VOLUME II: CHAPTER 4

PREFERRED AND ALTERNATIVE METHODS FOR ESTIMATING FUGITIVE EMISSIONS FROM EQUIPMENT LEAKS

Final Report

November 1996

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Volume II, Chapter 4, Equipment Leaks, II04.fin
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ACKNOWLEDGEMENT

This document was prepared by David Epperson of Eastern Research Group, Inc., Wiley Barbour of the Office of Policy, Planning and Evaluation, U.S. Environmental Protection Agency, and Marco Zarate of Radian International LLC for the Point Sources Committee, Emission Inventory Improvement Program and for Dennis Beauregard of the Emission Factor and Inventory Group, U.S. Environmental Protection Agency. Members of the Point Sources Committee contributing to the preparation of this document are:

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CONTENTS

Section **Page**

CONTENTS (CONTINUED)

Section **Page**

FIGURES AND TABLES

Figures **Page**

Tables **Page**

FIGURES AND TABLES (CONTINUED)

Tables **Page**

1

INTRODUCTION

The purposes of this document are to present general information on methodologies and/or approaches for estimating air emissions from equipment leaks in a clear and concise manner and to provide specific example calculations to aid in the preparation and review of emission inventories.

Because documents describing procedures for estimating emissions from equipment leaks are readily available, duplication of detailed information will be avoided in this document. The reader is referred to the following reports that were used to develop this document:

- Environmental Protection Agency (EPA). November 1995. *Protocol for Equipment Leak Emission Estimates*. EPA-453/R-95-017; U.S. Environmental Protection Agency, Office of Air and Radiation, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina;

- Chemical Manufacturers Association (CMA). 1989. *Improving Air Quality: Guidance for Estimating Fugitive Emissions.* Second Edition. Washington, DC; and,

During the development of this guideline document, results of recent studies developed by the EPA for the petroleum industry were incorporated (Epperson, January, 1995). This information is available on the Office of Air Quality Planning and Standards (OAQPS) Technology Transfer Network (TTN) bulletin board (under the Clearinghouse for Inventories and Emission Factors [CHIEF]).

Section 2 of this chapter contains a general description of the equipment leak sources, such as valves, pumps, and compressors and also includes information on equipment leak control techniques and efficiencies. Section 3 of this chapter provides an overview of available approaches for estimating emissions from equipment leaks. Four main approaches are discussed and compared in Section 3: (1) average emission factor; (2) screening ranges; (3) EPA correlation equation; and (4) unit-specific correlation equations. Also included in this section are descriptions of available procedures for collecting equipment leaks data and a comparison of available emission estimation approaches. Section 4 presents the preferred method for estimating emissions, while Section 5 presents alternative emission estimation methods. Quality assurance and control procedures are described in Section 6 and data coding procedures are discussed in Section 7. References are listed in Section 8.

Appendix A presents information on how to estimate the control effectiveness of leak detection and repair (LDAR) programs. Appendix B presents additional information on response factors (RFs) and some guidelines on how to evaluate whether an RF correction to a screening value should be made. Appendix C of this chapter presents general information on methods and calculation procedures for mass emissions sampling (bagging). Appendix D presents an example data collection form that can be used for gathering information to estimate fugitive emissions from equipment leaks.

2

GENERAL SOURCE CATEGORY DESCRIPTION

2.1 SOURCE CATEGORY DESCRIPTION

Emissions occur from process equipment whenever components in the liquid or gas stream leak. These emissions generally occur randomly and are difficult to predict. In addition, these emissions may be intermittent and vary in intensity over time. Therefore, measurements of equipment leak emissions actually represent a "snapshot" of the leaking process. There are several potential sources of equipment leak emissions. Components such as pumps, valves, pressure relief valves, flanges, agitators, and compressors are potential sources that can leak due to seal failure. Other sources, such as open-ended lines, and sampling connections may leak to the atmosphere for reasons other than faulty seals. The majority of data collected for estimating equipment leak emissions has been for total organic compounds and non-methane organic compounds. Equipment leak emission data have been collected from the following industry segments:

- Synthetic Organic Chemical Manufacturing Industry (SOCMI);
- Petroleum Refineries;
- Petroleum Marketing Terminals; and
- Oil and Gas Production Facilities.

Each of these emission sources is briefly described in this section. A more detailed discussion of these sources can be found in the *Protocol for Equipment Leak Emission Estimates* (EPA, November 1995) and the *Equipment Leaks Enabling Document* (EPA, July 1992).

2.1.1 PUMPS

Pumps are used extensively in the petroleum and chemical industries for the movement of liquids. The centrifugal pump is the most widely used pump type in the chemical industry; however, other types, such as the positive displacement (reciprocating) pump, are also used. Chemicals transferred by pump can leak at the point of contact between the moving shaft and the stationary casing. Consequently, all pumps except the sealless type, such as canned-motor, magnetic drive, and diaphragm pumps, require a seal at the point where the shaft penetrates the housing in order to isolate the pumped fluid from the environment.

Two generic types of seals, packed and mechanical, are used on pumps. Packed seals can be used on both reciprocating and centrifugal pumps. A packed seal consists of a cavity ("stuffing box") in the pump casing filled with packing gland to form a seal around the shaft. Mechanical seals are limited in application to pumps with rotating shafts. There are single and dual mechanical seals, with many variations to their basic design and arrangement, but all have a lapped seal face between a stationary element and a rotating seal ring.

2.1.2 VALVES

Except for connectors, valves are the most common and numerous process equipment type found in the petroleum and chemical industries. Valves are available in many designs, and most contain a valve stem that operates to restrict or allow fluid flow. Typically, the stem is sealed by a packing gland or O-ring to prevent leakage of process fluid to the atmosphere. Emissions from valves occur at the stem or gland area of the valve body when the packing or O-ring in the valve fails.

2.1.3 COMPRESSORS

Compressors provide motive force for transporting gases through a process unit in much the same way that pumps transport liquids. Compressors are typically driven with rotating or reciprocating shafts. Thus, the sealing mechanisms for compressors are similar to those for pumps (i.e., packed and mechanical seals).

2.1.4 PRESSURE RELIEF DEVICES

Pressure relief devices are safety devices commonly used in petroleum and chemical facilities to prevent operating pressures from exceeding the maximum allowable working pressures of the process equipment. Note that it is not considered an equipment leak-type emission when a pressure relief device functions as designed during an over pressure incident allowing pressure to be reduced. Equipment leaks from pressure relief devices occur when material escapes from the pressure relief device during normal operation. The most common pressure relief valve (PRV) is spring-loaded. The PRV is designed to open when the operating pressure exceeds a set pressure and to reseat after the operating pressure has decreased to below the set pressure. Another pressure relief device is a rupture disk (RD) which does not result in equipment leak emissions. The disks are designed to remain whole and intact, and burst at a set pressure.

