissions



Michael J. Wallace, Sandoz, Inc.

☐ Federal air-quality regulations have always implicitly included control measures for fugitive emissions, but, until recently, enforcement has been directed only at point-source emissions.

Now, however, the U.S. Environmental Protection Agency (EPA) has begun to concern itself with fugitive emissions.

EPA has written draft standards for controlling such emissions, and the agency is soliciting comments in order to issue a set of proposed rules and, eventually, standards. Here, we shall summarize the control methods described in the draft standards, as well as review alternative strategies for the control of fugitive emissions. Let us now:

1. Define fugitive emissions.
2. Estimate the degree to which these emissions contribute to the U.S.'s air pollution.
3. Review existing federal air-pollution regulations.
4. Summarize EPA's draft standards on monitoring, reporting and maintenance, along with some alternative methods.
5. Estimate industry's cost of a fugitive-emissions program.

What are fugitive emissions?

In contrast to a point-source emission such as that from a reactor vent or a boiler exhaust stack, a fugitive emission results from an equipment leak and is characterized by a diffuse release of volatile organic carbon (VOC) compounds or hydrocarbons into the atmosphere. These hydrocarbons are non-methanes (in the C_2 through C_6 range) and are generally photochemically reactive—that is, they are precursors to oxidants.

According to EPA's proposed generic standard, a fugitive emission is a leak that registers over 1,000 ppm on a hydrocarbon analyzer at the emission source. Point-source emissions can be measured quantitatively, since both concentration and volumetric flowrate are readily monitored in a confined system, while fugitive emissions, in contrast, being essentially leaks, are not confined in space. These leaks result in a diffuse discharge that is difficult to measure quantitatively.

(Methods of monitoring fugitive emissions will be discussed later on. We will not consider fugitive emissions of particulates, because EPA's main thrust is on controlling hydrocarbons.)

Amount of fugitive emissions

Table I shows sources of hydrocarbon emissions (including fugitive emissions), compiled from EPA [*1*] data.

For 1975, petroleum processes (refineries) accounted

U.S. hydrocarbon emissions declined in the early 1970s, probably due to pollution rules — Table I

Source	Emission rate million metric tons/yr 1974	1975
Transportation	11.3	10.6
Stationary fuel combustion	1.6	1.3
Petroleum processes	4.5	4.6
Chemical processes	9.7	9.0
Other industries	0.9	0.9
Solid waste	0.9	0.8
Forest and agricultural burns	0.9	0.9
Totals	29.8	28.1

Totals	1970	1971	1972	1973
Million metric tons/yr	30.7	30.2	30.9	30.8

Compiled from Ref. [1].

for about 16% of all hydrocarbon emissions. Chemical processes—petrochemical plants and synthetic-organic-chemical manufacturing industry (SOCMI) plants—accounted for some 32% of total emissions. And transportation (vehicles) produced approximately 38%.

There was about a 9% decline in total emissions from a peak of 30.9 million metric tons/yr in 1972, to 28.1 million m.t./yr in 1975. (Data for 1975 through 1978 were not available to the author at the time of writing this article.) The relatively large decrease of 9% is more than a standard statistical deviation, and it appears that a net decrease in hydrocarbon emissions has been brought about by air-pollution-control efforts.

As a comparison, EPA [2] reported that the total yearly hydrocarbon emission rate due to the natural degradation of vegetation and leaf litter is about 11 million m.t./yr. This equals nearly 40% of total yearly manmade hydrocarbon emissions as reported for 1975. How much of these manmade emissions are fugitive emissions?

There are no direct measurements or estimates of total fugitive-hydrocarbon emissions in the U.S. However, we can make a rough order-of-magnitude guess. Kremer [3] found that, depending on the type of plant, about one third of all air-pollutant emissions are due to leakage from sealing elements such as valves, pump seals and flanges. Assuming that these data apply universally, then, using EPA's 1975 figures, about 4.5 million m.t./yr of hydrocarbons result from fugitive emissions in the petroleum and chemical process industries (CPI). This corresponds to approximately 16% of all non-natural hydrocarbon emissions in the U.S., or, as stated above, about 33% of all hydrocarbons in the petroleum refining and chemical process industries. Even as only an order-of-magnitude estimate, this relatively high percentage of total emissions underscores the growing concern over fugitive emissions.

U.S. air-quality rules

The 1977 Amendments to the Clean Air Act of 1970 have given EPA power to implement broad control over all aspects of industrial air pollution. Most critical to chemical engineers are those restrictions placed on modification or expansion of existing facilities, or on construction of new ones.

The 1977 Amendments require that any industry proposing a new or modified major source of air pollutants must file for a New Source Review, so as to ob a construction permit. A major source is defined as that, without any control device, could potentially emit 100 tons/yr of pollutant. This is a small quantity, amounting to 23 lb/h for a source in continuous operation 365 days a year. Under this regulation, many facilities that had once escaped air-pollution control regulations are now required to apply for a New Source Review, and it may require from 6 to 42 mo to obtain a permit.

To determine the amount of uncontrolled emissions, one must consider all air-pollutant emissions upstream of any control device, such as a baghouse, scrubber or carbon-absorption unit. Any device, such as a reflux condenser, that is essential to the operation of an industrial process is not considered a control device. In this case, uncontrolled emissions are determined downstream of the device.

Fig. 1 shows a reactor with reflux- and after-condensers. There are two possible points, A or B, for evaluating potential air contaminants. Point B is between the reflux- and after-condensers, and Point A is downstream of the after-condenser. During normal reflux operation, the reflux-condenser is necessary in order to return solvent to the reactor, and the after-condenser is used primarily as an air-pollution control device to remove any remaining condensables from the reflux-condenser vent line. In this case, Point B would be used in determining the potential uncontrolled air-pollut emission rate.

However, the point at which potential emissions are determined is now being decided in a federal court. The court may rule that the point should be downstream of any control device. Such a decision would, of course, benefit industry, especially the smaller-volume SOCMI firms. This is because this decision would significantly raise the level that defines a major source.

If a plant modification, expansion or new facility is taken as one source, then fugitive emissions and the applicable control methods for them will have to be considered in determining the potential air-pollutant emissions.

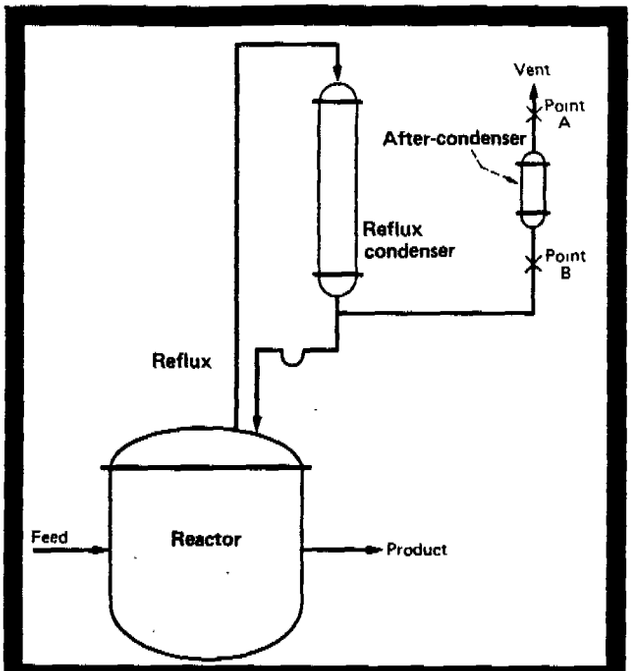
If a New Source Review is required, then it must be determined whether the facility is in what is called a nonattainment area. Such an area is one that does not meet the federal National Ambient Air Quality Standards (NAAQS) for ambient levels of either sulfur dioxide, carbon monoxide, hydrocarbons, nitrogen dioxide, particulate matter or photochemical oxidants. In such areas the planned production facility must proceed with what is termed the nonattainment process, the first step of which is application of control technology known as the Lowest Achievable Emission Rate (LAER).

