United States
Environmental Protection
Agency

Region IX
215 Fremont Street
San Francisco, CA 94105

EPA-909/9-81-003
September 1981

Air

Assessment of VOC Emissions from Well Vents Associated With Thermally Enhanced Oil Recovery

DCN 81-240-016-09-12
EPA 909/9-81-003

ASSESSMENT OF VOC EMISSIONS FROM WELL VENTS ASSOCIATED WITH THERMALLY ENHANCED OIL RECOVERY

FINAL REPORT

EPA Contract No. 68-02-3513
Work Assignment No. 9

Prepared by:

G.E. Harris, K.W. Lee, S.M. Dennis, C.D. Anderson, and D.L. Lewis
Radian Corporation
8501 Mo-Pac Blvd.
Austin, Texas 78759

Prepared for:

Tom Rarick
U.S. EPA Region IX
215 Fremont St.
San Francisco, CA. 94806

13 September 1981

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ACKNOWLEDGMENTS

Radian wishes to acknowledge the assistance provided by members of the Technical Advisory Committee whose expertise helped guide this study to a successful completion:

Tom Rarick	U.S. EPA Region IX
Harry Metzger	California Air Resources Board
Frances Cameron	California Air Resources Board
Dean Simeroth	California Air Resources Board
Grant Chin	California Air Resources Board
Larry Landis	Kern County Air Pollution Control District
Stan Bell	Tenneco Oil
Sam Durán	Getty Oil
Les Clark	Independent Oil Producers Association
David Farr	Chevron
Alex Nichols	Santa Fe Energy
Alan Schuyler	ARCO Oil and Gas
Craig Jackson	Getty Oil

A special acknowledgment is also due to Getty Oil for allowing the use of their portable fin fan condenser during the study.

SECTION 1

INTRODUCTION AND BACKGROUND

This document presents the results of a study of VOC (Volatile Organic Compounds)* emissions from wellhead casing vents associated with thermally enhanced oil recovery (TEOR) operations. The effort included a survey of existing source test and well population data, as well as a sampling and analysis program to measure emissions from uncontrolled cyclic well vents. These data were used to develop emission factors for both cyclic and steam drive production wells. This report also includes the results of the surveys and attempted correlations between well vent emissions and the characteristics of the well.

The objective of this program is to develop data to refine the estimates of total VOC emissions attributable to TEOR wellhead casing vents. The state of California is in the process of reviewing its emission inventories for those air pollution control districts (APCD's) which have not yet demonstrated attainment of the National Ambient Air Quality Standards (NAAQS) for oxidants. In several APCD's, the VOC emissions from TEOR operations account for a large portion of the total VOC emissions in the district. It is necessary, therefore, to refine the estimates of VOC emissions from TEOR well vents in order to accurately assess the need for future control.

This study was funded and administered by EPA Region IX. Additional technical input was received from a Technical Advisory Committee composed of representatives from the EPA, the California Air Resources Board (CARB), the Kern County APCD, and the oil industry. The committee met five times during the course of the program. A project kickoff meeting was held to discuss the overall objectives and approach to the study. Another meeting was held to

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* VOC is defined for this study as total non-methane, non-ethane organic material.

review the test plan before starting field sampling. A third meeting was called to discuss a problem encountered in the early testing concerning the distinction between a steam drive and a cyclic steam well. Another meeting was held to present the preliminary results shortly after completeing the field testing phase. The final meeting was held to review the draft final report.

The results of the testing and surveys are summarized in Section 2. Section 3 presents a brief discussion of TEOR operations to aid the reader who is unfamiliar with this type of oil production. Sections 4, 5 and 6 present the details of the experimental design and the sampling and analytical techniques used in testing cyclic wells. Section 7 presents a discussion of quality control for the test program. Section 8 presents the detailed results of emissions testing and survey data, while that information is used to test for various correlations in Section 9. Section 10 documents the methodology for calculating emission factors for both cyclic and drive wells. The appendices include example data sheets and sample calculations.

SECTION 2

SUMMARY OF RESULTS

The objective of this study is to estimate the VOC emissions from wellhead casing vents on TEOR projects. This section briefly summarizes all of the results pertinent to that objective.

2.1 TEOR WELL POPULATION DATA

A survey was made of several sources of population data for both steam drive and steam cycle wells. The most comprehensive and accurate source of well population data was found to be a survey made by the Kern County Air Pollution Control District, the results of which are presented in Table 2-1. For sources outside Kern County, the population data on file with the Division of Oil and Gas can be used, but it does have some inconsistencies in the classification of wells as either drive or cyclic.

2.2 EMISSION FACTORS

Emission factors were calculated for steam drive wells based on compliance testing of vapor recovery systems. A sampling and analysis program, which included a survey of 358 wells and quantitative testing of 58 wells, provided the data to develop an emission factor for cyclic wells. The emission factor data is summarized in Table 2-2.

2.3 WELL CHARACTERISTICS SURVEY

A questionnaire was completed by producers providing data to characterize the operations and physical characteristics of each steam cycle well surveyed. The results of that survey are presented in Table 2-3.

TABLE 2-1. KERN COUNTY PRODUCER SURVEY SUMMARY*

Producer	Oil Field	Drive Wells Total-Controlled	Cyclic Wells Total-Controlled
Arco	Midway-Sunset	52 - 0	195 - 0
Arco	Kern Front	2 - 2	42 - 42
Bell Western	Edison	0	12 - 0
Berry Holding	Midway-Sunset	0	588 - 139
Berry Holding	So. Belridge	0	0
Carrec Oil	Kern Front	0	21 - 0
Chevron USA	Cymric	62 - 56	175 - 0
Chevron USA	Midway-Sunset	90 - 90	440 - 0
Chevron USA	McKittrick	64 - 64	140 - 0
Chevron USA	Belridge	0	28 - 0
Chevron USA	Kern River	499 - 493	187 - 38
Chevron USA	Poso Creek	19 - 19	78 - 78
Chevron USA	Edison/Racetrak	12 - 12	53 - 0
Circle Oil	McKittrick	22 - 22	0
Elf Oil & Gas	Poso Creek	0	0
Emjayco	Edison	0	3 - 0
Energy Dev.	Kern Bluff	0	10 - 0
Exeter	Midway-Sunset	0	50 - 0
Exxon	Edison	0	158 - 26
General Oil	Midway-Sunset	0	36 - 16
Getty Oil	Midway-Sunset	84 - 84	219 - 0
Getty Oil	Lost Hills	27 - 27	40 - 0
Getty Oil	Cymric	0	70 - 0
Getty Oil	McKittrick	0	603 - 0
Getty Oil	Kern Front	0	97 - 0
Getty Oil	Poso Creek	0	76 - 0
Getty Oil	Kern River	2109 - 2109	875 - 638
Gulf	Midway-Sunset	0	32 - 28
Gulf	Cymric	0	16 - 0
Gulf	Kern Bluff	4 - 4	20 - 18
Gulf	Lost Hills	74 - 74	62 - 61
Gulf	Fruitvale	0	26 - 26

*Composite of responses to a questionnaire sent to the producers by a letter from Leon M. Hebertson, Air Pollution Control Officer, Kern County APCD, September 12, 1980.

Continued/

TABLE 2-1. (Continued)

Producer	Oil Field	Drive Wells Total-Controlled	Cyclic Wells Total-Controlled
Junniper	Jasmin	0	0
Johnson & Brown	Cymric	0	13 - 0
Kern Ridge	So. Belridge	2115 - 604	66 - 0
McCullock Oil	Midway-Sunset	0	140 - 0
McFarland	Midway-Sunset	0	44 - 0
McFarland	McKittrick	0	4 - 0
Mobil	Kern Front	0	40 - 0
Mobil	Midway-Sunset	0	330 - 0
Mobil	Cymric	0	45 - 0
Mobil	Belridge	111 - 39	157 - 0
Occidental	Midway-Sunset	0	52 - 0
Occidental	McKittrick	0	5 - 5
Petro-Lewis	Poso Creek	0	52 - 37
Petro-Lewis	Kern Front	36 - 0	82 - 0
Petro-Lewis	Kern River	27 - 27	26 - 0
Santa Fe	Midway-Sunset	163 - 95	983 - 84
Santa Fe	Kern River	41 - 0	136 - 0
Santa Fe	Kern Front	0	14 - 0
Santa Fe	Poso Creek	0	0
Shell	Midway-Sunset	239 - 0	376 - 0
Shell	Mt Poso	257 - 0	0
Shell	Kern River	0	608 - 0
Sun Production	Kern River	3 - 0	29 - 16
Sun Production	Midway-Sunset	35 - 0	254 - 0
Tannehill Oil	Midway-Sunset	0	147 - 147
Tenneco Oil	Kern River	189 - 0	36 - 0
Tenneco Oil	Midway-Sunset	152 - 0	103 - 0
Tenneco Oil	Poso Creek	0	0
Tenneco Oil	Wheeler Ridge	0	0

Continued/

TABLE 2-1. (Continued)

Producer	Oil Field	Drive Wells Total-Controlled	Cyclic Wells Total-Controlled
Texaco	Midway-Sunset	8 - 0	38 - 0
Union	No. Belridge	12 - 12	23 - 23
Union	McKittrick	17 - 17	50 - 8
Union	Midway-Sunset	39 - 39	150 - 56
Victory	Cymric	0	8 - 0
Victory	No. Midway	0	78 - 0
Whittier	No. Midway-Sunset	0	122 - 0
Whittier	Kern Front	0	9 - 0
TOTALS:	Kern Front	38 - 2	284 - 42
	Kern River	2868 - 2629	1761 - 692
	Poso Creek	19 - 19	128 - 115
	Edison	12 - 12	226 - 26
	Midway-Sunset	862 - 376	4377 - 470
	Belridge	2238 - 655	274 - 23
	Kern Bluff	4 - 4	30 - 18
	Lost Hills	101 - 101	102 - 61
	Cymric	62 - 56	327 - 0
	McKittrick	108 - 39	802 - 5
	Fruitvale	0	26 - 26
	Mt Poso	257 - 0	0
	Jasmin	0	0
	Wheeler Ridge	0	0
		6569-3893	8337-1478
		59%	18%

TABLE 2-2. EMISSION FACTORS

Source Type		VOC Emission Factors (lb/day/well)	95% Confidence Interval (lb/day/well)		Emission Factor Basis
			Lower	Upper	
Cyclic Steam Wells	Overall*	3.6	2.2	6.2	358 wells surveyed 58 wells tested
Cyclic Steam Wells	Western Kern County	4.3	2.3	7.6	271 wells surveyed 42 wells tested
Cyclic Steam Wells	Central Kern County	2.3	0.7	3.3	87 wells surveyed 16 wells tested
Steam Drive Wells		220.3	209.3	231.3	40 vapor recovery system tests 963 drive wells represented

* In deriving the overall estimates, average emissions in the cell were weighted by the proportion between the west and the central areas as determined in the survey. The VOC emissions of the wells actually tested were averaged within each flow rate group and each area group.

TABLE 2-3. SUMMARY OF CYCLIC WELL CHARACTERISTICS DATA

Parameter	Units	For All Wells Surveyed: Mean Value	For All Wells Surveyed: Range Lower	For All Wells Surveyed: Range Upper	For All Wells Surveyed: Number of Responses	For Only Wells Tested: Mean Value	For Only Wells Tested: Range Lower	For Only Wells Tested: Range Upper	For Only Wells Tested: Number of Responses
1. Total Steaming Cycles to Date	---	8.1	1	29	317	8.0	1	25	56
2. Time Since Last Steaming	days	242	1	1372	317	213	13	502	54
3. Steaming Frequency	mos./cycle	9.9	1	115	228	8.8	1	24	36
4. Soaking Period	days	5.8	0	23	230	5.5	1	19	36
5. Steam Dosage	bbl./cycle	9731	640	86,181	335	10,281	640	62,089	57
6. Oil Production Rate	bbl./day	21.2	0.4	1280	302	15.6	2	45	51
7. Cumulative Oil Production Since Steaming Began	bbl.	49,911	302	320,311	208	49,863	311	279,938	34
8. Gravity of the Oil	°API	12.9	10.5	18.9	308	12.8	10.5	16.0	50
9. Water to Oil Ratio	---	14.0	0.01	99	292	19.8	0.04	97	46

2.4 CORRELATION STUDIES

An attempt was made to correlate the VOC emissions from cyclic wells to their operating and physical characteristics. Although some vague trends could be identified, there was too much scatter in the data to provide significant correlations. The trends are strong enough to indicate that some variables do correlate to emissions, but the study population is too small to quantify the complex inter-relationships of the many variables involved.

SECTION 3

DESCRIPTION OF SOURCES

In order to understand the experimental design and to interpret the results, it is necessary to understand the fundamentals of oil production using thermally enhanced oil recovery (TEOR). This section presents a brief discussion of TEOR technology, especially as it affects the well vent emissions.

3.1 ENHANCED OIL RECOVERY

When an oil producing formation is first drilled, the formation pressure may be high enough for the oil to flow freely to the surface. As such free flowing production declines, it is necessary to use some mechanical aid to induce the flow of oil to the surface. Typically, this is done by pumping the liquid, but it can also be accomplished by gas lift or by artificially pressuring the formation with compressed gas. All of these methods are still considered to be primary production techniques.

As the oil production rate achievable with primary recovery methods drops off, the producer may consider secondary oil recovery such as water-flooding. TEOR is a tertiary recovery technique which may include in-situ combustion (fire-flooding) and steam stimulation. This report deals solely with the steam stimulation type of TEOR activities. TEOR is particularly advantageous in the production of very heavy oils where the high viscosity of the oil retards its migration through the formation to the well. The injection of steam, on either a continous or cyclic basis, raises the temperature in the producing zone and lowers the viscosity of the oil, which increases the achievable production rate.

3.2 WELLHEAD DESIGN

Oil production wellheads have essentially identical designs for both steam cycle and steam drive wells. Figure 3-1 presents a typical design of a production wellhead.

Crude oil production wells are typically completed in a pool or reservoir with a 6 to 10 inch diameter pipe casing surrounded by cement. The casing and cement are perforated at the desired depths of production. The crude then flows into the casing through the perforations and is pumped to the wellhead by a rod pump connected to the surface pumping unit by a string of rods. The crude flows through the production tubing into the crude flowline which is connected to either a main lease flowline or crude storage tank.

During normal production operation, the valve on the crude flowline is open and the valve on the casing flowline closed. The casing vent may be open or closed depending on the operational characteristics of the well. If a negative pressure (relative to atmospheric pressure) develops within the casing due to geological properties or pumping practices, the casing vent valve would be closed to increase the flow of crude through the perforations into the casing. A high pressure in the well casing would inhibit the flow of crude into the casing, and the casing vent valve would be opened to relieve that pressure. With atmospheric pressure in the casing, the casing vent valve might be open or closed depending on the well operator.

The primary emission point for both steam drive and steam cycle wells is the casing vent. The occurrence and amount of emissions may vary significantly between steam cycle and steam drive wells due to differences in steaming practices. The following two subsections discuss these differences and their impact on emissions.

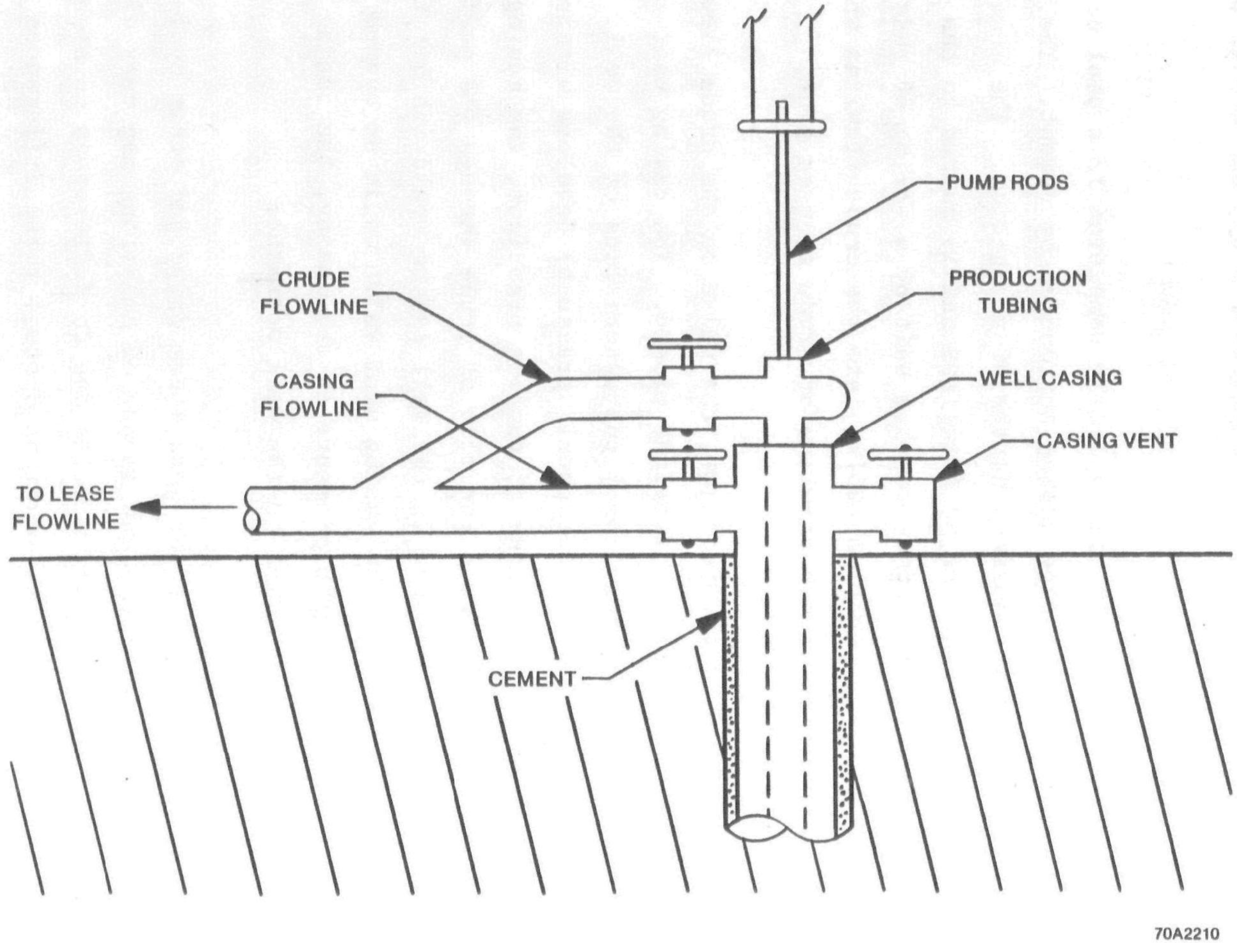

FIGURE 3-1 TYPICAL PRODUCTION WELLHEAD

3.3 STEAM DRIVE WELLS

Both steam drive wells and steam cycle wells are stimulated by the injection of steam into the producing formation. In a cyclic operation, the steam is intermittently injected into the production well itself. In a steam drive operation, the steam is continuously injected into one well that is dedicated to that service and oil and connate water is produced from wells clustered around the injection well.

It is not always straightforward to distinguish between cyclic and drive wells. A drive well may occasionally have steam injected directly into the production tubing, both to clean the tubing and to stimulate production. A cyclic well may also be indirectly affected by nearby steam injection wells. The Kern County APCD defines a drive well as a production well which is completed in the same zone and is within 250 feet of a steam injection well.* A steam cycle well can then be defined as any well which is intermittently steamed and produced and does not meet the requirements to be called a drive well.

Steam drive wells are typically situated in groups or patterns surrounding a steam injection well. Steam is continuously injected at high pressure into an injection well which resembles a typical producing well without the pumping apparatus. During the process of injection, a series of zones develop as the fluids move from injection well to production well. Nearest the injection well is a steam zone, followed by a zone of steam condensate, and in front of the condensate is a region of reduced-viscosity oil moving towards a production well.

The steam drive, or production well, may also be injected with steam to reduce the viscosity of the crude nearby. By warming the crude surrounding a steam drive well completion, the zone of crude moving towards the well may reach the completion more easily and quickly.

* This distance is based on a 2.5 acre steaming pattern.

Several conditions may exist which could result in an emitting steam drive well casing vent. A typical situation is when steam breakthrough occurs at the production well. Due to differences in permeability, the steam zone may overtake the condensate and reduced-viscosity crude zones near the production well completion. With the casing vent open, this steam rises through the casing and out the vent. Steam breakthrough usually results in high vent flowrates for sustained intervals.

Another situation which may result in casing vent emissions is steam "channeling" or short circuiting. In this case, steam from the injection well bypasses the crude reservoir via a geological fault in the formation. This steam would also rise through the casing and exit an open vent.

Emissions from steam drive well vents consist primarily of steam and entrained water, but may also include carbon dioxide, hydrocarbons, and hydrogen sulfide. Once steam drive wells begin to emit, they typically continue to emit.

3.4 CYCLIC STEAM WELLS

As mentioned in the previous section, a cyclic steam well is a production well that is intermittently steamed and is not affected by any nearby continuous steam injection wells. The objective of the steaming is to heat the crude oil in the reservoir surrounding the completion. This reduces the viscosity of the oil and allows it to flow more freely into the production well. Some major TEOR operations begin with cyclic steaming and convert to steam drive if the cyclic steaming project is successful.

When a cyclic well is steamed, the pump rods and pump unit are usually removed and the production tubing capped off. The crude flowline is then emptied, casing vent closed, and, depending on individual steaming practices, the casing flowline valve may be opened. High pressure steam from steam generators is then piped to the well through the crude flowline. The steam is typically injected through the well tubing and/or casing into the crude reservoir for a period of 5 to 15 days or until the total amount injected is between 5,000 and 15,000 barrels (as water). At this time the crude and casing flowline valves are closed and the well is allowed to "soak".

During the soaking period, typically 4 to 10 days, the surrounding crude becomes less viscous due to heat transfer from the injected steam. After the reservoir temperature has equilibrated, the pump rod assembly is placed again into the production tubing and production resumed. At this time, the casing vent valve is opened. With the vent open, the pressure in the reservoir is reduced, which causes hot water (condensed from injected high pressure steam) to flash into steam (and some entrained water), which is emitted from the casing vent. A crude and water mixture is then pumped to the wellhead. When crude production has declined significantly the steaming process is repeated. Such steaming cycles may range from 2 months up to 2 years or more.

Cyclic wells typically exhibit their highest casing vent flowrates immediately after soaking. The majority of the vent flow is caused by steam condensate flashing in the crude reservoir and is exemplified by a large steam plume. Also potentially contained in the casing vent flow are hydrocarbons, carbon dioxide, and hydrogen sulfide.

Depending on geological characteristics, cyclic wells will have higher than normal casing vent flowrates for from 1 to 20 days after soaking has ended. When the flow has decreased, the casing vent may be left open if positive pressure still exists within the casing, or closed if a negative pressure is present. If the casing vent is left open, the casing may continue to emit with little or no plume. It should be emphasized that actual steaming practices and emission characteristics vary widely depending on the field and well operator.