2.1.5 CONNECTORS AND FLANGES

Connectors and flanges are used to join sections of piping and equipment. They are used wherever pipes or other equipment (such as vessels, pumps, valves, and heat exchangers) require isolation or removal. Flanges are bolted, gasket-sealed connectors and are normally used for pipes with diameters of 2.0 inches or greater. The primary causes of flange leakage are poor installation, aging and deterioration of the sealant, and thermal stress. Flanges can also leak if improper gasket material is chosen.

Threaded fittings (connectors) are made by cutting threads into the outside end of one piece (male) and the inside end of another piece (female). These male and female parts are then screwed together like a nut and bolt. Threaded fittings are normally used to connect piping and equipment having diameters of 2.0 inches or less. Seals for threaded fittings are made by coating the male threads with a sealant before joining it to the female piece. The sealant may be a polymeric tape, brush-on paste, or other spreadable material that acts like glue in the joint. These sealants typically need to be replaced each time the joint is broken. Emissions can occur as the sealant ages and eventually cracks. Leakage can also occur as the result of poor assembly or sealant application, or from thermal stress on the piping and fittings.

In the 1993 petroleum industry studies, flanges were analyzed separately from connectors. Non-flanged connectors (or just connectors) were defined as plugs, screwed or threaded connectors, and union connectors that ranged in diameter from 0.5 to 8.0 inches, but were typically less than 3.0 inches in diameter. Flanged connectors (flanges) were larger, with diameters in some cases of 22.0 inches or more.

2.1.6 AGITATORS

Agitators are used in the chemical industry to stir or blend chemicals. Four seal arrangements are commonly used with agitators: packed seals, mechanical seals, hydraulic seals, and lip seals. Packed and mechanical seals for agitators are similar in design and application to packed and mechanical seals for pumps. In a hydraulic seal, an annular cup attached to the process vessel contains a liquid that contracts an inverted cup attached to the rotating agitator shaft. Although the simplest agitator shaft seal, the hydraulic seal, is limited to low temperature/low pressure applications, and can handle only very small pressure changes. A lip seal consists of a spring-loaded, nonlubricated elastomer element, and is limited in application to low-pressure, top-entering agitators.

2.1.7 OPEN-ENDED LINES

Some valves are installed in a system so that they function with the downstream line open to the atmosphere. A faulty valve seat or incompletely closed valve on such an open-ended line would result in a leakage through the open end.

2.1.8 SAMPLING CONNECTIONS

Sampling connections are used to obtain samples from within the process. Emissions occur as a result of purging the sampling line to obtain a representative sample of the process fluid.

2.2 POLLUTANT COVERAGE

2.2.1 TOTAL ORGANIC COMPOUNDS

The majority of data collected for estimating equipment leaks within the petroleum and gas industries and the SOCMI has been for total organic compounds and non-methane organic compounds. Therefore, the emission factors and correlations developed for emission estimation approaches are intended to be used for estimating total organic compound (TOC) emissions.

2.2.2 SPECIATED ORGANICS/HAZARDOUS AND TOXIC AIR POLLUTANTS

Because material in equipment within a process unit is often a mixture of several chemicals, equipment leak emission estimates for specific volatile organic compounds (VOCs), hazardous air pollutants (HAPs), and/or pollutants under Section 112(r) of the Clean Air Act, as amended can be obtained by multiplying the TOC emissions from a particular equipment times the ratio of the concentration of the specific VOC/pollutant to the TOC concentration, both in weight percent. An assumption in the above estimation is that the weight percent of the chemicals in the mixture contained in the equipment will equal the weight percent of the chemicals in the leaking material. In general, this assumption should be accurate for single-phase streams containing any gas/vapor material or liquid mixtures containing constituents of similar volatilities. Engineering judgement should be used to estimate emissions of individual chemical species, in cases when:

- The material in the equipment piece is a liquid mixture of constituents with varying volatilities; or

- It is suspected that the leaking vapor will have different concentrations than the liquid.

2.2.3 INORGANIC COMPOUNDS

The emission estimation approaches developed for estimating TOC emissions may be used to estimate emissions of inorganic compounds--particularly for volatile compounds or those present as a gas/vapor. Also, in the event that there is no approach available to estimate the concentration of the inorganic compound at the leak interface, the average emission factors developed for organic compounds can be used; however, the accuracy of the emission estimate will be unknown.

2.3 ESTIMATION OF CONTROL EFFICIENCIES FOR EQUIPMENT LEAK CONTROL TECHNIQUES

Two primary techniques are used to reduce equipment leak emissions: (1) modifying or replacing existing equipment, and (2) implementing an LDAR program. Equipment modifications are applicable for each of the leaking equipment described in this section. An LDAR program is a structured program to detect and repair equipment that are identified as leaking; however, it is more effective on some equipment than others.

The use of equipment modifications and equipment included in an LDAR program are predicated by state and federal regulations that facilities/process units are required to meet. In most equipment leak regulations, a combination of equipment modifications and LDAR requirements are used. Table 4.A-1 in Appendix A of this chapter summarizes requirements in several federal equipment leak control regulations.

2.3.1 REPLACEMENT/MODIFICATION OF EXISTING EQUIPMENT

Controlling emissions by modifying existing equipment is achieved by either installing additional equipment that eliminates or reduces emissions, or replacing existing equipment with sealless types. Equipment modifications that can be used for each type of equipment described in this section, and their corresponding emission control efficiencies are presented in Table 4.2-1. A closed-vent system is a typical modification for pumps, compressors, and pressure relief devices. A closed-vent system captures leaking vapors and routes them to a control device. The control efficiency of a closed-vent system depends on the efficiency of the vapor transport system and the efficiency of the control device. A closed-vent system can be installed on a single piece of equipment or on a group of equipment pieces. A description of the controls by equipment type are briefly presented below.

Pumps

Equipment modifications that are control options for pumps include: (1) routing leaking vapors to a closed-vent system, (2) installing a dual mechanical seal containing a barrier fluid, or (3) replacing the existing pump with a sealless type. Dual mechanical seals and sealless pumps are discussed in detail in Chapter 5 of the *Equipment Leaks Enabling Document* (EPA, July 1992). The control efficiency of sealless pumps and a dual mechanical seal with a barrier fluid at a higher pressure than the pumped fluid is essentially 100 percent, assuming both the inner and outer seal do not fail simultaneously.