Guidelines for LAER have not yet been developed. It assumes pollutant control by the best available technology, without considering the cost. Again, this refers to both point-source and fugitive air-pollutant emissi

After estimating the possible reduction in emissions by applying LAER, it is determined whether a detailed

From this group of 43 organic chemicals, EPA is expected to list 10 to 15 as hazardous — Table II

Acetaldehyde	Maleic anhydride
Acrolein	Manganese
Acrylonitrile	Methyl chloroform
Allyl chloride	Methylene chloride
Benzyl chloride	Methyl iodide
Bis(chloromethyl)ether	Nickel
Carbon tetrachloride	Nitrobenzene
Chlorobenzene	2-Nitropropane
Chloroform	*m*-Nitrosodiethylamine
Chloromethylmethyl ether	Nitrosoethylurea
Chloroprene	Nitrosomethylurea
o-,*m*-,*p*-Cresol	Nitrosomorpholine
p-Dichlorobenzene	Perchloroethylene
Dimethyl nitrosamine	Phenol
Dioxane	Phosgene
Dioxin	Polychlorinated biphenyls
Epichlorohydrin	Propylene oxide
Ethylene dibromide	Toluene
Ethylene dichloride	Trichloroethylene
Ethylene oxide	Vinylidene chloride
Formaldehyde	*o*-,*m*-,*p*-Xylene
Hexachlorocyclopentadiene	



Where potential emissions are measured depends upon the function of the control device — Fig. 1

New Source Review is necessary. If not, then the proposed facility may apply for a permit to construct. If a detailed review is required, then the facility must conduct a program of ambient and background air-quality monitoring and mathematical modelling to see if NAAQS are met. If so, then the facility may proceed with a Prevention of Significant Deterioration (PSD) review, which is outlined below. If not, the facility must apply control-technology offsets and proceed with additional mathematical modelling.

If the facility is to be located in an attainment area, then a PSD review is required. In this program, one applies control technology to meet New Source Performance Standards (NSPS). These standards can be specified as emission limitations, control-equipment specifications, or work-practice standards. Next, it must be determined whether applying NSPS reduces potential emissions to less than 50 tons/yr. If so, then a permit can be sought. If not, several additional steps may be required, including the monitoring of local air quality for one year.

The procedures for permit application are more complex than indicated here. A detailed analysis can sometimes be obtained from an in-house environmental staff, or, if not, from an environmental consultant.

Clean Air Act

Three sections of the Clean Air Act provide EPA with a basis to make rules for the control of fugitive emissions:

■ *Sec. 110* deals with *control technology guidelines*. Under this section, EPA is required to develop pollutant emission-control technologies for typical industrial facilities such as refineries or petrochemical plants. Development is based, in large part, upon data collected from monitoring surveys conducted by EPA or its designated consultants/contractors. Methods of monitoring and results of some specific major fugitive-emission studies will be discussed later on.

■ *Sec. 111* deals with *work-practice standards* for pollutant emission control. The theory and application of workplace standards will be discussed in detail in this report. This section also deals with the development of New Source Performance Standards. EPA has issued a 59-item list for the selection of NSPS projects by priority and by industry type. Synthetic organic chemical manufacturing is first on this list, followed by: No. 2—industrial surface coatings: cans; No. 3—petroleum refineries: fugitive sources; No. 4—industrial surface coatings: paper; and No. 5—dry cleaning.

■ *Sec. 112* deals with the development of *hazardous air-pollutant standards*. All regulations under Sec. 111 and 112 are scheduled to be issued by Aug. 7, 1982, as required by the Clean Air Act. Sec. 112 calls for the development of two regulations in regard to fugitive emissions: One deals with hazardous organic pollutants and the other with general organic pollutants. EPA is required to list, as necessary, such hazardous pollutants and to establish standards that provide an ample margin of safety to protect public health. Generic standards (treated next in this article) will be proposed when organic chemicals are listed as hazardous air pollutants. A list of 43 chemicals is being considered (see Table II). From this list, 10 to 15 chemicals will probably be listed as hazardous.

Proposed generic standard

We will now consider the generic standard that EPA is proposing for fugitive-emission control and compare it with the work practice standard being proposed by the Chemical Manufacturers Assn. (CMA), formerly the Manufacturing Chemists Assn., a Washington, D.C.,

EPA has set this schedule for issuing proposed fugitive-emissions guidelines and regulations — Table III

Control Techniques Guideline Document
Control of Volatile Organic Emissions from Chemical Plant Equipment Leaks
Draft (industry review)—May 1979
Final—September 1979

National Emission Standards for Hazardous Air Pollutants
1. Refinery Fugitive Benzene Sources
Pacific Environmental Services, Inc.
EPA contract No. 68-02-3060
Federal Register promulgation—early 1981
2. Synthetic Organic Chemical Manufacturing Industry
Fugitive Benzene Sources
Pacific Environmental Services, Inc.
EPA contract No. 68-02-3060
Federal Register promulgation—late 1981

New Source Performance Standards
Synthetic Organic Chemical Manufacturing Industry
Fugitive VOC Sources
Radian Corp.
EPA contract No. 68-02-3058
Federal Register promulgation—mid-1981

trade organization composed of major manufacturers of industrial chemicals.

CMA's proposed standard is summarized because it will influence EPA in setting a final standard. This is because the agency has been listening more to industry lately in setting policy.

EPA's projected schedule for fugitive-emissions guidelines and regulations is presented in Table III. In addition to the draft control-techniques-guideline document for the control of volatile organic emissions (VOC) from chemical-plant equipment leaks, it is assumed that draft documents for emissions and performance standards will also be available for comment prior to final promulgation of the regulations.

As stated in the December 1978 EPA draft standard, "Generic standards are standards which may be applied universally to similar emissions sources." These are independent of chemical type or process technology and are based on the similarity of processing equipment, particularly secondary equipment, such as valves and pump seals. As proposed by EPA, compliance would be affected by (1) a program of fugitive-emission detection, (2) correction of fugitive emissions by closer maintenance controls, and (3) good housekeeping practices.

The generic standards have to be implemented quickly, and with a minimum of capital. Also the standards have to remain essentially unchanged, even if additional other standards are promulgated. This is not only to keep costs down, but to expedite implementation and minimize retrofitting. Therefore, since direct quantitative monitoring of fugitive emissions is impractical, the new standard has to be centered on equipment or work-practice standards.

In fact, the draft generic standard contains an effective leak-detection program, with provisions for subsequent repair and maintenance. The generic standard requires different types of emission sources to be inspected at various predetermined intervals for subsequent repair. The intervals will be established from data collected in surveys of refineries and petrochemical plants, and will vary from weekly to annually, depending on the frequency of the particular types of leaks and their projected emission rates. Inspections will be most frequent for sources having a high probability of leakage and a likelihood of a large emission rate. The EPA proposed inspection intervals for compressor seals, pipelines, and pressure-relief valves are 1 to 3 mo. For pump seals, valves in liquid service, process drains and flanges, the rate is 3 to 12 mo. These ranges vary, depending upon the particular situation. So far, EPA has not defined these situations. More-specific inspection criteria will be treated later in this article when we discuss individual emission sources.

Cutoff range

To reduce the potential number of pieces of equipment that require inspection, EPA has proposed a lower cutoff range that excludes process streams carrying trace quantities of hazardous pollutants. The proposed lower limit is 1 to 10% by volume, depending upon the nature of the hazardous chemical constituent. This range is based upon results of recent engineering studies of refineries and petrochemical plants.

Using EPA's definition of a fugitive emission as one that produces a hydrocarbon concentration of at least 1,000 ppm at the source, the lower hazardous-pollutant concentration of 1% in the process stream would mean that the leak concentration would be limited to 10 ppm. Similarly, a lower cutoff of 10% would permit a hazardous-pollutant concentration of 100 ppm.