SECTION 4

EXPERIMENTAL DESIGN

It was determined early in the program that further steam drive well testing was not warranted, and that the sampling and analysis effort should concentrate on cyclic wells. The objective was set to quantitatively measure the emissions of 50 randomly selected uncontrolled steam cycle wells which were found to be emitting. It was recognized that many more cyclic wells would need to be surveyed in order to find 50 emitting wells, since cyclic wells do not always emit on a continous basis.

Data on cyclic well population was available from two sources:

- the Division of Oil and Gas (DOG), and
- the Kern County Air Pollution Control District (KCAPCD).

There were inconsistencies between these two data bases, largely because of differing definitions of what constitutes a steam cycle well. The DOG considers any well which is both steamed and produced in a single year to be a cyclic well. This results in excluding some cyclic wells which are steamed less frequently than once per year. It also includes some steam drive wells which are lightly steamed to clean out the production tubing. The DOG data base also gave no indication as to whether or not the wells were controlled by a vapor recovery system.

It was decided that only uncontrolled cyclic wells would be tested. Early survey efforts indicated that cyclic wells connected to a vapor recovery system without a check valve could experience a back flow of steam into the well. Since this might induce artificially high emissions if the vent were opened, it was decided to omit controlled cyclic wells from testing.

The Kern County APCD data offered a more realistic estimate of the population and distribution of uncontrolled cyclic wells. The definition used in compiling the KCAPCD survey data was adopted as the definition of a cyclic well for this program. A cyclic well was defined as one which was intermittently steamed and produced and was not affected by a nearby steam injection well. The well operator's judgement was used to determine if a steam injection well was affecting any given well, but some rough guidelines were that the well would be considered a drive well if it was completed in the same zone and within 250 feet of an injection well (based on 2.5 acre pattern).

Despite the inconsistencies in the DOG data base, it played an important part in the experiment design. The DOG data base was computerized and included individual listings for each cyclic well. The KCAPCD survey data, however, was available only in aggregated form (i.e. broken down only by field, producer, and controlled/uncontrolled). There was no way to preselect a random sample of wells based on the KCAPCD data. A hybrid approach was chosen in which a random list of 1600 candidate wells was generated from the DOG data. Wells were surveyed from this list, and those which were found to be drive wells or to be controlled were eliminated from the survey. As many such candidate wells were examined as necessary to fill survey quotas which were set to represent the distribution of uncontrolled cyclic wells according to the KCAPCD survey.

At the outset of the study, it was believed that cyclic wells emitted VOC primarily during the period of one to two weeks following steaming. The initial test plan, therefore, called for sampling all wells which were found to be emitting. The survey demonstrated, however, that while cyclic wells may emit at somewhat higher rates during the initial depressuring phase following steaming, that about half of them continue to emit throughout the cycle. A stratified sampling plan was developed to avoid spending too much effort testing low emitters, the details of which are given below:

Survey flow measurement	Sampling quota
less than 0.1 liters/minute	none
0.1 to 0.99 liters/minute	1 out of 10
1.0 to 5.0 liters/minute	1 out of 4
greater than 5.0 liters/minute	all

This plan put the most emphasis on the high emitting sources, especially those outside the range of an exact reading on the bubble-meter used to determine the flow rate during the survey.

The experiment design described here resulted in a survey which included only "true" cyclic wells chosen in a random manner and in proportion to the population distribution indicated by the KCAPCD survey. Table 4-1 shows the numbers of wells surveyed and tested compared to the KCAPCD data. The sampling quotas by survey group are given in Table 4-2. It should be noted that it was not always possible to sample all sources in the greater than 5.0 liter per minute category. Some sources were inaccessible for the large van used as a mobile laboratory during sampling. Others were omitted due to problems with scheduling or a variety of case specific causes. Those sources not sampled were characterized by the mean emissions of other sources in the same survey category for emission factor development.

TABLE 4-1. SUMMARY OF TESTING

Area / Field	KCAPCD Survey Population Uncont. Cyclics	% of Population	No. in Radian Survey	% of Radian Surv.	No. Tested	% of Tests
West Side/						
Midway-Sunset	3829	54.6%	189	52.8%	31	53.4%
Belridge	251	3.6%	15	4.2%	3	5.2%
Cymric	327	4.7%	22	6.2%	1	1.7%
McKittrick	789	11.3%	44	12.2%	7	12.1%
Lost Hills	41	0.6%	1	0.3%	0	0%
Subtotal	5237	74.2%	271	75.4%	42	72.4%
Central County/						
Kern River	1205	17.2%	42	11.7%	10	17.3%
Kern Front	263	3.8%	19	5.3%	4	6.9%
Poso Creek	91	1.2%	10	2.8%	0	0%
Kern Bluff	12	0.2%	0	0%	0	0%
Edison	200	2.8%	16	4.5%	2	3.4%
Subtotal	1771	25.8%	87	24.6%	16	27.6%
Grand Total	7008	100.0%	358	100.0%	58	100.0%

TABLE 4-2. SAMPLING QUOTAS

Flow Rate Group	No. in Survey	% in Survey	Sampling Quota	No. Sampled	% of Samples
less than 0.1 ℓ/min.	168	51%	0	0	0%
0.1 to 0.99 ℓ/min.	51	14%	5	4	7%
1.0 to 5.0 ℓ/min.	93	26%	24	26	45%
greater than 5.0 ℓ/min.	46	13%	46	28	48%
Totals	358	100%	75	58	100%

SECTION 5

SAMPLING METHODOLOGY

The testing of cyclic well vent emissions was done in two stages. A preliminary survey was conducted to locate the well and to get a rough idea of its emission status. Selected sources from this survey were then quantitatively measured. This section discusses the detailed procedures used in both surveying and sampling.

5.1 SURVEY PROCEDURES

The objectives of the survey included:

- finding the well,
- determining whether or not it was truly an uncontrolled cyclic well,
- measuring the casing vent flow rate,
- gathering well characteristics data, and
- selection of wells for quantitative sampling.

Each of these functions is discussed in detail in this section.

The first step was to arrange a meeting with a representative of the company to be tested. The list of random wells to be surveyed was examined, and the producer's files checked to identify any wells which should be eliminated from the survey (steam drive wells, fire-flood wells, water-flood wells, and wells connected to a vapor recovery system). Once this preliminary survey was completed, the producer's representative and the surveyor began a field inspection of the remaining candidate wells.

At each well site, the surveyor would make a number of observations which were recorded on the survey data sheet (an example of which is included in Appendix A). Each well was carefully checked to insure that it was an uncontrolled steam cycle well by inspecting the area for vapor recovery systems and steam injection wells. The position of the casing vent valve was noted. If the casing vent was closed, the well was recorded as a zero emitter. If the vent valve was open to the atmosphere, the flow rate through the casing vent was measured using a bubble meter (unless a visual inspection noted a high flow characterized by a steam plume). A stopwatch was used to measure the time it took for a bubble to be displaced by 100 ml on a graduated scale. The elapsed time was measured three times for each source, and the flow rate corresponding to the average time was recorded on the survey sheet. An exact flow rate could not be determined for sources emitting greater than 5 liters/minute using the bubble meter, so a static pressure measurement was also made to aid in characterizing the emissions. The position of the casing vent valve was left as it was found throughout the survey.

A well characterization data sheet was also filled out for each well remaining in the survey. This sheet included data on the oil production rates, life of the steaming project and particulars of steaming practice (a copy of the sheet is included in Appendix A). These data were taken for use in trying to correlate the emissions from a well with its physical characteristics. Since much of this information required a file search, the well characteristics data sheets were usually left with the producer for later completion.

The surveyor was also responsible for selecting those sources to be quantitatively sampled. The sampling quotas given in Section 4 were used as a guide in this selection. For instance, in the category of wells emitting between 0.1 and 0.99 liters per minute, only one well in ten was to be sampled. The surveyor kept a running log of all wells found in this category and selected for sampling the fifth, fifteenth, twenty-fifth, etc. A similar method was used to select the one in four wells in the 1.0 to 5.0 liter per minute category. An attempt was made to test all wells which surveyed at more than 5.0 liters per minute. Selected wells were typically tested the day following the survey, or as soon as possible.

5.2 QUANTITATIVE SAMPLING PROCEDURES

The estimate of flow rate and the presence of a steam plume from the survey were used to select the right sampling procedure for each well. The surveyor also noted fittings needed and special situations to be encountered by the sampling crew.

The following parameters were measured at each source test site in order to meet the objectives of this program:

- volumetric gas flow rate,
- gas phase composition, and
- density and volume of condensible organics.

Sampling procedures necessary to obtain volumetric gas flow rate and provide samples for analysis are described in this section. Only those systems actually used will be described. Some of the high flow techniques were not needed but were described in detail in the QA/QC manual.

5.2.1 Sampling Systems for Low, Medium and High Flow Wells

The sampling system varied depending on the noncondensible gas flow and amount of condensate. Static well casing pressure proved to be of little use as a third parameter to help in the selection of the sampling procedure. Table 5-1 contains a list of the two parameters and the systems used for sampling. The two basic sampling systems used are illustrated in Figures 5-1 and 5-2.

TABLE 5-1. SELECTION OF SAMPLING SYSTEMS

	Noncondensible Gas Flow	Amount of Condensate (Water plus Hydrocarbons)	Brief Description of System
①	∿0.1 - 1.0L/min	None	Preknockout pot, small condenser, small DGM (similar to system shown in Figure 5-1)
②	∿0.1 - 1.0L/min	Small amount present	As in ① plus second small condenser (see Figure 5-1)
③	∿1.0 - 5.0L/min	None	As in ①
④	∿1.0 - 5.0L/min	Moderate amount present	As in ②
⑤	>5.0L/min (up to ∿1000L/min)	None	As in ① except used large DGM
⑥	>5.0L/min (up to ∿1000L/min	Small amount present	As in ② except used large DGM
⑦	>5.0L/min (up to ∿1000L/min)	Moderate to large amount present (steam)	See Figure 5-2. Preknockout, large knockout, 55 gal. condenser, condenser knockout, small DGM
⑧	>1000L/min	None	As in ① except used 2 to 3 DGM's in parallel
⑨	>1000L/min	Large amount present (steam)	As in ⑦ except used large DGM
⑩	>>1000L/min	None	As in ① except used annubar in place of the DGM (See Figure 5-3)

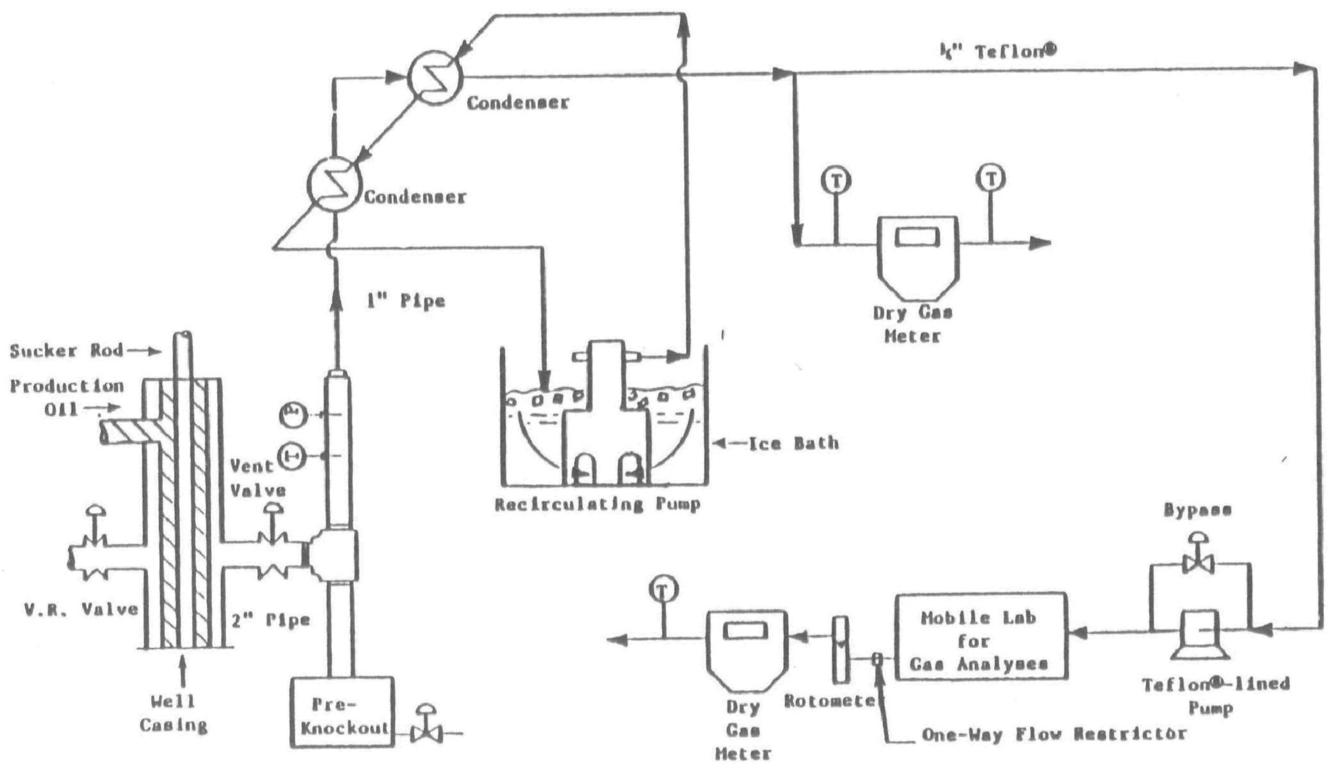

Figure 5-1. Low Flow Sampling Train

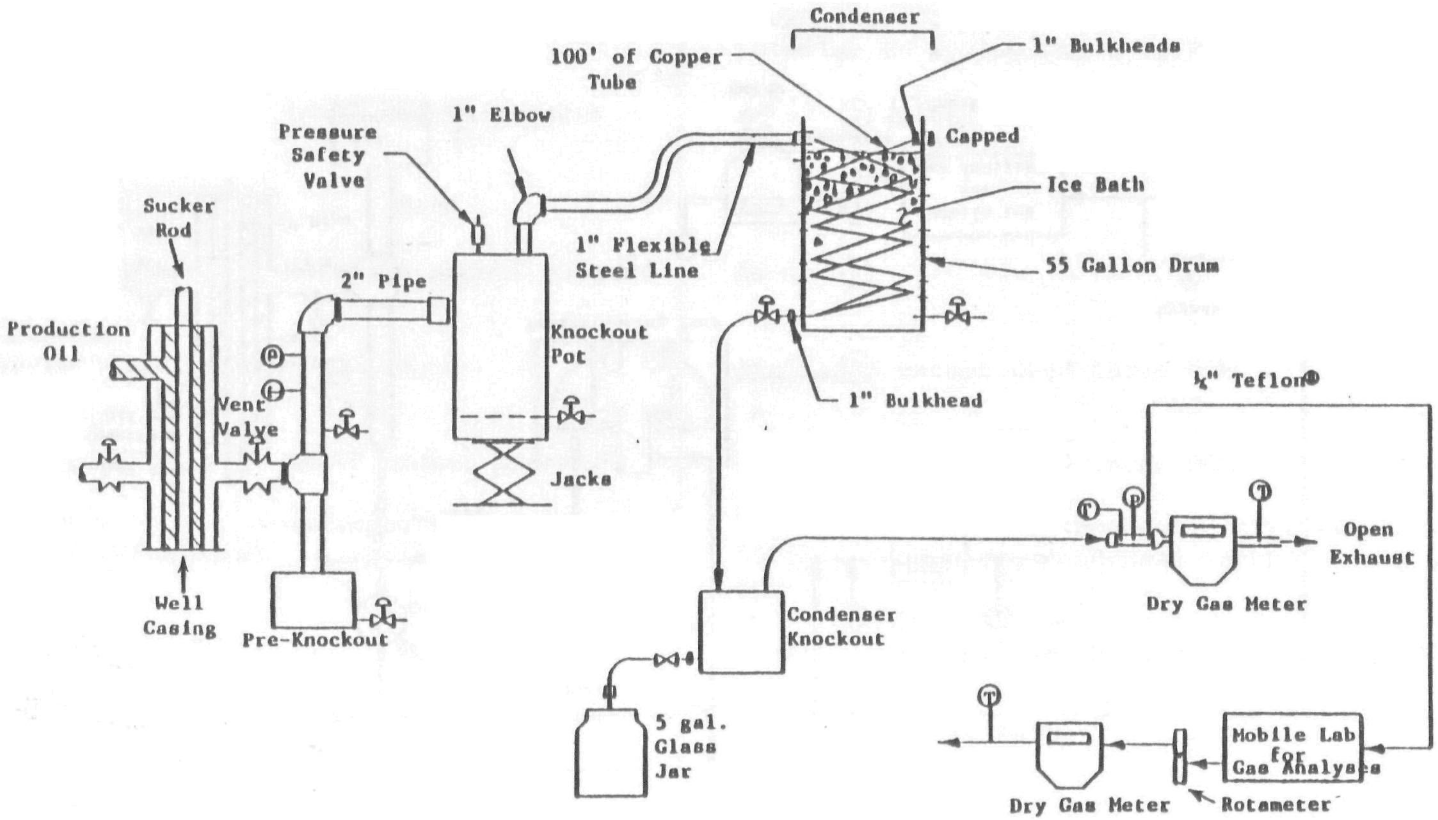

Figure 5-2. Moderate Flow Sampling Train

5.2.2 Sampling Procedures

Once a well was identified to be sampled, the surveyor and sampling crew looked over the survey sheet and decided on the best sampling system to use (see Table 5-1). Even though ten different systems were used for sampling, the steps in setting up and taking the samples were very similar. Table 5-2 contains a list of steps taken during sampling. A typical sampling run lasted from one to two hours.

Preparations were made for sampling high flow wells with very large condensate content (beyond the large condenser capacity). The apparatus used to measure the flow rates from this type of well is illustrated in Figure 5-3. Only one of the wells tested required the high flow measuring devices, and it had very little condensate. The following three paragraphs briefly describe the procedures which were to be used with each of these high flow methods. A more detailed discussion of these methods can be found in the QA/QC manual.

Flow measurement using an S-type pitot tube was based on determining the cross sectional area of the pipe and the average stream velocity. The average velocity was calculated from the differential pressure (ΔP), the average stream temperature, wet molecular weight, and the absolute static pressure. Barometric pressure readings were taken twice per day using the barometer in the mobile laboratory. Static pressure in the pipe was measured by disconnecting one leg of the S-type pitot and then rotating the pitot so that it was perpendicular to the gas flow. A liquid trap was inserted in the gauge line, leading to the upstream pitot tube leg. Static pressure and ΔP measurements were measured by connecting a Capsahelic® gauge to the pitot tube. Temperature of the gas stream was measured using a calibrated thermometer.

A second method for determining volumetric flow was the use of in-line calibrated orifices. Differential pressure across the orifice was measured

TABLE 5-2. MAJOR STEPS IN THE SAMPLING PROCEDURES

Step	Task
1	Identify well and mark extent of casing valve opening.
2	Place preknockout pot on well along with pipe containing P and T gauges. Take static temperature and pressure readings.
3	Open preknockout pot valve and set up rest of system.
4	Test system for leaks.
5	Start condenser and make all initial meter readings.
6	When analyst is ready for gases, start sampling by closing preknockout valve and starting pump inside mobile laboratory.
7	Record T, P and DGM readings periodically (~10 min intervals) during run.
8	Stop run by shutting off mobile laboratory pump and closing vent casing valve.
9	Record final DGM readings.
10	Test system for leaks.
11	Disassemble system and at the same time collect hydrocarbon/water mixtures from all collection devices.
12	Check to be sure casing valve is in the same position as when first observed.

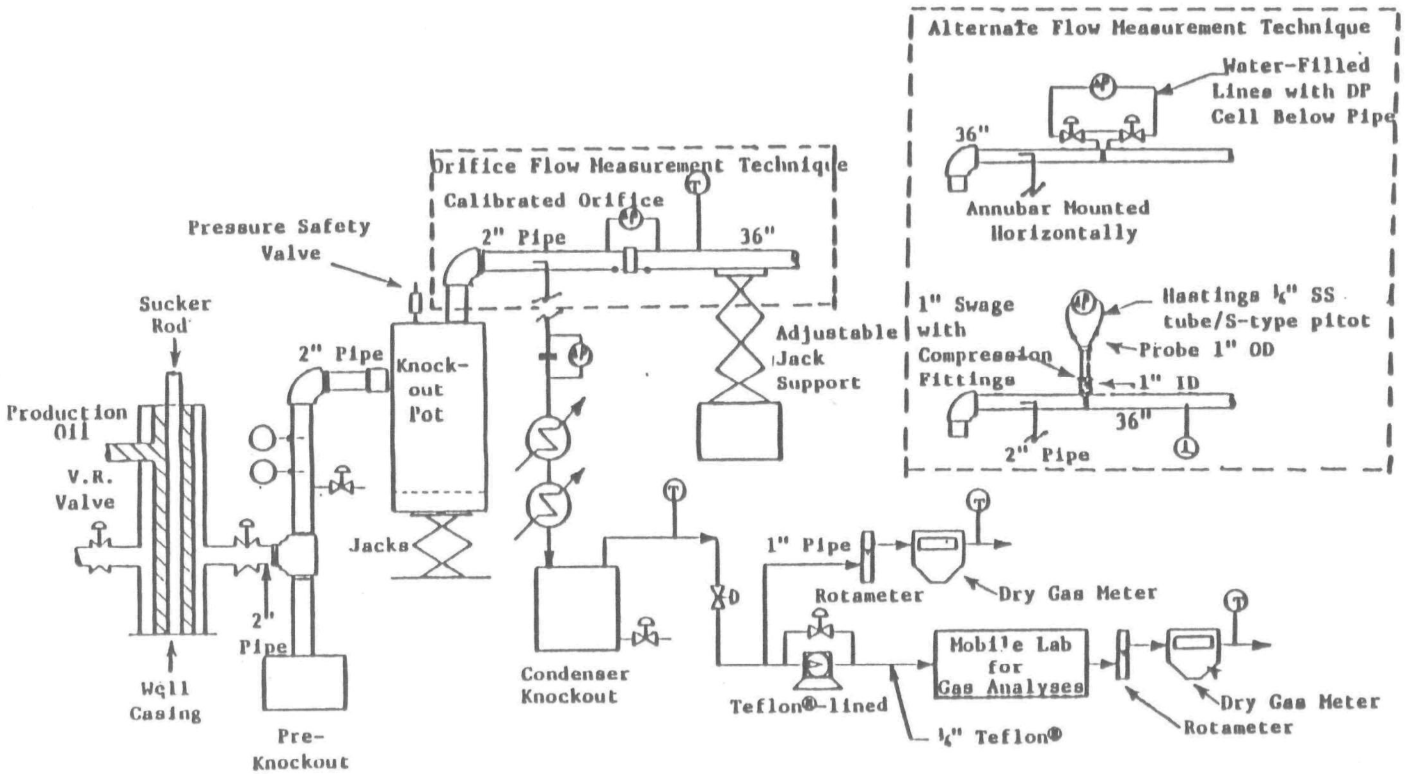

Figure 5-3. High Flow Sampling Train

using a Capsahelic® gauge. The flow rate was calculated from ΔP, pipe dimensions, orifice dimensions, and the orifice coefficient. The orifice coefficient is a function of the Reynolds number through the orifice and the ratio of the diameters of the orifice to the pipe. Two interchangeable orifices of different sizes were used to take measurements of the flow.