TABLE 4.2-1

SUMMARY OF EQUIPMENT MODIFICATIONS

Equipment Type	Modification	Approximate Control Efficiency (%)
Pumps	Sealless design	100[a]
	Closed-vent system	90[b]
	Dual mechanical seal with barrier fluid maintained at a higher pressure than the pumped fluid	100
Valves	Sealless design	100[a]
Compressors	Closed-vent system	90[b]
	Dual mechanical seal with barrier fluid maintained at a higher pressure than the compressed gas	100
Pressure relief devices	Closed-vent system	[c]
	Rupture disk assembly	100
Connectors	Weld together	100
Open-ended lines	Blind, cap, plug, or second valve	100
Sampling connections	Closed-loop sampling	100

[a] Sealless equipment can be a large source of emissions in the event of equipment failure.

[b] Actual efficiency of a closed-vent system depends on percentage of vapors collected and the efficiency of the control device to which the vapors are routed.

[c] Control efficiency of closed vent-systems installed on a pressure relief device may be lower than other closed-vent systems because they must be designed to handle both potentially large and small volumes of vapor.

Valves

Emissions from process valves can be eliminated if the valve stem can be isolated from the process fluid, (i.e., using sealless valves). Two types of sealless valves, diaphragm valves and sealed bellows, are available. The control efficiency of both diaphragm and sealed bellowed valves is essentially 100 percent.

Compressors

Emissions from compressors may be reduced by collecting and controlling the emissions from the seal using a closed-vent system or by improving seal performance by using a dual mechanical seal system similar to pumps. The dual mechanical seal system has an emissions control efficiency of 100 percent, assuming both the inner and outer seal do not fail simultaneously.

Pressure Relief Valves

Equipment leaks from pressure relief valves (PRVs) occur as a result of improper reseating of the valve after a release, or if the process is operating too close to the set pressure of the PRV and the PRV does not maintain the seal. There are two primary equipment modifications that can be used for controlling equipment leaks from pressure relief devices: (1) a closed-vent system, or (2) use of a rupture disk in conjunction with the PRV.

The equipment leak control efficiency for a closed-vent system installed on a PRV may not be as high as what can be achieved for other pieces of equipment because emissions from PRVs can have variable flow during an overpressure situation and it may be difficult to design a control device to efficiently handle both high and low flow emissions. Rupture disks can be installed upstream of a PRV to prevent fugitive emissions through the PRV seat. The control efficiency of a rupture disk/PRV combination is essentially 100 percent when operated and maintained properly.

Connectors and Flanges

In cases where connectors are not required for safety, maintenance, process modification, or periodic equipment removal, emissions can be eliminated by welding the connectors together.

Open-Ended Lines

Emissions from open-ended lines can be controlled by properly installing a cap, plug, or second valve to the open end. The control efficiency of these measures is essentially 100 percent.

Sampling Connections

Emissions from sampling connections can be reduced by using a closed-loop sampling system or by collecting the purged process fluid and transferring it to a control device or back to the process. The efficiency of a closed-loop system is 100 percent.

2.3.2 LEAK DETECTION AND REPAIR (LDAR) PROGRAMS

An LDAR program is a structured program to detect and repair equipment that is identified as leaking. A portable screening device is used to identify (monitor) pieces of equipment that are emitting sufficient amounts of material to warrant reduction of the emissions through simple repair techniques. These programs are best applied to equipment types that can be repaired on-line, resulting in immediate emissions reduction.

An LDAR program may include most types of equipment leaks; however, it is best-suited to valves and pumps and can also be implemented for connectors. For other equipment types, an LDAR program is not as applicable. Compressors are repaired in a manner similar to pumps; however, because compressors ordinarily do not have a spare for bypass, a process unit shutdown may be required for repair. Open-ended lines are most easily controlled by equipment modifications. Emissions from sampling connections can only be reduced by changing the method of collecting the sample, and cannot be reduced by an LDAR program. Safety considerations may preclude the use on an LDAR program on pressure relief valves.

The control efficiency of an LDAR program is dependent on three factors: (1) how a leak is defined, (2) the monitoring frequency of the LDAR program, and (3) the final leak frequency after the LDAR program is implemented. The leak definition is the screening value measured by a portable screening device at which a leak is indicated if a piece of equipment screens equal to or greater than that value. Screening values are measured as concentrations in parts per million by volume (ppmv). The leak definition is a given part of an LDAR program and can either be defined by the facility implementing the program or by an equipment standard to which the facility must comply. Table 4.A-1 in Appendix A of this document provides equipment leak screening values for several equipment leak control programs. The monitoring frequency is the number of times a year (daily, weekly, monthly, quarterly, yearly) that equipment are monitored with a portable screening device. The monitoring frequency may be estimated from the initial leak frequency before the LDAR program is implemented, and the final leak frequency after the LDAR program is implemented. The leak frequency is the fraction of equipment with screening values equal to or greater than the leak definition. The LDAR program control efficiency approach is based on the relationship between the percentage of equipment pieces that are leaking and the corresponding average leak rate for all of the equipment.

Most federal equipment leak control programs have quarterly or monthly monitoring requirements. However, the LDAR monitoring frequency and leak definitions at some state equipment leak control programs may be different from federal programs. During the planning of a LDAR program, it is recommended to contact the local environmental agency to find out about their LDAR program guidelines and/or requirements.

The EPA has developed control efficiencies for equipment monitored at specified leak definitions and frequencies. Tables 4.2-2 and 4.2-3 summarize the control efficiencies for equipment that are monitored quarterly and monthly at a leak definition of 10,000 ppmv, and equipment meeting the LDAR requirements of the National Emission Standard for Hazardous Air Pollutants (NESHAP) for hazardous organics known as the Hazardous Organic NESHAP (HON). Although it was developed for the SOCMI, it is the basis for most new equipment leak regulations for other industries. Appendix A presents information on how to develop process/facility-specific control efficiencies.

TABLE 4.2-2

CONTROL EFFECTIVENESS FOR AN LDAR PROGRAM AT A SOCMI PROCESS UNIT

	Control Effectiveness (%)		
Equipment Type and Service	**Monthly Monitoring 10,000 ppmv Leak Definition**	**Quarterly Monitoring 10,000 ppmv Leak Definition**	**HON[a]**
Valves - gas	87	67	92
Valves - light liquid	84	61	88
Pumps - light liquid	69	45	75
Compressors - gas	[b]	[b]	93
Connectors - gas and light liquid	[b]	33	[b]
Pressure relief devices - gas	[b]	44	[b]

[a] Control effectiveness attributed to the requirements of the HON equipment leak regulation is estimated based on equipment-specific leak definitions and performance levels.

[b] Data are not available to estimate control effectiveness.

