

# **Development of Instrument Detection Limits for Smart LDAR Application: Chemical Plant Testing**

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## **ABSTRACT**

To progress wider application of optical imaging technology for Smart LDAR (Leak Detection And Repair), confirmatory field test data on instrument detection limits for several chemical species were collected. During this testing, the optical imaging instrument was used to monitor over 73,000 components in 11 different chemical plant process unit areas. Twenty-eight leaks were found using the optical imaging instrument and 16 of these leaks were bagged to quantify the mass emission rate. The monitoring team was able to check over 3,600 components per hour on average. Included in this paper are a summary of the process areas monitored with the optical imaging instrument and the times these were monitored, the approximate number of components monitored in each process area, the time for this monitoring and the corresponding rate of monitoring for each process area and for the overall test period, list of the components found leaking by the optical imaging instrument, a rough description of the chemical in the process line, the Method 21 reading and the mass emission rate if bagging was done. A comparison of the previously published detection

limits and the results from the present study show that for all species tested, the chemical plant detection limits fell within the range of the laboratory wind tunnel testing. This confirms the applicability of the wind tunnel tests as a predictive tool for evaluating optical imaging instrument performance in a process plant.

## **INTRODUCTION**

Fugitive emissions typically account for approximately 50% of total hydrocarbon emissions from process plants. Federal and state regulations aimed at controlling these emissions require refineries and petrochemical plants in the United States to implement a Leak Detection and Repair (LDAR) Program. The current regulatory work practice, U.S. EPA Method 21, requires designated components to be monitored individually at regular intervals. The annual costs of these LDAR programs in a typical large chemical plant or refinery can exceed \$1,000,000. Previous studies have shown that a majority of controllable fugitive emissions come from a very small fraction of components that are large leakers (Taback, 1997). In a Smart LDAR program, these large leakers are targeted for more rapid identification and repair. Optical imaging has been identified as a technology that can more efficiently and cost effectively identify the large fugitive emissions leaks (ICF Consulting, 2004; Siegell et al., 2006).

The objective of this effort was to obtain additional data on the detection capabilities of available instruments to locate leaking components in a process plant. A significant amount of data on detection capabilities for specific chemicals was previously obtained in laboratory wind tunnel studies sponsored by both API and vendors (Panek et al., 2006; Bensen et al., 2006). This testing program was aimed at collecting data that would confirm the applicability of the previous wind tunnel laboratory results.

### **Fugitive Emissions**

Fugitive emissions is the term used to describe hydrocarbon leaks from valves, piping connections, pump and compressor seals and other piping system components that occur as part of the normal wear and tear in plant operations. They are characterized as

largely random occurrences of point-source releases into the atmosphere. While the quantity of emissions is very small for a single component, the large number of components in a typical processing plant results in fugitive emissions being the source of about half the plant total hydrocarbon emissions.

Since the late 1970's, regulations have existed to control fugitive emissions. The Clean Air Act Amendments of 1990, as well as requirements in a large number of states, require all major sources of volatile organic carbon compounds (VOCs) and hazardous air pollutants (HAPs) to control fugitive emissions. As a result, nearly all refineries and petrochemical plants in the U.S. have implemented a Leak Detection and Repair (LDAR) Program to control fugitive emissions. In addition, many plants outside the United States voluntarily conduct LDAR programs to reduce hydrocarbon losses and improve safety and reliability.

In the currently required U.S. program, piping components (generally valves, pump seals, compressor seals and other components) are surveyed for fugitive emissions using a portable hydrocarbon leak detection instrument (organic or total vapor analyzer: OVA or TVA), according to U.S. EPA Reference Method 21. Under EPA Method 21, the probe of a hydrocarbon leak detection instrument is placed at the potential leak surface of a component. Air and any leaked hydrocarbon are drawn into the probe and pass through a flame ionization detector (in the case of the OVA or TVA) to measure the concentration of organic hydrocarbons. The instrument measures the hydrocarbon concentration in the air stream in parts per million by volume (ppmv). If the measured concentration exceeds the regulatory definition of leak for the type of component being monitored action must be taken to repair the leak within a certain number of days after it is identified. If the repair would substantially impact the operation of a process unit, it may be postponed until the next process unit shutdown. Records of each component inspection and any repairs must be maintained and made available for regulatory agency inspection.