The third method for flow measurement was an annubar. Its principle of operation is similar to that of the S-type pitot tube. The major difference is that the high pressure sensor uses four impact ports facing upstream, where an S-type pitot has but a single impact port on the upstream face. Based on Chebychef calculus for observation averaging, the properly located ports sense the impact pressure caused by the flow velocity in each of the four equal cross sectional areas of the stream. The high pressure side of the ΔP gauge sees a continuous average of the impact pressure detected by the four sensing ports. The impact pressure is the sum of pressure due to velocity of the fluid and the line static pressure. The difference between the high and low pressure, the ΔP, is proportional to flow rate according to Bernoulli's Theorem. An Eagle Eye® differential flow meter was used to measure ΔP for the well on which the annubar was used.

SECTION 6

ANALYTICAL METHODOLOGY

The two on-site analytical procedures included the determination of the noncondensible gas composition and the measurement of volumes, density and temperature of the condensed hydrocarbons. The methods used for gas phase analysis were independent of the sampling approach. Table 6-1 summarizes the methods for gas phase analysis, including instrumentation and detection limits. Figure 6-1 is a block diagram depicting the mobile laboratory instrumentation.

Two of the condensates were chosen for boiling point distribution analysis. This off-site analysis is described in the final subsection of this section.

6.1 NONCONDENSIBLE GAS ANALYSIS

Before the gas stream from the wellhead casing vent was analyzed, it was passed through a condenser system. After the condenser a slipstream of the noncondensible gas stream was diverted to the mobile laboratory for analysis.

Figure 6-1 illustrates in block form how the 1/4" Teflon® sampling line was initially attached to the analytical instruments in the mobile laboratory. This procedure gave variations in analyses due either to well gas variability or line purging problems. The well gas variability was confirmed on a day-to-day basis (see Section 7). In order to integrate the samples over the sampling period, a 100L Tedlar® bag was attached to the dry gas meter with all other connections to the instruments eliminated. A comparison of this technique to the original technique gave identical results using a well which showed no variation.

TABLE 6-1. METHODS FOR GAS PHASE ANALYSIS

Parameter	Description of Method	Instrument	Lower Detection Levels*
Fixed Gases (N_2, O_2, CO, CO_2, H_2, CH_4)	Dual Column Gas Chromatographic Separation with Thermal Conductivity Detection	Fisher Model 1200 Gas Partitioner	0.1% (V/V)
Methane, Ethane, C_3-C_6, C_6+	Single Column Gas Chromatographic Separation Including Backflush with Flame Ionization Detector	Hewlett-Packard Model 5730 with Model 3380A Integrator	0.1% (V/V)

*Lower Detection Levels were set by calibration range and program needs and not by the detection limit of the instruments.

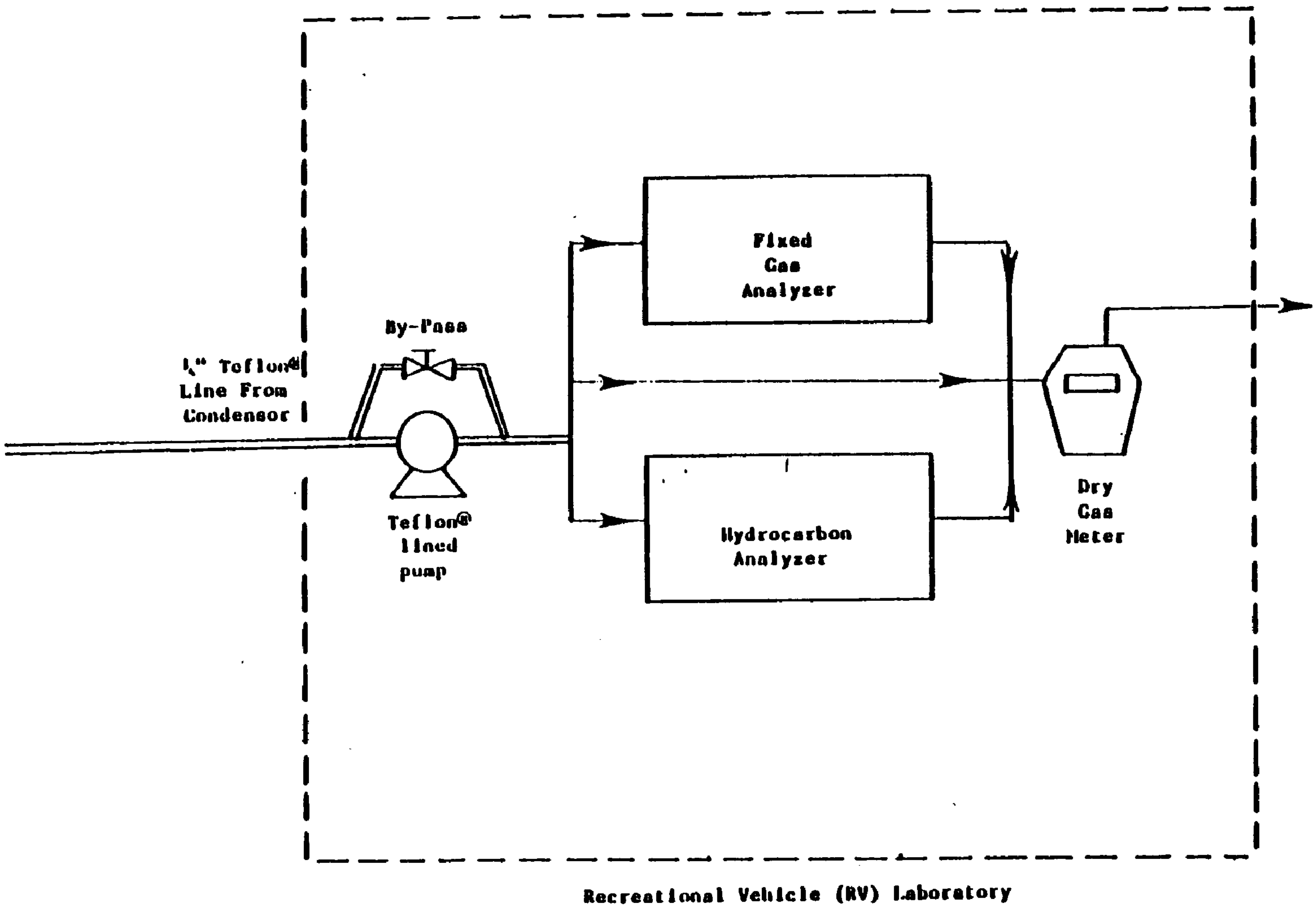

Figure 6-1. Diagram of Instruments in Mobile Laboratory

Once the sample was obtained, it was analyzed for fixed gases and hydrocarbons. The following two sections describe these analytical methods.

6.1.1 Fixed Gases

A Fischer Model 1200 Gas Partitioner was used to measure the fixed gases (CO_2, CO, O_2, N_2, and CH_4) concentrations. This instrument was set up with a 0.25cc sample loop, dual columns and dual thermal conductivity (TC) detectors. When the gases were introduced from the sample loop, they were carried into Column 1 where CO_2 was retained while the other gases passed quickly through to the first TC detector to produce a composite peak. The CO_2 then eluted and was detected. The early eluting composite and the CO_2 were subsequently detected by the second TC detector. The carbon dioxide was permanently adsorbed upon entering Column 2. The operating parameters for the analysis are listed below:

- Column 1: 1/8" x 6.5' aluminum packed with 80-100 mesh Porapak PQ.
- Column 2: 3/16" x 11' aluminum packed with 60-80 mesh Molecular Sieve 13x.
- Oven Temperature: 50°C.
- Carrier Gas: 8.5% H_2 in He at 30 cc/min.

The concentration of each of the species present was determined from calibration curves generated from the analysis of certified standard mixtures. The dry molecular weight of the gas stream was calculated, if needed, from the fixed gas concentrations and major hydrocarbon species (other than CH_4 which was determined in the fixed gas analyses).

6.1.2 Hydrocarbon Species

A Hewlett-Packard Model 5730 Gas Chromatograph equipped with dual flame ionization detectors was used to measure the hydrocarbon species in the noncondensible gas. A two valve arrangement allowed the introduction of a known volume of sample (and standards) into the chromatograph and provided for a blackflush to measure the hydrocarbons with retention times greater than hexane (C_6+). The column in this instrument was a 3 meter, 1/8" OD stainless steel tube packed with 10 percent SP1000 (Carbowax plus substituted terephthalic acid) on 100/120 mesh Chromosorb W AW. This column provided the optimum separation of the hydrocarbons (C_1 to n-C_6). The signal from the flame ionization detector was recorded with a Hewlett-Packard Model 3380A integrator. A comparison of peak areas to standards was used to quantify the samples. Species identification was achieved using retention times of species in the standard mixture. The peak with the retention time closest to the standard component was assigned that standard component's identity.

6.2 ANALYSIS OF COLLECTED LIQUIDS

There were one to four liquid samples collected at any one source test site. These included the knockout drum catches and the outlet of the condenser(s). These catches usually contained both a water and an organic phase. The water was separated from the hydrocarbons in a separatory funnel. The volume of the water was measured in a calibrated graduated cylinder and the temperature measured with a calibrated thermometer. The water was then discarded.

The hydrocarbon liquids were analyzed for density, temperature, and total volume. The total volume of the liquids was determined in a calibrated graduated cylinder. In order to determine density on small amounts of hydrocarbon that were available, the following procedure was used. Previously calibrated volumetric flasks (0.500 ml through 10.00 ml sizes) were used to measure an accurate volume of the liquids. The temperature and the weight of the liquid were determined using an NBS traceable thermometer and a calibrated analytical balance, respectively. From these measurements the density was calculated.

6.3 BOILING POINT DISTRIBUTION

Two samples from the organic condensates were selected for boiling point distribution analysis. The distribution procedure involved the determination of the chromatographable organics in the normal hydrocarbon range of C_7 to C_{17}. The following gas chromatographic conditions were used for this procedure:

- Column: 10' x 2mm ID glass column packed with 10 percent OV101 on 100-120 mesh Supelcoport.
- Oven Program: 50°C for 4 min., 10°C/min to 250°C and hold.
- Carrier Gas: 25 ml/min N_2.
- Detector: Flame Ionization

A standard mixture of C_7 to C_{17} normal alkanes was injected into the chromatograph to determine retention times. The samples were then injected and an integrator slicing routine was used to assign that part of the sample chromatographed between two adjacent hydrocarbons. The results of this procedure are discussed in Section 8.

SECTION 7

QUALITY ASSURANCE AND QUALITY CONTROL

Quality Assurance (QA) and Quality Control (QC) procedures were developed for this program to assess and document the precision, accuracy, and adequacy of the test data collected during the project. Quality Control procedures included calibrations, systems checks for each sample run, control sample analyses, and duplicate samples and analyses. Quality Assurance activities included a systems audit of sampling procedures, a systems audit of analytical procedures, a performance audit of laboratory analyses using audit samples, and a check of the field data reduction procedures. Table 7-1 summarizes the precision and accuracy of the test data generated during this program. The test data are adequate for the purposes of this program.

The QA/QC data and implications are discussed below. Appendix C provides details of the various QA/QC data generated in support of the program, including:

- control charts for analytical quality control samples,
- chain-of-custody forms,
- equipment calibration documentation, and
- systems audit checklists.

7.1 SYSTEMS AUDIT RESULTS

As part of the Quality Assurance program for this project, a systems audit was performed during the period 27 April through 30 April, 1981. The

TABLE 7-1. ESTIMATED PRECISION AND ACCURACY OF TEST DATA

Measurement Parameter (Method)	Experimental Conditions	Precision (Std. Dev.)	Accuracy	Comments
Volumetric Gas Flow Rates				
Noncondensible Gases	Wellhead Gas	20%	±10%	Estimates are based upon systems audit results, equipment calibration and repeat test data agreement as discussed in Section 7.3.1.
Low Flow Steam and Gases (Total Stream Condensation)	Wellhead Gas	20%	±10%	
High Flow Steam and Gases				
a) Total Stream Condensation	Wellhead Gas	20%	±10%	
b) Annubar (CARB) Method	Wellhead Gas	20%	±10%	Estimates based on expected bias of the method; only one test conducted using annubar.
Condensible Hydrocarbons	Condensate from Wellhead Gas	10%	±10%	Estimates are based upon systems audit results.
Fixed Gases	Noncondensible Wellhead Gas	20%	±20%	Estimates are based upon performance audit results and QC data evaluation.
Hydrocarbon Species	Noncondensible Wellhead Gas	20%	±20%	
Density	Condensate from Wellhead Gas	10%	±5%	Estimates are based upon performance and systems audit results.

audit was designed to provide a comprehensive qualitative review of the critical elements of the sampling/analytical procedures to assess their effectiveness. The audit included evaluations of facilities, equipment, training, procedures, recording keeping, QC, and reporting.

The precision and accuracy of certain measurement parameters are not easily quantified by means of performance audits or replicate determinations. The systems audit provides an alternative means of estimating and confirming the precision and accuracy of these measurements which include volumetric gas flow rates and condensible hydrocarbon determinations.

Both sampling and analytical activities were observed on 27, 28, and 29 April, 1981. Surveying activities were observed 29 April, 1981. Generally the surveying, sampling, and analytical activities observed were consistent with those specified in the Quality Assurance Project Plan (1) prepared for this project. Deviations other than those discussed below were deemed to be justifiable field modifications of the prescribed procedures which would not adversely affect the data quality.

Several procedural changes and/or corrective actions were initiated as a result of the systems audit. The most significant modification was the initation of a bag sample technique for collection and analysis of noncondensible gases. The QA Plan stated that duplicate analyses of all noncondensible gases would be performed, and that ±20% agreement would be required for acceptability. Due to the temporal variability of emissions from each well, repeated injections using a sample loop, as prescribed in the Quality Assurance Project Plan (QAPP) constituted replicate samples rather than replicate analysis of a given sample. Data obtained in this manner measured sample-to-sample variability but not analytical variability as desired. Also, the 20% agreement limit imposed was inappropriate when applied to variability of emissions rather than to analytical variability as intended.

The sampling/analysis procedures were amended to include the use of a Tedlar® bag for sample collection. This procedure allowed the noncondensible emissions to be collected over a period of time and provided a homogeneous sample amenable to replicate analysis.

Other actions resulting from the QA system audit included the following:

- A modification was made to the sample logging procedures to incorporate the use of a bound and paginated master sample logbook rather than a looseleaf binder.

- The multipoint calibration of the Fisher Partitioner and Hewlett-Packard Gas Chromatograph was redefined as a linearity check. The daily single-point response factor checks were accepted as providing the best calibration in terms of day-to-day precision (repeatability). Response factor agreement on a day-to-day basis was required to be ±20%.

- The practice of recording intermediate dry gas meter volume readings during sampling was instituted. Previously, only initial and final readings had been recorded.

- A larger capacity dry gas meter was sent to the field for use with wells exhibiting high (>200 ft^3/min) noncondensible gas flow rates.

- A positive pressure leak check procedure for pre- and post-test systems checks was defined and initiated.

- The 55 gallon drum condenser used for wet and/or moderate flow wells was rebuilt to provide for easier condensate drainage. Problems had occurred with pockets of condensate forming in low spots in the condenser coil.

None of the problems above were judged to be serious enough to have had significant adverse effects on data quality. The changes made represented an effort to maximize the efficiency and adequacy of the overall sampling/ analytical system and the quality of the data output.

7.2 PERFORMANCE AUDIT RESULTS

A performance audit is a quantiative assessment of the quality of the data output of a sampling and/or analytical system. The performance audit was conducted concurrently with the systems audit and addressed the analytical procedures used for noncondensible gas analyses and for condensate density determination. The results are expressed as relative accuracy (%A) calculated as

$$\%A = \frac{M-T}{T} \times 100,$$

where, %A = relative accuracy
M = measured value of a standard
T = "true" value of the standard

7.2.1 Density

The performance audit or the density determinations were performed using four liquid hydrocarbon standards:

- 2-propanol,
- methylene chloride,
- acetone, and
- 3-methylpentane.

Two determinations of density were performed on each standard. The average value is reported. No correction has been made for temperature. The results are summarized in Table 7-2 below.

TABLE 7-2. PERFORMANCE AUDIT RESULTS FOR DENSITY DETERMINATIONS

Compound	d measured	d actual-20°C	%A
2-propanol	0.774	0.781	-0.9
methylene chloride	1.30	1.3266	-2.0
acetone	0.774	0.7899	-2.0
3-methylpentane	0.654	0.6645	-1.6

The average accuracy of the density determination, -1.6%, is well within the ±10% acceptability criteria. The slight low bias indicated is most likely due to the elevated temperature (~95°F) at which the determinations were made.

7.2.2 Noncondensible Gas Analysis

The performance audit of the gas phase analyses was performed by challenging the Fisher Partitioner and Hewlett Packard gas chromatograph with bottled standard gases. Four separate gas mixtures were used as audit standards for the noncondensible analyses:

(1) CO_2, CH_4, N_2 and O_2, cylinder #A9541;

(2) H_2, CO, and N_2, cylinder #A10753;

(3) C_2H_6, C_3H_8 and N_2, cylinder #A5401; and,

(4) CH_4, C_2H_6, C_3H_8, n-C_4H_{10}, i-C_4H_{10}, n-C_5H_{12}, i-C_5H_{12} and N_2, Scotty II® cylinder, SSG Project #44915.

Mixtures #1, #2 and #4 are Certified Master Standards (±2% analytical accuracy) obtained from Scott Specialty Gases, Inc. Mixture #3 is a Certified Plus Standard (±1% analytical accuracy) obtained from Scientific Gas Products, Inc. All four mixtures were analyzed for fixed gases (CO_2, O_2, CO and CH_4) using the Fisher Gas Partitioner. Hydrocarbon analyses of mixtures #3 and #4 were performed using the Hewlett Packard gas chromatograph. The audit results are summarized in Table 7-3.

TABLE 7-3. PERFORMANCE AUDIT RESULTS, NONCONDENSIBLE GASES

Standard	Species	Instrument	Measured Concentration (% V/V)	Actual Concentration (% V/V)	%A
#1	CO_2	FP	50.9	46.00	10.7
	CH_4	FP	42.6	39.98	6.6
	N_2	FP	11.6	9.96	16.5
	O_2	FP	4.5	4.04	11.4
#2	H_2	FP	NA	4.95	--
	CO	FP	6.38	5.10	25.1
	N_2	FP	84.7	89.95	-5.8
#3	C_2H_6	GC	32.9	29.90	10.0
	C_3H_8	GC	10.6	9.99	6.1
	N_2	FP	51.5	60.11	-14.3
#4	CH_4	GC	0.215	0.261	-17.6
	C_2H_6	GC	0.563	0.251	124
	C_3H_8	GC	0.312	0.314	-0.6
	$\Sigma\ C_3+$	GC	1.08	0.954	13.2
	N_2	FP	81.2	98.2	-17.3

NA = Not Analyzed
FP = Fisher Gas Partitioner
GC = Hewlett Packard Gas Chromatograph

The measured accuracies of the gas phase analyses are generally within the specified ±20% accuracy limits. Exceptions include:

- CO concentration of standard #2, and
- C_2H_6 concentration of standard #4.

The discrepancy in the CO determination for mixture #2 was found to be due in part to the way in which the baseline was established for measurement of the calibration standard peak height. Because of the presence of a large CH_4 peak in the calibration chromatogram which is partially merged with the CO peak, the baseline for the CO peak is difficult to determine. If the peak height for CO is measured assuming a flat baseline (rather than by the crude tangent skim method which was used), and a new CO response factor calculated, the measured concentration of CO in the audit gas becomes 5.5%. This new value represents a relative accuracy of 13.7%. In any event, the accuracy of the fixed gas analyses does not adversely impact the emission factors since the fixed gas composition is used only for calculation of molecular weight of the gas.

The high positive bias in the C_2H_6 analysis may be attributed to the low concentration in the audit standard (0.251%) as compared to the calibration standard (5.0%). The purpose of this low range standard was to assess the validity of precision data generated early in the program using a QC standard for C_1-C_6 hydrocarbons at 0.1%. Furthermore, the C_2H_6 values also do not adversely impact the calculated emission factors since neither CH_4 nor C_2H_6 values are included in the calculations.

Although it is not indicated in the table of results, analysis of audit standard #3 using the Fisher Partitioner gave a false positive result for O_2 (25.7% reported). Ethane (C_2H_6) apparently has the same retention time as oxygen on the Fisher. The O_2 to N_2 ratio of air is used to subtract this false positive out of the analytical data for samples. Due to the synthetic nature of the audit standard, this correction could not be applied, so the O_2 value was simply not reported. If the C_2H_6 to N_2 ratio in the audit standard (0.497) is used to correct the analytical result, as below,

$$26.7 - (0.497 \times 51.5),$$

where 26.7 = reported concentration of O_2, %

0.497 = ratio of C_2H_6 to N_2 in the audit gas mixture

51.5 = audit gas mixture measured concentration of N_2 in the audit gas mixture, %,

the resulting O_2 concentration is 1.1%. This method of correcting the data seems to be a satisfactory solution.

7.3 ANALYTICAL PRECISION

Table 3-1 of the Quality Assurance Project Plan (1) and Table 7-1 present the original precision estimates for each major measurement parameter. The estimates represent the maximum expected standard deviation of the measurement, expressed as percent of the mean (relative standard deviation, RSD).

7.3.1 Volumetric Gas Flow Rate

The precision of the volumetric gas flow rate determinations was estimated to be 20%. All flow measurements for this program with the exception of well number 3 were made using the total stream condensation methods discussed in the QAPP and in Section 5. The precision of the method is thus a function of the precision of the dry gas meter volume measurement and the measurement of elapsed time. The systems audit indicated acceptable compliance with gas flow rate measurement procedures and the calibration of the gas meters indicated that all were within the required ±5% accuracy limit. Three wells were tested twice each during the program. The results of the repeat measurements of volumetric flow rates are summarized in Table 7-4.

TABLE 7-4. VOLUMETRIC GAS FLOW RATE VARIABILITY

Well No.	Date of First Test	Flow Rate (ACFM)	Date of Second Test	Flow Rate (ACFM)	Repeatability (RSD)
164	4/16/81	0.51	4/23/81	0.54	1.0%
173	4/16/81	0.20	4/23/81	0.22	6.7%
176	4/21/81	0.102	4/22/81	0.075	21.6%

Only the tests of well number 176 showed a flow rate precision (repeatability) for the two measurements in excess of 20%. It is believed that this was due primarily to a temporal variation in well emissions rather than variability in the sampling procedure. The reduction in emissions during the second test was obvious at the time the well was sampled, and was significant enough that the sampling team switched to the "low flow" sampling apparatus for the second test.