TABLE 4.2-3

CONTROL EFFECTIVENESS FOR LDAR COMPONENT MONITORING FREQUENCIES FOR PETROLEUM REFINERIES

	Control Effectiveness (%)		
Equipment Type and Service	**Monthly Monitoring 10,000 ppmv Leak Definition**[a]	**Quarterly Monitoring 10,000 ppmv Leak Definition**[a,b]	**HON**[a,c]
Valves - gas	88	70	96
Valves - light liquid	76	61	95
Pumps - light liquid	68	45	88
Compressors - gas	[d]	33	[e]
Connectors - gas and light liquid	[f]	[f]	81
Pressure relief devices - gas	[d]	44	[e]

[a] Source: EPA, July 1992.

[b] Source: EPA, April 1982.

[c] Control effectiveness attributed to the requirements of the HON equipment leak regulation is estimated based on equipment-specific leak definitions and performance levels.

[d] Monthly monitoring of component is not required in any control program.

[e] Rule requires equipment modifications instead of LDAR.

[f] Information not available.

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3

OVERVIEW OF AVAILABLE METHODS

This section contains general information on the four basic approaches for estimating equipment leak emissions. The approach used is dependent upon available data, available resources to develop additional data, and the degree of accuracy needed in the estimate.

Regulatory considerations should also be taken into account in selecting an emission estimation approach. These considerations may include air toxic evaluations, nonattainment emission inventory reporting requirements, permit reporting requirements, and employee exposure concerns.

Each approach is briefly described including its corresponding data requirements. Since data collection procedures will impact the accuracy of the emission estimate, this section also includes a general description of the two variable procedures for collecting equipment leaks data, screening and bagging procedures, and available monitoring methods. Finally, a general description for estimating control efficiencies for equipment leak control techniques is presented. Table 4.3-1 lists the variables and symbols used in the following discussions on emissions estimates.

3.1 EMISSION ESTIMATION APPROACHES

There are four basic approaches for estimating emissions from equipment leaks in a specific processing unit. The approaches, in order of increasing refinement, are:

- Average emission factor approach;
- Screening ranges approach;
- EPA correlation approach; and
- Unit-specific correlation approach.

The approaches increase in complexity and in the amount of data collection and analysis required. All the approaches require some data collection, data analysis and/or statistical evaluation.

These approaches range from simply applying accurate equipment counts to average emission factors to the more complex project of developing unit-specific correlations of mass emission

TABLE 4.3-1

LIST OF VARIABLES AND SYMBOLS

Variable	Symbol	Units
TOC mass emissions	E_{TOC}	kg/hr of TOC
VOC mass emissions	E_{VOC}	kg/hr of VOC
Mass emissions of organic chemical x	E_x	kg/hr of organic chemical x
Concentration of TOCs	WP_{TOC}	weight percent of TOCs
VOC concentration	WP_{VOC}	weight percent of VOCs
Concentration of organic chemical x	WP_x	weight percent of organic chemical x
Average emission factor	F_A	typically, kg/hr per source
Emission factor for screening value ≥10,000 ppmv	F_G	kg/hr per source
Emission factor for screening value <10,000 ppmv	F_L	kg/hr per source
Concentration from screening value	SV	ppmv

rates and screening values. In general, the more refined approaches require more data and provide more accurate emission estimates for a process unit. Also, the more refined approaches, especially the unit-specific correlation approach which requires bagging data, require a larger budget to implement the program and develop the correlation equations.

Figure 4.3-1 shows an overview of the data collection and analysis required to apply each of the above approaches. All of the approaches require an accurate count of equipment components by the type of equipment (e.g., valves, pumps, connectors), and for some of the equipment types, the count must be further described by service (e.g., heavy liquid, light liquid, and gas).

The chemical industry has developed alternative methods for estimating equipment component count (CMA, 1989). One of the methods calls for an accurate count of the number of pumps in the process and the service of the pumps. Equipment components in the entire process are then estimated through use of the number of pumps. Another method calls for an accurate count of valves directly associated with a specific piece of equipment using process flow sheets; and then based on the number of valves, the number of flanges and fittings are estimated using ratios (e.g., flanges/valves) A careful selection/development of the methodology used to quantify the equipment component count should be made to accurately reflect the equipment leak emission estimates for any facilities and/or process units.

Except for the average emission factor approach, all of the approaches require screening data. Screening data are collected by using a portable monitoring instrument to sample air from potential leak interfaces on individual pieces of equipment. A screening value is a measure of the concentration of leaking compounds in the ambient air that provides an indication of the leak rate from an equipment piece, and is measured in units of parts per million by volume (ppmv). See "Source Screening" in this section for details about screening procedures.

In addition to equipment counts and screening data, the unit-specific correlation approach requires bagging data. Bagging data consist of screening values and their associated measured leak rates. A leak rate is measured by enclosing an equipment piece in a bag to determine the actual mass emission rate of the leak. The screening values and measured leak rates from several pieces of equipment are used to develop a unit-specific correlation. The resulting leak rate/screening value correlation predicts the mass emission rate as a function of the screening value. See "Mass Emissions Sampling (Bagging)" in this section for details about bagging procedures.

These approaches are applicable to any chemical- and petroleum-handling facility. However, more than one set of emission factors or correlations have been developed by the EPA and other regulatory agencies, depending upon the type of process unit being considered.