Method 21 has numerous shortcomings. The technique measures an ambient concentration adjacent to the actual point of the leak. For a specific component mass emission rate, the measured Method 21 reading may vary over several orders of magnitude. Since Method 21 does not measure actual mass emissions rates of the detected leaks, empirical equations are used to convert ppmv concentrations to mass emission rates. These empirical equations do not correlate well with actual measured emissions rates. In addition, Method 21 measures only the hydrocarbon gas that is drawn through its probe. It cannot distinguish between a point source leak and leaks from a wider component area or any combination of point and component area sources.

Routine monitoring using Method 21 requires an operator to visit and screen each regulated component on a defined frequency to identify the one component out of thousands that is a large leak. This process is very labor intensive and inefficient and is often quite expensive as well. In a typical U.S. refinery or large chemical plant with over 200,000 regulated components, the annual cost for an LDAR program often exceeds \$1,000,000.

### **Smart LDAR (Leak Detection And Repair)**

A study by the American Petroleum Institute (API) found that over 90% of controllable fugitive emissions come from only about 0.13% of the components, and that these leaks are largely random (Taback, 1997). The majority of the mass emissions come from a small number of components with high leak rates. A more efficient and smarter method for fugitive emissions control would more cost-effectively locate these large leakers so that they could be repaired sooner. Optical imaging has been identified as an alternative to Method 21 to locate large leaks more efficiently (ICF Consulting, 2004; Siegell et al., 2006).

Optical imaging technology has been demonstrated and successfully applied in a number of chemical plants and refineries. In addition, there has been extensive laboratory calibration of the imaging unit detection limits for a large range of chemical species (Panek et al., 2006; Bensen et al., 2006). The optical imaging technology has

the potential to meet Smart LDAR principles, which are to more quickly scan components in a plant, identify the large leakers and reduce emissions.

### **Optical Leak Imaging Technology**

Technology generally referred to as optical leak imaging, offers an instrument operator the ability to view leaking gas as a real-time video image. The remote sensing and instantaneous detection capabilities of optical imaging technologies allow an operator to scan areas of potentially leaking components much more efficiently, eliminating the need to measure all components individually. While many other technologies can detect the presence of hydrocarbons, optical leak imaging provides a real-time image of the gas plume and the process equipment that allows identification of the exact source of the emission.

There are two basic types of optical leak imaging technologies: laser illuminated imaging, referred to as “active imaging,” and natural conventional infrared imaging, referred to as “passive imaging.” A passive gas image is produced by the reflection of sunlight in the infrared region off the equipment, with the gas cloud absorbing infrared light and thus appearing darker. Additionally, the relative difference between the radiance (temperature plus emissivity) between the gas cloud and the background behind the gas cloud creates a contrasting image of the gas. With active imaging, the equipment is illuminated with infrared laser light, with the gas cloud image produced by the absorption of the laser light passing through and backscattered from the background behind the gas cloud. In both technologies, the leaking vapor appears as a cloud of "smoke" on a video display of the scene under inspection. This field test was conducted using a passive imaging instrument manufactured by Flir Instruments (TheraCam GasFind IR) which was operated by Leak Surveys Inc (Early, Texas). The technology is similar to that used in the earlier Leak Surveys Inc. "Hawk" camera.

Wind speed, optical resolution, plume motion, and viewing angle affect detection sensitivity. The higher the wind speed, the more quickly the plume is dispersed as it

leaves the leak source and the less visible it becomes. However, some motion is desirable for detecting a leak. A stationary gas cloud is very difficult to distinguish against a non-uniform black and white image of the background.

Viewing angle also influences detection. Gas coming directly towards the camera provides the longest path for laser light absorption. While this may provide the most favorable leak detection condition at greater distances, it could also decrease the ability to see plume movement, which enhances detectability. During this field test, leaks were viewed from multiple directions.

## **PROJECT DESCRIPTION**

The purpose of this effort was to provide additional data that would help promote wider application of optical imaging to locate fugitive emission leaks as a replacement for US EPA Reference Method 21. The proposed regulation, which was published in the Federal register on April 6, 2006, requires that the optical imaging instrument identify leaks at specified thresholds. Previous work sponsored by API and instrument vendors using a laboratory wind tunnel established detection limits for a wide range of chemical species (Panek et al., 2006; Bensen et al., 2006). This field testing was aimed at collecting confirmatory field data to support the results from this previous laboratory work.