As stated in the draft generic standard, processing equipment containing concentrations at or above the cutoff levels would be inspected to determine whether gaseous or liquid leaks were occurring. If a gaseous leak occurred and the concentration were greater than 1,000 ppm (converted to an equivalent basis of hexane) when using a standard portable hydrocarbon detector, then repair would be required within a specified period of time.

This proposed time limit is between 5 and 15 days, depending upon the nature of the leaks. For example, more time is required when certain repairs are needed, as is the case of a damaged single mechanical seal. If repair of a fugitive-emission source prior to a plant shutdown would result in still greater emissions, then repair could be delayed until the shutdown. The delay, however, would be subject to review and approval by EPA.

The above summary noted the more salient features of the draft generic standard. The actual draft goes into much more detail, including extensive test methods and instrument-calibration techniques.

CMA proposed standard

Major portions of industry have taken exception to the proposed draft generic standard. Recently, the Chemical Manufacturers Assn. has proposed its own standard—a work-practice standard—for the chemical industry. This includes all the fugitive-emission sources listed in EPA's draft generic standard, but differs in the

particulars of leak detection, monitoring, repair, recordkeeping and reporting. In general, CMA has proposed that:

- Each facility develop its own leak detection and repair plan based upon EPA's criteria.
- Each facility maintain a log of when leaks are detected and repaired.
- All leaks should be repaired as soon as feasible.
- An annual report should be submitted to EPA.
- Weekly visual checks and operational checks must be made every time there is a transfer process.
- Quarterly monitoring checks should be made on equipment most liable to leak.
- Measures should be included to allow modification of the plan, as required, once results based on new studies or experience are available.

CMA intends to use EPA's proposed standard as a basis for its own standard. However, CMA feels that each facility should be allowed to develop its own cost-effective detection and control program, based on its own experience. Whatever form the EPA guidelines finally take, they should be flexible enough to allow a company to depart from them as long as such a departure is justified by the facility's past experience.

CMA's proposed work-practice standard applies to hazardous air pollutants as treated under Sec. 112 of the Clean Air Act. The standard will be applied for fugitive emissions of a hazardous air pollutant in cases where the EPA administrator, after a thorough study, determines that the work-practice standard is necessary to control the fugitive emission.

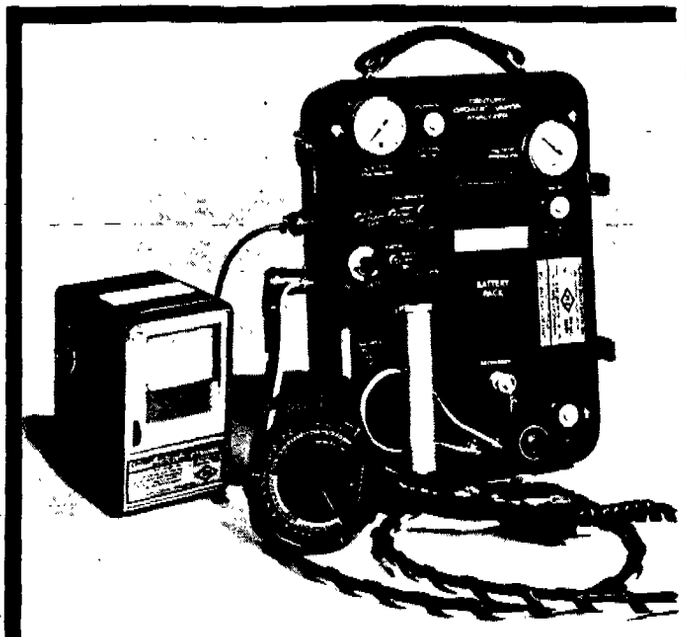
Further, the standard will be limited to facilities that process, store or transfer fluid mixtures containing 10% or more, by volume, of a hazardous air pollutant. The standard is not applicable to any fugitive-emission source that does not emit a hazardous air pollutant into the ambient air, nor does it apply to research and development facilities that process less than 5,000 lb/d of a hazardous chemical.

An essential part of the proposed CMA standard is the development of a Leak Detection and Repair Plan (LDRP) by each facility that processes hazardous air pollutants as described under Sec. 112. The facility shall adhere to the LDRP and keep a copy of it. The LDRP must also be certified by the owner of the facility as meeting the fugitive-emission criteria as established by EPA under the Clean Air Act.

The plan is to be reviewed and updated, as required, once every three years, or within 90 days of a major modification of the facility.

The LDRP shall, at the minimum: (1) develop a schedule and recordkeeping program for routine surveillance and/or monitoring of fugitive emissions; (2) establish a written plan for detection and repair of leaks, and a reasonable schedule for repair; (3) provide a written plan for sampling procedures, housekeeping (e.g., spill cleanup) and onsite waste handling; (4) develop recordkeeping procedures for all aspects of the LDRP and save these records for one year; and (5) establish a written plan for specifying sufficient personnel to fulfill the LDRP, and provide a training program with a written manual.

CMA's proposed standard also contains a detailed description of how an LDRP should be prepared, and includes discussions of housekeeping and sampling, chemical storage, chemical transfer and handling, waste handling, process vents, air-pollution control devices, and administrative procedures.



Century Systems Corp.

Portable organic-vapor analyzer used extensively in making individual source surveys for EPA Fig. 2

Having dealt exclusively thus far with the regulatory aspects of fugitive-emission control, we now turn to the more technical areas of concern. We will first look at monitoring and reporting, then at individual sources of fugitive emissions, and then at costs of these programs.

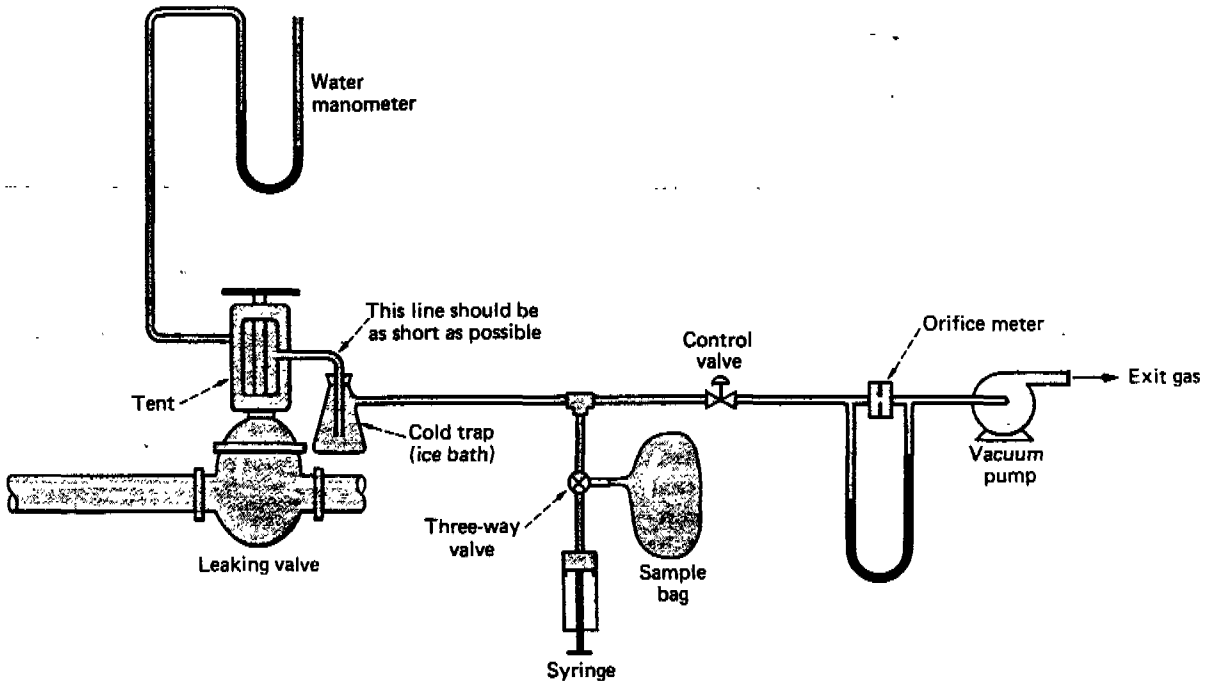
Monitoring fugitive emissions

There are several methods for detecting fugitive emissions and thereby enabling their control. These include source monitoring, area monitoring, and fixed-point monitoring. Only source monitoring has been investigated enough to establish its effectiveness. EPA has suggested that the use of a combination of monitoring techniques may be effective in locating large leaks that result in the more-significant releases of fugitive emissions in a plant.