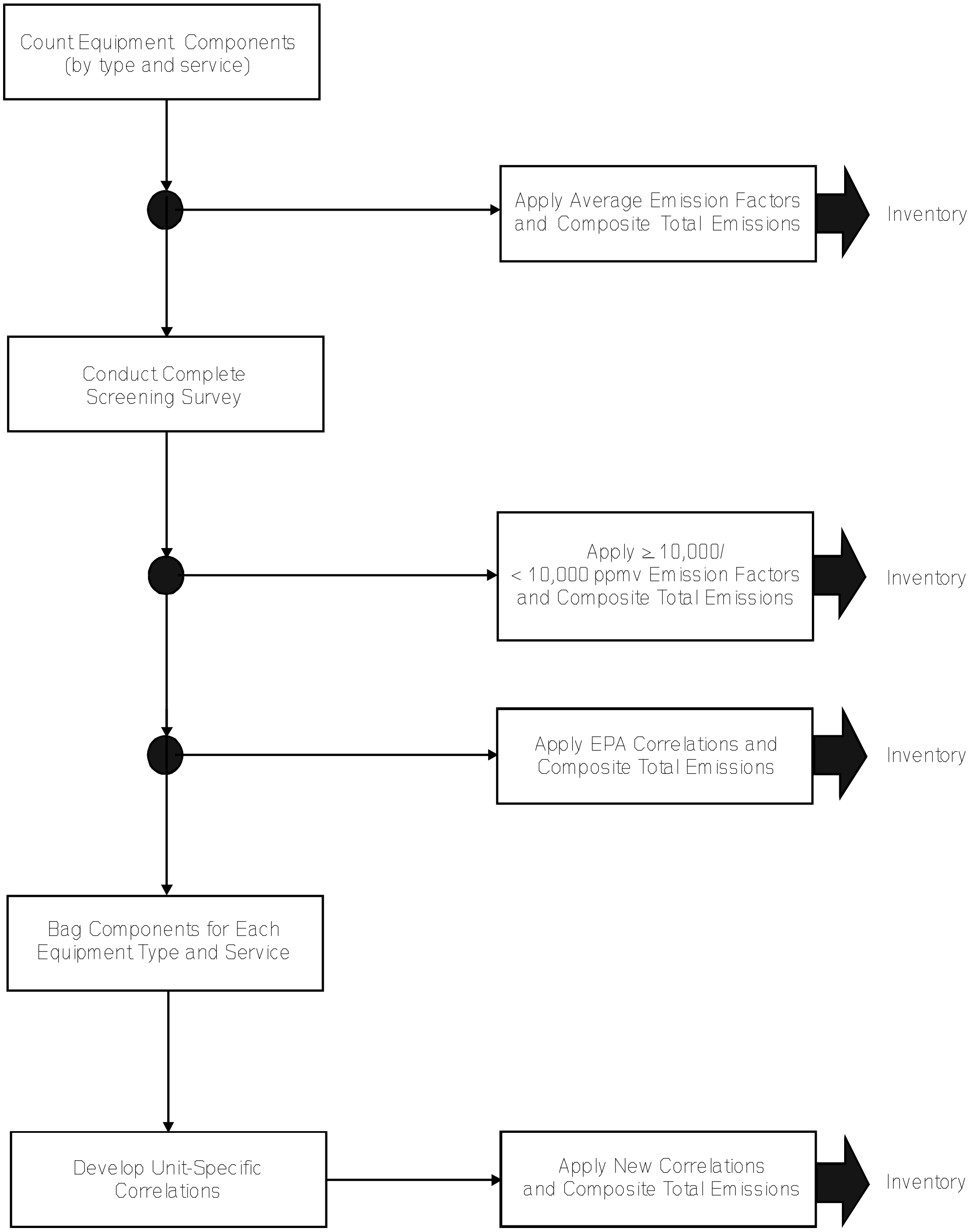


Figure 4.3-1. Overview of Data Collection and Analysis Approaches For Developing Equipment Leak Emissions Inventory

EPA data collection on emissions from equipment leaks in SOCMI facilities, refineries, oil and gas production operations, and marketing terminals has yielded emission factors and correlations for these source categories. Emission factors and correlations for oil and gas production facilities, including well heads, have also been developed by regulatory agencies and the American Petroleum Institute (CARB, August 1989; API, 1993).

For process units in source categories for which emission factors and/or correlations have not been developed, the factors and/or correlations already developed can be utilized. However, appropriate evidence should indicate that the existing emission factors and correlations are applicable to the source category in question. Criteria for determining the appropriateness of applying existing emission factors and correlations to another source category may include one or more of the following: (1) process design; (2) process operation parameters (i.e., pressure and temperature); (3) types of equipment used; and, (4) types of material handled. For example, in most cases, SOCMI emission factors and correlations are applicable for estimating equipment leak emissions from the polymer and resin manufacturing industry. This is because, in general, these two industries have comparable process design and comparable process operations; they use the same types of equipment and they tend to use similar feedstock with similar operations, molecular weight, density, and viscosity. Therefore, response factors should also be similar for screening values.

In estimating emissions for a given process unit, all equipment components must be screened for each class of components. However, in some cases, equipment is difficult or unsafe to screen or it is not possible to screen every equipment piece due to cost considerations. The latter is particularly true for connectors. The *Protocol for Equipment Leak Emission Estimates* (EPA, November 1995) provides criteria for determining how may connectors must be screened to constitute a large enough sample size to identify the screening value distribution for connectors. However, if the process unit to be screened is subject to a standard which requires the screening of connectors, then all connectors must be screened. If the criteria presented in the *Protocol* document are met, the average emission rate for connectors that were connected can be applied to connectors that were not screened. For equipment types other than connectors, including difficult or unsafe-to-screen equipment, that are not monitored, the average emission factor approach or the average emission rate for the equipment components that were screened can be used to estimate emissions.

Also, screening data collected at several different times can be used for estimating emissions, as long as the elapsed time between values obtained is known. For example, if quarterly monitoring is performed on a valve, four screening values will be obtained from the valve in an annual period. The annual emissions from the valve should be calculated by determining the emissions for each quarter based on the operational hours for the quarter, and summing the quarterly emission together to get entire year emissions.

3.2 SPECIATING EMISSIONS

In some cases, it may be necessary to estimate emissions of a specific VOC in a mixture of several chemicals. The equations developed for each one of the approaches (see Sections 4 and 5) are used to estimate total VOC emissions; the following equation is used to speciate emissions from a single equipment piece:

$$E_x = E_{TOC} \times WP_x/WP_{TOC} \qquad (4.3\text{-}1)$$

where:

E_x = The mass emissions of organic chemical "x" from the equipment (kg/hr);

E_{TOC} = The TOC mass emissions from the equipment (kg/hr) calculated from either the Average Emission Factor, Screening Ranges, EPA Correlation, or Unit-Specific Correlation approaches;

WP_x = The concentration of organic chemical x in the equipment in weight percent; and

WP_{TOC} = The TOC concentration in the equipment in weight percent.

An assumption in the above equation is that the weight percent of the chemicals in the mixture contained in the equipment will equal the weight percent of the chemicals in the leaking material. In general, this assumption should be accurate for single-phase streams containing any gas/vapor material or liquid mixtures containing constituents of similar volatilities.

Engineering judgement should be used to estimate emissions of individual chemical species from liquid mixtures of constituents with varying volatilities or in cases where it is suspected that the leaking vapor has different concentrations than the liquid.

3.3 ORGANIC COMPOUND EMISSION ESTIMATES FROM EQUIPMENT CONTAINING NON-VOCS

A very similar approach to the one used to speciate emissions can be used to estimate organic compound emissions from equipment containing organic compounds not classified as VOCs. Because the concentrations of these compounds (such as methane or ethane) are included with VOC concentrations in the screening value, the emissions associated with the screening value will include emissions of the "non-VOCs."