### **Objectives**

- Promote progress to reduce hydrocarbon emissions by demonstrating the ability of optical imaging technology to find leak sources in process plants.
- Compare the ability of an optical imaging instrument to US EPA Reference Method 21 for locating large leaks in process plant environments.

- Using selective bagging, expand the database of quantified in-plant mass detection levels for optical imaging identified leaks by monitoring in additional plant areas (e.g. aromatics, light aliphatic gases).

The results of the field data collection effort include:

- i) A summary of the process areas monitored with the optical imaging instrument and the times these were monitored.
- ii) The approximate number of components monitored in each process area, the time for this monitoring and the corresponding rate of monitoring for each process area and for the overall test period.
- iii) A list of the components found leaking by the optical imaging instrument, a rough description of the chemical in the process line, the Method 21 reading and the mass emission rate if bagging was done.

### **Activities**

A one week plant data collection test was conducted. The test included use of an optical imaging instrument to locate leaking components (e.g. valves, pumps, connectors, etc.). Components found to be leaking with the optical imaging instrument were monitored using US EPA Reference Method 21. The optical imaging instrument used in this study was a ThermoCam GasFind IR manufactured by Flir Instruments and operated by Leak Surveys Inc. Some of the leaks found by the optical imaging instrument were "bagged" to quantify the actual mass emissions rate. Minimum detection limits for this instrument have previously been determined in a laboratory wind tunnel and selected field data is being collected to confirm these laboratory results.

The plant data collection effort included four days of process unit area monitoring with the optical imaging instrument. On the fifth day, remaining bagging and gas chromatography (GC) analyses were completed.

Process areas included for monitoring were chosen so as to broaden the currently available database of field detected species. Areas of current need are aromatics (e.g. benzene, toluene, xylenes) and light aliphatic hydrocarbons (e.g. methane, ethane propane, butane). The most useful data are for small leaks that are on lines with high concentrations of a single chemical. The quantity and type of data collected was dependent on the presence of appropriate leaks in the plant at the time the test program was conducted and were beyond the control of the test team or the facility. Decisions on which leaking components to bag were made based on the above criteria at the time a leak was first identified without exact knowledge of the mass leak rate or composition.

### **Detailed Testing Procedures**

Plant areas for monitoring were selected so as to increase the likelihood of finding component leaks on streams with very high concentrations of a single chemical species. This allowed comparison to the laboratory results where "pure" species were used. The planned focus of this work was to identify leaks in plant areas with relatively high concentrations of single aromatic and light aliphatic hydrocarbons. Where opportunities arose, other chemical species were also included.

Each day, there was one test period in the morning and one in the afternoon. The optical imaging instrument was checked before each test period to ensure that it was operating properly. The TVA-1000B (for Method 21 readings) was calibrated prior to each test period. Once the operation of the equipment was confirmed, the test team proceeded to the selected process area.

The optical imaging instrument operator scanned each process area slowly and deliberately first from a distance of about 20 feet and then sometimes closer to

individual components. The initial scan from further away was to identify any large leaks quickly and also to ensure that the instrument and operator were not entering an area with high hydrocarbon concentrations. Independent and continuous monitoring of the background concentration in each area was done using a TVA-1000B to ensure a safe operating environment. Since the optical imaging instrument is relatively light weight, the operator was able to move closer and more freely within congested areas of process equipment to view components from different directions. The operator was able to easily view components close to the ground and underneath process equipment. This flexibility allowed identification of the exact location of a leak on the individual components.

Once a leak was detected by the optical imaging instrument, data were collected including identification of the component type and LDAR ID tag number. All leaks were independently confirmed by other members of the test team viewing the leak through a monitor. After confirmation, a Method 21 screening value was obtained with a TVA-1000B. All leaking components identified during the test were tagged for repair by the plant maintenance staff.

After a leak was identified by the optical imaging instrument, representative stream component information about the chemicals likely to be present in the stream was obtained from process operations. An assessment of the ease and safety of bagging and the need for additional data on the chemicals present was made. The estimated size of the leak was also considered with a greater interest placed on smaller leaks. Using these criteria, a decision on bagging the leak was made by the test team.

