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METHANE EMISSIONS FROM THE
NATURAL GAS INDUSTRY

Volume 13: Chemical Injection Pumps

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Prepared by

National Risk Management
Research Laboratory
Research Triangle Park, NC 27711

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**METHANE EMISSIONS FROM
THE NATURAL GAS INDUSTRY,
VOLUME 13: CHEMICAL INJECTION PUMPS**

FINAL REPORT

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RESEARCH SUMMARY

Title	Methane Emissions from the Natural Gas Industry, Volume 13: Chemical Injection Pumps Final Report
Contractor	Radian International LLC GRI Contract Number 5091-251-2171 EPA Contract Number 68-D1-0031
Principal Investigator	Theresa M. Shires
Report Period	March 1991 - June 1996 Final Report
Objective	This report describes a study to quantify the annual methane emissions from natural gas-driven chemical injection pumps.
Technical Perspective	<p>The increased use of natural gas has been suggested as a strategy for reducing the potential for global warming. During combustion, natural gas generates less carbon dioxide (CO₂) per unit of energy produced than either coal or oil. On the basis of the amount of CO₂ emitted, the potential for global warming could be reduced by substituting natural gas for coal or oil. However, since natural gas is primarily methane, a potent greenhouse gas, losses of natural gas during production, processing, transmission, and distribution could reduce the inherent advantage of its lower CO₂ emissions.</p> <p>To investigate this, Gas Research Institute (GRI) and the U.S. Environmental Protection Agency's Office of Research and Development (EPA/ORD) cofunded a major study to quantify methane emissions from U.S. natural gas operations for the 1992 base year. The results of this study can be used to construct global methane budgets and to determine the relative impact on global warming of natural gas versus coal and oil.</p>
Results	<p>The 1992 national methane emissions for chemical injection pumps used in the production segment are $1.5 \pm 203\%$ Bscf.</p> <p>Based on data from the entire program, methane emissions from natural gas operations are estimated to be 314 ± 105 Bscf for the 1992 base year. This is about $1.4 \pm 0.5\%$ of gross natural gas production. The overall program showed that the percentage of methane emitted for an</p>

incremental increase in natural gas sales would be significantly lower than the baseline case.

The program reached its accuracy goal and provides an accurate estimate of methane emissions that can be used to construct U.S. methane inventories and analyze fuel switching strategies.

Technical
Approach

The gas industry has two primary types of chemical injection pumps that discharge natural gas: piston pumps and diaphragm pumps. Gas-driven pumps used for glycol circulation are presented in a separate study.

An emission rate for chemical injection pumps was determined by developing an annual emission factor for typical practices and extrapolating this value based on the total number of chemical injection pumps (activity factor) to develop a national estimate, where the national emission rate is the product of the emission factor and activity factor.

Chemical injection pumps are small positive displacement, reciprocating units designed to inject precise amounts of chemicals into process streams. These pumps are used in the production segment to control processing problems or protect equipment. Typical chemicals injected in an oil or gas field are biocides, demulsifiers, clarifiers, corrosion inhibitors, scale inhibitors, hydrate inhibitors, dewaxers, surfactants, and scavengers.

The emission-affecting characteristics of chemical injection pumps include: frequency of operation, unit size, supply gas pressure, and inlet methane composition. The frequency of operation was based on timed stroke rates and operator information on the annual use of the devices. Manufacturer data provided the gas consumption rates per stroke. An equation relating these parameters was developed and used to calculate annual methane emissions from a typical chemical injection pump used in natural gas production.

The activity factor development (i.e., the number of chemical injection pumps nationally) is presented in a separate report. In general though, the activity factor is based on the number of chemical injection pumps per active gas well that markets gas. The national methane emission rate for chemical injection pumps was then based on the product of the emission factor and activity factor.

Project
Implications

For the 1992 base year, the annual methane emissions estimate for the U.S. natural gas industry is 314 Bscf \pm 105 Bscf (\pm 33%). This is equivalent to 1.4% \pm 0.5% of gross natural gas production. Results from this program were used to compare greenhouse gas emissions from the

fuel cycle for natural gas, oil, and coal using the global warming potentials (GWPs) recently published by the Intergovernmental Panel on Climate Change (IPCC). The analysis showed that natural gas contributes less to potential global warming than coal or oil, which supports the fuel switching strategy suggested by IPCC and others.

In addition, results from this study are being used by the natural gas industry to reduce operating costs while reducing emissions. Some companies are also participating in the Natural Gas-Star program, a voluntary program sponsored by EPA's Office of Air and Radiation in cooperation with the American Gas Association to implement cost-effective emission reductions and to report reductions to EPA. Since this program was begun after the 1992 baseline year, any reductions in methane emissions from this program are not reflected in this study's total emissions.

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1.0 SUMMARY

This report is one of several volumes that provide background information supporting the Gas Research Institute and U.S. Environmental Protection Agency Office of Research and Development (GRI-EPA/ORD) methane emissions project. The objective of this comprehensive program is to quantify methane emissions from the gas industry for the 1992 base year to within $\pm 0.5\%$ of natural gas production starting at the wellhead and ending immediately downstream of the customer meter.

This report describes a study to quantify the annual emissions from chemical injection pumps. Piston pumps and diaphragm pumps are the most common types of natural gas-powered chemical injection pumps used in the production segment. An emission factor for these types of pumps was developed based on site data, manufacturer's data, and results from a Canadian study. The resulting annual methane emissions from chemical injection pumps are 1.5 Bscf $\pm 203\%$.

2.0 INTRODUCTION

Chemical injection pumps are small positive displacement, reciprocating units designed to inject precise amounts of chemicals into process streams. These pumps are used in the natural gas production segment to control processing problems or protect equipment. Gas-driven chemical injection pumps, which use gas pressure to drive other fluids, are commonly used in production fields where electricity is not readily available.

The characteristics that affect emissions from chemical injection pumps include: the size of the unit, frequency of operation, supply gas pressure, and inlet methane composition. Emission factors for diaphragm and piston pumps were determined by converting a manufacturer's reported gas consumption per volume of chemical pumped to gas emitted per stroke, based on the plunger diameter and stroke length of typical pumps. The frequency of operation was based on timed stroke rates from site visits and operator information on the annual use of the devices. An equation relating these parameters was developed for each type of chemical injection pump (piston pumps and diaphragm pumps). The number of gas-operated pumps in the U.S. production segment was determined by establishing a ratio of pumps to wells that market natural gas. Annual methane emissions from chemical injection pumps were calculated based on the product of the emission factor for a typical pump and the activity factor (count of chemical injection pumps nationally).

This report presents an estimate of total U.S. emissions from these pumps. The following sections quantify the amount of methane that is released from chemical injection pumps nationwide. A description of chemical injection pumps typically used in the natural gas industry is provided in Section 3. Section 4 describes the sources of information used to determine methane emission factors for these pumps. National annual emissions are calculated in Section 5.

3.0 GAS-DRIVEN PUMP TYPES

This section describes chemical injection pumps found in the natural gas industry, as well as differences in installations in various segments of the industry.

3.1 Operation Overview

All industrial pumps have two major components: a driver side and a motive side. The driver provides the energy for the pumping operation; the motive side delivers the energy to the fluid being moved. For a typical industrial centrifugal pump, the driver might be an electric motor; the motive side is an impeller and case arrangement.

In the natural gas industry, gas-driven pumps are small pumps used in the production field where electricity is not readily available. These pumps use gas pressure to drive other fluids. The supply gas can be compressed air (as in gas processing plants), but most often it is natural gas taken directly from the production stream. The vast majority of gas-driven pumps in the field have one of two purposes: glycol circulation (see Volume 15 on gas-assisted glycol pumps¹) or chemical injection.

Chemical injection is needed in the field to add small amounts of chemicals that control processing problems and protect the equipment. Typical chemicals injected in an oil or gas field are biocides, demulsifiers, clarifiers, corrosion inhibitors, scale inhibitors, hydrate inhibitors, paraffin dewaxers, surfactants, oxygen scavengers, and hydrogen sulfide (H₂S) scavengers. These chemicals are normally injected at the wellhead and into gathering lines or at production separation facilities. Since the injection rates are typically small, the pumps are also small. They are often attached to barrels containing the chemical being injected.