The data above and the systems audit observations support the conclusion that the overall precision of the flow rate measurement data is within the estimated 20%.

7.3.2 Condensible Hydrocarbon Emissions

The results of the condensible hydrocarbon emissions for the repeat tests discussed above are summarized in Table 7-5 below.

TABLE 7-5. CONDENSIBLE HYDROCARBON EMISSIONS VARIABILITY

Well No.	Date of First Test	Condensible HC Emissions (lbs/hr)	Date of Second Test	Condensible HC Emissions (lbs/hr)	Repeatability (RSD)
164	4/16/81	0.002	4/23/81	0.004	47.1%
173	4/16/81	1.050	4/23/81	0.899	2.7%
176	4/21/81	0.454	4/22/81	0.015	132%

As discussed previously, the high variability for well number 3 is believed to represent the actual temporal variation in the emissions, and as such, the variability does not reflect measurement variability. The precision of 47% indicated for well number 1 is attributed to the low condensible emissions. The systems audit of the condensible hydrocarbon emissions measurement sampling procedures indicated that proper procedures were used for sample collection. Based upon the above data and the systems audit results, it is felt that the overall precision of the condensible hydrocarbons measurement was within 20% as estimated.

7.3.3 Fixed Gases

As discussed in Section 7.1, the systems audit of the analytical system resulted in a revision of the sampling/analytical procedures for fixed gases and noncondensible hydrocarbons. Prior to the audit, the method of gas phase analysis consisted of analysis of replicate samples. After instituting the bag sampling procedures, replicate analyses were performed upon each sample. Thus, two different types of variability may be calculated from these data:

- sample-to-sample variability of well emissions, (sample repeatability), and
- analytical variability with respect to analysis of samples (sample replicability).

The data from the quality control standard analyses may also be used to assess analytical variability. The data from replicate analyses of the QC standard at one site under a given set of instrument conditions and using the same response factor represent one measure of analytical variability: standard replicability. Since the QC standard was analyzed at each site with each set of sample analyses, the site-to-site or day-to-day analytical variability may also be quantified. This measure of precision is referred to as standard repeatability. The data for both standard and sample repeatability and replicability for fixed gases are summarized in Table 7-6 below.

TABLE 7-6. SUMMARY OF PRECISION FOR FIXED GAS ANALYSES

Species	Analytical Variability			Sample Variability
	Standard Replicability (PRSD)	Standard Repeatability (RSD)	Sample Replicability (PRSD)	Sample Repeatability (PRSD)
CO	1.81%	3.5%	ND	ND
CO_2	1.23%	4.6%	3.44%	4.47%
O_2	2.18%	5.2%	2.52%	45.8%
N_2	5.00%	7.8%	0.79%	21.2%
CH_4	1.67%	2.8%	0.34%	4.88%

ND= Not Detected

The values in Table 7-6 above for standard repeatability represent the relative standard deviation for the measurements. Values indicated for standard and sample replicability and for sample repeatability represent the pooled relative standard deviation (PRSD), which is a measure of the variability of the relative standard deviations for n sets of data calculated as

$$PRSD = \sqrt{\frac{\sum_{i=1}^{n} X_i^2 \, DF_i}{\sum_{i=1}^{n} DF_i}}$$

where X_i = relative standard deviation of data set i

DF_i = degrees of freedom for data set i (k_i-1)

n = total number of data sets

k_i = number of data points in data set i

i = data set 1, 2, 3, ... n

The terms for degrees of freedom in the above equation allow the data to be weighted according to the number of data points in each data set.

It should be noted that the last category, "Sample Repeatability", is not actually a measure of analytical precision. Rather, it indicates the net variability arising from two sources:

- temporal variability of well emissions, plus
- analytical variability.

Comparing these values to either standard or sample replicability indicates that the analytical variability was generally less than short-term temporal variations in the emissions themselves. As indicated in Table 7-6, the precision of the fixed gas analyses is well within the 20% estimate for all categories, except N_2 and O_2 sample repeatability.

7.3.4 Noncondensible Hydrocarbon Species

The data for precision of noncondensible hydrocarbon speciation analyses may be categorized in the same way as those for fixed gases. The only major difference is that several different hydrocarbon QC standards were used during the course of the program. The data for analytical repeatability and replicability of samples is summarized in Table 7-7 below.

TABLE 7-7. ANALYTICAL VARIABILITY OF HYDROCARBON SAMPLES ANALYSES

Species	Replicability (PRSD)	Repeatability (PRSD)
CH_4	3.44%	7.38%
C_2H_6	5.09%	23.6%
$\Sigma\ C_3-C_6$	11.6%	17.5%
$\Sigma\ C_{6+}$	8.21%	11.5%

Repeatability and replicability for each of the various QC standards is summarized in Table 7-8 below. The validity of these estimates of precision is limited in some cases due to the small number of applicable data points. In each case, the number of pairs of analyses upon which the calculated precision is based is indicated (n = number of pairs).

TABLE 7-8. SUMMARY OF PRECISION FOR HYDROCARBON QC STANDARD ANALYSES

Species	Low Standard Mixture[1]		High Standard Mixture[2]		0.5% Propane Standard[3]		5.0% Propane Standard[3]	
	Replicability (RSD, n = 1)	Repeatability (RSD, n = 10)	Replicability (PRSD, n = 1)	Repeatability (RSD, n = 25)	Replicability (PRSD, n = 2)	Repeatability (RSD, n = 7)	Replicability[4] (n = 0)	Repeatability (RSD, n = 4)
CH_4	13.0	13.0	8.06	6.52	--	--	--	--
C_2H_6	6.22	65.6	6.78	7.17	--	--	--	--
C_3H_8	5.82	66.1	5.02	7.59	11.1	11.1	--	8.2

[1] CH_4 = 0.074%; C_2H_6 = 0.109%; C_3H_8 = 0.103%; Scotty II® Mix #236.

[2] CH_4 = 40.0%; C_2H_6 = 4.0%; C_3H_8 = 1.6%; SSG Cylinder #1A5924

[3] Mixture contained only C_3H_8 in N_2, therefore no values for CH_4 or C_2H_6 could be obtained using this standard; SGP Mini-Mix®, Ref. 229987.

[4] No replicate analyses of this standard were made

The data in Tables 7-7 and 7-8 indicate that the precision was generally well within the estimated 20%. The exceptions to this generally represent cases where the analyte concentration approached the detection limit and/or was more than an order of magnitude lower than the concentration of the calibration standard. The performance audit results relect the difficulty of obtaining accurate measurements near the detection limit of the method, and confirm this conclusion.

7.3.5 Density

The systems audit of analytical procedures revealed that daily control sample density determinations were not being performed as prescribed in the QAPP. This procedural deviation was documented in the QA audit report and corrective action was recommended. However, the use of a control standard for density was never implemented as a routine procedure. There is therefore no data available for calculating the precision of the method over the duration of the project. Two density determinations were performed on each of the audit standards, however, and the analytical variability may be estimated from these data. These results are summarized in Table 7-9 below.

TABLE 7-9. ANALYTICAL VARIABILITY OF DENSITY DETERMINATION

Compound	d Measured (Mean)	Repeatability (RSD)
2- Propanol	.774	0.09%
Methylene Chloride	1.30	0.0%
Acetone	.774	0.09%
3- Methylpentane	.652	0.11%

Based on these data, the pooled relative standard deviation is less than 0.1%.

Despite the limited data available for estimating the precision of the density analyses, the performance audit results support the conclusion the overall precision was within the specified 10%.

7.4 EQUIPMENT CALIBRATION

The checkout and calibration of source sampling equipment is essential to maintaining data quality. Accepted calibration procedures were used to calibrate the sampling equipment used in this program. These procedures are detailed in the Quality Assurance Project Plan. The results of the pertinent calibrations are documented in Appendix C. These data indicate that the test data were obtained using acceptable equipment.

7.5 DATA CAPTURE

Table 3-3 of the QAPP indicates an expected data capture of 90% for each applicable measurement parameter. A total of 62 tests were conducted on 59 wells during the course of the project. Three tests (Table 7-4) were judged to be questionable in the field and the wells were retested. The results of the first test on these wells are not included in the emissions factor data base. One test was rejected as invalid during the data review and validation process. Thus, a total of 58 valid tests were conducted. The valid data percentage of the total tests conducted is therefore 93.5%. The scope of work required 50 tests. The valid data percentage of the total tests required in the scope of work is therefore 116%.

7.6 DATA VALIDATION

The overall sampling, analytical, and data reduction scheme for this project was designed to maximize valid data output. A number of different criteria were used to assess the validity of the test results. The validation process was an integral part of all phases of the testing. Specific aspects related to validation included:

- the use of preformatted data sheets which served as procedural checklists,

- the delineation of specific control limits and acceptability criteria for leak checks, calibrations, analytical precision, etc.,

- on-site review of field data,

- review and evaluation of comments and notations concerning problems and/or special situations related to all sampling and analyses,

- recalculation of all data for 10% of the tests (six wells chosen at random), and

- subjective evaluation of reasonableness of test data and resulting correlations.

Three wells were retested during the course of the project, as mentioned in Section 7.5. The initial tests of these wells were judged to be of questionable validity due to apparent equipment problems. A fourth test was rejected during the final review process because of a number of sampling and analytical problems which were noted on the data sheets.

The calculations check on 10% of the tests identified a number of minor calculation errors. Of these, however, only one ultimately impacted the emission data by more than 5%. This error was a failure to add the condensible VOC emissions to the noncondensible VOC emissions for total VOC emissions. Although the manually calculated data indicated a total VOC emissions value equal to only the noncondensible VOC emissions for that well, the error was ultimately corrected during the computerized phase of the data reduction process and did not impact the reported result.

Statistical treatment of the audit data and QC data is consistent with the definitations and procedures outlined in Volume I of the EPA Quality Assurance Handbook for Air Pollution Measurement Systems (2). Outliers were identified using the Dixon criteria and rejected at the 5% significance level.

REFERENCES

1. Balfour, W.D. and D.L. Lewis, Assessment of VOC Emissions From Well Vents Associated with Thermally Enhanced Oil Recovery, Quality Assurance Project Plan, Austin, Texas, Radian Corporation, 1981.

2. "Quality Assurance Handbook for Air Pollution Measurement Systems", Volume I, "Principles", U.S. Environmental Monitoring and Support Laboratory, Research Triangle Park, North Carolina, January 1976. EPA-600/9-76-005.

SECTION 8

DETAILED RESULTS

The preliminary field survey was designed to confirm that candidate wells were true uncontrolled cyclic wells and to make a rough estimate of the emission range for each well. A total of 829 candidate wells were examined, out of which 358 were determined to be uncontrolled cyclic wells. The flow rate from the casing vent valve was measured using a bubble meter, a dry gas meter, or a visual estimate for each well remaining in the survey. Table 8-1 presents a summary of the results of the survey categorized by the producing field and the casing vent flow rate. In addition to the individual fields, data are presented for all the fields in western Kern County and those in central Kern County in aggregate form. Table 8-2 provides a breakdown of the non-blowing wells by field. Table 8-3 presents survey data broken down by producer.

A total of 58 wells (out of the 358 surveyed) were selected for quantitative emission measurement. The distribution of these sampled wells by field is given in Table 8-4 and by producer in Table 8-5. The results of each of the 58 tests is given, organized by field, in Table 8-6.

A well characterization survey form was left with each producer to be completed for each well retained in the survey. This form was designed to provide information on steaming practices and production characteristics of the well, which were to be used in correlating casing vent emissions. Table 8-7 presents a summary of the well characterization data obtained. The mean value of all responses is presented for each parameter, along with the standard error and the number of responses. No data is presented here on the oil/water ratio because it appears that many respondents used widely differing forms of expressing that ratio; the resulting indicators would have no meaning. A full

TABLE 8-1. SURVEY RESULTS BY FIELD

Survey Flow Rate Range (liters per minute)	Number of Wells Found in Each Survey Range											
	Midway-Sunset	McKittrick	Cymric	Belridge	Lost Hills	Subtotal Western Region	Kern River	Kern Front	Poso Creek	Edison	Subtotal Central Region	Total Kern County
less than 0.1	101	18	14	8	0	141	15	3	4	5	27	168
0.1 to 0.99	28	10	3	1	0	42	4	1	3	1	9	51
1.0 to 5.0	44	12	4	3	1	64	15	7	1	6	29	93
greater than 5.0	16	4	1	3	0	24	8	8	2	4	22	46
Total Surveyed	189	44	22	15	1	271	42	19	10	16	87	358

TABLE 8-2. BREAKDOWN OF NON-BLOWERS BY FIELD

Type of Non-Blower \ Field	Midway-Sunset	McKittrick	Cymric	Belridge	Lost Hills	Kern River	Kern Front	Poso Creek	Edison	All Fields Combined
	Number of Wells of Each Type Found in Each Field									
No detecable flow	58	13	8	5	0	8	0	0	2	94
Detectable flow less than 0.1ℓ/min.	4	0	0	0	0	1	1	1	0	7
Negative flow	6	3	1	0	0	3	1	1	0	15
Normal production-casing closed	16	2	2	2	0	0	1	0	2	25
Well being steamed	9	0	2	1	0	0	0	0	1	13
Well soaking	2	0	1	0	0	1	0	2	0	6
Well being worked over	3	0	0	0	0	0	0	0	0	3
Casing vent clogged	3	0	0	0	0	2	0	0	0	5

TABLE 8-3 SURVEY RESULTS BY PRODUCER

Survey Flow Rate Range (liters per minute)	Number of Wells Found in Each Survey Range																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Total
less than 0.1	12	0	4	2	1	2	33	1	28	1	7	15	3	2	5	17	12	12	1	3	3	3	1	168
0.1 to 0.99	2	0	0	0	0	0	6	0	14	1	1	9	1	0	1	7	3	3	0	0	0	1	2	51
1.0 to 5.0	2	2	0	0	0	0	13	5	22	0	1	6	0	0	2	17	11	4	0	4	0	2	2	93
greater than 5.0	3	0	0	1	0	0	3	4	10	0	0	9	0	0	4	2	8	1	0	0	0	1	0	46
Total Surveyed	19	2	4	3	1	2	55	10	74	2	9	39	4	2	12	43	34	20	1	7	3	7	5	358

TABLE 8-4. SAMPLING DISTRIBUTION BY FIELD

Survey Flow Rate Range (liters per minute)	Number of Wells Sampled											
	Midway-Sunset	McKittrick	Cymric	Belridge	Lost Hills	Subtotal Western Region	Kern River	Kern Front	Poso Creek	Edison	Subtotal Central Region	Total Kern County
less than 0.1	0	0	0	0	0	0	0	0	0	0	0	0
0.1 to 0.99	3	0	0	0	0	3	1	0	0	0	1	4
1.0 to 5.0	18	3	0	1	0	22	3	1	0	0	4	26
greater than 5.0	10	4	1	2	0	17	6	3	0	2	11	28
Total Sampled	31	7	1	3	0	42	10	4	0	2	16	58

TABLE 8-5. SAMPLING DISTRIBUTION BY PRODUCER

Survey Flow Rate Range (liters per minute)	Number of Wells Sampled																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Total
less than 0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.1 to 0.99	1	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
1.0 to 5.0	1	1	0	0	0	0	3	0	9	0	1	2	0	0	0	4	1	1	0	2	0	0	1	26
greater than 5.0	1	0	0	0	0	0	3	2	6	0	0	5	0	0	1	2	6	1	0	0	0	1	0	28
Total Surveyed	3	1	0	0	0	0	8	2	16	0	1	7	0	0	1	6	7	2	0	2	0	1	1	58

TABLE 8-6. SAMPLING RESULTS BY FIELD

SUMMARY OF MASS EMISSIONS
CYCLIC TEOR WELLHEAD CASING VENTS

FIELD: BELRIDGE

WELL NUMBER	VOC EMISSIONS (LB/DAY)	TOTAL HYDROCARBON EMISSIONS (LB/DAY)	CONDENSIBLE HYDROCARBONS (LB/DAY)	NON-CONDENSIBLES			
				CH4 (LB/DAY)	C2H6 (LB/DAY)	C3-C6 (LB/DAY)	C6+ (LB/DAY)
1	13.19	131.86	8.58	117.88	0.79	1.92	2.69
2	3.18	68.57	0.00	65.21	0.18	1.21	1.97
3	35.61	85.66	0.00	39.93	10.12	29.68	5.94

Continued/

TABLE 8-6. (Continued)

SUMMARY OF MASS EMISSIONS
CYCLIC TEOR WELLHEAD CASING VENTS

FIELD: CYMRIC

WELL NUMBER	VOC EMISSIONS (LB/DAY)	TOTAL HYDROCARBON EMISSIONS (LB/DAY)	CONDENSIBLE HYDROCARBONS (LB/DAY)	NON-CONDENSIBLES: CH4 (LB/DAY)	C2H6 (LB/DAY)	C3-C6 (LB/DAY)	C6+ (LB/DAY)
16	105.87	229.07	101.24	122.87	0.33	0.64	3.99

Continued/

TABLE 8-6. (Continued)

SUMMARY OF MASS EMISSIONS
CYCLIC TEOR WELLHEAD CASING VENTS

FIELD: EDISON

WELL NUMBER	VOC EMISSIONS (LB/DAY)	TOTAL HYDROCARBON EMISSIONS (LB/DAY)	CONDENSIBLE HYDROCARBONS (LB/DAY)	NON-CONDENSIBLES CH4 (LB/DAY)	C2H6 (LB/DAY)	C3-C6 (LB/DAY)	C6+ (LB/DAY)
38	1.43	136.49	0.00	133.85	1.21	0.19	1.24
39	1.80	362.58	0.00	185.33	175.46	0.16	1.63

Continued/

TABLE 8-6. (Continued)

SUMMARY OF MASS EMISSIONS
CYCLIC TEOR WELLHEAD CASING VENTS

FIELD: KERN FRONT

WELL NUMBER	VOC EMISSIONS (LB/DAY)	TOTAL HYDROCARBON EMISSIONS (LB/DAY)	CONDENSIBLE HYDROCARBONS (LB/DAY)	NON-CONDENSIBLES CH4 (LB/DAY)	NON-CONDENSIBLES C2H6 (LB/DAY)	NON-CONDENSIBLES C3-C6 (LB/DAY)	NON-CONDENSIBLES C6+ (LB/DAY)
54	0.22	27.34	0.00	27.05	0.08	0.04	0.18
55	0.39	90.66	0.00	90.25	0.01	0.00	0.39
56	2.07	144.82	0.57	142.39	0.35	0.38	1.13
57	3.31	186.39	1.46	182.71	0.38	0.39	1.46

Continued/

TABLE 8-6. (Continued)

SUMMARY OF MASS EMISSIONS
CYCLIC TEOR WELLHEAD CASING VENTS

FIELD: KERN RIVER

WELL NUMBER	VOC EMISSIONS (LB/DAY)	TOTAL HYDROCARBON EMISSIONS (LB/DAY)	CONDENSIBLE HYDROCARBONS (LB/DAY)	NON-CONDENSIBLES CH4 (LB/DAY)	C2H6 (LB/DAY)	C3-C6 (LB/DAY)	C6+ (LB/DAY)
73	0.51	86.70	0.00	84.09	2.11	0.05	0.45
74	1.74	22.02	0.00	20.24	0.04	0.45	1.29
75	0.69	91.08	0.00	90.33	0.06	0.03	0.66
76	0.24	32.60	0.00	32.25	0.11	0.11	0.13
77	2.86	8.79	0.74	5.90	0.02	0.60	1.52
78	0.84	110.30	0.00	109.39	0.07	0.00	0.84
79	4.46	5.42	4.29	0.96	0.00	0.04	0.13
80	2.16	198.37	0.41	195.66	0.56	0.29	1.46
81	25.89	30.24	25.68	4.33	0.02	0.12	0.09
82	40.95	65.24	40.53	24.18	0.11	0.16	0.26
83	0.54	41.22	0.00	40.33	0.35	0.08	0.46

Continued/

TABLE 8-6. (Continued)

SUMMARY OF MASS EMISSIONS
CYCLIC TEOR WELLHEAD CASING VENTS

FIELD: MCKITTRICK

WELL NUMBER	VOC EMISSIONS (LB/DAY)	TOTAL HYDROCARBON EMISSIONS (LB/DAY)	CONDENSIBLE HYDROCARBONS (LB/DAY)	NON-CONDENSIBLES CH4 (LB/DAY)	C2H6 (LB/DAY)	C3-C6 (LB/DAY)	C6+ (LB/DAY)
116	16.01	39.55	3.12	23.44	0.10	4.41	8.48
117	2.48	2.89	2.17	0.41	0.00	0.01	0.30
118	1.73	37.49	0.04	35.73	0.03	0.14	1.55
119	88.56	396.14	1.54	307.25	0.32	10.36	76.87
120	0.21	8.13	0.08	7.92	0.00	0.03	0.09
121	2.37	4.17	0.27	1.78	0.02	0.70	1.40
122	8.37	509.51	0.00	500.83	0.31	0.46	7.91

Continued/

TABLE 8-6. (Continued)

SUMMARY OF MASS EMISSIONS
CYCLIC TEOR WELLHEAD CASING VENTS

FIELD: MIDWAY-SUNSET

WELL NUMBER	VOC EMISSIONS (LB/DAY)	TOTAL HYDROCARBON EMISSIONS (LB/DAY)	CONDENSIBLE HYDROCARBONS (LB/DAY)	NON-CONDENSIBLES CH4 (LB/DAY)	NON-CONDENSIBLES C2H6 (LB/DAY)	NON-CONDENSIBLES C3-C6 (LB/DAY)	NON-CONDENSIBLES C6+ (LB/DAY)
161	33.79	44.35	0.00	10.18	0.37	13.01	20.78
162	1.21	23.21	0.00	21.88	0.12	0.32	0.89
163	3.23	8.41	1.38	5.09	0.09	0.88	0.96
164	1.84	27.70	0.09	25.78	0.07	0.42	1.33
165	0.71	47.79	0.00	46.89	0.19	0.34	0.37
166	1.64	17.07	0.00	15.29	0.13	0.42	1.23
167	0.01	0.21	0.00	0.20	0.00	0.01	0.00
168	26.91	33.92	26.38	6.92	0.10	0.20	0.33
169	5.88	10.33	1.22	4.36	0.09	1.56	3.10
170	4.34	16.06	0.57	11.52	0.19	2.28	1.49
171	141.49	286.51	112.35	139.69	5.32	11.83	17.31
172	6.76	7.89	1.63	1.08	0.06	1.52	3.61
173	21.91	26.53	21.57	4.58	0.05	0.10	0.24
174	2.07	92.95	0.64	90.13	0.75	0.65	0.78
175	10.07	74.75	2.62	64.10	0.59	2.43	5.02