### **Mass Emissions Measurement**

A representative number of reasonably accessible leaking components were “bagged” to determine the mass emissions rate and chemical composition of the leak. Bagging involves encasing the leak source such that the flow rate of gas passing over the

component can be accurately measured and sampling the released gas mixture to determine the concentration.

The bagging methodology was performed in accordance with EPA's Protocol for Equipment Leak Emission Estimates. There are two basic variations in the bagging approach: the blow-through method and the vacuum method. This test used the vacuum method. Knowing the flow rate through the bag and the hydrocarbon concentration, the mass emissions rate was calculated. GC analyses provided speciation of the emitted and collected gas.

In choosing which components to bag, priority was given to including the smallest leaks with the highest relative concentration of a single chemical species. Accessibility of the leak for bagging and safety were also considered.

## **PROJECT RESULTS**

The results from this field test will significantly increase the knowledge base for application of optical imaging instruments when used for locating leaking components. New information on detection sensitivity in a plant setting was obtained for several chemical species. These will assist in confirming performance for process areas that can substitute an alternative optical imaging work practice for Method 21. In addition, monitoring efficiency was measured, which will help in planning plant applications.

Twenty hours over four days were spent viewing piping components during the test. Based on plant LDAR ID tags, over 73,000 components were monitored in 11 process areas. This includes valves, pumps and connectors as well as sampling connection, sight glasses, heat exchanger bonnet flanges and other miscellaneous potential fugitive leak sources. Details of the test schedule are provided in Table 1, which includes the process plant locations for each monitoring and bagging activity.

Twenty-eight (28) leaks were identified using the optical imaging instrument and 16 of these leaks were bagged to quantify the mass emission rates. Details on the leaks found are presented in Table 2 including the LDAR ID tag, date and time, component type and Method 21 screening value at the time the leak was identified by the optical imaging instrument. All leaks were verified by requiring viewing by more than one member of the test team. Table 2 indicates which components were included in the bagging. Mass emission rates and compositions for the bagged components are provided in Tables 3 and 4 and the lowest component mass emission rates detected by the optical imaging instrument during this study are summarized in Table 5. These values do not necessarily represent the minimum detection limits for the instrument since the data were limited to leak sizes that were present at the time of the test program. It is possible that, if there had been smaller leaks to bag, lower detection limits could have been demonstrated.

Details on the monitoring efficiency of the optical imaging instrument are provided in Table 6. Analysis determined that the monitoring rate during the test was about 61 components per minute (over 3600 components per hour). This monitoring does not represent a typical or anticipated maximum rate when using optical leak imaging as an alternative to Method 21. Significant time was spent collecting data and allowing participants to view the leaks. Table 6 shows the count of components monitored in the different processing units and the monitoring rate in each area and the average for the entire test period.

### **Data Analysis – Qualitative Results**

In addition to the quantitative results, several qualitative observations further characterize the performance of the instrument during the test.

Weather during the week of testing was mostly clear and hot. On Thursday afternoon, May 4th, there were strong storms that passed through the Houston area and resulted

in about two hours of lost time. No other weather or meteorological conditions impacted the performance of the instrument in detecting leaks.

Leaks were successfully detected against various backgrounds of differing reflectivity in all test areas. The reflective backgrounds were flat, angular, and convex curved surfaces that included concrete pads and support structures upon which equipment is mounted, (dull gray/silver metal insulation sheathing around process vessels, insulation materials, shiny metal tubing and fittings, and matte beige painted metal surfaces and piping). There was no apparent impact due to these differences.

Detected leaks were found in both bright, open, uncluttered areas where the operator could easily walk around the component, and in more dense equipment areas where access was limited. Leaks were found on components that were elevated and only accessible by ladder and on components low to the ground. There were no limitations in viewing desired components during this test.

In general, monitoring was mostly limited to those components that could be bagged if a leak was found. Thus, many inaccessible components, where scaffolding would be necessary to bag the component, were not monitored. Additionally, some components where temperature would have prevented achieving an adequate bagging seal, were not monitored. Since the objective of the work was to measure mass emission rates by bagging the leaks found with the optical imaging instrument, the focus of the monitoring was on components that were accessible for bagging.

### **Quality Assurance, Quality Control and Data Verification**

Consideration of Data Verification and Data Validation procedures were incorporated in all aspects of this project. Plans for project execution were developed and reviewed by a multi-disciplinary team and were reviewed and approved by US EPA. The QA/QC effort focused on assuring that data collection would satisfy the stated goals of the field study. Draft data collection sheets were developed and reviewed prior to the field test

activities. Members of the team were assigned primary and secondary responsibility for different aspects of the data collection (e.g. leak list, activity summary, etc.) during the field study.