Chemical injection pumps are positive displacement, reciprocating units designed to inject precise amounts of chemical into a process stream. Positive displacement

pumps work by allowing a fluid to flow into an enclosed cavity from a low-pressure source, trapping the fluid, and then forcing it out into a high-pressure receiver by decreasing the volume of the cavity. A complete reciprocating stroke includes two movements, referred to as an upward motion or suction stroke, and a downward motion or power stroke. During the suction stroke, the chemical is lifted through the suction check valve into the fluid cylinder. The suction check valve is forced open by the suction lift produced by the plunger and the head of the liquid being pumped. Simultaneously, the discharge check valve remains closed, thus allowing the chemical to remain in the fluid chamber. During the power stroke, the plunger assembly is forced downwards, immediately shutting off the suction check valve. Simultaneously, the chemical is displaced, forcing open the discharge check valve and allowing the fluid to be discharged. This complete movement represents one full stroke.

The two types of gas-driven pumps commonly used in the natural gas industry are the piston pump and the diaphragm pump. These pumps operate in the same manner, but with different reciprocating mechanisms. The barrel-type piston pump, illustrated in Figures 3-1 and 3-2, consists of a cylindrical piston-plunger assembly.² Movement of the larger-diameter piston provides the force needed to move the plunger. Another type of piston pump observed at sites in California (Figures 3-3 and 3-4) uses a horizontal plunger to operate a gear mechanism that drives the plunger.³ The diaphragm pump, illustrated in Figures 3-5 and 3-6, uses a flexible diaphragm to move the plunger.^{4,5}