Once TOC emissions have been estimated, the organic compound emissions from a group of equipment containing similar composition can be calculated using the equation:

$$E_{VOC} = E_{TOC} \times WP_{VOC}/WP_{TOC} \tag{4.3-2}$$

where:

E_{VOC} = The VOC mass emissions from the equipment (kg/hr);
E_{TOC} = The TOC mass emissions from the equipment (kg/hr) calculated from either the Average Emission Factor, Screening Ranges, EPA Correlation, or Unit-Specific Correlation approaches;
WP_{VOC} = The concentration of VOC in the equipment in weight percent; and
WP_{TOC} = The TOC concentration in the equipment in weight percent.

3.4 INORGANIC COMPOUND EMISSION ESTIMATES

The emission factors and correlations presented in this document are intended to be applied to estimate emissions of total organic compounds. However, in some cases, it may be necessary to estimate equipment leak emissions of inorganic compounds, particularly for those existing as gas/vapor or for volatile compounds.

Equipment leak emission estimates of inorganic compounds can be obtained by the following methods:

- Develop unit-specific correlations;

- Use a portable monitoring instrument to obtain actual concentrations of the inorganic compounds and then enter the screening values obtained into the applicable correlations developed by the EPA;

- Use the screening values obtained above and apply the emission factors corresponding to that screening range; or

- Multiply the average emission factor by the component count to estimate the leak rate.

Also, surrogate measurements can be used to estimate emissions of inorganic compounds. For example, potassium iodide (KI) or a similar salt solution is an indicator for equipment leaks from acid (hydrochloric acid [HCl], hydrofluoric acid [HF]) process lines.

3.5 DESCRIPTION OF AVAILABLE PROCEDURES FOR COLLECTING EQUIPMENT LEAKS DATA

The *Protocol* document (EPA, November 1995) provides a consistent approach for collecting equipment leaks data, which will ensure the development of acceptable emission factors and/or correlation equations for emission estimation purposes. Recognizing the importance of the above statement, general information on the two available procedures for collecting equipment leaks data, screening and bagging, is presented in this section.

3.5.1 SOURCE SCREENING

This part of the section provides general information for conducting a screening program on-site and provides a short description of the type of portable analyzers that can be used when conducting screening surveys.

Source screening is performed with a portable organic compound analyzer (screening device). The *Protocol* document (EPA, November 1995) requires that the portable analyzer probe opening be placed at the leak interface of the equipment component to obtain a "screening" value. The screening value is an indication of the concentration level of any leaking material at the leak interface.

Some state and local agencies may require different screening procedures with respect to the distance between the probe and the leak interface. The reader should contact their state or local agency to determine the appropriate screening guidelines. However, use of the leak rate correlations require screening values gathered as closely as practicable to the leak interface.

The main objective of a screening program is to measure organic compound concentration at any potential leak point associated with a process unit. A list of equipment types that are potential sources of equipment leak emissions is provided in Table 4.3-2.

The first step is to define the process unit boundaries and obtain a component count of the equipment that could release fugitive emissions. A process unit can be defined as the smallest set of process equipment that can operate independently and includes all operations necessary to achieve its process objective. The use of a simplified flow diagram of the process is recommended to note the process streams. The actual screening data collection can be done efficiently by systematically following each stream.

The procedures outlined in EPA Reference Method 21 — *Determination of Volatile Organic Compound Leaks* (40 CFR 60, Appendix A) should be followed to screen each equipment type that has been identified. The *Protocol* document (EPA, November 1995) describes the location on each type of equipment where screening efforts should be concentrated. For equipment with no moving parts at the leak interface, the probe should be placed directly on

TABLE 4.3-2

EQUIPMENT LEAK EMISSION SOURCES

Equipment Types
Pump seals
Compressor seals
Valves
Pressure relief devices
Flanges
Connectors
Open-ended lines
Agitator seals
Other[a]
Services
Gas/vapor
Light liquid
Heavy liquid

[a] Includes instruments, loading arms, stuffing boxes, vents, dump lever arms, diaphragms, drains, hatches, meters, polished rods, and vents.

the leak interface (perpendicular, not tangential, to the leak potential interface). On the other hand, for equipment with moving parts, the probe should be placed approximately 1 centimeter off from the leak interface (EPA, November 1995). The Chemical Manufacturers Association has also made some suggestions to maintain good screening practices (CMA, 1989). Recent ongoing efforts by the American Petroleum Institute have also been focused on increasing the accuracy of screening readings.

Various portable organic compound detection devices can be used to measure concentration levels at the equipment leak interface. Any analyzer can be used provided it meets the specifications and performance criteria set forth in EPA Reference Method 21.

Reference Method 21 requires that the analyzer meet the following specifications:

- The VOC detector should respond to those organic compounds being processed (determined by the response factor [RF]);
- Both the linear response range and the measurable range of the instrument for the VOC to be measured and the calibration gas must encompass the leak definition concentration specified in the regulation;
- The scale of the analyzer meter must be readable to ±2.5 percent of the specified leak definition concentration;
- The analyzer must be equipped with an electrically driven pump so that a continuous sample is provided at a nominal flow rate of between 0.1 and 3.0 liters per minute;
- The analyzer must be intrinsically safe for operation in explosive atmospheres; and
- The analyzer must be equipped with a probe or probe extension for sampling not to exceed 0.25 inch in outside diameter, with a single end opening for admission of sample.

Note that the suction flow rate span allowed by Reference Method 21 is intended to accommodate a wide variety of instruments, and manufacturers guidelines for appropriate suction flow rate should be followed.

In addition to the specifications for analyzers, each analyzer must meet instrument performance criteria, including instrument response factor, instrument response time, and calibration precision. Table 4.3-3 presents the performance criteria requirements that portable organic compound detectors must meet to be accepted for use in a screening program.

TABLE 4.3-3

EPA REFERENCE METHOD 21 PERFORMANCE CRITERIA FOR PORTABLE ORGANIC COMPOUND DETECTORS[a]

Criteria	Requirement	Time Interval
Instrument response factor[b]	Must be <10 unless correction curve is used	One time, before detector is put in service.
Instrument response time[c]	Must be ≤30 seconds	One time, before detector is put in service. If modification to sample pumping or flow configuration is made, a new test is required.
Calibration precision[d]	Must be ≤10 percent of calibration gas value	Before detector is put in service and at 3-month intervals or next use, whichever is later.

[a] Source: 40 CFR Part 60, Appendix A, EPA Reference Method 21. These performance criteria must be met in order to use the portable analyzer in question for screening.

[b] The response factor is the ratio of the known concentration of a VOC to the observed meter reading when measured using an instrument calibrated with the reference compound specified in the applicable regulation.

[c] The response time is the time interval from a step change in VOC concentration at the input of the sampling system to the time at which 90 percent of the corresponding final value is reached as displayed on the instrument readout meter.