Continued/

TABLE 8-6. (Continued)

SUMMARY OF MASS EMISSIONS
CYCLIC TEOR WELLHEAD CASING VENTS

FIELD: MIDWAY-SUNSET

WELL NUMBER	VOC EMISSIONS (LB/DAY)	TOTAL HYDROCARBON EMISSIONS (LB/DAY)	CONDENSIBLE HYDROCARBONS (LB/DAY)	NON-CONDENSIBLES CH4 (LB/DAY)	NON-CONDENSIBLES C2H6 (LB/DAY)	NON-CONDENSIBLES C3-C6 (LB/DAY)	NON-CONDENSIBLES C6+ (LB/DAY)
176	0.79	2.49	0.35	1.69	0.01	0.19	0.24
177	8.17	13.44	0.78	4.47	0.80	4.85	2.53
178	4.00	8.94	0.00	4.65	0.29	2.96	1.04
179	1.26	61.22	0.15	59.85	0.11	0.07	1.04
180	1.26	15.95	0.00	14.46	0.24	0.59	0.67
181	12.08	38.50	8.54	26.07	0.35	2.11	1.43
182	4.61	89.63	0.49	84.69	0.34	0.35	3.78
183	4.05	164.63	0.53	158.95	1.63	1.13	2.39
184	7.31	182.46	3.62	172.62	2.53	0.35	3.33
185	3.40	81.87	1.00	77.65	0.83	1.46	0.93
186	3.59	25.42	0.19	21.64	0.19	1.29	2.11
187	1.21	35.86	0.00	34.62	0.03	0.12	1.09
188	2.37	50.81	0.83	48.41	0.04	0.07	1.46
189	1.28	25.19	0.41	23.32	0.58	0.34	0.53
190	11.92	44.31	8.69	32.24	0.15	0.81	2.42

Continued/

TABLE 8-6. (Continued)

SUMMARY OF MASS EMISSIONS
CYCLIC TEOR WELLHEAD CASING VENTS

FIELD: MIDWAY-SUNSET

WELL NUMBER	VOC EMISSIONS (LB/DAY)	TOTAL HYDROCARBON EMISSIONS (LB/DAY)	CONDENSIBLE HYDROCARBONS (LB/DAY)	NON-CONDENSIBLES CH4 (LB/DAY)	NON-CONDENSIBLES C2H6 (LB/DAY)	NON-CONDENSIBLES C3-C6 (LB/DAY)	NON-CONDENSIBLES C6+ (LB/DAY)
191	45.74	71.83	41.39	25.70	0.39	1.98	2.38

TABLE 8-7. WELL CHARACTERIZATION SURVEY RESULTS

Well Parameter		Western Region	Central Region	Overall
1. Total Number of Steam Cycles to Date				
	Mean Value ($\bar{X}$)	8.5	6.9	8.1
	Standard Error (SE)	0.6	0.6	0.3
	Number of Observations (N)	240	77	317
2. Frequency of Steaming (Months/Cycle)				
	$\bar{X}$	10.0	7.5	9.9
	SE	0.7	1.5	0.7
	N	224	4	228
3. Time Since Last Steaming (Days)				
	$\bar{X}$	236.3	260.5	242.3
	SE	10.6	22.0	9.7
	N	238	79	317
4. Steam Dosage (Barrels)				
	$\bar{X}$	9719	9798	9731
	SE	573	531	448
	N	250	85	335
5. Soaking Period (Days)				
	$\bar{X}$	5.8	3.0	5.8
	SE	0.3	0	0.3
	N	226	4	230
6. Oil Production Rate (Bbl/day)				
	$\bar{X}$	25.2	11.3	21.2
	SE	6.0	1.0	4.3
	N	215	87	302
7. Cumulative Oil Production Since Steaming Began (10^3 Bbl)				
	$\bar{X}$	54.9	21.1	49.9
	SE	4.6	4.4	4.1
	N	181	27	208
8. API Gravity of the Oil (°API)				
	$\bar{X}$	12.7	13.7	12.9
	SE	0.1	0.2	0.1
	N	245	63	308

listing of the site survey data, the testing results, and the well characterization data for all 358 wells is presented in Table 8-8.

Two of the organic condensate samples were chosen for further characterization by gas chromatography. The two samples selected both came from Kern River field and the same producer but had widely differing steaming project ages. The intent was to determine if the composition of the condensible organics emitted from a well changes after an extended period of steaming. Figure 8-1 presents the results of that analysis in graphical form. Well number 82 is the newer well, having undergone 4 steaming cycles during a steaming project 40 months old. Well number 77 that has been steamed more appears to be emitting a lower molecular weight condensate, but it is difficult to determine whether that might be due to the steaming history or other factors.

TABLE 8-8. LISTING OF EMISSION AND CHARACTERIZATION DATA FOR INDIVIDUAL CYCLIC WELLS

FIELD: BELRIDGE

NUMBER	FLOW RATE (L/MIN)	VOC EMISSIONS (LB/DAY)	TOTAL STEAMING CYCLES TO DATE	TIME SINCE STEAMING (DAYS)	STEAMING FREQUENCY (MOS/CYCLE)	SOAKING PERIOD (DAYS)	STEAM DOSAGE (BBL/CYCLE)	OIL PRODUCTION RATE (BBL/DAY)	CUMULATIVE OIL PRODUCTION (BBL)	GRAVITY OF THE OIL (DEG API)	OIL TO WATER RATIO
1	6.0	13.19	14	279	14.0	.	8317	3.0	17910	12.7	0.1
2	1.5	3.18	12	259	9.0	.	10516	15.0	54000	13.2	0.0
3	6.0	35.61	7	190	9.0	.	11062	39.0	80730	13.4	0.7
4	0.0	.	5	368	27.0	.	9636	2.0	8940	15.2	0.0
5	0.0	.	.	.	.	.	.	.	.	.	.
6	0.2	.	18	124	8.0	.	1577	4.0	17760	12.5	0.0
7	1.2	.	.	.	.	.	.	.	.	.	.
8	0.0	.	13	421	8.0	.	10099	11.0	39600	12.0	0.0
9	0.0	.	17	4	8.0	.	11476	20.0	77970	12.9	0.2
10	0.0	.	.	.	.	.	.	.	.	.	.
11	0.0	.	13	463	8.0	.	2538	17.0	62220	13.6	0.2
12	6.0	.	11	165	5.0	.	7772	31.0	59520	16.5	1.9
13	0.0	.	10	410	8.0	.	7323	16.0	38400	12.5	0.1
14	0.0	.	2	380	8.0	.	7938	12.0	5760	13.6	1.0
15	1.2	.	2	231	2.0	.	9677	9.0	.	15.0	1.1

Continued/

TABLE 8-8. (Continued)

FIELD: CYMRIC

NUMBER	FLOW RATE (L/MIN)	VOC EMISSIONS (LB/DAY)	TOTAL STEAMING CYCLES TO DATE	TIME SINCE STEAMING (DAYS)	STEAMING FREQUENCY (MOS/CYCLE)	SOAKING PERIOD (DAYS)	STEAM DOSAGE (BBL/CYCLE)	OIL PRODUCTION RATE (BBL/DAY)	CUMULATIVE OIL PRODUCTION (BBL)	GRAVITY OF THE OIL (DEG API)	OIL TO WATER RATIO
16	6.0	105.87	3	180	7.0	7	12400	30.0	24300	12.0	0.1
17	0.0	.	13	130	14.0	.	11424	18.0	102060	12.0	0.3
18	0.0	.	7	327	24.0	9	11109	2.0	10920	13.5	0.0
19	0.0	.	8	169	20.0	9	8114	4.0	20040	15.8	0.7
20	0.0	.	11	247	16.0	5	12369	17.0	95370	11.9	0.7
21	0.0	.	4	153	29.0	9	12222	24.0	87840	12.6	0.1
22	0.7	.	14	468	11.0	.	11036	2.0	26250	12.0	0.4
23	3.6	.	4	.	6.0	2	9965	30.0	26448	14.7	0.1
24	0.0	.	.	.	.	.	.	.	.	.	.
25	0.0	.	.	.	.	.	.	.	.	.	.
26	0.6	.	.	.	.	.	.	.	.	.	.
27	0.0	.	9	400	10.0	9	12103	30.0	96300	12.2	0.8
28	1.8	.	1	.	6.0	2	2360	6.0	1500	13.0	.
29	0.0	.	9	385	12.0	9	12199	15.0	53100	13.3	1.5
30	4.0	.	7	187	9.0	9	11058	7.0	14070	11.2	0.0
31	0.0	.	4	321	8.0	8	12423	40.0	51600	12.3	2.5
32	0.0	.	5	.	8.0	9	13384	40.0	46800	12.4	0.1
33	0.6	.	3	43	12.0	7	10396	15.0	35100	11.7	0.8
34	0.0	.	3	267	6.0	9	9211	12.0	10440	13.0	0.2
35	3.4	.	3	344	6.0	7	8200	12.0	11160	12.3	0.0
36	0.0	.	1	406	.	.	7837	3.0	1350	12.5	0.4
37	0.0	.	1	265	.	7	7996	30.0	9000	13.0	2.5

Continued/

TABLE 8-8. (Continued)

FIELD: EDISON

NUMBER	FLOW RATE (L/MIN)	VOC EMISSIONS (LB/DAY)	TOTAL STEAMING CYCLES TO DATE	TIME SINCE STEAMING (DAYS)	STEAMING FREQUENCY (MOS/CYCLE)	SOAKING PERIOD (DAYS)	STEAM DOSAGE (BBL/CYCLE)	OIL PRODUCTION RATE (BBL/DAY)	CUMULATIVE OIL PRODUCTION (BBL)	GRAVITY OF THE OIL (DEG API)	OIL TO WATER RATIO
38	5.0	1.43	1	255	.	.	8600	24.0	2100	16.0	68.3
39	6.0	1.80	1	317	.	.	11000	44.6	8500	15.6	26.4
40	2.4	.	1	335	.	.	10000	10.4	4000	18.9	32.5
41	4.0	.	15	.	.	.	7000	8.0	72000	15.8	97.8
42	0.0	.	11	.	.	.	6500	1.0	17000	14.4	91.7
43	0.0	.	3	182	.	.	9500	11.9	23000	15.6	83.1
44	0.0	.	11	323	.	.	6500	4.0	21600	14.0	77.3
45	0.6	.	8	336	.	.	7000	1.0	12600	15.3	85.7
46	0.0	.	8	254	.	.	7300	3.0	17640	15.4	91.4
47	0.0	.	7	264	.	.	6500	5.0	19800	14.0	94.6
48	3.0	.	2	425	.	.	9800	8.2	8700	18.6	60.4
49	4.0	.	2	335	.	.	7900	15.3	16400	15.6	41.5
50	1.2	.	1	396	.	.	6300	24.7	7500	15.6	71.8
51	3.0	.	1	396	.	.	6500	35.3	12900	16.1	54.2
52	6.0	.	2	31	.	.	8500	38.4	15000	16.5	62.5
53	5.0	.	1	212	.	.	9900	23.0	4600	18.6	24.1

Continued/

TABLE 8-8. (Continued)

FIELD: KERN FRONT

NUMBER	FLOW RATE (L/MIN)	VOC EMISSIONS (LB/DAY)	TOTAL STEAMING CYCLES TO DATE	TIME SINCE STEAMING (DAYS)	STEAMING FREQUENCY (MOS/CYCLE)	SOAKING PERIOD (DAYS)	STEAM DOSAGE (BBL/CYCLE)	OIL PRODUCTION RATE (BBL/DAY)	CUMULATIVE OIL PRODUCTION (BBL)	GRAVITY OF THE OIL (DEG API)	OIL TO WATER RATIO
54	2.0	0.22	15	408	.	.	13962	9.0	.	13.5	0.1
55	6.0	0.39	.	52	.	.	5317	11.0	.	13.0	.
56	6.0	2.07	3	181	.	.	12209	13.0	.	13.5	0.1
57	6.0	3.31	2	219	.	.	15319	17.0	.	12.5	0.1
58	0.0	.	17	147	.	.	17620	7.0	.	13.6	0.1
59	3.0	.	12	336	.	.	13176	19.0	.	14.0	0.1
60	4.5	.	13	473	.	.	14096	10.0	.	13.0	0.3
61	4.0	.	15	391	.	.	11689	6.0	.	14.0	0.1
62	5.0	.	.	233	.	.	7756	3.0	.	13.0	.
63	2.0	.	.	21	.	.	5391	10.0	.	13.0	.
64	5.0	.	.	79	.	.	8609	12.0	.	13.0	.
65	2.4	.	.	5	.	.	5919	16.0	.	13.0	.
66	6.0	.	.	23	.	.	5862	5.0	.	13.0	.
67	0.0	.	.	26	.	.	5516	11.0	.	13.0	.
68	6.0	.	5	59	.	.	14755	41.0	.	12.5	0.5
69	4.5	.	5	386	.	.	13635	9.0	.	12.8	0.2
70	6.0	.	6	267	.	.	11852	9.0	.	12.8	0.1
71	0.0	.	4	278	.	.	14955	15.0	.	12.7	0.3
72	0.5	.	2	191	.	.	11608	6.0	.	12.6	0.0

Continued/

TABLE 8-8. (Continued)

FIELD: KERN RIVER

NUMBER	FLOW RATE (L/MIN)	VOC EMISSIONS (LB/DAY)	TOTAL STEAMING CYCLES TO DATE	TIME SINCE STEAMING (DAYS)	STEAMING FREQUENCY (MOS/CYCLE)	SOAKING PERIOD (DAYS)	STEAM DOSAGE (BBL/CYCLE)	OIL PRODUCTION RATE (BBL/DAY)	CUMULATIVE OIL PRODUCTION (BBL)	GRAVITY OF THE OIL (DEG API)	OIL TO WATER RATIO
73	4.0	0.51	15	443	.	.	659	8.0	.	13.6	0.0
74	1.5	1.74	19	411	.	.	640	17.0	.	13.5	10.3
75	3.0	0.69	4	112	.	.	6200	20.0	25200	13.8	94.1
76	0.6	0.24	17	171	.	.	7000	10.0	72000	13.1	97.0
77	6.0	2.86	12	269	.	.	11032	9.0	.	.	44.0
78	6.0	0.84	4	206	.	.	11310	2.0	.	.	96.0
79	6.0	4.46	8	30	.	.	14617	9.0	.	.	73.0
80	6.0	2.16	10	370	.	.	6500	10.0	17280	12.2	87.3
81	6.0	25.89	3	36	.	.	12628	7.0	.	.	92.0
82	6.0	40.95	4	83	.	.	16023	9.0	.	.	97.0
83	6.0	0.54	5	141	.	.	13236	13.0	.	.	90.0
84	0.0	.	11	727	.	.	13159	7.0	.	.	62.0
85	0.0	.	15	135	.	.	6000	5.0	28800	12.0	96.0
86	0.6	.	11	280	12.0	3	4000	2.0	.	14.0	64.0
87	0.0	.	20	276	6.0	3	3000	2.0	.	13.0	98.0
88	0.0	.	4	265	.	.	3000	4.0	10000	12.0	95.0
89	0.0	.	2	86	.	.	6250	1.0	350	13.0	91.2
90	0.6	.	10	250	.	.	7000	8.0	72000	12.7	96.8
91	4.0	.	7	105	.	.	7200	20.0	72000	13.2	90.9
92	1.5	.	15	236	.	.	8354	2.0	.	.	89.0
93	6.0	.	13	1353	.	.	10595	9.0	.	.	52.0
94	1.5	.	12	886	.	.	11100	12.0	.	.	62.0
95	0.0	.	12	294	.	.	10811	8.0	.	.	63.0
96	1.2	.	12	147	.	.	11266	16.0	.	.	44.0
97	0.0	.	24	318	6.0	3	4000	2.0	.	14.0	70.0
98	4.0	.	6	264	.	.	11061	1.0	.	.	99.0
99	2.4	.	9	280	.	.	10055	13.0	.	.	58.0
100	2.0	.	4	301	.	.	10306	5.0	.	.	97.0
101	0.0	.	8	208	.	.	10353	11.0	.	.	53.0
102	0.0	.	6	378	.	.	16890	19.0	.	.	66.0
103	1.5	.	5	292	.	.	15078	22.0	.	.	48.0

Continued/

TABLE 8-8. (Continued)

FIELD: KERN RIVER

NUMBER	FLOW RATE (L/MIN)	VOC EMISSIONS (LB/DAY)	TOTAL STEAMING CYCLES TO DATE	TIME SINCE STEAMING (DAYS)	STEAMING FREQUENCY (MOS/CYCLE)	SOAKING PERIOD (DAYS)	STEAM DOSAGE (BBL/CYCLE)	OIL PRODUCTION RATE (BBL/DAY)	CUMULATIVE OIL PRODUCTION (BBL)	GRAVITY OF THE OIL (DEG API)	OIL TO WATER RATIO
104	2.4	.	5	230	.	.	11039	13.0	.	.	65.0
105	1.2	.	4	414	.	.	16828	6.0	.	.	51.0
106	4.0	.	3	181	.	.	18905	16.0	.	.	56.0
107	0.0	.	3	555	6.0	3	3000	1.0	.	13.0	99.0
108	0.0	.	.	.	.	.	.	4.0	.	13.0	.
109	0.0	.	.	.	.	.	1592	1.5	.	13.0	.
110	0.6	.	.	.	.	.	.	3.0	.	13.0	.
111	0.0	.	1	277	.	.	28112	14.0	.	.	51.0
112	0.0	.	1	272	.	.	27515	12.0	.	.	36.0
113	0.0	.	1	291	.	.	12891	19.0	.	.	59.0
114	2.0	.	2	65	.	.	6400	2.0	2400	12.5	98.8

Continued/

TABLE 8-8. (Continued)

FIELD: LOST HILLS

NUMBER	FLOW RATE (L/MIN)	VOC EMISSIONS (LB/DAY)	TOTAL STEAMING CYCLES TO DATE	TIME SINCE STEAMING (DAYS)	STEAMING FREQUENCY (MOS/CYCLE)	SOAKING PERIOD (DAYS)	STEAM DOSAGE (BBL/CYCLE)	OIL PRODUCTION RATE (BBL/DAY)	CUMULATIVE OIL PRODUCTION (BBL)	GRAVITY OF THE OIL (DEG API)	OIL TO WATER RATIO
115	4.8	.	1	243	.	.	3981	10.0	3000	15.8	0.6

Continued/

TABLE 8-8. (Continued)

FIELD: MCKITTRICK

NUMBER	FLOW RATE (L/MIN)	VOC EMISSIONS (LB/DAY)	TOTAL STEAMING CYCLES TO DATE	TIME SINCE STEAMING (DAYS)	STEAMING FREQUENCY (MOS/CYCLE)	SOAKING PERIOD (DAYS)	STEAM DOSAGE (BBL/CYCLE)	OIL PRODUCTION RATE (BBL/DAY)	CUMULATIVE OIL PRODUCTION (BBL)	GRAVITY OF THE OIL (DEG API)	OIL TO WATER RATIO
116	6.0	16.01	.	.	.	.	.	.	.	.	.
117	6.0	2.48	15	.	10.0	2	11200	18.0	81360	13.0	0.6
118	2.8	1.73	.	.	.	.	.	.	.	.	.
119	6.0	88.56	4	.	6.0	2	10000	8.0	10853	13.0	0.5
120	1.2	0.21	3	170	5.0	.	10314	18.0	10800	13.0	1.1
121	1.8	2.37	2	.	6.0	2	10000	33.0	9302	13.0	0.2
122	6.0	8.37	1	.	6.0	2	10420	4.0	1064	13.0	0.5
123	1.2	.	6	342	19.0	9	7890	11.0	41910	15.6	2.8
124	0.3	.	.	.	.	.	.	.	.	.	.
125	0.5	.	15	.	6.0	2	10000	4.0	181731	13.0	1.6
126	0.0	.	9	.	17.0	2	8630	1.0	51042	13.0	0.7
127	0.0	.	10	.	6.0	2	10000	.	60070	13.0	1.0
128	0.0	.	8	.	6.0	2	10000	9.0	58273	13.0	0.5
129	0.0	.	14	.	12.0	2	9278	2.0	104231	13.0	1.0
130	2.4	.	16	.	10.0	2	10690	17.0	121904	13.0	0.8
131	0.0	.	14	.	11.0	2	11150	10.0	115257	13.0	1.0
132	0.0	.	18	.	10.0	2	10900	22.0	134702	13.0	1.0
133	0.6	.	14	.	12.0	2	10864	8.0	165153	13.0	0.9
134	0.0	.	14	.	6.0	2	10000	6.0	117405	13.0	0.9
135	0.5	.	13	.	6.0	2	12000	24.0	105728	13.0	0.6
136	2.4	.	7	.	6.0	2	10000	1.0	17206	13.0	0.5
137	0.0	.	14	.	105	2	12389	24.0	101552	13.0	0.6
138	0.6	.	12	.	115	2	12600	10.0	90896	13.0	0.7
139	0.0	.	10	.	13.0	2	11530	7.0	53261	13.0	0.5
140	0.0	.	13	.	6.0	2	10000	5.0	70802	13.0	0.8
141	2.8	.	9	.	6.0	2	10000	8.0	13528	13.0	0.3
142	0.5	.	11	.	11.0	2	12500	7.0	79201	13.0	0.3
143	0.0	.	6	407	18.0	9	7086	3.0	10890	11.7	0.4
144	0.0	.	4	183	28.0	9	8300	3.0	10800	12.9	0.2
145	0.7	.	8	.	12.0	2	11500	16.0	57718	13.0	0.6
146	1.8	.	5	277	14.0	9	11445	7.0	17010	11.8	1.0

Continued/

TABLE 8-8. (Continued)

FIELD: MCKITTRICK

NUMBER	FLOW RATE (L/MIN)	VOC EMISSIONS (LB/DAY)	TOTAL STEAMING CYCLES TO DATE	TIME SINCE STEAMING (DAYS)	STEAMING FREQUENCY (MOS/CYCLE)	SOAKING PERIOD (DAYS)	STEAM DOSAGE (BBL/CYCLE)	OIL PRODUCTION RATE (BBL/DAY)	CUMULATIVE OIL PRODUCTION (BBL)	GRAVITY OF THE OIL (DEG API)	OIL TO WATER RATIO
147	0.0	.	7	790	9.0	9	9610	2.0	5100	12.9	0.2
148	0.0	.	4	.	15.0	2	8808	25.0	13786	13.0	0.5
149	0.6	.	5	.	6.0	2	10000	32.0	36085	13.0	0.8
150	0.4	.	6	.	6.0	2	10000	15.0	26083	13.0	0.8
151	1.6	.	5	.	11.0	2	12172	26.0	36085	13.0	0.5
152	0.0	.	2	.	6.0	2	10000	8.0	5502	13.0	0.9
153	1.8	.	4	.	6.0	2	10000	7.0	6920	13.0	0.4
154	0.0	.	4	.	13.0	2	10696	16.0	7022	13.0	0.4
155	0.0	.	3	344	6.0	9	7982	15.0	13500	13.8	0.0
156	1.2	.	2	303	5.0	.	10680	11.0	6930	13.0	0.4
157	0.9	.	2	.	6.0	2	10000	5.0	2547	13.0	0.4
158	0.0	.	2	.	6.0	2	10000	4.0	1375	13.0	0.0
159	2.5	.	1	.	6.0	2	9440	12.0	1763	13.0	0.6
160	0.0	.	2	.	6.0	2	10000	10.0	302	13.0	0.9