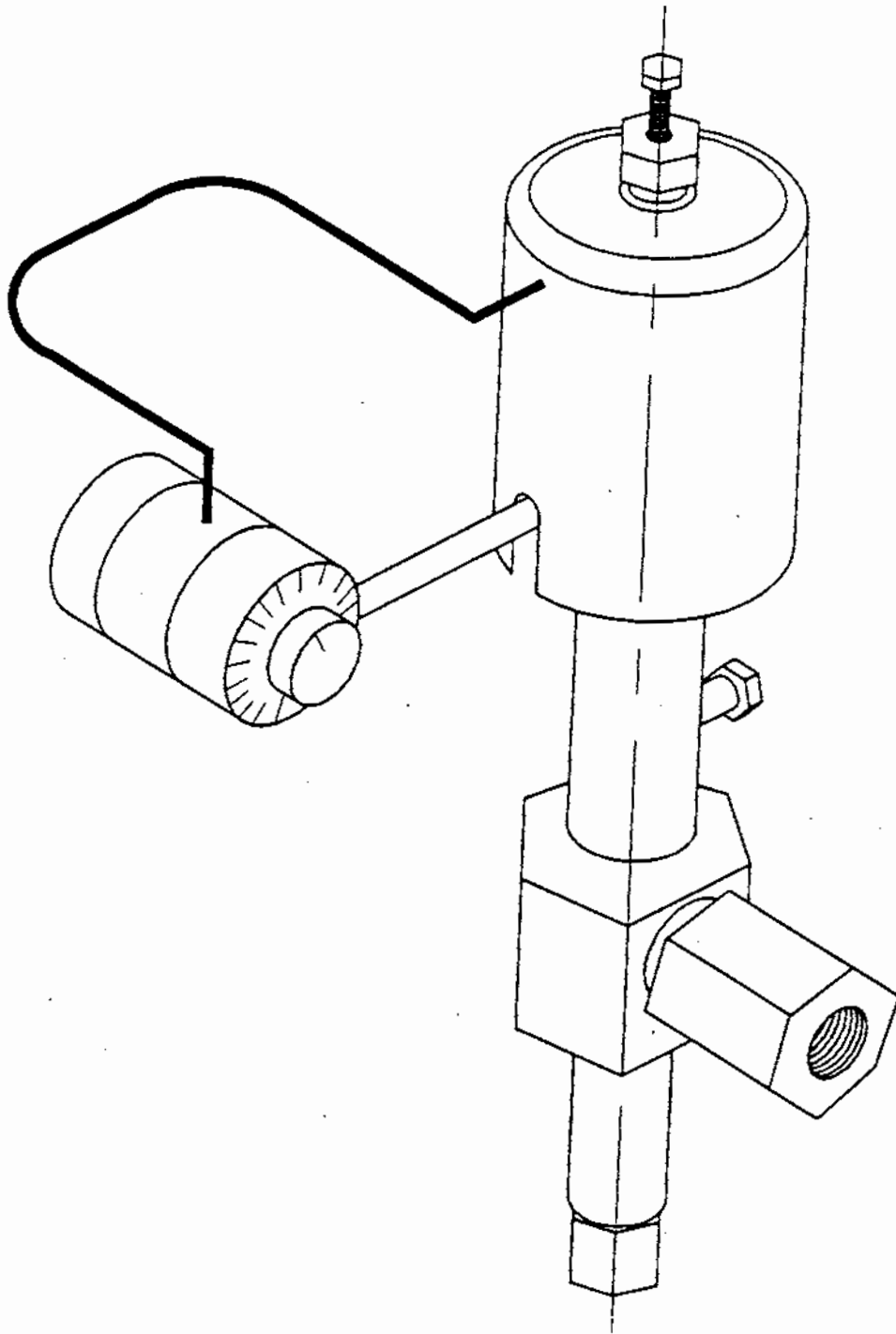


Figure 3-1. Piston Pump Schematic

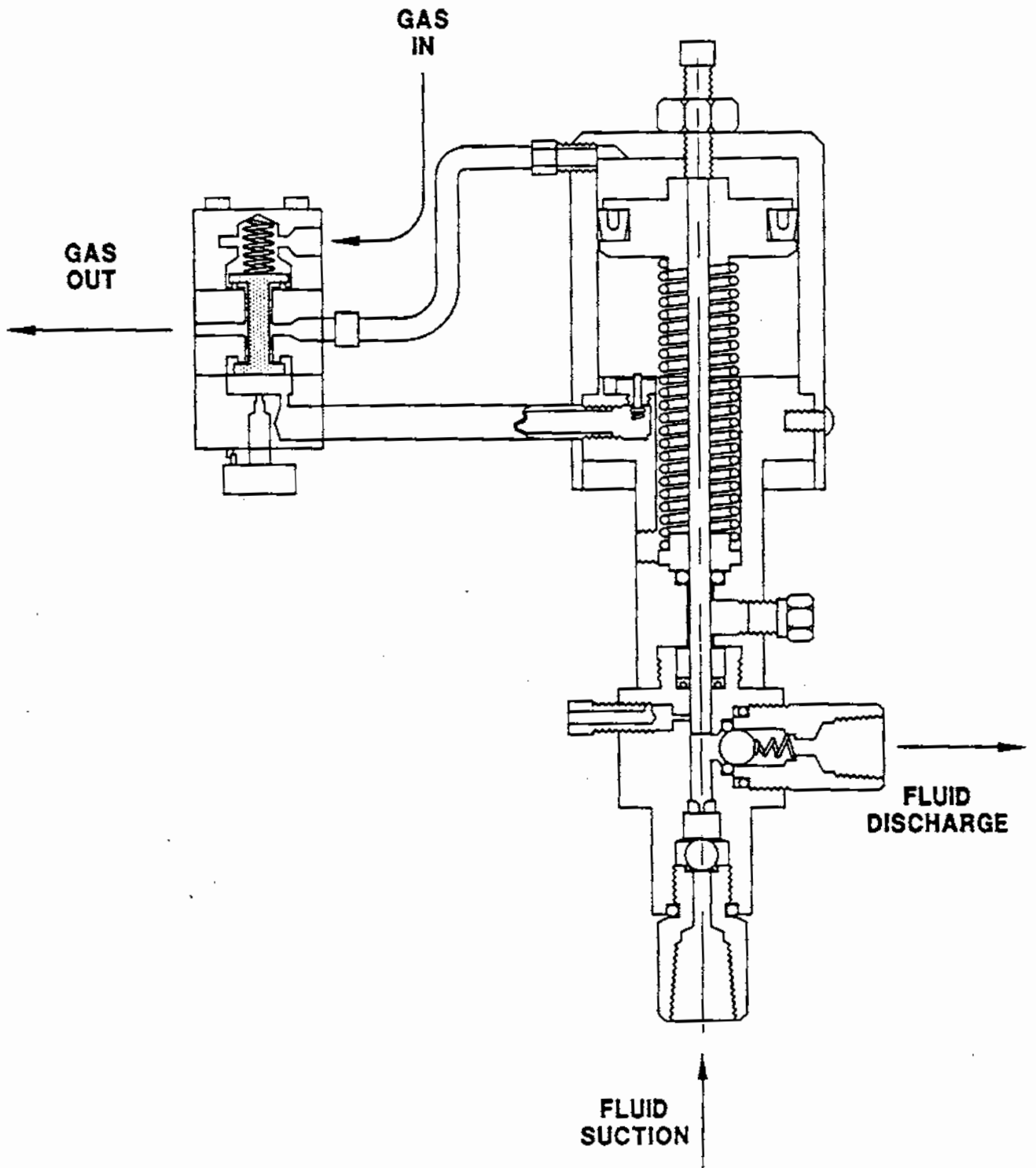


Figure 3-2. Piston Pump Cut-away Schematic

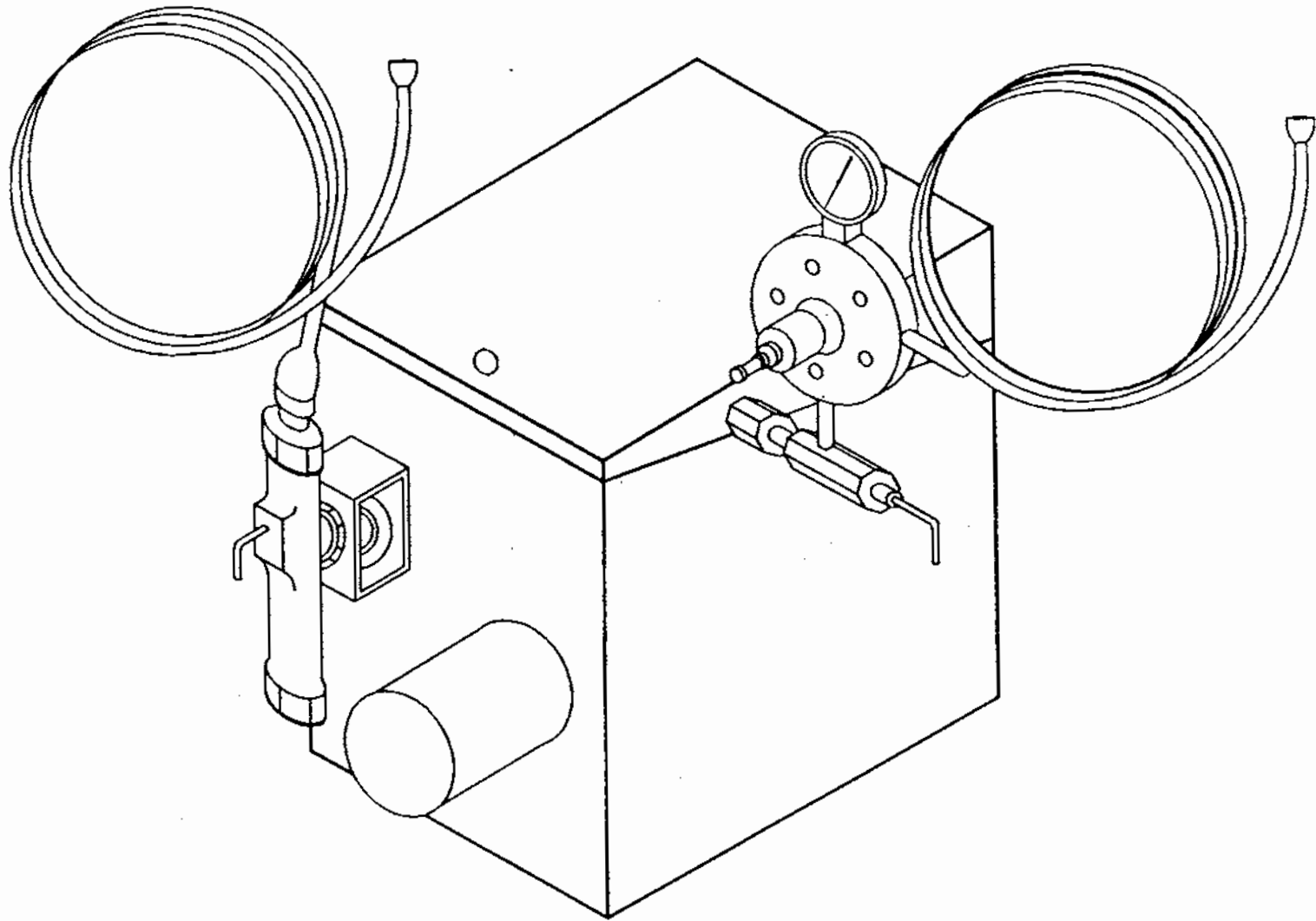


Figure 3-3. Texsteam Piston Pump Schematic

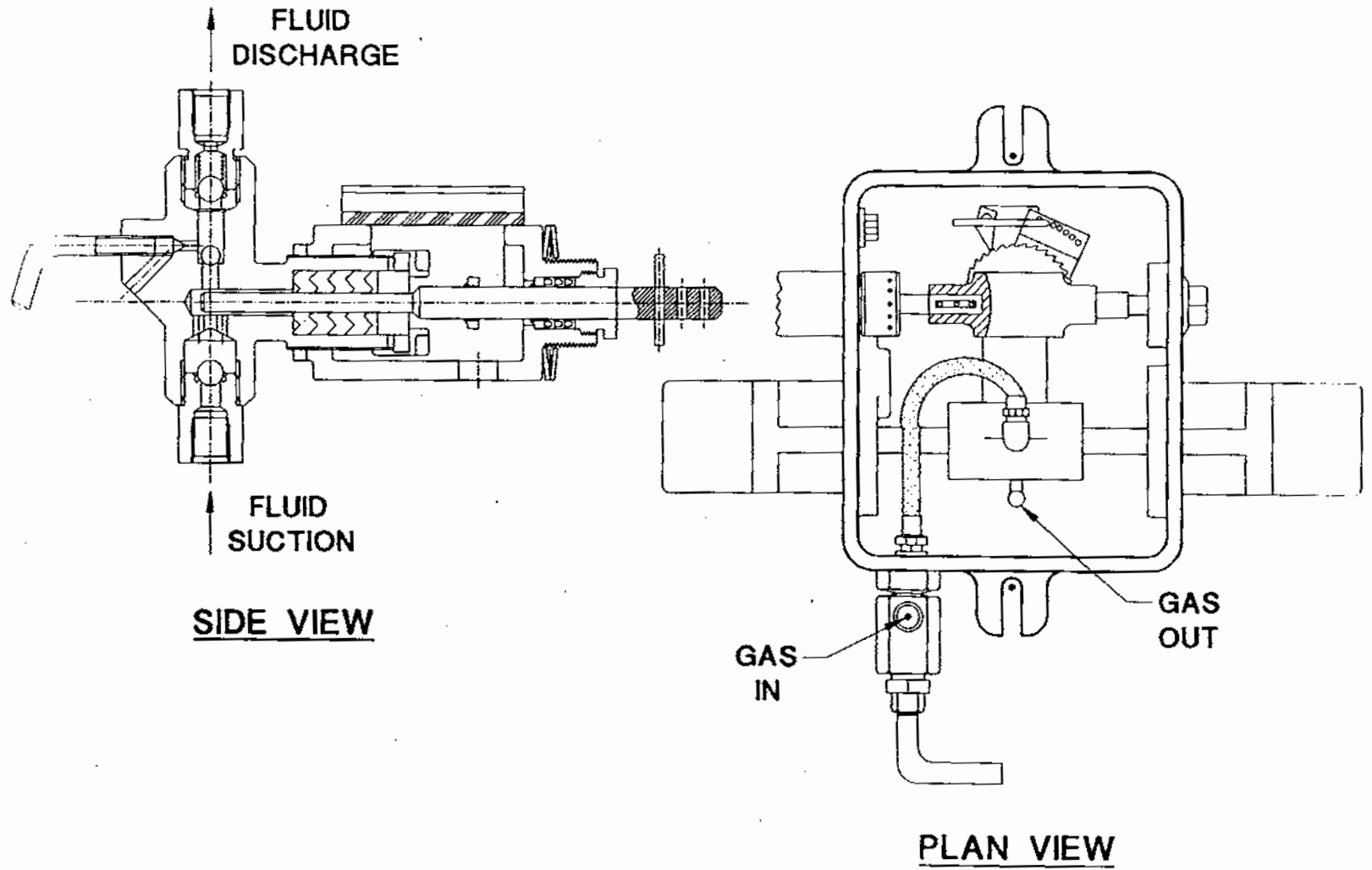


Figure 3-4. Texsteam Piston Pump Cut-away Schematic

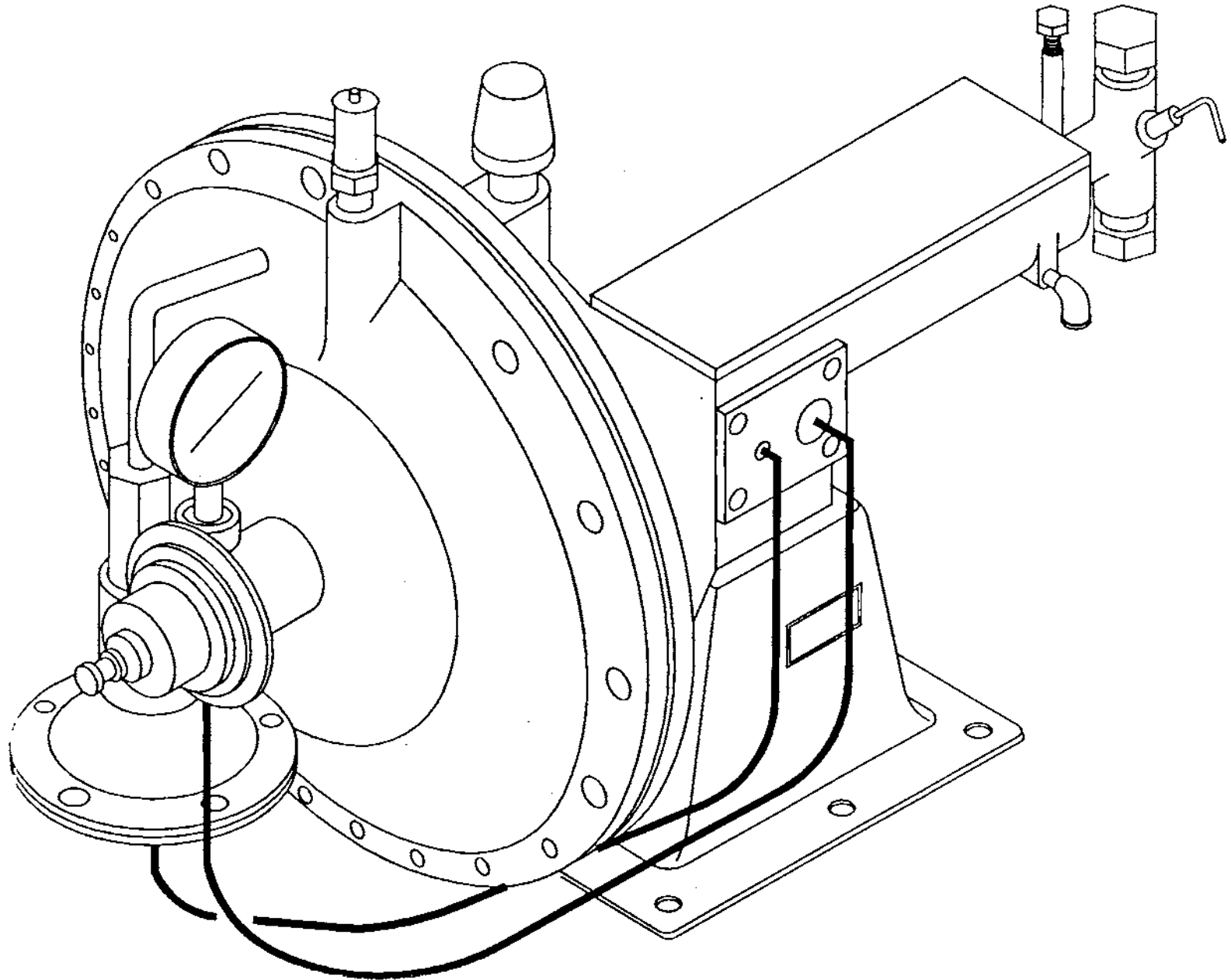


Figure 3-5. Diaphragm Pump Schematic

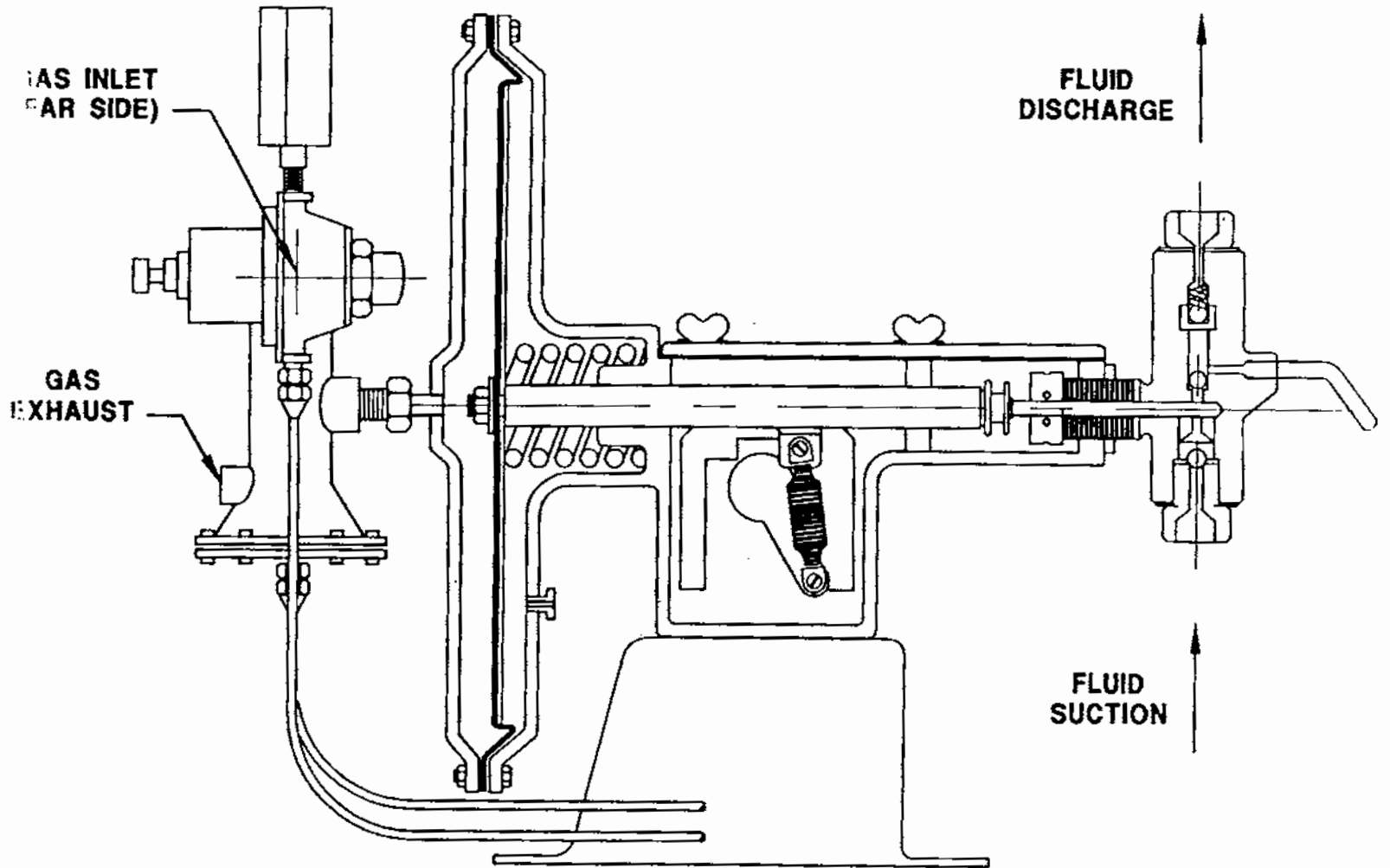


Figure 3-6. Diaphragm Pump Cut-away Schematic

3.2 Emission-Affecting Characteristics

Characteristics that affect methane emissions from the gas-driven pumps in chemical injection service include:

- Frequency of operation (pumping rate);
- Size of the unit (volume displacement of the motive chamber);
- Supply gas pressure (which affects density); and
- Inlet methane composition.

For this study, the frequency of operation was determined by timing the stroke intervals and collecting information about pump operating schedules. Determination of the unit size was based on manufacturers' data for the types of pumps observed during site visits. Supply gas pressure, which affects the density of the gas, was noted during site visits. Estimation of an average natural gas methane concentration was based on literature data. These characteristics are discussed in more detail in relation to their effect on the emission calculations in the following section.

4.0 EMISSION FACTOR DATA

Four sources of information were used to determine methane emissions from chemical injection pumps: results of a study performed by the Canadian Petroleum Association, literature data for methane composition, data collected from site visits, and pump manufacturers' data.