Methods other than source monitoring are presented here, in part, in case there is a desire to develop data and to compare these with EPA's.

In evaluating the various monitoring techniques, a fundamental axiom of fugitive-emission detection and control is that a small number of sources contribute the majority of fugitive emissions. This will be discussed in greater detail later when we cover the sources of such emissions.

Area monitoring requires that an instrument operator, using a portable voc analyzer with a stripchart recorder, follow a predetermined path through a process unit. voc emissions are measured at a given distance, for example, 3 ft, from all equipment within the area. The operator makes a complete survey around each piece of equipment, being careful that the upwind and down-



"Bagging" fugitive emissions from a leaking valve. A tent encloses the leak Fig. 3

wind sides of the equipment are sampled. If a peak in concentration is observed, the location is noted, and a subsequent, more-detailed survey is made to locate the source.

It is estimated that as much as 50% of all significant leaks in the process unit can be detected by the walk-through unit-area survey, if all major leaks in the area have been repaired via an ongoing monitoring process, and if the plant has reduced voc background concentrations.

An advantage of this type of survey is that leaks from accessible equipment can be located quickly, and with considerably less manpower than required for an individual component survey. Disadvantages include possible detection of voc emissions from adjacent units, and low or missed voc readings due to high winds or gusts that dilute emissions. In addition, followup source monitoring is still required to determine the exact location of the source.

EPA considered continuous area monitoring to detect gaseous leaks of hazardous organic compounds—but found it impractical. The main reason for rejecting this method was that continuous monitoring equipment for measuring ambient-air concentrations of specific hazardous organic air pollutants would most likely not be available by the time that the particular air pollutant was identified as hazardous.

Fixed-point monitoring places analyzers at specific fixed points in a process area to monitor automatically for fugitive emissions. voc is monitored both locally and centrally, so that action can be taken when elevated concentrations are observed. Fixed-point monitoring is used only in those areas where voc compounds are handled.

EPA says that such monitoring may also be used as a maintenance tool to detect pending or existing equipment failures that can result in leaks. In this method, the individual samplers are placed either near specific pieces of equipment that handle vocs or in a grid pattern throughout the process area. If a concentration peak is observed, then the operator performs an individual component survey to locate the leak.

A major advantage of fixed-point monitoring is that it readily adapts to a particular processing facility's specific needs. Another advantage is that it has the lowest manpower requirement of the fugitive-emission monitoring systems.

Some of the disadvantages are that this system has the highest capital cost and still requires the use of a portable voc analyzer to locate the leak, especially if the process-area method is used. If background voc concentrations have been minimized by a proper monitoring, detection and repair program that has corrected major leaking equipment, this method is estimated to detect one third of all leaks.

Source monitoring detects leaks by checking individual sources—valves, flanges and seals, among others. A portable voc detector is used in this method. The sample probe of the instrument is placed at a point of a particular pipeline component where leakage could occur. The probe is moved along the surface with particular care that both upwind and downwind areas are sampled. The probe should traverse the source within one centimeter of the surface.

For sources having leak areas open directly to the atmosphere, such as cooling towers, process effluent drains, and pressure-relief valves, the probe is placed at both the center of the emission area and around its

periphery. A more-detailed description of the fugitive-emission survey protocol for each type of source is presented later on under the discussion of individual emission sources.

For measuring the organic vapor concentration in the collected sample, EPA has made extensive use of the Century Systems Corp.'s (Arkansas City, Kans.) Model 128 organic vapor analyzer (see Fig. 2). This instrument uses a flame-ionization detector that is accurate to 1 ppm of organic vapor, and the unit gives a direct readout with a 2-s response time.

Other source-monitoring methods

Several other methods of fugitive-emission source-testing have been used in Europe and in the U.S. Kremer [3] describes four ways to evaluate such losses under laboratory-type conditions. The first is the pressure-drop method, in which an isolated and completely sealed unit is pressurized, the source gas turned off, and the drop in static pressure noted. This method is useful mainly for detection of leak rates of whole sections of lines, including flanges, valves and other fittings.

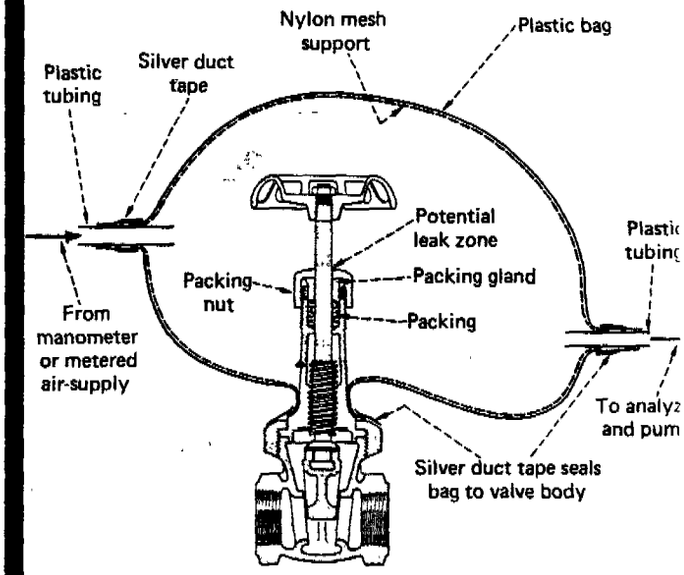
In the pressure-retention method, pressure drop due to leakage is compensated for by introducing a source gas, and the rate at which gas must be added to bring the fitting back up to pressure is recorded.

The capsule method measures leakage rates of individual components, such as flanges and seals, both in the laboratory and in the field. In this method, the component is enclosed in a globe, and a flush gas is circulated through the globe in a closed loop by means of a pump. A hydrocarbon detector measures the concentration of the fugitive gas in the flush gas. This method is reliable, but too much time is needed for setting it up.

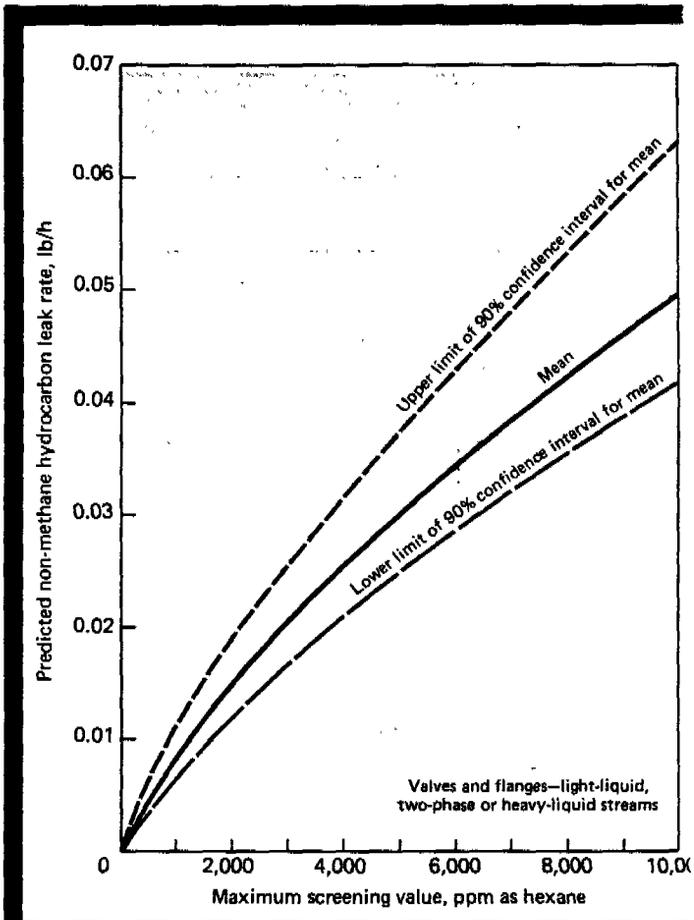
The fourth method—in more-common use in the U.S.—is to enclose the component in a plastic bag ("bagging"). Emissions are captured and then measured volumetrically. A typical setup is shown in Fig. 3. The sampling train operates under a slight negative pressure. The fugitive emission is exhausted from a polyester-film bag or tent that has been placed around the emission source. Fig. 4 shows the tent construction.