[d] The precision is the degree of agreement between measurements of the same known value, expressed as the relative percentage of the average difference between the meter readings and the known concentration to the known concentration; i.e., between two meter readings of a sample of known concentration.

Table 4.3-4 lists several portable organic compound detection instruments, their manufacturers, model number, pollutants detected, principle of operation, and range. Figure 4.3-2 shows the HW-101 (HNU Systems, Inc.) instrument, Figure 4.3-3 shows the Foxboro OVA-108, and Figure 4.3-4 shows the Foxboro TVA-1000. When a monitoring device does not meet all of the EPA Reference Method 21 requirements, it can still be used for the purpose of estimating emissions if its reliability is documented. For information on operating principles and limitations of portable organic compound detection devices, as well as specifications and performance criteria, please refer to the *Protocol for Equipment Leak Emission Estimates* document (EPA, November 1995).

Data loggers are available for use with portable organic compound detection devices to aid in the collection of screening data and in downloading the data to a computer. Database management programs are also available to aid in screening data inventory management and compiling emissions. Contact the American Petroleum Institute or state and local agencies for more information about data loggers and database management programs.

As mentioned earlier, screening values are obtained by using a portable monitoring instrument to detect TOCs at an equipment leak interface. However, portable monitoring instruments used to detect TOC concentrations do not respond to different organic compounds equally. To correct screening values to compensate for variations in a monitor’s response to different compounds, response factors (RFs) have been developed. An RF relates measured concentrations to actual concentrations for specific compounds using specific instruments.

Appendix B of this chapter presents additional information on response factors and includes some guidelines on how to evaluate whether an RF correction to a screening value should be made.

3.5.2 MASS EMISSIONS SAMPLING (BAGGING)

An equipment component is bagged by enclosing the component to collect leaking vapors. A bag (or tent) made of material that is impermeable to the compound(s) of interest is constructed around the leak interface of the piece of the equipment.

A known rate of carrier gas is introduced into the bag. A sample of the gas from the bag is collected and analyzed to determine the concentration (in parts per million by volume [ppmv]) of leaking material. The concentration is measured using laboratory instrumentation and procedures. The use of analytical instrumentation in a laboratory is critical to accurately estimate mass emissions. A gas chromatograph (GC) equipped with a flame ionization detector or electron capture detector is commonly used to identify individual constituents of a sample (EPA, November 1995).

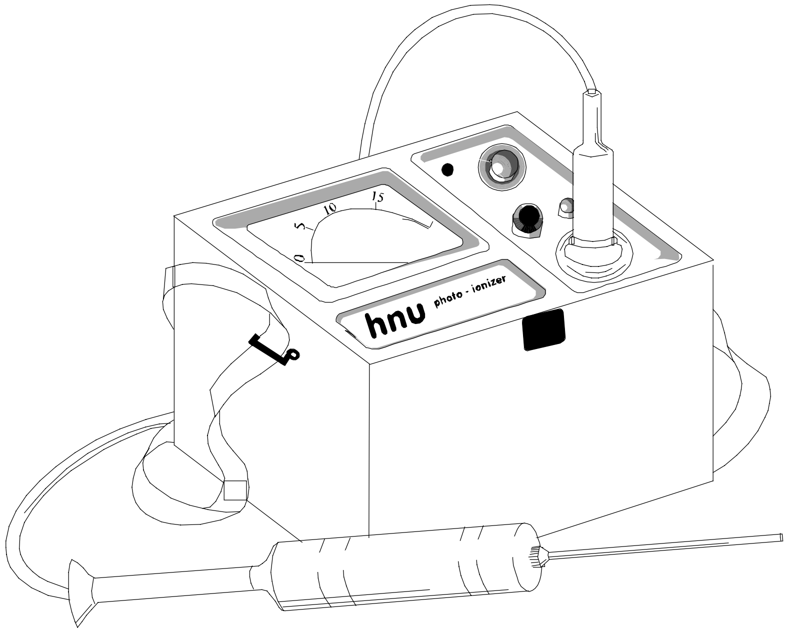
Appendix C of this chapter presents general information on the methods generally employed in sampling source enclosures (vacuum and blow-through methods) and presents the

TABLE 4.3-4

PORTABLE ORGANIC COMPOUND DETECTION INSTRUMENTS

Manufacturer	Model Number	Pollutant(s) Detected	Detection Technique	Range
Bacharach Instrument Co., Santa Clara, California	L	Combustible gases	Catalytic combustion	0 - 100% LEL[a]
	TLV Sniffer	Combustible gases	Catalytic combustion	0 - 1,000 and 0 - 10,000 ppm
Foxboro S. Norwalk, Connecticut	OVA-128	Most organic compounds	FID/GC[b]	0 - 1,000 ppm
	OVA-108	Most organic compounds	FID/GC	0 - 10,000 ppm
	Miran IBX	Compounds that absorb infrared radiation	NDIR[c]	Compound specific
	TVA-1000	Most organic and inorganic compounds	Photoionization and FID/GC	0.5-2,000 ppm (photoionization) 1-50,000 ppm (FID/GC)
Health Consultants	Detecto- PAK III	Most organic compounds	FID/GC	0 - 10,000 ppm
HNU Systems, Inc. Newton Upper Falls, Massachusetts	HW-101	Chlorinated hydrocarbons, aromatics, aldehydes, ketones, any substance that ultraviolet light ionizes	Photoionization	0 - 20, 0 - 200 and 0 - 2,000 ppm
Mine Safety Appliances Co., Pittsburgh, Pennsylvania	40	Combustible gases	Catalytic combustion	0 - 10% and 0 - 100% LEL
Survey and Analysis, Inc., Northboro, Massachusetts	On Mark Model 5	Combustible gases	Thermal conductivity	0 - 5% and 0 - 100% LEL
Rae Systems Sunnyvale, California	MiniRAE PGM-75K	Chlorinated hydrocarbons, aromatics, aldehydes, ketones, any substance that ultraviolet light ionizes	Photoionization	0 - 1,999 ppm

[a] LEL = Lower explosive limit.
[b] FID/GC = Flame ionization detection/gas chromatography.
[c] NDIR = Nondispersive infrared analysis.



950236-LN-CRTP

FIGURE 4.3-2. HW-101 PORTABLE ORGANIC COMPOUND DETECTION INSTRUMENT (HNU SYSTEM, INC.)