4.1 Canadian Petroleum Association (CPA) Report

The Canadian Petroleum Association (CPA) conducted a study to quantify methane emissions from oil and gas production operations in Alberta.⁶ Emissions from diaphragm chemical injection pumps were determined from bagging tests of five pumps. The measurements were very consistent, ranging from 254 to 499 scfd/pump (see Table 4-1). The average natural gas emission factor from the Canadian study was $334 \pm 30\%$ scfd/pump.

4.2 Methane Composition

Emission factors for methane are calculated from the rate of natural gas released multiplied by the methane composition. The percentage of methane in produced natural gas was determined to be $78.8\% \pm 5\%$. Details about this value are available in Volume 6 on vented and combustion sources.⁷

TABLE 4-1. CPA MEASUREMENTS OF FUEL-GAS VENTING RATES FOR GAS-OPERATED CHEMICAL INJECTION PUMPS

Type of Inst.	Type of Facility	Type of Equipment	Quantity Measured at Once	Min. Flow Rate/Pump	Max. Flow Rate/Pump	Avg. Flow Rate/Pump
CIP ^a	Oil Battery	Line Heater	1	0	0	498.9 scfd
CIP	Oil Battery	Sales Line	1	165.8 scfd	349.6 scfd	254.4 scfd
CIP	Oil Battery	Sales Line	1	0	>1917 scfd	373.7 scfd
CIP	Minor Oil Field	Wellhead	1	b	b	254.3 scfd
CIP	Minor Oil Field	Wellhead	1	b	b	290.3 scfd
AVERAGE						334 scfd ± 30%

^a CIP = Chemical Injection Pump

^b Minimum and maximum flow rates were not measured in these cases, only the average rate.

4.3 Site Data

Characteristics that allow populations and average pump emission factors to be estimated were gathered from 19 sites by telephone contacts or site visits. The information collected included:

- Total number of chemical injection pumps for a particular site;
- Number of chemical injection pumps used in natural gas production (see Volume 5 on activity factors⁸ for more information on the industry boundary definition);
- Energy source (gas, air, or electric);
- Frequency of operation (pumping rate in strokes/min);
- Number of pumps active or idle;
- Pump operation schedule;
- Size of the unit (volume displacement of the motive chamber);

- Manufacturer and model number of the unit; and
- Supply gas pressure.

Table 4-2 lists the site information and Table 4-3 summarizes the site data by pump type. This information was used to produce an estimate of equipment populations and characteristics for the U.S. population of gas-driven chemical injection pumps.

The frequency of operation, or pumping rate (stroke/min), was based on timed stroke intervals measured during site visits. The number of rate samples is shown in Table 4-2 for sites where this parameter was measured. For sites with no rate sample measurements, calculation of an average value for the pump type (either piston or diaphragm) was based on measurements from other sites.

The fraction of each pump type, piston versus diaphragm, was calculated based on the total number of each type of pump observed. Table 4-2 shows that piston and diaphragm pumps are equally distributed for the sites visited (49.8% piston pumps compared with 50.2% diaphragm pumps).

Some of the pumps are only operated on a seasonal basis. Therefore, operator information and observations from site visits were used to determine the fraction of time the pump operated annually. Table 4-3 shows that piston pumps operate approximately 45% of the year, while diaphragm pumps are in use 40% of the year.

At four of the sites visited, both piston and diaphragm pumps were observed. However, no estimate of the relative number of each type of pump was made; only the total number of chemical injection pumps was provided. For these sites, the fraction of piston versus diaphragm pumps observed from the other sites were applied so that the pump operating data collected at the four sites could be used.

TABLE 4-2. SUMMARY OF SITE DATA

Site	Pump Type	Power Media	Total Number of CIPs at the Site	CIPs Within Gas Industry Boundaries at the Site	Number of Rate Samples	Strokes/min	% Operating	Number Operating
1	Piston	Nat. Gas	108	10	14	6.64	63.6	68.7
2	Piston	Nat. Gas	5	5	0	--	93	4.6
3	Piston	Nat. Gas	203	0	8	16.8	61.9	125.7
4	Piston	Nat. Gas	666	0	0	--	27.3	90.4
	Diaphragm	Nat. Gas			0	--	27.3	91.1
5	Diaphragm	Nat. Gas	5	5	1	2	90	4.5
6	Diaphragm	Nat. Gas	28	28	1	12	25	6.9
7	Diaphragm	Nat. Gas	273	273	1	30	50	136.4
8	Piston	Nat. Gas	60	0	0	--	3.8	1.2
	Diaphragm	Nat. Gas			0	--	3.8	1.2
9	Piston	Nat. Gas	36	36	1	0.5	100	17.9
	Diaphragm	Nat. Gas			2	15	100	18.1
10	Diaphragm	Nat. Gas	4	0	3	9.2	81.3	3.3
11	Diaphragm	Nat. Gas	12	12	0	--	100	12.0
12	Diaphragm	Nat. Gas	8	8	0	--	50	4.0
13	Piston	Nat. Gas	25	25	0	--	100	12.5
	Diaphragm	Nat. Gas			0	--	100	12.5
14	Piston	Electric	115	0	--	--	--	--
15	Piston	Electric	24	0	--	--	--	--
16	Piston	Nat. Gas	1	0	1	0.33	--	--
17	Piston	Air	4	0	4	55	--	--
18	Piston	Air	5	0	3	65	--	--
19	Piston	Nat. Gas	1	1	1	40	--	--

TABLE 4-3. SITE DATA RESULTS

	Piston Pumps	Diaphragm Pumps
Total Number of Gas Operated CIPs Observed from Site Visits	327	329
% by Type	49.8 ± 38%	50.2 ± 38%
% Operating	44.6 ± 62%	40.0 ± 52%
Average Strokes/min	26.3 ± 29%	13.6 ± 49%

4.4 Industry Boundaries

The "gas industry" boundaries include all gas well equipment but excludes equipment associated with oil production. This boundary definition is significant for chemical injection pumps since a large number of these pumps are used specifically for chemical addition to oil wells.

During site visits, data were collected for all pneumatic chemical injection pumps regardless of the associated equipment. As shown in Tables 4-2 and 4-3, data collected for the purpose of this characterization report consist of actuation measurements and pump make/model types for pneumatic chemical injection pumps, including pumps operated by compressed air and pumps related to the oil industry. The decision was made to include all data for the emission factor calculations but to account for the industry boundary definition in the activity factor. (That is, the activity factor only includes natural gas powered chemical injection pumps associated with the natural gas industry.)

To examine the effect of this decision, emission estimates were determined using two data sets: one containing all of the available data, and the other using only data for gas-operated chemical injection pumps within the natural gas industry. The results of this comparison are presented in Table 4-4.

TABLE 4-4. DATA SET COMPARISON FOR CHEMICAL INJECTION PUMPS

	Using All Data		Using Only Natural Gas Industry Data	
	Piston	Diaphragm	Piston	Diaphragm
Percent of Total Pumps, %	49.8 ± 38%	50.2 ± 38%	4.5 ± 678%	95.5 ± 32%
Pump Actuation Rate, strokes/min	26.32 ± 29%	13.64 ± 49%	3.57 ± 42%	14.75 ±
Number of measurements	32	8	15	61%
Number of sites	7	5	2	5
				4
Operating Fraction, %	44.6 ± 62%	40.0 ± 52%	77.5 ± 148%	58.0 ± 39%
Number of sites	7	10	4	6
Methane Emissions Factor, ^a scfd/pump	248 ± 83%		668 ± 88%	

^aDetails on the emission factor calculation are presented in Section 5.

Limiting the data to strictly gas-operated pumps within the natural gas industry significantly reduces the database from which the emission factors are calculated and results in a much larger emission factor. A follow-up conversation with a manufacturer of both types of pumps indicated that although the pumps are sized based on the volume of chemical required and the injection pressure, the type of production (natural gas or crude) is not a leading factor for selecting the pump type. Both pump types can accommodate conditions associated with either natural gas production or crude production. This was confirmed by industry contacts as well. Therefore, because a definitive reason for choosing one pump type for natural gas production could not be determined, the larger data set—using all of the data—was used to determine the emission factor per pump. The actual number of pumps operating on gas within the natural gas industry boundaries is accounted for in the activity factor.