Standard data verification and validation procedures were applied to all sample handling. These followed standard published protocols and procedures.

Field data collection (leak identification, data recording, etc.) was verified by duplicate and independent recording of all pertinent data. All leaks observed with the optical imaging instrument were verified by a second and often a third member of the team. Duplicate paper recording of work records were maintained and reviewed after each test day to identify and correct any inconsistencies.

A variety of QA/QC checks were performed on both the analytical and sampling portions of the bagging and GC sample analysis. The QC activities consisted of the following:

- Collection of duplicate samples;
- Duplicate sample analysis;
- Analysis of ambient (laboratory) air blanks; and
- Analysis of continuing calibration samples.

Each component that was bagged was sampled and analyzed in duplicate, with a background sample collected if the leak concentration, as measured by Method 21, was less than 100 ppm total hydrocarbon (THC).

Once a multipoint calibration was developed for a method (aliphatic or aromatic), single point continuing calibration check standards were analyzed periodically during the run day and at the completion of a run day to assess the stability of the multi-point calibration and verify retention time stability.

In addition to the alkane standard used to quantitate the aliphatic compounds, an alkene standard was analyzed several times to determine retention times for these compounds and to determine if there was any bias associated with using the alkane standard to quantitate the alkene compounds found in the bag samples.

A leak rate check of the bagging system was performed at the beginning and at the end of the sampling effort. The leak-rate check test involved introducing a known artificial leak rate into a dummy bag and then running the bagging test in the normal fashion. The emission rate calculated from the bagging test was then compared to the known leak rate, with a quality criterion of 20% (80% to 120% recovery) of the known rate to pass the test. The known leak rate test is a primary QA on the sampling system and flow measurement.

A dry gas meter that was calibrated against NBS standards was used for bagging flow measurements. During the known leak rate test, the standard gas flow rate was measured using a DryCal flow meter, which is a positive displacement flow meter that can also be traced to NBS standards. The known leak rate tests were conducted twice at the beginning of the week of testing (once with a low known leak rate and once with a higher known leak rate) and twice at the end of the field test activities.

For the field bagging measurements, two sets of flow, temperature, and pressure data were taken along with the two samples that were collected for analysis. The leak rates were calculated for each sample run on a component, and an average the results was used when the two runs were close. Where there was a significant difference, the source data was reviewed to determine if one of the runs had an anomaly. Where this was found, the other run was used to represent the component.

### **Leaking Components Identified**

In all cases, a second and often a third member of the test team verified the presence of a leak visible with the instrument. A Method 21 reading was made by a technician

employed by the plant contracted LDAR Inspection Group using a ThermoElectron TVA. In most cases, an approximate speciation was obtained from process operation knowledge. Based on the estimated size of the leak, the composition knowledge and the ability to successfully bag the component, a decision was made on bagging.

### **Component Monitoring Efficiency**

The amount of time in each process area was recorded and, using the known component counts, an estimate of the monitoring rate was calculated. This was done for each process area and an overall efficiency for the entire week was estimated.

In some cases, where the entire unit was not monitored, an estimate of the percent of the unit was used along with the known number of components to calculate an efficiency. It is believed that these estimates are conservative in that not all potential leak sources are included in the regulatory required database and many potential leak sources are located by "sub-numbers" off of primary components. Therefore, it is certain that many more components were monitored than are indicated in Table 6. The monitoring team was able to check over 3,600 components per hour on average.

## **COMPARISON TO PUBLISHED LABORATORY RESULTS**

Previous researchers have conducted laboratory wind tunnel testing to establish leak detection thresholds for passive IR instruments like the one used in this chemical plant study (Panek et al., 2006; Bensen et al., 2006). Due to the great expense of conducting plant studies of instrument detection limits for all chemical species of interest, it is important to establish that the wind tunnel tests are representative of the expected field performance.

A comparison of the previously published detection limits and the results from the present study are shown in Table 7. The data clearly show that for all species, the chemical plant detection limits fell within the range of the laboratory wind tunnel testing.