In Fig. 3, the captured fugitive gas enters a cold trap, where heavier hydrocarbons and water condense to prevent fouling of the sampling train. From there, the gas is drawn past a sampling syringe by means of a vacuum pump. An orifice meter measures the rate of flow of the fugitive gas. The syringe is filled with a measured volume of the gas, and the water manometer measures pressure to allow conversion to standard conditions (when the sample is being analyzed for voc concentration). By means of a three-way valve, the gas sample in the syringe is transferred to a tetrafluoroethylene sample bag. The sample voc concentration is measured by standard analytical means and, knowing the gas flowrate in the system, the mass emission rate of the fugitive emission is calculated.

Before samples are taken, ambient air is drawn through the tent for a specified time in order to equilibrate the volume inside the tent. At the same time, the background voc concentration is determined in the area immediately around the tented component. If the



A tent placed around the seal area of a valve collects emissions for study Fig. 4



Nomographs such as this will permit use of screening value to predict leak rate Fig. 5

EPA drafted this standard for oil refineries, based upon the use of screening values — Table IV

Source type	VOC emission factor estimate lb/(h)(source) Attainment areas	Nonattainment areas
Light-liquid pumps	0.26	0.097
Pipeline valves		
a. Gas/vapor streams	0.046	0.007
b. Light-liquid streams	0.022	0.009
Pressure-relief devices	0.35	0.15
Pipeline flanges	0.00057	0.00057
Compressors	0.97	0.277
Process drains	0.070	0.046
Sampling connections	0.033	0.026
Open-ended lines	0.0070	0.0
Wastewater separators	NA	NA
Vacuum-producing systems	NA	NA
Cooling towers	Negligible	Negligible
Process-unit turnarounds	NA	NA
Accumulator vents	2.71	2.71
Pressure-relief-device discharges	NA	NA

NA—No factor available

background concentration is too high (greater than 10 ppm), a pressurized sampling train can be used.

Screening values

Since EPA intends to add fugitive emissions to point source emissions in order to determine whether air-pollution regulations are being met, a quantitative measure of these leaks is needed. Such a measure has been developed by Radian Corp. (Austin, Tex.) [4] for EPA.

Radian studied fugitive emissions at nine petroleum refineries. One of the main objectives of its study was to establish a relationship between the screening values of fugitive-emission sources and quantitatively measured leakrates from the sources.

Screening values are defined as the maximum hydrocarbon concentration around a fugitive-emission source, as measured by a portable voc analyzer. The quantitative measurements were obtained from those same sources by "bagging" them as shown in Fig. 4, and measuring their mass fugitive-emission rates by means already described under the source-monitoring section of this article. These "baggable" sources include process valves, flanges, pump seals, compressor seals, relief valves and process drains.

The report develops nomographs that correlate mass emission rate of non-methane hydrocarbons with maximum screening values (in ppm as hexane).

Pump seals, inline valves and relief valves are among major fugitive-emission sources — Table V

Fugitive-emission source	Emission rate—lb/h Ref. 6	Ref. 7	Ref. 8	Ref. 9	Ref. 4	Percent leaking Ref. 4
Valves						
Gas/vapor streams	0.02	0.062	0.082 to 0.085	0.046 to 0.022	0.047	29
Light-liquid/2-phase streams					0.023	37
Heavy-liquid streams				—	0.0007	7
Flanges						
Gas/vapor streams		0.0004	0.1 to 1.1	0.0006	0.0005	3
Light-liquid/2-phase streams		0.004			0.0005	5
Heavy-liquid streams		—			0.0007	2
Pump seals						
Light-liquid streams	0.11		0.16 to 0.48	0.26	0.26	64
Heavy-liquid streams					0.045	23
Compressor seals						
Hydrocarbon service	0.064		0.077 to 0.65	0.968	0.98	70
Hydrogen service					0.10	81
Relief valves						
Gas/vapor streams		0.121	0.031 to 0.4	0.352	0.36	46
Light-liquid/2-phase streams					0.013	25
Heavy-liquid streams					0.019	35
Sampling connections				0.033		
Process drains						
Light-liquid/2-phase streams			0.15	0.0704	0.085	26
Heavy-liquid streams					0.029	18
Rotary mechanical seals on pumps and compressors		0.13				
Packing seals on piston compressors		0.23				

A typical nomograph, as developed in the Radian report, is presented in Fig. 5. The nomograph was derived for the mean and for the upper and lower 90%-confidence intervals around the mean. Radian developed these nomographs not only for different fugitive-emission sources, but also for different types of process streams within a source-type category. For example, there is one nomograph for valves and flanges carrying gas or vapor streams, and another for light-liquid, two-phase or heavy-liquid streams. These nomographs approximate mass emission rate of a fugitive emission source by measuring the non-methane hydrocarbon concentration. Once this relationship is established for a given source, it may be used to determine the maximum concentration that corresponds to a maximum allowable fugitive-source mass-emission rate, as determined by an NAAQS.

Using such data, EPA will likely set some limits on mass emissions from fugitive sources, at least in guideline form. An example of this: the EPA draft baseline VOC emission factors for refineries shown in Table IV. This table gives regulatory baseline fugitive-emission factors for all refinery sources in both NAAQS attainment and nonattainment areas. For refineries in nonattainment areas, regulations following the EPA guidelines will be enforced.

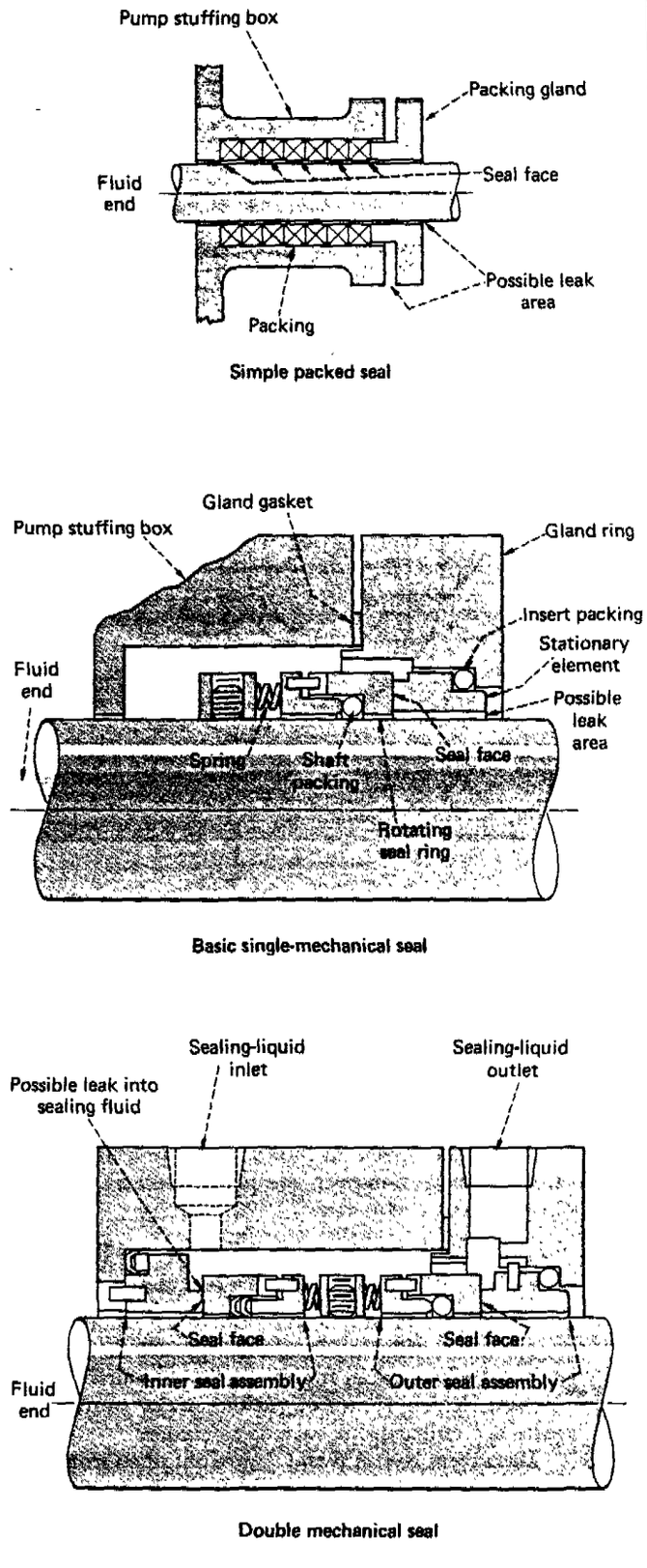
Petroleum refineries in attainment areas will most likely operate with uncontrolled fugitive emissions unless a hazardous-pollutant standard is established under Sec. 112 of the Clean Air Act.