4.5 Manufacturers' Data

Stroke frequency (strokes per minute) was determined from site data; however chemical injection pump manufacturers relate gas usage to the volume of chemical pumped (scf/gal). To convert scf/gal to scf/stroke, the volume of chemical displaced per stroke was calculated based on manufacturers' data for stroke length and plunger diameter (for diaphragm pumps) or piston diameter (for piston pumps) as shown.^{2,3,4,5,9,10,11}

$$\frac{\text{Gas Usage, scf}}{\text{stroke}} = \frac{\text{Stroke Length (in.)}}{\text{stroke}} \times \frac{\pi \text{ Diameter (in.)}^2}{4} \times \frac{\text{gal.}}{231 \text{ in.}^3} \times \text{Gas Usage} \left(\frac{\text{scf}}{\text{gal.}} \right) \quad (1)$$

Tables 4-5 and 4-6 summarize the information provided by the diaphragm and piston pump manufacturers, respectively. The calculated gas usage per stroke is also shown for each pump size.

4.5.1 Diaphragm Pumps

The diaphragm pump manufacturers provided gas usages in terms of standard cubic feet of gas (at 1 atm and 60°F) required to pump one gallon of liquid, where gas usage for each pump varies slightly with discharge pressure. Despite the wide range of pump sizes available, the measured stroke rates were used to calculate an average emission rate per stroke (with a 90% confidence interval of $\pm 10\%$) for the pumps shown in Table 4-5. The pump manufacturer data were examined over the discharge pressure range of 0 psig to 1000 psig (discharge pressure ranged from 20 to 1060 psig for sites visited), for which the gas usage varied by only 20%. For example, the gas usage for the 3/8-inch Western Chemical pump was 105 to 118 scf/gal over the discharge pressure range of 0 psig to 1000 psig.⁹ Calculation of the liquid displacement per stroke was based on the plunger diameter and stroke length as shown by Equation 1. Combining the calculated liquid displacement for each plunger size over the range of gas usage values, results in a matrix of calculated scf/stroke values. Table 4-5 shows these values which vary from 0.0451 to 0.1660

TABLE 4-5. PUMP MANUFACTURERS' DATA FOR DIAPHRAGM PUMPS

Diaphragm Pumps				
Manufacturer/ Model	Plunger Diameter, in.	Stroke Length, in.	Natural Gas Usage, scf/gal ^a	Calculated Natural Gas Usage scf/stroke ^a
Western Chemical Pumps, Inc. ⁹	3/8	7/8	105-118	0.047-0.051
	5/8	7/8	42-57	0.054-0.073
				Average = 0.0563
Texsteam Series 5000 ⁴	1/4	1/2 - 1 1/4	280 - 756	0.0744 - 0.0813
	3/8		140 - 368	0.0837 - 0.0914
	1/2		80.6 - 212	0.0853 - 0.0978
	3/4		36 - 117	0.0851 - 0.1329
	1		20.6 - 62	0.0860 - 0.1360
	1 1/4		13.6 - 44	0.0866 - 0.1660
				Average = 0.0962
Texsteam Series 5100 ⁵	1/8	1/3 - 1	457 - 1407	0.0546 - 0.0561
	1/4		244 - 810	0.0519 - 0.0574
	3/8		120 - 492	0.0574 - 0.0784
	1/2		53 - 186	0.0451 - 0.0527
				Average = 0.0567
CPA Measurements ⁶				Average = 0.0170 ^b
Diaphragm Pump Average				0.0719 ± 10%

^a To convert from scf of natural gas to scf of methane, multiply by mol % methane in natural gas.

^b The Canadian emissions, reported in Table 4-1 as scfd/pump, were converted to scf/stroke based on the diaphragm pump actuation rate determined from site data and shown in Table 4-3.

TABLE 4-6. PUMP MANUFACTURERS' DATA FOR PISTON PUMPS

Piston Pumps			
Manufacturer/ Model	Piston Diameter, in.	Stroke Length, in.	Calculated Natural Gas Usage scf/stroke ^a
Linc Mfg. ²	2 1/2	1/4	0.0022
		1	0.0086
Arrow Specialty Co. ¹⁰	--	--	0.0080 ^b
Williams Chemical Instruments ¹¹	1 1/4	1/8	0.0003
	1 1/4	1/2	0.0011
	2 1/4	1/8	0.0009
	2 1/4	1	0.0070
Texsteam Model 3703 ³	--	--	0.0013 ^b
Piston Pump Average			0.0037 ± 65%

^a Conversion of acf to scf is based on a typical supply gas pressure of 30 psig determined from reference material¹² as well as pressures observed at eight sites.

^b The piston size and stroke length were not specified for this type of device. Instead, the manufacturer provided the gas usage per gallon of chemical pumped, which ranged from 160 to 500 scf/gallon for discharge pressures of 0 to 1000 psig. Based on the average stroke frequency observed at Sites 17 and 18, the corresponding gas usage per stroke ranges from 0.00063 to 0.00195, with an average value of 0.0013 scf/stroke.

scf/stroke. Calculating the average of the range of manufacturer data and the Canadian measurements results in the average gas emission of 0.0719 scf/stroke \pm 10% for the diaphragm pumps.

4.5.2 Piston Pumps

Manufacturer data for the Texsteam piston pump were similar to that provided for the diaphragm pumps: standard cubic feet of gas required to pump one gallon of liquid. In addition, the manufacturer provided ranges for the volume of chemical pumped (gal/day), corresponding to different actuation rates (stroke/min). Actuation measurements from the two sites where the Texsteam pumps were observed were used to convert the gas discharge rate per volume of chemical to the discharge rate per stroke as shown in the following equation:

$$\frac{\text{Gas Usage, scf}}{\text{stroke}} = \frac{\text{scf}}{\text{gal.}} \times \frac{\text{gal.}}{\text{day}} \times \frac{\text{day}}{\text{strokes}} \quad (2)$$

For the barrel type piston pumps, the gas usage was calculated based on the manufacturer specifications for the piston diameter and stroke length:

$$\frac{\text{Gas Usage, acf}}{\text{stroke}} = \frac{\text{Stroke Length (in.)}}{\text{stroke}} \times \frac{\pi \text{ Diameter (in.)}^2}{4} \times \frac{\text{ft}^3}{1728 \text{ in.}^3} \quad (3)$$

Piston pumps are not as diverse as diaphragm pumps and have a limited number of piston sizes. Based on the use of these pumps in the natural gas industry, the 1¼-inch to 2½-inch piston diameters would be typical.

The stroke length is adjustable for the piston-type pumps. Since specifics concerning the typical stroke length for pumps at each site were not known, the range of manufacturers' values (1/8 to 1-inch) were used. In addition, the supply gas pressure can affect the gas usage for these pumps due to the effect of pressure on gas density. Based on

manufacturers' data, piston pumps are designed for supply gas pressures ranging from 15 to 85 psig. A supply gas pressure of 30 psig was used for the emission calculations based on an average of site data and reference material.¹² Combining the data from the four manufacturers, the average gas usage for the piston pumps was determined to be 0.0037 scf/stroke \pm 65% (Table 4-6).

5.0 EMISSION RATE CALCULATIONS

Site information was used to determine the average actuation rate (strokes/min), the fraction of each type of pump (piston versus diaphragm), and the percentage of operating time for each type of pump. The manufacturers' data were used to determine the volume of gas released per pump stroke (scf of gas/stroke). Radian combined the site information and manufacturers' data, as presented in this section, to calculate methane emissions for each type of pump in standard cubic feet per day per pump. An average pump emission factor was calculated by combining the emission factors (EF) for diaphragm and piston pumps:

$$EF_{\text{avg. pump}} = \text{Fraction}_{\text{piston pumps}} \times EF_{\text{piston pumps}} + \text{Fraction}_{\text{diaphragm pumps}} \times EF_{\text{diaphragm pumps}} \quad (4)$$

$$EF_{\text{avg. pump}} = (48.9\% \times 50 \text{ scfd methane/pump})_{\text{piston}} + (50.2\% \times 446 \text{ scfd methane/pump})_{\text{diaphragm}}$$

$$EF_{\text{avg. pump}} = 248 \text{ scfd methane/pump}$$

where, the fraction of each pump type is from Table 4-3. Details concerning the data values, emission factor calculations, and the resulting national emission rates are discussed in this section.

5.1 Diaphragm Pumps

Calculation of the emission factor for the diaphragm pumps was based on the following equation:

$$EF_{\text{diaphragm pump}} = \text{Gas Usage (scf/stroke)} \times \text{Frequency (strokes/day)} \times \text{Operating time} \times \% \text{ Methane} \quad (5)$$

where:

Gas usage	=	calculated gas usage from Equation 1 ($0.0719 \pm 10\%$ scf/stroke).
Frequency	=	strokes per day of the average pump ($19,642 \pm 49\%$ stroke/day).
Operating time	=	portion of the year that the pump is operating ($0.40 \pm 52\%$).
% Methane	=	$78.8 \text{ mol } \% \pm 5\%$ for the production segment.