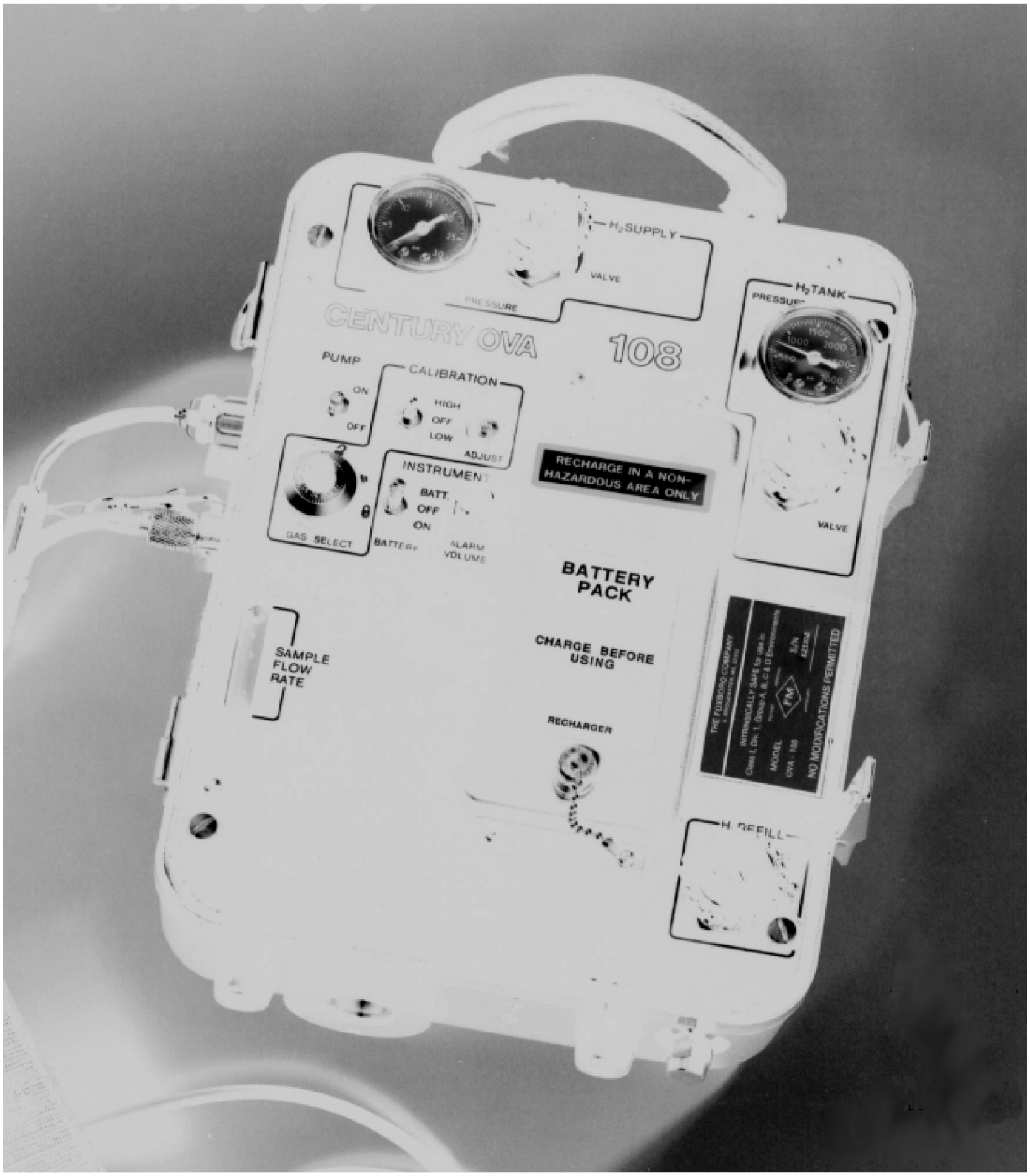


FIGURE 4.3-3. OVA-108 PORTABLE ORGANIC COMPOUND DETECTION INSTRUMENT (FOXBORO)

FIGURE 4.3-4. TVA-1000 PORTABLE ORGANIC/INORGANIC COMPOUND DETECTION INSTRUMENT (FOXBORO)

calculation procedures for leak rates when using both methods.

The *Protocol for Equipment Leak Emission Estimates* document provides detailed information on sampling methods for bagging equipment, considerations for bagging each equipment type and analytical techniques (EPA, November 1995).

3.6 COMPARISON OF AVAILABLE EMISSION ESTIMATION METHODOLOGIES/APPROACHES

Table 4.3-5 identifies the preferred and alternative emission estimation approaches for equipment leaks, and presents their advantages and disadvantages. All four emission estimation approaches presented are more appropriately applied to the estimation of emissions from equipment population rather than individual equipment pieces.

The preferred approach for estimating fugitive emissions from equipment leaks is to use the EPA correlation equations that relate screening values to mass emission rates. The selection of the preferred method for emission estimation purposes is based on the degree of accuracy obtained and the amount of resources and cost associated with the method.

Because the equipment leak emissions may occur randomly, intermittently, and vary in intensity over time, the "snapshot" of emissions from a given leak indicated by screening and/or bagging results, which are used either to develop or apply all of the approaches, may or may not be representative of the individual leak. However, by taking measurements from several pieces of a given equipment type, the snapshots of individual deviations from the actual leaks offset one another such that the ensemble of leaks should be representative. All of these approaches are imperfect tools for estimating fugitive emissions from equipment leaks; however, they are the best tools available. The best of these tools, the preferred method, can be expected to account for approximately 50 to 70 percent of the variability of the snapshot ensemble of equipment leak emissions.

TABLE 4.3-5

SUMMARY OF THE ADVANTAGES AND DISADVANTAGES OF PREFERRED AND ALTERNATIVE EMISSION ESTIMATION APPROACHES FOR EQUIPMENT LEAKS

Preferred Emission Estimation Approach	Alternative Emission Estimation Approach	Advantages	Disadvantages
EPA Correlation Equations		Provides a refined emission estimate when actual screening values are available. Provides a continuous function over the entire range of screening values instead of discrete intervals.	Screening value measurements used with these correlations should have the same format as the one followed to develop the correlations (OVA[a]/methane). The development of an instrument response curve may be needed to relate screening values to actual concentration.
	Average Emission Factors	In the absence of screening data, offers good indication of equipment leak emission rates from equipment in a process unit.	They are not necessarily an accurate indication of the mass emission rate from an individual piece of equipment. Average emission factors do not reflect different site-specific conditions among process units within a source category. May present the largest potential error (among the other approaches) when applied to estimate emissions from equipment populations.
	Screening Ranges	Offers some refinement over the Average Emission Factor approach. Allows some adjustment for individual unit conditions and operation.	Available data indicate that measured mass emission rates can vary considerably from the rates predicted by the use of these emission factors.
	Process-Unit Specific Correlation	The correlations are developed on a process unit basis to minimize the error associated with different leak rate characteristics between units.	High cost.

[a] Organic vapor analyzer.