Continued/

TABLE 8-8. (Continued)

FIELD: MIDWAY-SUNSET

NUMBER	FLOW RATE (L/MIN)	VOC EMISSIONS (LB/DAY)	TOTAL STEAMING CYCLES TO DATE	TIME SINCE STEAMING (DAYS)	STEAMING FREQUENCY (MOS/CYCLE)	SOAKING PERIOD (DAYS)	STEAM DOSAGE (BBL/CYCLE)	OIL PRODUCTION RATE (BBL/DAY)	CUMULATIVE OIL PRODUCTION (BBL)	GRAVITY OF THE OIL (DEG API)	OIL TO WATER RATIO
161	6.0	33.79	10	502	15.0	9	11642	29.0	134444	13.6	1.8
162	0.8	1.21	1	330	.	10	12163	9.0	.	12.3	1.5
163	0.9	3.23	24	125	11.0	0	11200	21.0	279938	13.7	0.1
164	0.9	1.84	9	295	10.0	5	1646	4.0	10800	12.9	0.1
165	2.4	0.71	25	405	7.0	3	6209	.	.	12.0	.
166	1.2	1.64	5	360	24.0	9	15000	30.0	150000	11.4	0.7
167	1.2	0.01	20	.	8.4	3	4878	.	.	12.0	.
168	6.0	26.91	8	15	3.0	5	2654	15.0	10800	13.5	2.5
169	1.5	5.88	11	97	10.0	9	12454	22.0	73810	14.1	0.4
170	1.0	4.34	15	.	9.0	7	8060	29.0	111360	.	1.8
171	6.0	141.49	7	.	17.0	8	9000	10.0	.	13.4	0.3
172	1.2	6.76	2	311	.	19	62089	13.0	3388	12.6	1.3
173	6.0	21.91	19	31	5.0	9	11077	22.0	66890	11.9	0.8
174	1.2	2.07	15	165	6.9	3	5016	.	.	12.0	.
175	6.0	10.07	8	224	11.0	7	7000	20.0	.	10.5	0.1
176	6.0	0.79	14	158	12.0	7	11228	35.0	176400	11.0	3.5
177	1.2	8.17	11	76	6.0	5	5000	25.0	36930	12.0	2.1
178	1.2	4.00	6	157	10.0	8	8000	4.0	.	11.2	4.0
179	1.8	1.26	7	188	8.0	5	11928	17.0	30090	11.0	2.1
180	1.2	1.26	6	176	11.0	4	12900	6.0	151852	13.7	0.8
181	2.2	12.08	7	13	9.0	0	12500	18.0	23758	13.2	0.7
182	6.0	4.61	6	336	6.0	7	9000	9.0	.	12.5	0.6
183	6.0	4.05	4	82	9.0	3	5497	.	.	12.0	.
184	4.0	7.31	6	274	.	8	9340	23.0	7333	12.8	0.6
185	6.0	3.40	4	26	8.5	3	4773	.	.	12.0	.
186	1.2	3.59	4	464	4.0	5	2647	6.0	2880	14.6	0.0
187	2.8	1.21	2	381	12.0	0	12200	18.0	4435	13.7	3.8
188	2.5	2.37	4	144	5.0	0	10500	5.0	4076	13.7	0.1
189	1.8	1.28	1	251	0.0	3	6454	.	.	12.0	.
190	1.2	11.92	2	115	6.0	9	15000	2.0	460	11.4	0.2
191	6.0	45.74	1	218	.	9	8527	3.0	311	12.0	0.9

Continued/

TABLE 8-8. (Continued)

FIELD: MIDWAY-SUNSET

NUMBER	FLOW RATE (L/MIN)	VOC EMISSIONS (LB/DAY)	TOTAL STEAMING CYCLES TO DATE	TIME SINCE STEAMING (DAYS)	STEAMING FREQUENCY (MOS/CYCLE)	SOAKING PERIOD (DAYS)	STEAM DOSAGE (BBL/CYCLE)	OIL PRODUCTION RATE (BBL/DAY)	CUMULATIVE OIL PRODUCTION (BBL)	GRAVITY OF THE OIL (DEG API)	OIL TO WATER RATIO
192	0.0	.	6	42	6.0	5	1217	6.0	6480	13.6	0.1
193	0.0	.	.	.	.	.	.	.	.	.	.
194	0.6	.	29	141	6.4	3	4880	.	.	12.0	.
195	0.0	.	6	466	12.0	9	10370	9.0	19215	13.6	0.1
196	0.0	.	7	427	8.0	9	10588	16.0	28792	12.5	0.1
197	0.0	.	4	158	8.0	11	12200	21.0	24979	13.3	0.1
198	0.0	.	10	319	11.0	10	10665	50.0	178425	14.5	0.8
199	0.0	.	3	1372	19.0	10	15366	7.0	23912	15.1	0.0
200	0.0	.	5	330	17.0	10	12497	63.0	163327	14.8	0.4
201	1.2	.	2	402	12.0	5	11000	1.0	1129	17.1	0.0
202	0.0	.	16	196	14.0	0	11200	58.0	235433	13.7	0.4
203	0.0	.	21	137	9.0	0	11900	9.0	182572	13.7	0.1
204	0.0	.	17	85	3.0	5	11642	37.0	56610	11.0	3.7
205	0.0	.	5	265	6.0	5	2889	18.0	16200	13.6	0.5
206	0.0	.	8	42	4.0	5	2660	4.0	3840	13.5	0.1
207	0.0	.	11	242	12.0	7	6000	15.0	.	13.5	1.7
208	0.6	.	.	.	.	.	.	.	.	.	.
209	0.4	.	22	286	8.3	3	7073	.	.	12.0	.
210	0.0	.	20	366	9.4	3	7597	.	.	12.0	.
211	0.0	.	29	89	6.5	3	5814	.	.	12.0	.
212	0.0	.	.	.	.	.	.	.	.	.	.
213	0.0	.	16	151	11.0	6	9113	42.0	211170	12.8	0.5
214	0.0	.	14	295	6.0	16	7998	15.0	92031	12.0	0.3
215	0.0	.	11	436	10.0	12	12116	30.0	94237	12.0	0.5
216	1.0	.	16	317	6.0	7	8054	41.0	78272	12.0	0.7
217	0.0	.	17	.	10.0	7	5250	23.0	120060	.	2.1
218	0.6	.	16	194	11.0	6	8060	12.0	60480	.	4.0
219	0.0	.	.	420	.	4	10987	22.0	.	11.3	1.6
220	0.0	.	.	338	.	4	10646	1.0	.	11.3	0.0
221	0.0	.	.	365	.	4	3931	3.0	.	12.6	2.0
222	2.5	.	20	197	5.0	.	6209	23.0	70000	11.9	3.5

Continued/

TABLE 8-8. (Continued)

FIELD: MIDWAY-SUNSET

NUMBER	FLOW RATE (L/MIN)	VOC EMISSIONS (LB/DAY)	TOTAL STEAMING CYCLES TO DATE	TIME SINCE STEAMING (DAYS)	STEAMING FREQUENCY (MOS/CYCLE)	SOAKING PERIOD (DAYS)	STEAM DOSAGE (BBL/CYCLE)	OIL PRODUCTION RATE (BBL/DAY)	CUMULATIVE OIL PRODUCTION (BBL)	GRAVITY OF THE OIL (DEG API)	OIL TO WATER RATIO
223	0.0	.	7	473	14.0	.	10000	18.0	65569	11.9	0.6
224	2.5	.	15	323	6.0	8	5430	12.0	30399	11.9	0.3
225	0.8	.	9	264	12.0	7	7000	15.0	.	13.2	0.6
226	0.0	.	9	298	12.0	7	7000	2.0	.	10.7	0.7
227	0.8	.	9	179	14.0	7	7000	41.0	.	12.8	5.8
228	0.0	.	9	172	9.0	5	5000	0.4	20734	12.0	0.0
229	0.0	.	18	268	6.0	11	8565	49.0	152351	12.8	0.5
230	0.5	.	11	221	15.0	12	2907	33.0	141116	12.8	0.6
231	0.0	.	24	22	6.9	5	4209	.	.	12.0	.
232	0.0	.	19	257	12.0	5	6746	10.0	103234	12.8	0.7
233	0.0	.	14	253	12.0	5	10290	60.0	289800	11.0	1.8
234	0.0	.	25	197	6.4	3	5076	.	.	12.0	.
235	1.2	.	.	.	.	.	.	.	.	.	.
236	0.0	.	20	85	8.0	5	11418	50.0	243000	11.0	2.0
237	1.2	.	.	.	.	.	.	.	.	.	.
238	0.0	.	12	21	18.0	10	70000	34.0	.	12.1	2.8
239	0.6	.	11	273	13.0	6	6000	30.0	.	12.5	3.3
240	0.5	.	5	1169	24.0	7	7000	79.0	.	12.4	2.5
241	0.5	.	20	214	7.3	3	4716	.	.	12.0	.
242	0.0	.	18	205	8.0	3	5624	.	.	12.0	.
243	0.0	.	20	146	7.0	5	10234	25.0	105750	11.0	2.5
244	0.6	.	19	271	7.0	7	4500	15.0	59850	.	7.5
245	4.5	.	18	11	8.0	3	9849	.	.	12.0	.
246	0.0	.	8	42	4.0	5	2400	10.0	9600	13.4	1.0
247	0.0	.	.	425	.	4	6173	16.0	.	12.6	0.9
248	6.0	.	7	12	4.0	5	1516	2.0	1680	13.4	0.3
249	0.0	.	6	73	3.0	5	2646	7.0	3780	13.5	0.2
250	3.6	.	3	286	24.0	5	2500	5.0	40600	13.0	0.3
251	1.8	.	17	4	8.1	5	5067	.	.	12.0	.
252	0.0	.	.	.	.	.	.	.	.	.	.
253	1.2	.	7	337	12.0	7	7500	11.0	65800	13.0	0.8

Continued/

TABLE 8-8. (Continued)

FIELD: MIDWAY-SUNSET

NUMBER	FLOW RATE (L/MIN)	VOC EMISSIONS (LB/DAY)	TOTAL STEAMING CYCLES TO DATE	TIME SINCE STEAMING (DAYS)	STEAMING FREQUENCY (MOS/CYCLE)	SOAKING PERIOD (DAYS)	STEAM DOSAGE (BBL/CYCLE)	OIL PRODUCTION RATE (BBL/DAY)	CUMULATIVE OIL PRODUCTION (BBL)	GRAVITY OF THE OIL (DEG API)	OIL TO WATER RATIO
254	0.6	.	.	.	.	.	.	.	.	.	.
255	5.0	.	5	.	15.0	5	2000	1.0	.	13.0	1.0
256	1.5	.	9	.	13.0	10	9000	15.0	.	13.2	0.4
257	0.0	.	12	223	10.0	9	11932	89.0	320311	13.0	3.9
258	4.0	.	9	251	13.0	7	7000	29.0	.	11.0	3.6
259	2.4	.	11	267	9.0	3	6059	.	.	12.0	.
260	6.0	.	8	.	11.0	7	9000	13.0	.	14.6	0.8
261	0.0	.	16	129	6.0	5	5000	54.0	175387	12.0	0.0
262	0.0	.	7	63	11.0	5	3089	35.0	80850	12.7	0.7
263	2.4	.	12	55	8.0	7	9278	60.0	94226	12.0	0.3
264	0.0	.	9	415	9.0	10	10056	9.0	80451	12.0	0.3
265	0.0	.	8	158	11.0	13	4394	14.0	92380	12.0	0.8
266	0.0	.	13	418	7.0	5	5000	32.0	112971	12.0	0.0
267	1.5	.	13	263	6.7	3	8461	.	.	12.0	.
268	0.7	.	12	191	7.0	9	10234	15.0	37800	11.9	0.4
269	0.0	.	6	64	.	.	62223	.	.	12.5	.
270	1.5	.	9	358	8.7	3	6538	.	.	12.0	.
271	0.0	.	9	274	9.0	6	7780	76.0	215574	12.0	4.1
272	0.0	.	3	344	.	9	13267	7.0	2057	13.0	0.4
273	0.0	.	10	320	8.0	5	5000	45.0	105749	12.0	0.0
274	0.6	.	7	257	11.0	3	6132	.	.	12.0	.
275	0.0	.	10	277	8.0	22	9299	1280.0	75115	12.8	0.2
276	0.0	.	8	176	4.0	5	2402	9.0	8640	15.1	1.3
277	0.0	.	17	135	5.0	5	5000	35.0	59881	12.0	0.0
278	0.0	.	.	.	.	.	.	.	.	.	.
279	0.1	.	13	141	6.0	5	14698	10.0	23400	11.0	1.0
280	1.8	.	8	168	9.1	3	6375	.	.	12.0	.
281	0.0	.	9	188	8.0	3	6892	.	.	12.0	.
282	0.0	.	2	310	.	9	9965	14.0	3049	12.6	1.0
283	0.0	.	5	149	6.0	5	2424	14.0	12600	14.5	0.6
284	2.4	.	2	392	.	13	51232	43.0	13083	12.5	1.3

Continued/

TABLE 8-8. (Continued)

FIELD: MIDWAY-SUNSET

NUMBER	FLOW RATE (L/MIN)	VOC EMISSIONS (LB/DAY)	TOTAL STEAMING CYCLES TO DATE	TIME SINCE STEAMING (DAYS)	STEAMING FREQUENCY (MOS/CYCLE)	SOAKING PERIOD (DAYS)	STEAM DOSAGE (BBL/CYCLE)	OIL PRODUCTION RATE (BBL/DAY)	CUMULATIVE OIL PRODUCTION (BBL)	GRAVITY OF THE OIL (DEG API)	OIL TO WATER RATIO
285	0.6	.	17	113	4.0	5	5000	26.0	36937	12.0	0.0
286	2.4	.	10	50	7.0	.	3420	44.0	96360	.	1.3
287	0.0	.	10	41	8.0	18	12100	11.0	74582	13.4	0.6
288	0.0	.	16	90	4.0	5	5000	20.0	49344	12.0	0.0
289	0.0	.	9	49	6.0	5	10217	33.0	55440	11.0	2.3
290	0.6	.	6	225	10.0	8	8000	33.0	.	11.2	11.0
291	0.0	.	6	120	11.0	10	10000	15.0	.	11.2	0.5
292	0.0	.	3	271	.	11	38891	29.0	5862	13.2	0.7
293	0.8	.	9	174	7.0	5	11928	15.0	26550	11.0	2.1
294	0.0	.	7	410	9.0	0	11700	16.0	30123	13.4	1.5
295	0.0	.	.	.	.	5	4000	3.0	.	13.5	0.3
296	0.0	.	6	372	9.0	7	7000	9.0	.	11.5	0.9
297	6.0	.	6	408	10.0	7	7000	2.0	.	11.9	2.0
298	0.6	.	.	412	.	.	10202	7.0	.	11.3	0.3
299	0.0	.	.	.	.	.	.	.	.	.	.
300	0.0	.	.	.	.	.	.	.	.	.	.
301	3.0	.	7	258	7.0	3	5933	.	.	12.0	.
302	0.0	.	5	196	9.0	11	11932	28.0	45262	14.4	0.1
303	1.8	.	.	.	.	.	.	.	.	.	.
304	0.0	.	7	157	5.0	5	2420	23.0	24150	13.5	1.8
305	0.0	.	.	.	.	.	.	.	.	.	.
306	0.0	.	7	279	6.0	9	5970	10.0	48422	12.0	0.3
307	0.6	.	8	254	5.0	11	6003	25.0	33804	12.0	0.2
308	0.0	.	4	257	12.0	0	9074	6.0	23056	13.7	0.3
309	0.0	.	3	245	11.0	7	10000	10.0	.	11.4	5.0
310	0.0	.	3	177	14.0	10	10000	38.0	.	10.9	1.4
311	0.9	.	4	419	9.0	7	7000	10.0	.	11.4	5.0
312	0.8	.	6	315	6.0	12	9599	4.0	11430	11.6	0.9
313	0.6	.	3	.	12.0	10	9000	6.0	.	12.5	0.4
314	0.0	.	2	347	16.0	5	7124	.	.	12.0	.
315	0.0	.	10	42	4.0	5	2285	45.0	54000	14.1	0.9

Continued/

TABLE 8-8. (Continued)

FIELD: MIDWAY-SUNSET

NUMBER	FLOW RATE (L/MIN)	VOC EMISSIONS (LB/DAY)	TOTAL STEAMING CYCLES TO DATE	TIME SINCE STEAMING (DAYS)	STEAMING FREQUENCY (MOS/CYCLE)	SOAKING PERIOD (DAYS)	STEAM DOSAGE (BBL/CYCLE)	OIL PRODUCTION RATE (BBL/DAY)	CUMULATIVE OIL PRODUCTION (BBL)	GRAVITY OF THE OIL (DEG API)	OIL TO WATER RATIO
316	1.2	.	5	119	7.4	3	7153	.	.	12.0	.
317	1.2	.	5	24	6.8	4	7892	.	.	12.0	.
318	1.8	.	2	348	13.0	3	6032	.	.	12.0	.
319	0.0	.	.	.	.	5	15377	17.0	.	11.9	0.6
320	0.6	.	4	347	5.0	3	5902	.	.	12.0	.
321	0.0	.	3	15	11.0	11	7400	2.0	976	13.3	0.3
322	0.0	.	3	110	4.0	0	11700	59.0	1009	13.7	0.5
323	0.0	.	3	366	6.0	0	12000	10.0	5067	13.8	0.5
324	0.0	.	3	303	10.0	0	11800	17.0	7623	13.7	2.5
325	0.0	.	4	447	5.0	7	10000	33.0	.	10.8	1.6
326	0.0	.	.	.	.	.	12000	5.0	.	10.5	0.5
327	0.8	.	6	100	4.0	5	1795	15.0	10800	14.7	0.1
328	2.0	.	4	144	9.0	5	5083	37.0	39960	18.0	3.1
329	0.0	.	6	114	6.0	5	3964	16.0	11520	15.0	2.0
330	0.0	.	6	77	5.0	5	5000	24.0	12198	12.0	0.0
331	0.0	.	2	299	5.0	3	6532	.	.	12.0	.
332	0.0	.	4	91	3.5	3	5797	.	.	12.0	.
333	0.0	.	1	271	.	23	86181	20.0	3883	11.5	0.3
334	1.2	.	4	203	3.0	20	6978	17.0	8768	12.0	0.7
335	0.0	.	3	176	6.0	0	11800	7.0	3607	13.7	0.3
336	0.0	.	1	101	5.0	3	10944	.	.	12.0	.
337	0.0	.	2	106	7.5	3	7560	.	.	12.0	.
338	0.0	.	1	251	.	11	7531	10.0	2064	12.9	0.6
339	6.0	.	3	53	5.0	5	3879	25.0	11250	14.2	0.3
340	0.0	.	2	231	3.0	5	2646	122.0	21960	14.6	3.6
341	0.0	.	.	241	.	11	13623	18.0	3279	11.8	1.2
342	6.0	.	1	270	.	12	11526	20.0	4469	12.9	2.0
343	0.0	.	1	290	.	11	12894	18.0	3571	11.5	0.8
344	0.0	.	1	87	6.0	3	7197	.	.	12.0	.
345	0.0	.	4	74	3.0	7	7830	63.0	332	11.6	0.5
346	0.0	.	4	219	2.0	5	8045	8.0	1920	11.9	0.6

Continued/

TABLE 8-8. (Continued)

FIELD: MIDWAY-SUNSET

NUMBER	FLOW RATE (L/MIN)	VOC EMISSIONS (LB/DAY)	TOTAL STEAMING CYCLES TO DATE	TIME SINCE STEAMING (DAYS)	STEAMING FREQUENCY (MOS/CYCLE)	SOAKING PERIOD (DAYS)	STEAM DOSAGE (BBL/CYCLE)	OIL PRODUCTION RATE (BBL/DAY)	CUMULATIVE OIL PRODUCTION (BBL)	GRAVITY OF THE OIL (DEG API)	OIL TO WATER RATIO
347	0.0	.	.	331	.	4	8423	31.0	.	11.3	2.4
348	0.0	.	.	.	.	.	.	.	.	.	.
349	0.0	.	3	85	3.0	7	6571	18.0	1029	12.0	0.3

Continued/

TABLE 8-8. (Continued)

FIELD: POSO CREEK

NUMBER	FLOW RATE (L/MIN)	VOC EMISSIONS (LB/DAY)	TOTAL STEAMING CYCLES TO DATE	TIME SINCE STEAMING (DAYS)	STEAMING FREQUENCY (MOS/CYCLE)	SOAKING PERIOD (DAYS)	STEAM DOSAGE (BBL/CYCLE)	OIL PRODUCTION RATE (BBL/DAY)	CUMULATIVE OIL PRODUCTION (BBL)	GRAVITY OF THE OIL (DEG API)	OIL TO WATER RATIO
350	0.3	.	4	141	.	.	9002	8.0	.	12.5	0.0
351	0.0	.	4	.	.	.	3000	5.0	2500	12.7	0.0
352	0.0	.	4	.	.	.	3000	10.0	5100	13.0	0.0
353	6.0	.	4	.	.	.	8816	11.0	.	12.9	0.1
354	0.0	.	3	214	.	.	10216	9.0	.	12.9	0.0
355	2.0	.	2	184	.	.	10843	14.0	.	12.7	0.0
356	0.5	.	3	201	.	.	13951	8.0	.	12.5	0.0
357	0.4	.	3	82	.	.	10937	5.0	.	12.5	0.0
358	0.0	.	2	113	.	.	9212	4.0	.	12.9	0.0
359	5.0	.	1	169	.	.	10204	45.0	.	12.5	0.2

Footnote:

Well #146 was not included in the study.