The total methane emission factor for diaphragm pumps is $446 \text{ scfd/pump} \pm 77\%$.

5.2 Piston Pumps

Calculation of the emission factor for piston pumps was based on the following equation:

$$EF_{\text{piston pump}} = \text{Gas usage (acf/stroke)} \times \text{Density (scf/acf)} \times \text{Frequency (strokes/day)} \times \text{Operating time} \times \% \text{ methane} \quad (6)$$

where:

Gas Usage	=	Calculated gas usage from Equation 3 (in actual $\text{ft}^3/\text{stroke}$).
Density	=	scf/acf at supply gas pressure (average 30 psig) (combined average value of volume and density is $0.0037 \pm 65\%$ scf/stroke).
Frequency	=	strokes per day of the average pump ($37,901 \pm 29\%$ strokes/day).
Operating time	=	portion of the year that the pump is operating ($0.446 \pm 62\%$).
% methane	=	$78.8 \text{ mol } \% \pm 5\%$ for the production segment.

The resulting methane emission factor for piston pumps is $48.9 \text{ scfd/pump} \pm 106\%$.

Using Equation 4, the diaphragm pump and piston pump emission factors are expressed in a ratio based on the fraction of each type of pump observed from site visits ($0.498 \pm 38\%$ piston pumps and $0.502 \pm 38\%$ diaphragm pumps from Table 4-3) to produce an emission factor for a typical chemical injection pump of $248 \pm 83\%$ scfd/pump.

5.3 National Emission Rate

The national emission rate is calculated using the emission factor per average pump (248 scfd/pump from Equation 4) multiplied by the number of pumps used in production fields nationwide. The number of gas-operated pumps in the gas industry production segment was determined by establishing the ratio of the number of pumps to active wells that market gas. Details on this calculation are provided in Volume 5 on activity factors.⁸ The resulting national activity factor is a total of 16,971 ± 143% pumps in the production sector.

Multiplying the chemical injection pump emission factor by the activity factor yields the total annual emissions for gas-operated chemical injection pumps:

$$ER_{CP} = 248 \pm 83\% \frac{\text{scfd}}{\text{pump}} \times 365 \frac{\text{days}}{\text{year}} \times 16,971 \pm 143\% \text{ pumps} \quad (7)$$

The resulting methane emissions for the production segment are 1.5 Bscf ± 203%.

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APPENDIX A
Production Source Sheet

PRODUCTION SOURCE SHEET

SOURCES: Wells, Gathering Facilities
COMPONENTS: Chemical Injection Pumps
OPERATING MODE: Normal Operation
EMISSION TYPE: Unsteady, Vented
ANNUAL EMISSIONS: 1.5 Bscf \pm 203%

BACKGROUND:

Gas-driven chemical injection pumps use gas pressure acting on a piston to pump a chemical on the opposite side of the piston. The gas is then vented directly to the atmosphere. The pumps are used to add chemicals such as corrosion inhibitors, scale inhibitors, biocide, demulsifier, clarifier, and hydrate inhibitors to operating equipment. Two types of pumps were observed: 1) piston pumps, and 2) diaphragm pumps. Some of the pumps observed were inactive at the time or had seasonal operation.

EMISSION FACTOR: 248 scfd/average pump \pm 83 %

(This was adjusted for the production methane content in natural gas at 78.8 mol%.)

This average emission factor is based upon the following equation:

$$EF_{\text{avg. pump}} = F_{\text{piston}} \times EF_{\text{piston}} + F_{\text{diaphragm}} \times EF_{\text{diaphragm}}$$

where:

F_{piston} = fraction of the pump population that is the piston type = 49.8% \pm 38%
 EF_{piston} = emission factor of an average piston pump = 48.9 scfd/pump \pm 106%
 $F_{\text{diaphragm}}$ = fraction of the pump population that is the diaphragm type = 50.2% \pm 38%
 $EF_{\text{diaphragm}}$ = emission factor of an average diaphragm pump = 446 scfd/pump \pm 77%

The average device emission factor was determined by an aggregation of device emissions calculated for multiple U.S. sites. For piston pumps, the emission factor was determined by the following equation:

$$EF_{\text{piston}} = \frac{\text{Gas usage (acf/stroke)} \times \text{Density (scf/acf)} \times \text{Frequency (strokes/day)} \times \text{Operating time} \times \% \text{ methane}}{\text{Operating time} \times \% \text{ methane}}$$

where:

Gas usage = calculated gas usage based on piston diameter and stroke length (in actual ft³);
Density = scf/acf at supply gas pressure (average 30 psig) (combined average value of volume and density is 0.0037 \pm 65% scf/stroke);
Frequency = strokes per day of the average pump (37,901 \pm 29% strokes/day);
Operating time = portion of time that the pump is operating (0.446 \pm 62%); and
% methane = 78.8 mol% \pm 5% for the production segment.

Based on site and manufacturer data, the resulting national piston pump emission factor is 48.9 scfd/pump \pm 106%.

For diaphragm chemical injection pumps, the emission factor was determined by the following equation:

$$EF_{\text{diaphragm}} = \frac{\text{Gas usage (scf/gal)} \times \text{Volume (gal/stroke)} \times \text{Frequency (strokes/day)}}{\text{Operating time} \times \% \text{ methane}}$$

where:

Gas usage	=	volume of gas (in standard ft ³) required to pump one gallon of liquid chemical (provided by the manufacturer);
Volume	=	liquid displaced per stroke based on the plunger diameter and stroke length (combined average value of gas consumption and volume is 0.0719 ± 10% scf/stroke);
Frequency	=	strokes per day of the average pump (19,642 ± 49% strokes/day);
Operating time	=	portion of time that the pump is operating (0.40 ± 52%); and
% methane	=	78.8 mol% ± 5% for the production segment.

Using the site, manufacturer, and measured data to calculate the emission factor equation terms, the total diaphragm pump emission factor was determined to be 446 scfd/pump ± 77%.

Stroke volume was calculated from pump manufacturers' data and site observations of manufacturer and model number. Density was calculated based upon observed site supply gas pressure, and frequency was based upon timed stroke intervals observed while on site. Operating time was estimated by site personnel (if seasonal), or was based upon the percent of pumps at the site that were operating during the visit. The emission factors shown above (in scfd/pump) have been corrected for the natural gas composition in the production segment of 78.8 mol % methane.

EF DATA SOURCES:

1. The report entitled *Methane Emissions from the Natural Gas Industry, Volume 13: Chemical Injection Pumps* (1) establishes the important emission-affecting characteristics.
2. Site visit data and reference material established the density from supply gas pressure at 30 psig.
3. For the piston pumps, the stroke volume was estimated from manufacturers' data of pumps found at each site.
4. Manufacturers' data for the diaphragm pumps provided scf of gas required to pump one gallon of chemical. This information was used with the calculated liquid displaced for a range of pumps to give an average gas volume.
5. The frequency of actuations per day was determined from 40 timing measurements taken at 12 sites. The operating time was determined from data at 13 sites.
6. Measurements of 5 diaphragm chemical injection pumps were provided from an emissions estimate program by the Canadian Petroleum Association.

EF ACCURACY:

Basis:

1. Operating time confidence bounds (at 90% confidence) were calculated by analysis of the spread of 7 sites for piston pumps and 10 sites for diaphragm pumps.
2. Actuation confidence bounds (at 90% confidence) were based on measurements from 7 sites for the piston pumps and 5 sites for the diaphragm pumps.
3. It was assumed that the manufacturers' data are completely accurate. Data for the piston pumps were based on information from 4 manufacturers. Diaphragm pump data were provided by 2 manufacturers.

4. 90% confidence bounds for each value were carried through error propagation to result in the final 90% confidence bound.