Rather than measure quantitatively the suspected fugitive-emission sources within a chemical production facility in order to determine compliance or non-compliance, it is being proposed to establish maximum concentrations by means of these nomographs.

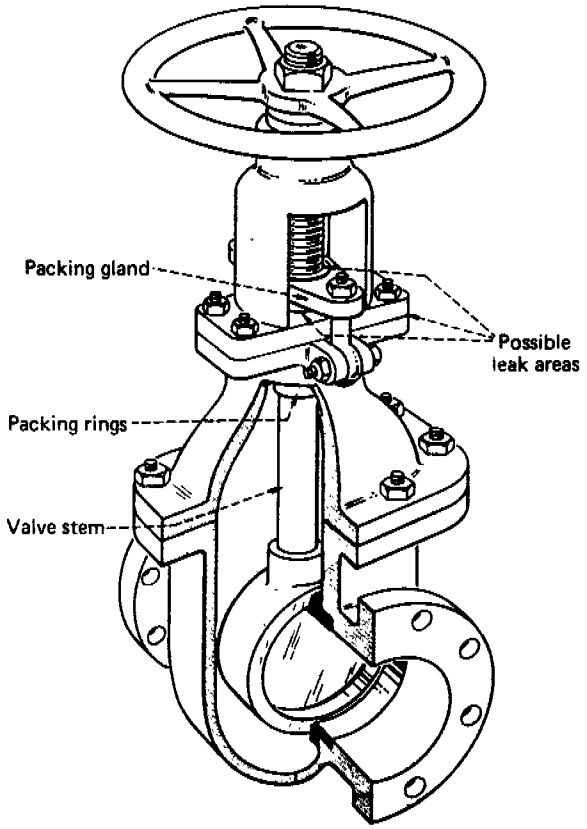
The Radian report also establishes a set of curves correlating percent of fugitive-emission sources with maximum screening value. There are also curves correlating maximum screening values with percent of total mass emissions. These curves indicate that, in most cases, screening values above 1,000 ppm account for 50% to 90% or more of all sources of emissions. EPA is using these data to establish what it believes is a practical screening value limit that will help control the majority of emissions.

Monsanto Research Corp.'s Dayton Laboratory (Dayton, Ohio) [5] studied fugitive emissions in four chemical plants producing monochlorobenzene, butadiene, ethylene oxide/glycol, and dimethylterephthalate. Hydrocarbon fugitive-emission rates were determined for pumps, valves, flanges, process drains, compressors, agitators, sample valves, and relief devices. Monsanto used the Century Systems Corp. Model 128 organic vapor analyzer.

Their data show a significant variation in leakage rates with petrochemical process, for the same source. For example, when processing monochlorobenzene, pumps had five times the leakage rate of valves, and the flange leakage-rate was 29 times that of the pumps (0.2, 1.0, and 29 m.t./yr for valves, pumps and flanges, respectively). Yet when processing butadiene, valves had 10 times the fugitive-emission rate of pumps, and flanges showed no leakage (1,000, 96, and 0 m.t./yr for



Of these three common shaft seals, double mechanical seals leak the least Fig. 6



Three areas of a typical gate valve that can leak and result in fugitive emissions Fig. 7

valves, pumps and flanges, respectively). This large variation is of concern to the CPI, because it poses a potential stumbling block to the setting of a maximum screening value for monitoring and detection of fugitive emissions.

The report also concludes that, for significant fugitive sources, average emission rates in petrochemical plants are markedly lower than those for corresponding sources for petroleum refineries.

Monsanto Research found there are also fewer fugitive-emission sources in the petrochemical plants than in petroleum refineries.

Monitoring individual sources

Having reviewed parts of the Clean Air Act that deal with fugitive emissions and gained an insight into EPA's proposed monitoring methodology, let us consider in detail the individual fugitive-emission sources. Table V presents leakage rates of various major sources. These rates are culled from various references.

Data from Ref. *4, 6* and *9* were obtained from surveys of petroleum refineries; while Refs. *7* and *8* are from petrochemical plants. Now, we will consider the individual sources:

Pumps with packed seals—Before discussing monitoring techniques for these, consider the possible leak areas of the packed seal, single mechanical seal, and double mechanical seal. Fig. 6 shows the simple packed seal. In this system, there are two possible leak areas: between the rotating shaft and the packing gland, and between the packing gland and the stuffing box.

The single mechanical seal in Fig. 6 reduces the possibility of leakage and limits fugitive emissions to one source point—the area between the seal's stationary element and the rotating shaft. The source of the leak is, of course, the seal face between the rotating seal ring and the seal's stationary element.

The double mechanical seal, also shown in Fig. 6, practically eliminates leakage by utilizing an externally pressurized liquid to seal the rotating and stationary seal elements. The only possibility of leakage is into the sealing liquid. With a properly chosen liquid, leakage can be controlled by absorption or reaction, with subsequent disposal of a purge stream.

It is a common fact that reciprocating pumps and compressors leak more than centrifugal units. This is because reciprocating units use packed seals, while centrifugals employ mechanical seals. Studies have shown that the leakage rate of mechanical seals is 50% less than that of packed seals.

Packed pump-seals account for approximately 5% of all fugitive emissions. Only 9% of all pumps account for this 5%-figure. The most effective method of reducing pump-seal emissions is to replace the packed seal with a mechanical seal.

According to EPA [*1*], the average uncontrolled emission rate, equal to 5 lb/d, can be reduced to 3 lb/d by seal replacement.

To perform an individual-source survey for detection of fugitive emissions from pump seals, EPA proposes the following: The probe of the portable VOC analyzer is traversed circumferentially around the outer periphery of the sealing element, i.e., the seal housing interface and the pump shaft. The probe should be held as closely as possible to the sealing element. When this cannot be done, because of physical restrictions, the probe should be placed within 1 cm of the interface between the shaft and seal.

In addition, any other possible points of fugitive emissions on the pump should be surveyed. When external seal fluids are employed, the seal fluid reservoir should also be surveyed.

Process valves—According to various literature sources, these account for about 75% of total fugitive emissions, or about 23% of total hydrocarbon emissions in the refinery and chemical process industries. Also, EPA surveys show that about 4% of all valves account for approximately 70% of total fugitive emissions. Clearly, then, industry should concentrate its efforts on valves to reduce fugitive emissions.

Fig. 7 shows a gate valve. The possible leakage areas are around the stem packing, the bonnet assembly and between the valve stem and packing gland.