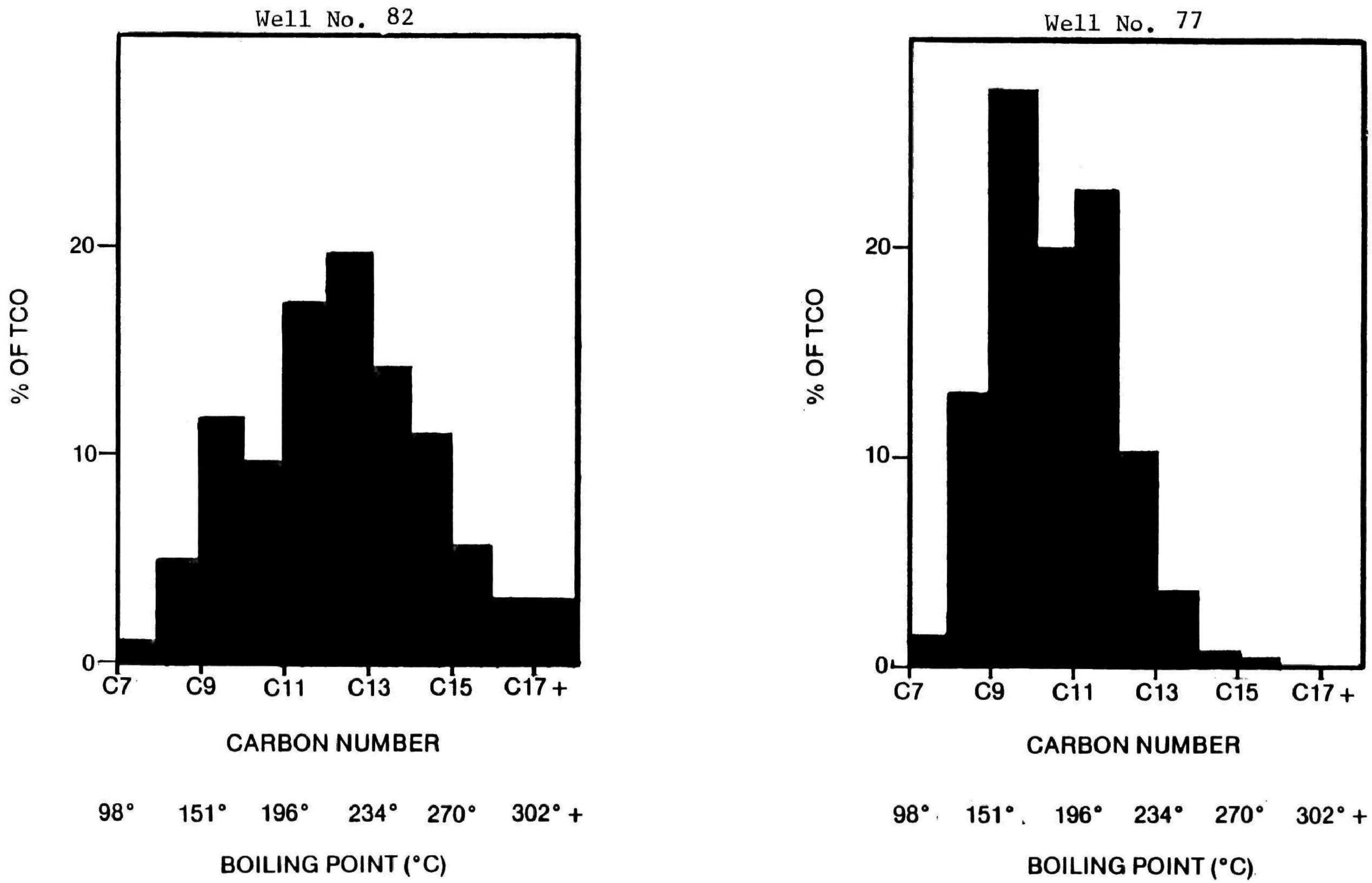

Figure 8-1. Condensate characterization.

SECTION 9

CORRELATION STUDIES

It was desired to determine if any strong correlations existed between the rate of VOC emissions from a well and any of its physical characteristics or operating practices. This was attempted by plotting VOC emissions versus each well parameter, performing correlation analysis, and finally, multiple regression analysis. It was evident from the results of these efforts that VOC emissions are affected by so many variables in such a complex manner that no clear-cut correlations could be developed.

The remainder of this section presents the results of the correlation studies. The graphical presentations indicate some logical trends, but as the numerical analyses indicate, there is too much scatter (caused by variable interdependency) to quantify the relationships.

9.1 CORRELATIONS BETWEEN SURVEY PARAMETERS

One of the first steps in this effort was to check for correlations between the variables which characterize the well. Such interdependency of variables could mask potential correlations to the VOC emissions. Table 9-1 presents the results of this check in the form of paired variables which have a significant correlation coefficient.

9.2 CORRELATION OF VOC EMISSIONS

The objective of this portion of the study is to relate VOC emissions to other characteristics of the well. Figures 9-1 through 9-7 present plots of VOC emissions against well characteristic data available. The plotting

TABLE 9-1. CORRELATION COEFFICIENTS* FOR THE SURVEY DATA

	Variable Pair		Pearson Correlation Coefficient	Sample Size
1.	Age of Steaming	Frequency	0.41	204
2.	No. of Cycles	Steam Dosage	-0.15	317
3.	No. of Cycles	Soaking Period	-0.18	222
4.	No. of Cycles	Cumulative Production	0.65	207
5.	Frequency	Steam Dosage	0.17	228
6.	Frequency	Soaking Period	0.22	194
7.	Steam Dosage	Soaking Period	0.38	230
8.	Soaking Period	Production Rate	0.29	190
9.	Age of Steaming	Cumulative Production	0.65	177
10.	Flow Rate	No. of Cycles	-0.13	317
11.	Time Since Last Steaming	Frequency	0.23	219
12.	Time Since Last Steaming	Soaking Period	0.16	219

*Only coefficients significant at 95% or higher

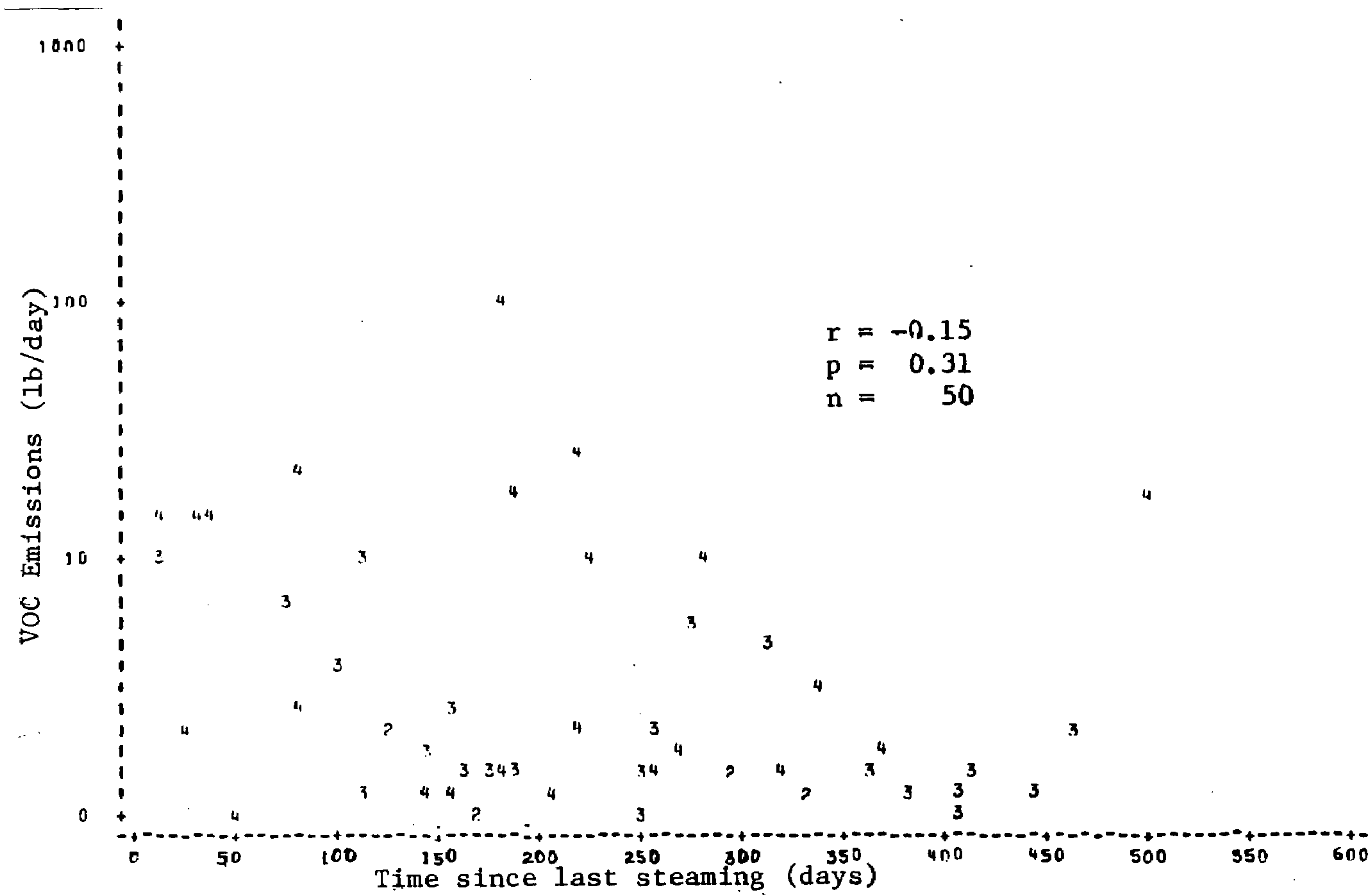

Figure 9-1. VOC emissions vs. time since last steaming.

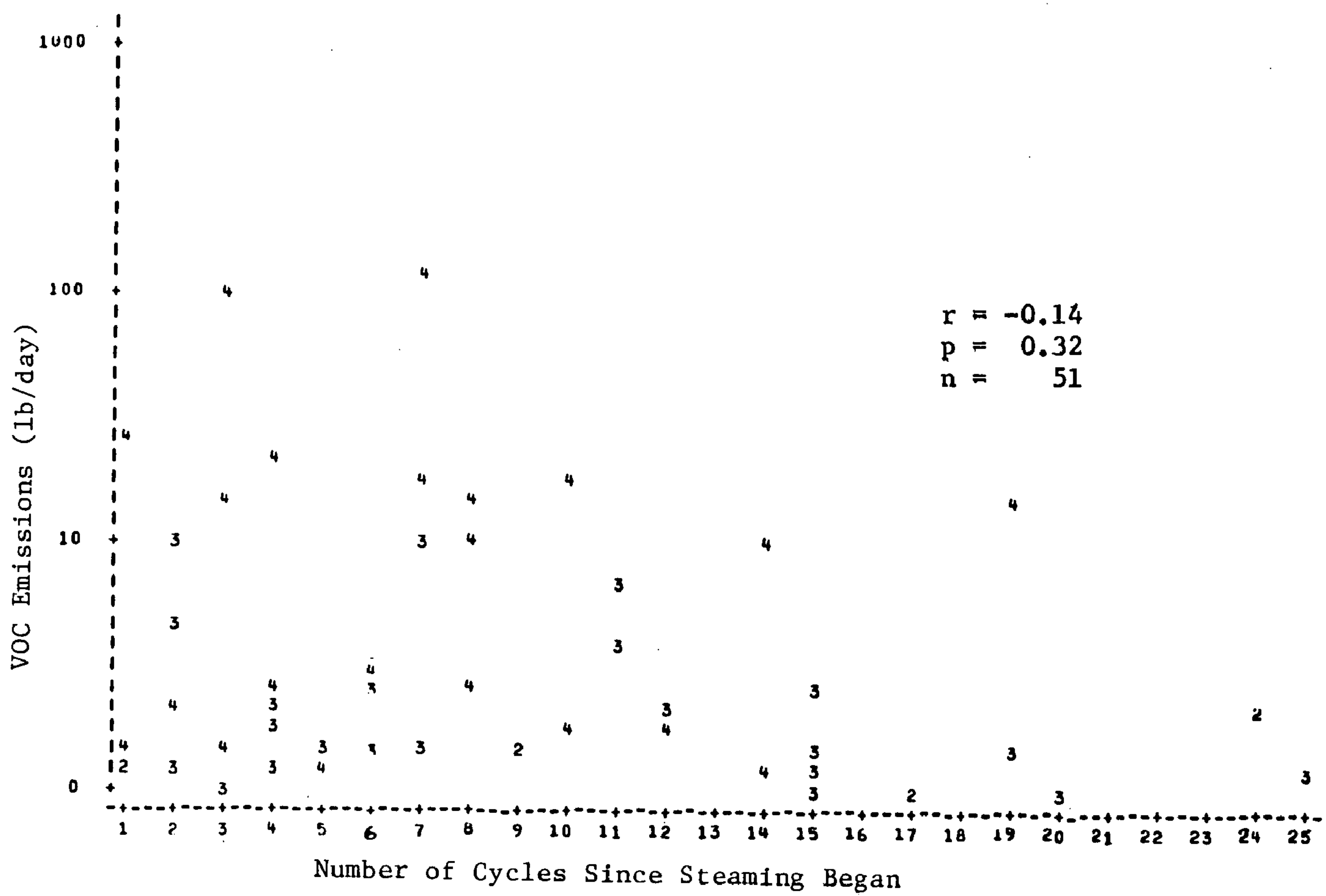

Figure 9-2. VOC emissions vs. number of cycles.

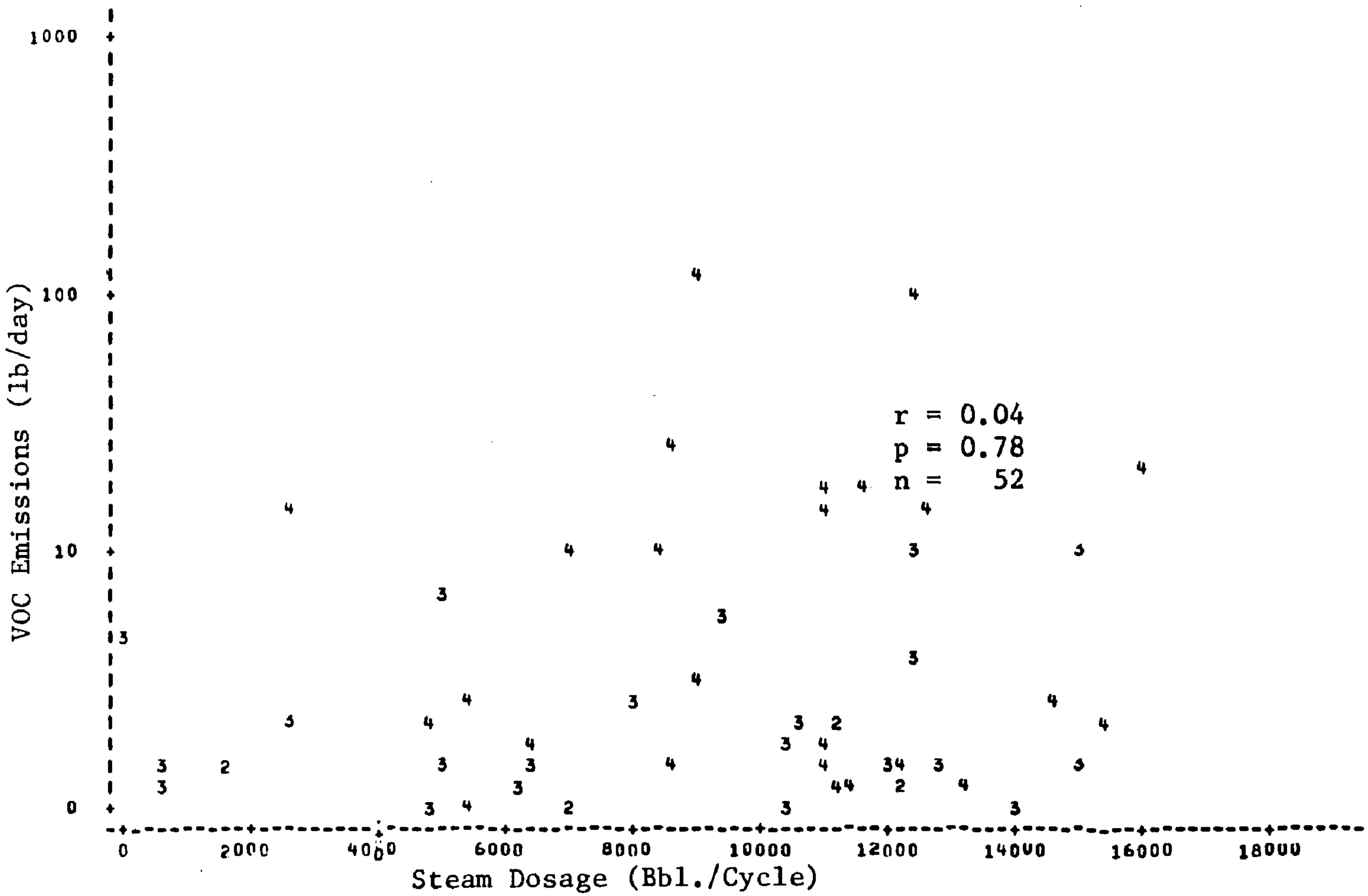

Figure 9-3. VOC emissions vs. steam dosage.

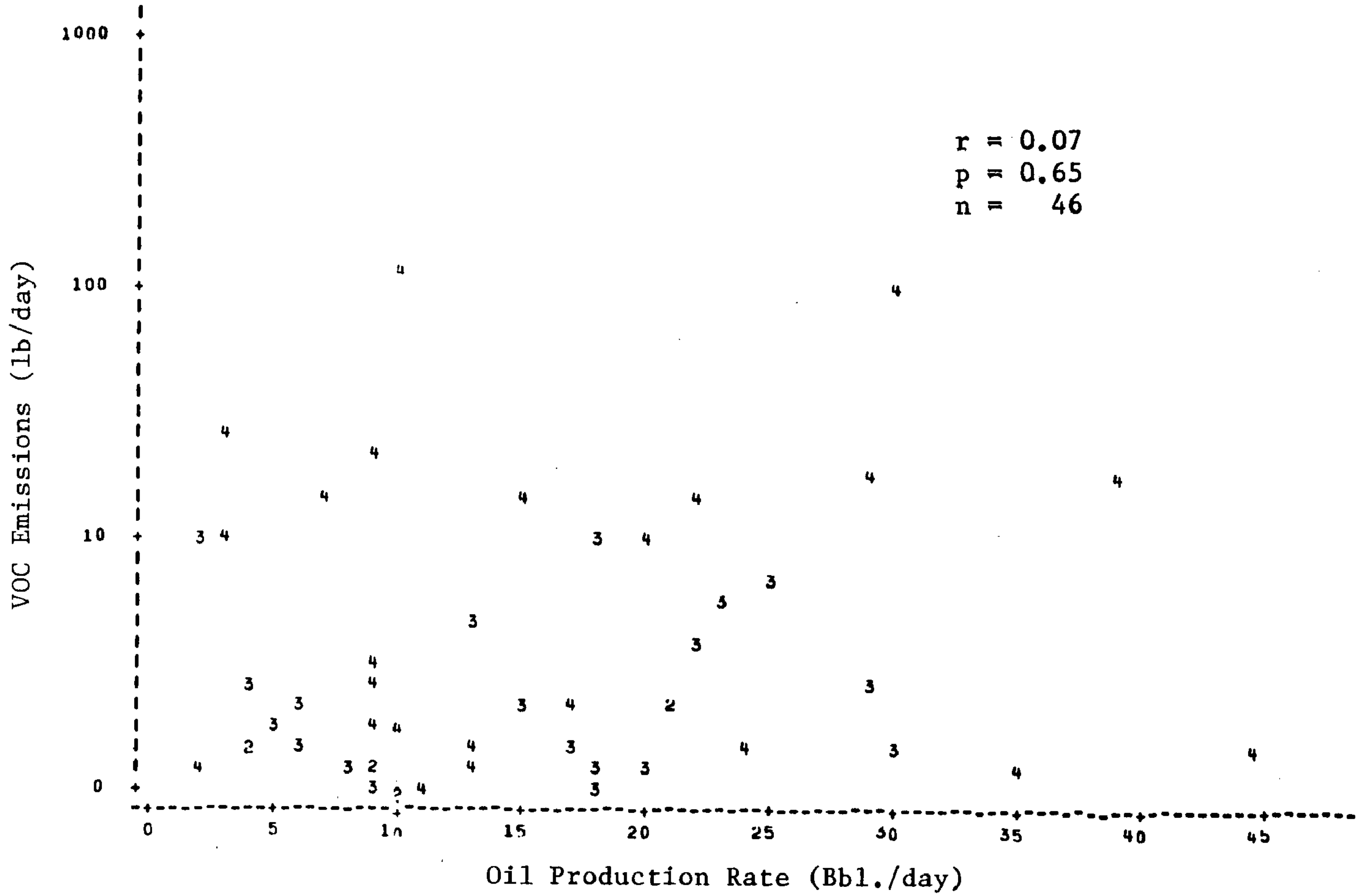

Figure 9-4. VOC emissions vs. oil production rate.

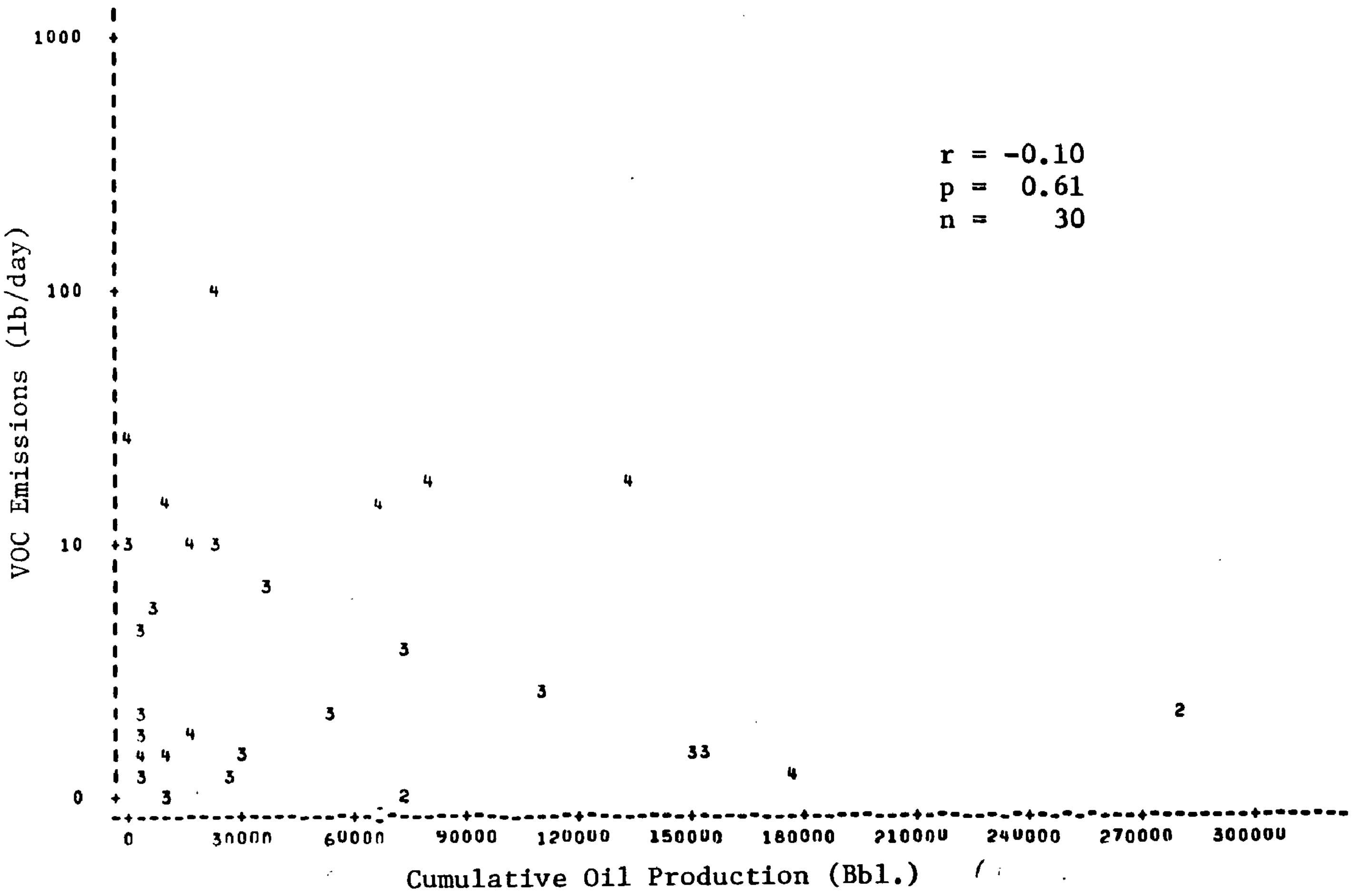

Figure 9-5. VOC emissions vs. cumulative oil production.