ACTIVITY FACTOR: 16,971 pumps in the production segment ± 143 %

The number of gas actuated pumps used in the production segment was determined by establishing the ratio of the number of pumps to active wells (oil or gas) that market gas. Site data were organized into regions and regional values were determined. The regional ratios were then multiplied by the regional count of active wells that market gas in that region to produce the total count of chemical injection pumps in the region. Finally, regions were added together to determine the national number. The activity factor is then:

$$(1) \quad \text{National AF} = \sum_{i=1}^n (\text{Regional AF}) \quad \text{where } n = \text{total number of regions}$$

$$(2) \quad \text{Regional AF} = (R_j\text{'s}) \times (W)$$

where R_j = ratio of total pumps to total wells in Region j
where W = number of wells in the region

AF DATA SOURCES:

1. The active oil and gas wells are from A.G.A. *Gas Facts* (2). The active oil wells that market gas are determined by multiplying the total national active oil wells times the fraction that market gas. The fraction is determined from a Texas Railroad Commission lease study that shows the percent of oil leases that market the associated gas in Texas (3).
2. The pump counts were obtained during the site visits. Inactive, electrically driven, or air driven pumps were not counted.
3. Regional extrapolation by gas well count was used.

AF ACCURACY:

Basis:

1. The accuracy for the active gas wells is assigned by engineering judgement, based upon the fact that the number of active wells is tracked nationally and known accurately by A.G.A./DOE, etc.
2. The accuracy for the national AF is based upon error propagation from the production sites visited.

ANNUAL EMISSIONS: 1.5 Bscf ± 203 %

The national annual emissions were determined by multiplying an emission factor for a typical pump by the population of chemical injection pumps in the production segment.

REFERENCES

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APPENDIX B

Conversion Table

Unit Conversion Table

English to Metric Conversions

1 scf methane	=	19.23 g methane
1 Bscf methane	=	0.01923 Tg methane
1 Bscf methane	=	19,230 metric tonnes methane
1 Bscf	=	28.32 million standard cubic meters
1 short ton (ton)	=	907.2 kg
1 lb	=	0.4536 kg
1 ft ³	=	0.02832 m ³
1 ft ³	=	28.32 liters
1 gallon	=	3.785 liters
1 barrel (bbl)	=	158.97 liters
1 inch	=	2.540 cm
1 ft	=	0.3048 m
1 mile	=	1.609 km
1 hp	=	0.7457 kW
1 hp-hr	=	0.7457 kW-hr
1 Btu	=	1055 joules
1 MMBtu	=	293 kW-hr
1 lb/MMBtu	=	430 g/GJ
T (°F)	=	1.8 T (°C) + 32
1 psi	=	51.71 mm Hg

Global Warming Conversions

Calculating carbon equivalents of any gas:

$$\text{MMTCE} = (\text{MMT of gas}) \times \left(\frac{\text{MW, carbon}}{\text{MW, gas}} \right) \times (\text{GWP})$$

Calculating CO₂ equivalents for methane:

$$\text{MMT of CO}_2 \text{ equiv.} = (\text{MMT CH}_4) \times \left(\frac{\text{MW, CO}_2}{\text{MW, CH}_4} \right) \times (\text{GWP})$$

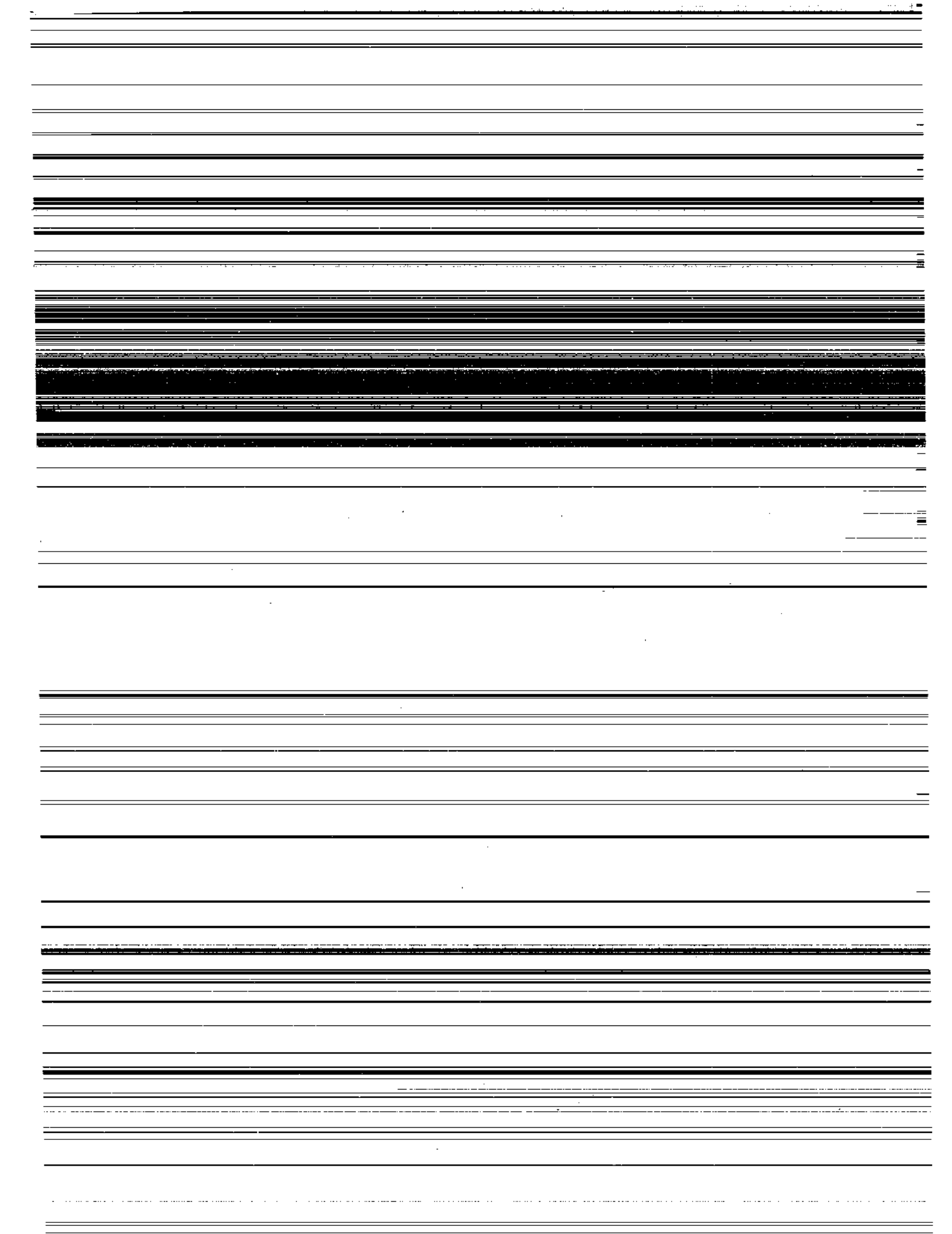
where MW (molecular weight) of CO₂ = 44, MW carbon = 12, and MW CH₄ = 16.

Notes

scf	=	Standard cubic feet. Standard conditions are at 14.73 psia and 60°F.
Bscf	=	Billion standard cubic feet (10 ⁹ scf).
MMscf	=	Million standard cubic feet.
Mscf	=	Thousand standard cubic feet.
Tg	=	Teragram (10 ¹² g).
Giga (G)	=	Same as billion (10 ⁹).
Metric tonnes	=	1000 kg.
psig	=	Gauge pressure.
psia	=	Absolute pressure (note psia = psig + atmospheric pressure).
GWP	=	Global Warming Potential of a particular greenhouse gas for a given time period.
MMT	=	Million metric tonnes of a gas.
MMTCE	=	Million metric tonnes, carbon equivalent.
MMT of CO ₂ eq.	=	Million metric tonnes, carbon dioxide equivalent.

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(Please read Instructions on the reverse before completing)

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16. ABSTRACT The 15-volume report summarizes the results of a comprehensive program to quantify methane (CH ₄) emissions from the U. S. natural gas industry for the base year. The objective was to determine CH ₄ emissions from the wellhead and ending downstream at the customer's meter. The accuracy goal was to determine these emissions within +/-0.5% of natural gas production for a 90% confidence interval. For the 1992 base year, total CH ₄ emissions for the U. S. natural gas industry was 314 +/- 105 Bscf (6.04 +/- 2.01 Tg). This is equivalent to 1.4 +/- 0.5% of gross natural gas production, and reflects neither emissions reductions (per the voluntary American Gas Association/EPA Star Program) nor incremental increases (due to increased gas usage) since 1992. Results from this program were used to compare greenhouse gas emissions from the fuel cycle for natural gas, oil, and coal using the global warming potentials (GWPs) recently published by the Intergovernmental Panel on Climate Change (IPCC). The analysis showed that natural gas contributes less to potential global warming than coal or oil, which supports the fuel switching strategy suggested by the IPCC and others. In addition, study results are being used by the natural gas industry to reduce operating costs while reducing emissions.				
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