In an analysis of leakage rates of the various valve types, Bierl, et al. [*7*] found that leakage rate varies with the type of packing used. In order of decreasing unit fugitive-emission rate, piston compressors (packed seals), centrifugal compressors (mechanical seals), safety-relief valves, and gate and control valves gave leakage rates of 42%, 24%, 21% and 10%, respectively, of total emissions for the source types listed. Ball valves

and flanges resulted in unit fugitive-emission rates of about 1% and 0.5%, respectively.

Referring to the influence of packing on leakage, Bierl lists the following packings in order of decreasing leakage: string, closed compressed rings, polytetrafluoroethylene (PTFE) packing, and PTFE lift rings. Regarding the effect of age on fugitive emissions from valves, Bierl pointed out that there was a five-fold increase in rate after 2 years. Also, more frequent use of a valve will result in earlier packing failure. In addition, leakage can be reduced by 90% through maintenance.

To perform an individual source survey of valves, EPA suggests placing the analyzer probe at the interface of valve stem and housing, and traversing the probe around the periphery of this interface. If other parts of the valve, such as those in a multi-piece bonnet construction, are suspected as emission sources, these should be surveyed in a similar manner.

Safety-relief valves—These are said to account for 10% of total VOC fugitive emissions.

Fig. 8 shows such a valve. Relief valves leak when subjected to repeated overpressures. In addition, the valve seat may become fouled, preventing the valve plug from closing properly, and this allows process gases and vapors to escape.

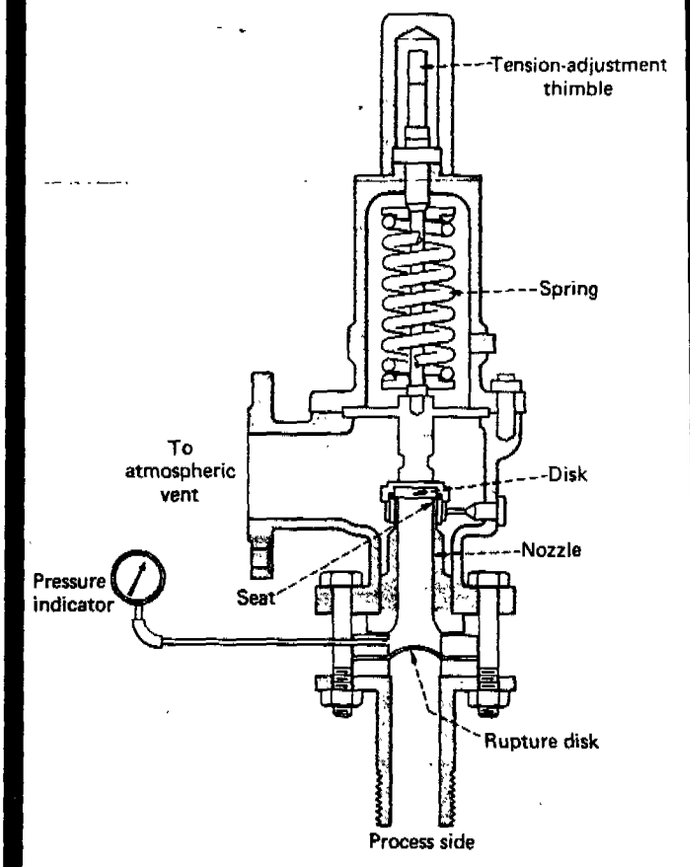
EPA proposes two methods to control fugitive emissions from relief valves: One is to vent all such devices to a flare system, which will burn up any fugitive emissions. A second method is to place a rupture disk just upstream of the relief valve to prevent its becoming fouled from normal pressure fluctuations. A pressure indicator placed between the rupture disk and the relief valve permits ready detection of a ruptured disk. EPA's suggested method for individual source surveying of these valves is to place the hydrocarbon detector probe at the center of the relief-valve exhaust horn.

Open-ended valves—These can leak from two sources: The first is the valve stem, as discussed under inline valves. The second area is at the valve seat, where leaks go directly into the atmosphere. EPA's recommended procedure for open-ended valves is to add either a second valve as backup or to place a blind flange on the atmospheric side of the valve. The suggested individual-source survey method is to place the hydrocarbon analyzer probe at the center of the uncovered opening to the atmosphere.

Sample valves—To reduce fugitive emissions from these devices, EPA proposes bleeding the sample into a closable container. The sample valve must remain closed whenever samples are not being drawn. Any samples of gases or vapors bled out of the system must be captured and either returned to the process or destroyed in an environmentally acceptable manner.

Less-significant sources

Process piping flanges—These account for only 4% of all fugitive emissions. For flanges, the emission rate increases as gasket size gets larger, and as gasket surface pressure also increases. A three- to tenfold increase in leak rate can be expected if good maintenance practices are *not* followed. To detect fugitive emissions from flanges, EPA suggests that individual-source surveys be made by placing the probe at the outer edge of the flange/gasket interface, and taking air samples around the periphery of that interface.



To control leaks, rupture disk with pressure indicator is added before safety-relief valve Fig. 8

Compressors—As indicated in Table V, compressors have the highest leak rate, but because relatively few of them are used in the CPI, compressors account for only 2% of all fugitive emissions.

To make an individual-source survey for compressors, the same procedure is followed as is used for pumps. When the compressor has an externally applied liquid seal, the seal liquid reservoir must be surveyed by placing the probe inlet at the center of the exhaust area to the atmosphere.

Cooling towers—Though normally considered a secondary-emissions source, cooling towers should be mentioned. Generally, most of the VOC compounds in cooling water result from leaks on the process side of heat-transfer equipment. Because of the large volume of air being handled, and the resulting immediate dilution of any fugitive emission, VOC-emission-rate data for cooling towers are not accurate. Because of this high dilution rate, it has been proposed to base future emission-calculation studies on total-organic-carbon (TOC) analyses. TOC analyses are made on the cooling water itself.

Wastewater treatment plants—When considering plants as potential fugitive-emission sources, one of the first areas to look at is process drains, which account for approximately 3% of all fugitive emissions. Process

Leak detection and repair survey log

Instrument operator:_____

Recorder:_____

Tag number	Unit	Component	Hazardous organic chemical concentration in stream	Date leak located	Date maintenance performed	Component recheck after maintenance	
						Date	Instrument reading (ppm)

Survey log would record leaks and their repair for hazardous organic chemicals Fig. 9

drains and wastewater separators contribute as much as 5 lb per thousand gal of wastewater. Through the use of vapor recovery systems and/or separator covers, EPA estimates, these emissions can be reduced to 0.2 lb per thousand gal.

To perform an individual-source survey of process drains, EPA suggests that the portable hydrocarbon probe be placed at the center of a process drain area that is open to atmosphere. For covered drains, place the probe at the surface of the cover, and traverse the periphery of the cover.

Spills—Regarding fugitive emissions due to spills, EPA has proposed housekeeping practices to reduce their amount. The recommended procedure is to clean the spill up within 8 h by siphoning it into a storage container, or by using chemical absorbents or an equivalent cleanup scheme.

Recordkeeping and reporting

EPA's draft generic standards for fugitive emissions propose requirements for recordkeeping and reporting. The draft standards state that such administrative procedures are necessary to ensure that the monitoring, detection, repair and housekeeping activities proposed by the standards are followed effectively. Any detected leaks are to be recorded in a logbook, and a notation is to be entered when the leak is repaired. EPA also wants to be notified quarterly about leaks that have not been repaired within the required interval.

The draft standard further specifies that the quar-

Tag number	Unit	Component	Hazardous organic chemical concentration in stream	Date leak located	Date maintenance performed	Dates maintenance attempted	Reasons repairs postponed or failed

EPA-proposed quarterly leak report would explain why leaks were not fixed Fig. 10

Estimated unit capital and operating costs for fugitive-emission control devices — Table VI

Control device	Capital cost per unit, $	Annual capital-recovery cost, $	Annual miscellaneous cost, $	Annual maintenance cost, $	Total annual operating cost, $
Double mechanical seals					
New	575	90	20	30	140
Retrofitted	850	140	30	40	210
Rupture disk	610	100	23	31	154
Blinds on open-ended valves	30	5	1	2	8
Closed-loop sampling	310	50	12	15	77
Closed-vent system	6,530	1,100	300	300	1,700

terly reports include a detailed listing of the units and components that have leaked beyond the specified repair interval. In addition, the date and duration of the leak must be given, as well as concentrations of hazardous pollutants in the fugitive emission.