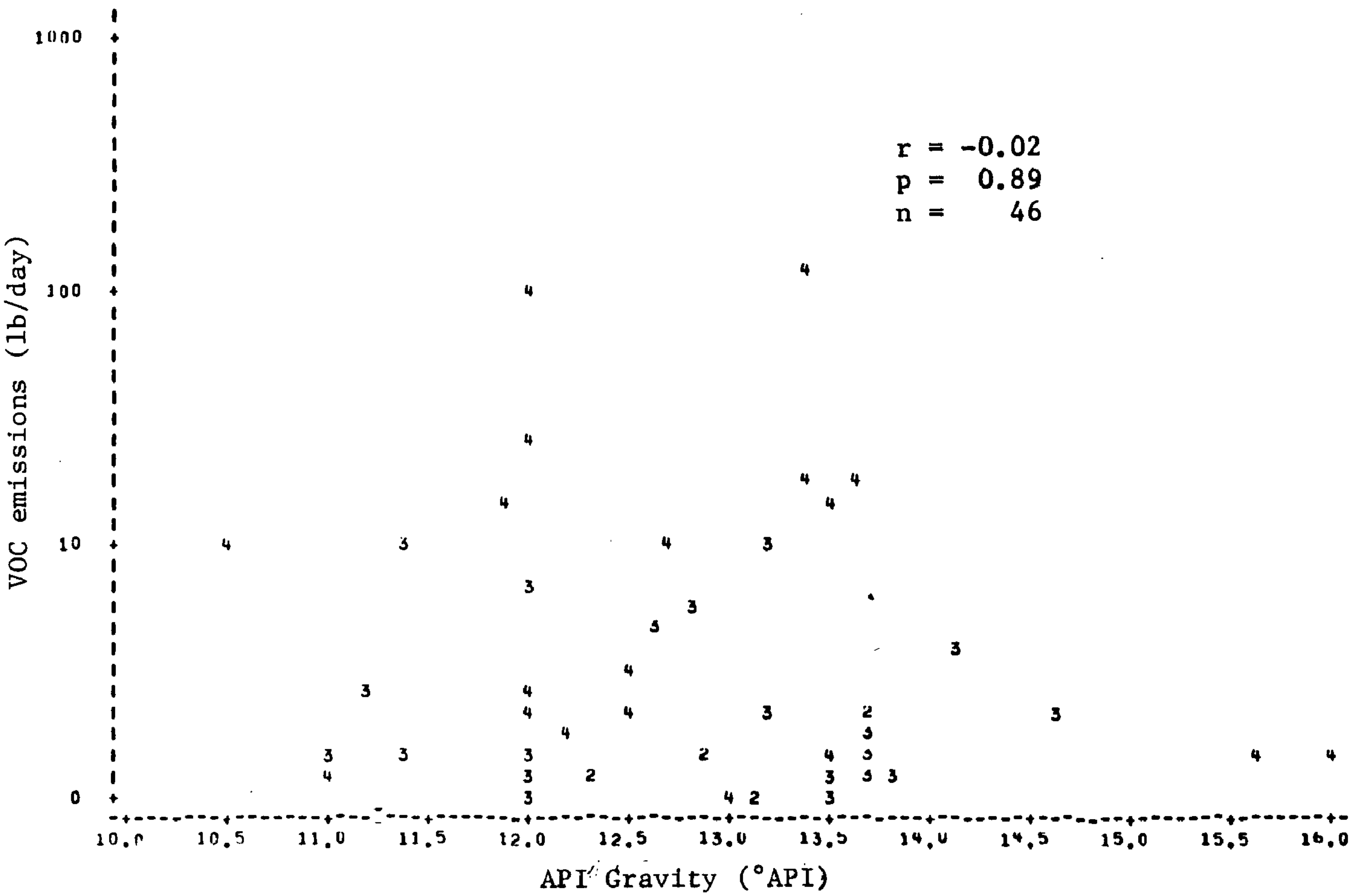

Figure 9-6. VOC emissions vs API gravity of the oil.

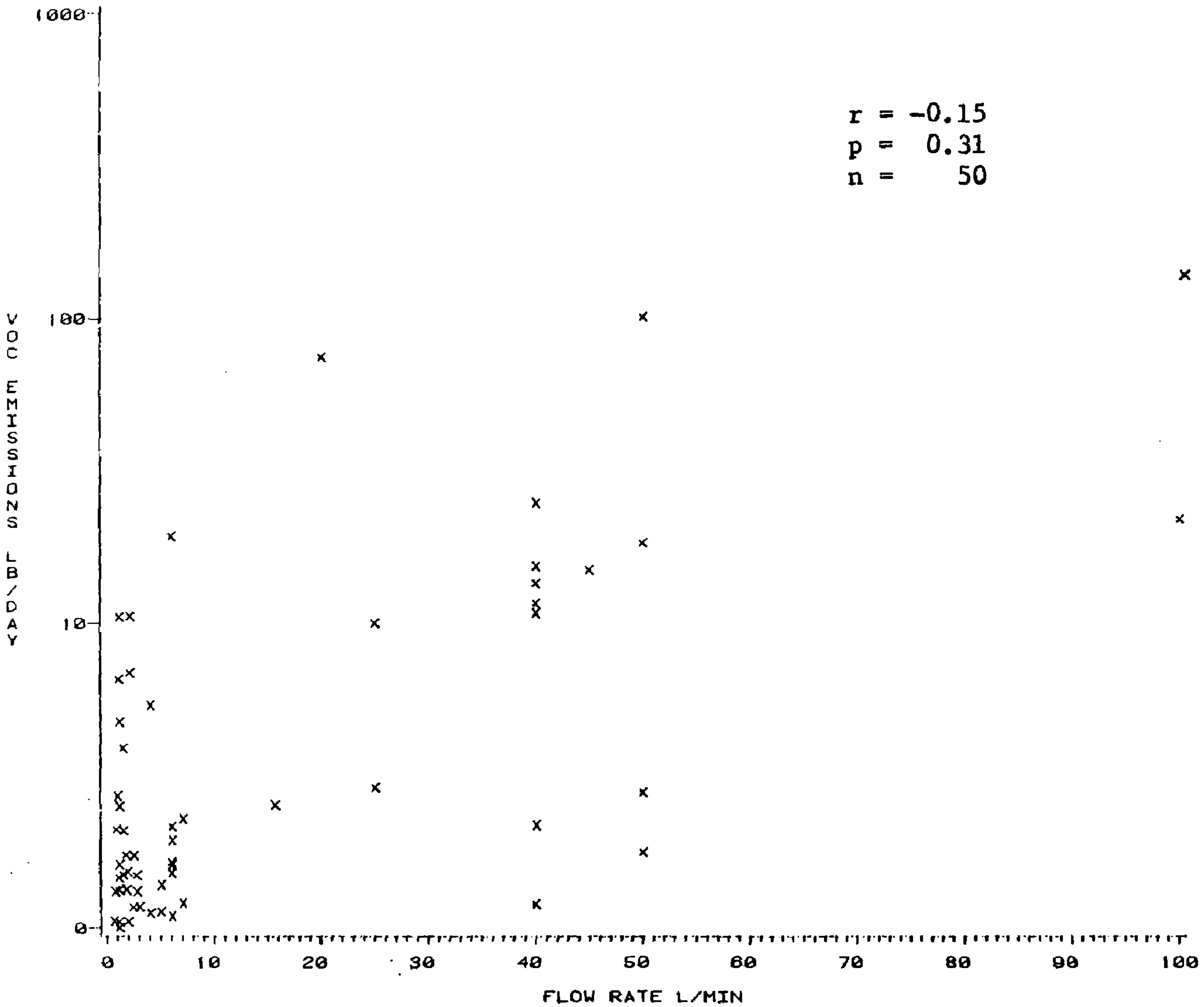

Figure 9-7. VOC emissions vs. survey flow rate.

symbols 2, 3, and 4 represent the flow rate category from the preliminary survey. Although some vague trends are recognizable, the scatter effectively prohibits any strong conclusions from this size of data set.

The variable "VOC emissions" was added to the list of variables tested for correlation in the previous subsection, and the results were presented in Table 9-2. Most of the same variable pairs repeated their significant correlation. VOC emissions was found to correlate significantly with only the survey flow rate (which was not a true well characteristic, but only a rougher measurement of the emission rate).

9.3 REGRESSION ANALYSIS ON TESTED DATA

Multiple regression analysis was used to evaluate the combined effects of all the possible independent variables upon the logarithm of the VOC emissions as the dependent variables. A logarithmic transformation of the VOC emissions was used due to the lack of normality of this variable. Many responses to the questions about well characteristics were missing, so the analysis involved a trade-off between sample size for the analyses and inclusion of some of the variables.

A "dummy variable" was created to denote the area of the well. It was coded as a "1" if the well was in the western portion of the county and a "Ø" otherwise. After a series of models were evaluated, the most important two variables appear to be the flow rate and the variable distinguishing west and central wells. Table 9-3 shows the regression model using the log (VOC emissions) as the dependent variable. The R^2 value or multiple correlation coefficient is 0.37. This says that 37% of the variability in the data is accounted for with this model. The addition of other variables made only a negligible improvement in this. The remaining variability must be explained by one or more factors that were not measured in this study.

An additional analysis was carried out for Western wells only since a few of the well characteristics were only available for this group. The model

TABLE 9-2. CORRELATION COEFFICIENTS* FOR DATA ON WELLS TESTED

	Variable Pair		Spearmans Correlation Coefficient	Sample Size
1.	Age of Steaming	Frequency	0.55	30
2.	Age of Steaming	Cumulative Production	0.79	28
3.	No. of Cycles	Steam Dosage	-0.29	56
4.	No. of Cycles	Cumulative Production	0.76	34
5.	Frequency	Steam Dosage	0.34	36
6.	Frequency	Cumulative Production	0.62	26
7.	Production Rate	Cumulative Production	0.46	34
8.	VOC emissions	Flow Rate	0.39	58

*Only coefficients significant at 95% level or higher

TABLE 9-3. RESULTS OF MULTIPLE REGRESSION ANALYSIS ON LOG (VOC EMISSIONS)

Independent Variables	Regression Coefficients	Significance
Intercept	-1.63	
Survey Flow Rate	0.43	p< 0.01*
Area (West/Central)	1.70	p< 0.01

R = 0.37

Significance of Regression equation

	degrees of freedom	F	Significance
Regression	2	16.19	p< 0.01**
Error	55		
Total	57		

*p is the probability that the coefficients are significantly different than 0.

**p is the probability that this model accounts for a significant portion of the variability.

selected for this is given in Table 9-4. In addition to flow rate, soaking period and possibly API gravity of the oil had a significant effect. 44% of the variability of the Western wells is accounted for with this model.

TABLE 9-4. RESULTS OF MULTIPLE REGRESSION ANALYSIS ON LOG (VOC EMISSIONS) FOR WESTERN AREA OF KERN COUNTY

Independent Variables	Regression Coefficients	Significance
Intercept	-7.21	
Survey Flow Rate	0.43	$p < 0.01$*
Soaking period	0.16	$p=0.03$
API gravity	0.51	$p=0.06$

R = 0.44

Significance of Regression equation

	degrees of freedom	F	Significance
Regression	3	7.06	$p < 0.01$**
Error	27		
Total	30		

*p is the probability that the coefficients are significantly different than 0.

**p is the probability that this model accounts for a significant portion of the variability.

SECTION 10

EMISSION FACTOR DEVELOPMENT

The objective of this study was to provide refined data for calculating the VOC emissions from wellhead casing vents associated with TEOR operations. To that end, the test data on steam cycle wells and the test data on vapor recovery systems serving steam drive wells was used to develop emission factors.

The emission factors, their confidence intervals, and a brief explanation of the methods of development are contained in the next two subsections. A more rigorous explanation of the development of the steam cycle emission factor follows in Appendix B.

10.1 STEAM DRIVE WELL EMISSION FACTOR

Although very little testing has been done on individual steam drive wells, a large body of data is available on vapor recovery systems which serve steam drive wells. The vapor recovery system compliance tests measure the VOC recovered through condensation and lost out the stack. The sum of the recovered and lost VOC represents the total emissions of the steam drive wells connected to the system and, therefore, can be used to calculate the average uncontrolled emissions. Table 10-1 presents a summary of the vapor recovery system data used in calculating the steam drive well emission factor.

The use of vapor recovery system tests to calculate uncontrolled steam drive well emission factors represents an approximate model. The actual emissions from the wells may be affected by the recovery system back-pressure or by back-flow of vapors into wells with a casing pressure lower than the recovery system header.

The data listed in Table 10-1 represents only about half of the existing vapor recovery system source test data. Other tests were omitted from the emission factor calculation for a variety of reasons. In some cases, there were anomalies noted in the test results or procedures. For some tests, the number of wells connected to the system was not known. Many tests were done on systems with a mixture of steam drive and steam cycle wells. It was noted in the early testing on this program that when cyclic wells were attached to a vapor recovery system without a check valve, that it was possible to induce back-flow from the vapor recovery system into the casing. Since this factor could not be quantified easily, tests on hybrid systems without check valves were not used in calculating the emission factor for drive wells. The remaining data base is still quite large with 963 observations.

The emission factor is based on a weighted average of the individual system test results. This results in an emission factor estimate of 220.3 pounds per day per well. An analysis of the variation between individual system tests was used to calculate the confidence intervals surrounding the emission factor estimate, which were found to range from 209.3 to 231.3 lb/day/well.

10.2 STEAM CYCLE WELL EMISSION FACTOR

The results of the field testing done in this study were used to develop the cyclic well emission factor. The data consisted of a survey of 358 randomly selected wells which classified each well into one of four casing vent flow rate strata. The lowest flow rate strata (less than 0.1 liter/minute) was assigned a zero emission rate. A subsample of each of the other three strata were tested to determine the mass emission rate of VOC from the casing vent. A total of 58 wells were tested, with most emphasis being placed on the highest flow strata.

Calculation of the emission factor was done in two steps. The first step was to obtain an emission factor and confidence interval for wells emitting at a rate greater than or equal to 0.1 liters/minute, referred to here as blowing

TABLE 10-1. SUMMARY OF VAPOR RECOVERY SYSTEM SOURCE TESTS USED IN THE STEAM DRIVE WELL EMISSION FACTOR

Chemecology Test Report Number	Producer	Vapor Recovery System No.	Date Tested	Total VOC in Feed (lb/day)	Number of Wells	Emission Factor (lb/day/well)
A-647	Chevron	CC-1-31	10/19/78	791	3	263.7
		CC-2-31	10/19/78	1773	5	354.6
		CC-1-32	10/20/78	764	3	254.6
		CC-2-32	10/20/78	1910	5	382.0
		CC-3-32	10/20/78	1375	6	229.2
A-661	Chevron	CC-1-5	11/13/78	19704	55	358.3
		CC-4-32	11/14/78	4066	8	508.3
		CT-3-5	11/15/78	756	12	63.0
		CC-1-9	11/15/78	12859	44	292.3
		CT-2-5	11/16/78	7212	28	257.6
		CT-3-31	11/20/78	24432	29	842.5
		CT-1-4	11/20/78	2352	40	58.8
		CT-2-4	11/21/78	4356	31	140.5
		CT-5-3	11/22/78	7212	28	257.6
A-685	Chevron	CC-3-3	1/16/79	4298	15	286.5
		CT-4-3	1/16/79	5998	33	181.8
A-824	Belridge	-	10/9/79	1462	41	35.6
		-	10/9/79	4090	21	194.7
A-979	Chevron	CT-4-3	7/29/80	3730	33	113.0
		3-CC-1	7/29/80	806	13	62.0
		CT-1-3	7/30/80	2297	17	135.1
		CC-3-3	7/30/80	3955	15	263.7
		CT-2-4	7/31/80	9322	31	300.7
		CC-2-9	7/31/80	9451	25	378.0
		CC-4-32	8/1/80	2540	8	317.5

Continued/

TABLE 10-1. (Continued)

Chemecology Test Report Number	Producer	Vapor Recovery System No.	Date Tested	Total VOC in Feed (lb/day)	Number of Wells	Emission Factor (lb/day/well)
A-992	Chevron	CC-1-9	8/4/80	4596	44	104.5
		CC-1-5	8/5/80	8681	55	157.8
		CT-2-5	8/5/80	10841	28	387.2
		CT-3-5	8/6/80	2013	12	167.8
		CC-1-31	8/6/80	1308	3	436.0
		CC-3-31	8/7/80	11963	29	412.5
		CC-3-32	8/7/80	1075	6	179.2
		CC-2-32	8/8/80	1918	5	383.5
		CC-1-32	8/8/80	2659	3	886.3
		CC-2-31	8/11/80	3850	5	770.0
		CC-1-27	8/11/80	1650	31	53.2
		CT-16Z	8/12/80	3037	37	82.1
		CC-36W-1	8/12/80	7970	62	128.5
A-1002	Chevron	CC-31X	8/13/80	6305	41	153.8
		CC-26C	8/14/80	6794	53	128.2
			Totals =	212,171	963	

Weighted Average = 220.3 lb/day/well

95% Confidence Interval = 209.3 to 231.3 lb/day/well wells. The second step was to combine this with an estimate and a confidence interval for the proportion of blowing wells. This estimate was obtained from the survey data. A brief description of these steps is included here and more detail is included in Appendix B.

The emission factor for the blowing wells was calculated using the assumption that this data had a lognormal distribution. The wells selected for testing were stratified by flow rate and area. The mean emission rate for these blowing wells was a weighted average using estimates of the proportions within each strata that were obtained from the survey data. The variance was calculated as a variation of the variance for a stratified sample. This was necessary since only estimates of these proportions were available. A 97.5% confidence interval was calculated for the mean emissions. A scale bias correction factor was calculated to convert the log scale values to data scale.

The second step involved calculating a 97.5% confidence interval for the proportion of wells that were blowing. This information was combined with the information from step one to produce an emission factor and 95% confidence interval for both blowing and non-blowing wells combined. This emission factor was calculated as follows:

Emission factor = proportion of wells emitting X average emissions from emitting wells

The confidence intervals were combined in a similar manner.

This analysis resulted in an emission factor of 3.6 pounds per day per well. The 95 percent confidence interval surrounding that emission factor is estimated to be 2.2 to 6.2 pounds per day per well. This emission factor estimate compares favorably with the simple arithmetic model which results in a mean emissions estimate of 3.75 pounds per day per well. The lognormal model was chosen because it allows the computation of more meaningful confidence intervals.

The emission factor presented above represents all wells in Kern County. Emission factors were also calculated on a more dissociated basis, by field and by areas. The calculation of emission factors by field was not productive, since most fields had too few tests to make a firm estimate. The grouping of fields in western Kern County separate from those in central Kern County, however, provided some interesting results. Table 10-2 presents a comparison of the overall cyclic well emission factor to those for the western and central county areas.

TABLE 10-2. EMISSION FACTORS AND VARIANCE DATA FOR STEAM CYCLE WELLS

Area	Emission Factor (lb/day/well)	95% Confidence Interval (lb/day/well)		Scale Bias Correction Factor	Variance of Data in Logs	Standard Error in Logs	Arithmetic Model Estimate (lb/day/well)
		Lower	Upper				
Kern County - Overall*	3.60	2.21	6.24	3.34	2.41	0.182	3.75
Western Kern County	4.31	2.32	7.61	3.02	2.21	0.210	4.19
Central Kern County	2.26	0.70	3.34	2.51	1.84	0.272	2.10

* In deriving the overall estimates, average emissions in the cell were weighted by the proportion between the west and the central areas as determined in the survey. The VOC emissions of the wells actually tested were averaged within each flow rate group and each area.

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. EPA 909/9-81-003	2.	3. Recipient's Accession No.
4. Title and Subtitle Assesment of VOC Emissions from Well Vents Associated with Thermally Enhanced Oil Recovery			5. Report Date Issued September 1981
			6.
7. Author(s) G.E. Harris, K.W. Lee, S.M. Dennis, C.D. Anderson, D.L. Lewis			8. Performing Organization Rept. No. DCN 81-240-016-09-12
9. Performing Organization Name and Address Radian Corporation 8501 Mo-Pac Blvd. P.O. Box 9948 Austin, Texas 78766			10. Project/Task/Work Unit No. 9
			11. Contract(C) or Grant(G) No. (C) EPA #68-02-3513 (G)
12. Sponsoring Organization Name and Address U.S. EPA Region IX 215 Fremont St. San Francisco, CA 94806			13. Type of Report & Period Covered Final
			14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

The objective of this document is to provide improved data for determining the inventory of VOC emissions from wellhead casing vents associated with thermally enhanced oil recovery (TEOR) in California. Both steam drive and cyclic steam wells are examined in terms of emissions and population. The study concentrates on Kern County.

The details of a testing program conducted to determine the emissions from cyclic steam wells are presented, along with the results of a survey of the characteristics of the well, the producing field, and the steaming operation. The results of correlation studies are also presented. An emission factor for cyclic wells is developed. The data base presented consists of a survey of 358 wells of which 58 were quantitatively tested.

Emission data for steam drive wells is presented in the form of compliance tests for vapor recovery systems associated with steam drive operations. This report presents a summary of the applicable test data which was found and an emission factor developed from that data.

17. Document Analysis a. Descriptors

Air Pollution
Crude Oil
Hydrocarbons

b. Identifiers/Open-Ended Terms

Thermally Enhanced Oil Recovery
Emission Factors
Volatile Organic Compounds

c. COSATI Field/Group 13H

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Release Unlimited	Unclassified	
	20. Security Class (This Page)	22. Price
	Unclassified	

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