In the draft generic standard, EPA wants to have the option of witnessing the fugitive-emission inspections, observations and monitoring. The draft generic standard, therefore, requires that the industrial facility notify EPA of the date of any monthly, quarterly or annual inspections, observations and monitoring at least one week in advance.

Further, the standards require that once an organic chemical is listed as hazardous (under the Clean Air Act, Sec. 112), the industrial facility must send EPA an estimate of the type and amount of emissions of that pollutant. This estimate must be sent within four months after the organic has been listed as hazardous. The estimate is to be categorized by specific fugitive-emission sources, such as those included in the draft generic standards. The fugitive-emission estimates would be calculated from nominal operating capacities.

The draft generic standards require that once a fugitive emission has been detected, it must be noted in a survey log (see Fig. 9), together with information as to the hazardous-pollutant concentration, the dates that the leak was detected and repaired, and the dates and results of subsequent recheck monitoring. A weatherproof and easily seen tag containing the date the leak was detected and the component identification number must be affixed to the fugitive-emission source. After repair of the leak, the log will be completed and the tag discarded. The log must be kept for two years.

Fig. 10 shows a proposed quarterly leak report that is to be submitted to EPA. Besides listing all the leaks that had been detected since the previous report and that had not been repaired within the specified 5 to 15-d interval, a statement signed by the manager of the facility must accompany the report. This statement attests to the fact that all required weekly, monthly, quarterly and yearly inspections, observations and monitoring had been performed.

Cost of control

The cost of a fugitive-emissions control program will now be estimated for a SOCMI plant, based on a report prepared by Hydroscience, Inc. [9] for EPA. Hydroscience lists scenarios for small, medium and large plants. Here, however, we will list only unit control costs, as well as develop monitoring and manpower requirements.

This report is the first major fugitive-emission study done for EPA on a SOCMI plant. Previous work dealt with refinery emissions at first, and then, more recently, with petrochemical plants. This report comprehensively discusses individual sources of fugitive emissions in the SOCMI facilities. After providing a detailed characterization and description of each source, the report concisely discusses the applicable technologies for controlling

Annual unit manpower requirements for monitoring process equipment — Table VII

Component	Type of monitoring	Estimated time for monitoring, min	Times monitored, no/yr
Pump seals	Instrument	5	1
	Visual	0.5	52
Compressor seals	Instrument	10	4
Inline valves (gas)	Instrument	1	4
Inline valves (liquid)	Instrument	1	1
Open-ended valves	Instrument	1	1
Safety-relief valves	Instrument	8	4
Pipeline flanges	None	—	—
Cooling towers	Instrument	10	1

Annual unit manpower maintenance requirements. Pump seals take the most time to repair — Table VIII

Component	Leakage frequency, %/yr	Repair time h/leak
Pump seals	12	80
Process valves	6	1.13
Safety-relief valves	7	0
Flanges	Minor	—
Compressor seals	7	40

fugitive emissions. It also details methods that are used for leak detection.

Table VI lists unit capital and operating costs for fugitive-emission control devices. Table VII gives unit monitoring manpower requirements, and Table VIII lists fugitive-emission-source unit-maintenance manpower requirements. Tabulation of unit costs and manpower requirements allows the reader to develop a cost scenario for his own plant.

Now, we will develop costs for a typical medium-sized (100 million to 400 million lb/yr) SOCMI plant, using Hydroscience's costs. Assume such a plant has the following pieces of process equipment, which are potential sources of fugitive emissions:

Equipment	Units
Pump seals:	
Mechanical (43 single; 10 double)	53
Packed	6
Process valves:	
Inline, gas	365
Inline, liquid	670
Open-ended	415
Compressor seals	2
Safety-relief valves	50
Pipeline flanges	2,400
Cooling towers	1

To comply with EPA's proposed guidelines, it is estimated that the plant would have to install the following emission-control equipment:

Equipment	Units
Double mechanical seals (retrofitted)	43
Rupture disks (before safety-relief valves)	50
Blind flanges (on open-ended valves)	415
Closed-loop sampling trains	104
Closed-vent systems (flares)	1

For this medium-sized plant, the total estimated monitoring manpower requirement would be 177 man-hours/yr (based on a two-man crew) for individual component surveys with visual inspection. Maintenance manpower requirements are estimated to be 680 man-hours/yr. Assuming monitoring and maintenance manpower costs $15/h, the total yearly labor cost would be $12,900.

In addition, Hydroscience estimates an additional annual $5,200 for administrative costs, $2,600 for instrumentation capital-related costs (based on two portable hydrocarbon analyzers at $4,800 each), and $2,700 for instrumentation supplies, maintenance, and calibration costs. This gives a grand total fugitive-emission monitoring and repair operating cost of $23,400 per year.

In addition, one must calculate the capital and operating costs associated with the purchase, installation, maintenance and operation of the fugitive-emission control-equipment listed above, using the unit costs listed in Table VI. It is then calculated that the total installed capital cost for this equipment is $118,300.

Similarly, the following annual costs are calculated: annual capital recovery = $19,400; annual control equipment maintenance cost = $5,800; and annual miscellaneous cost = $4,800. This gives a total annual equipment operating cost of $30,000. The total fugitive-emission control operating cost is, therefore, estimated at $53,400/yr. The capital required for purchasing and installing the individual-component monitoring and fugitive-emission control equipment is $127,900.

It can thus be readily seen that the economic impact of an industrywide fugitive-emission control program can be great, particularly on the small- to medium-sized chemical producer.

It would be advantageous to chemical producers to check Hydroscience's fugitive-emission and cost data against their experience in their own facilities. Such a comparison would be invaluable in providing comments to EPA as its proposed standards proceed toward final promulgation.

Richard Greene, Editor

References

1. U.S. EPA, Compilation of Air Pollutant Emission Factors, 3rd ed., supplement No. 8, May 1978. Pub. No. PB-288-905, National Technical Information Service, Springfield, VA 22161.
2. U.S. EPA, Air Quality Criteria for Photochemical Oxidants and Oxidant Precursors, Vol. 1—External Review Draft No. 1, Sept. 1977, U.S. EPA, Office of Research and Development, Washington, DC 20460.
3. Kremer, H., Leckraten statischer und dynamischer Dichtelemente an chemischen und petrochemischen Anlagen, Paper presented at 4th meeting OGEW/DGMK, Oct. 4-6, 1976 in Salzburg, Austria.
4. Radian Corp., Emission Factors and Frequency of Leak Occurrence for Fittings In Refinery Process Units, Feb. 1979, EPA 600/2-79-044, U.S. National Technical Information Service, Springfield, VA 22161.
5. Monsanto Research Corp., Source Assessment—Fugitive Hydrocarbon Emissions From Petrochemical Plants, EPA 600-4-78-004, Apr. 1978.
6. U.S. EPA, Guideline Document EPA-450/2-78-036, Control of Volatile Organic Compound Leaks From Petroleum Refinery Equipment, June 1978.
7. Bierl, A., et al., Leckraten von Dichtelementen, *Chemie Ingenieur Technik*, Vol. 49, No. 2 (1977), pp. 80-95.
8. Hughes, T. W., et al., Measurement of Fugitive Emissions From Petrochemical Plants, paper presented at 1979 AIChE meeting in Miami, Fla.
9. Hydroscience, Inc., Emission Control Options for the Synthetic Organic Chemicals Manufacturing Industry—Fugitive Emissions Report, report written for EPA's Emission Standards and Engineering Div., Office of Air Quality Planning and Standards, March 1979.

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