This confirms the applicability of the wind tunnel tests as a predictive tool for evaluating optical imaging instrument performance in a process plant.

## **SUPPLEMENTAL ENVIRONMENTAL PROJECT**

This project was undertaken in connection with the settlement of an enforcement action taken by the U.S. Environmental Protection Agency for alleged violations of the CAA.

## **REFERENCES**

Taback, H. (1997). Analysis of Refinery Screening Data, American Petroleum Institute, Publication Number 310.

ICF Consulting (2004). Smart Leak Detection and Repair (LDAR) for Control of Fugitive Emissions, American Petroleum Institute.

Siegell, J., Ritter, K. Taback, H., Lev-On, M. (2006). Cheaper, Faster and Smarter: Next-Generation LDAR Programs, EM, April , 46-49.

Panek, J, Drayton, P., Ritter, K., Fashimpaur, D. (2006). Controlled Laboratory Sensitivity Performance Evaluation of Optical Leak Imaging Infrared Cameras for Identifying Alkane, Alkene and Aromatic Compounds, AWMA 99th Annual Meeting, New Orleans, Louisiana, June Paper 06-A-159.

Benson, R., Madding, R., Lyons, J., Czerepuszko, P. (2006). Standoff Passive Optical Leak Detection of Volatile Organic Compounds Using a Cooled InSb Based Infrared Imager, AWMA 99th Annual Meeting, New Orleans, Louisiana, June, Paper 06-A-131.

**Table 1: Schedule of Activities During Test**

DATE	TIME	ACTIVITY	LOCATION	COMMENTS
Monday May 1, 2006	AM	Monitoring	NRU-1	High aromatics / xylene
Monday May 1, 2006	PM	Monitoring	NRU-2 Ground Level	
		Bagging	NRU-1	
Tuesday May 2, 2006	AM	Monitoring	NRU-2 upper levels	
		Monitoring	TDU	
		Bagging	NRU-1	Man lift required for access
Tuesday May 2, 2006	PM	Monitoring & Bagging	PAU	Aromatics
Wednesday May 3, 2006	AM	Bagging	PAU Ground level	aromatics
		Monitoring & Bagging	PCU	Propane / propylene
Wednesday May 3, 2006	PM	Bagging	PCU	
		Monitoring	BPU	Butane/butene
		Monitoring	PFU	Xylenes
Thursday May 4, 2006	AM	Bagging	BPU	
		Monitoring	CMPR	
		RAIN at 11:15		
Thursday May 4, 2006	PM	Bagging	CMPR & SRP/BR	
		Monitoring	SRP/BR	
		RAIN at 14:20		
Friday May 5, 2006	AM	Bagging attempt	PRU	

**Table 2: Leaks Found Using the Optical Imaging Instrument**

ID	LDAR TAG	DATE	TIME	COMPONENT TYPE	PPMV (FO-flameout)	SPECIES	BAG? Y/N	COMMENTS
1	NRU-1 1347.1	5-1-06	1050	Flange	~120,000	79% Xylene 17% EB 3% Toluene	Y	Above valve 1347, top valve flange. C9A reflux, P-104
2	NRU-2 15029	5-1-06	1404	Plug	FO	Pentanes	Y	End of valve 1216
3	TDU 4248	5-2-06	1138	HX Flange	FO		N	E-503, entire top of flange, many injections for on-line repairs
4	TDU 4330	5-2-06	1151	HX Flange	FO		N	E-501, top center, many injections for on-line repairs
5	PAU 10531	5-2-06	1512	Union	FO	Toluene	Y	Off top of P-320A
6	PAU 7409	5-2-06	1521	Control Valve	10,000	Para Diethyl Benzene	N	T321 Bottoms
7	PAU 7419	5-2-06	1525	Block Valve	12,000	Para Diethyl Benzene	N	Under insulation, T311 Bottoms
8	PAU 7413	5-2-06	1527	Block Valve	1,500	Para Diethyl Benzene	N	Under insulation, T311 Bottoms
9	PAU 2930	5-2-06	1619	Flange	7,600	Para Diethyl Benzene	Y	
10	PCU 7675	5-3-06	0912	Threaded Connector	FO	94% propylene 6% propane	Y	Off E-163B
11	PCU 6614.1	5-3-06	0945	Plug	FO	99% propylene	Y	Off valve 6614
12	PCU Not in program	5-3-06	1007	Valve Stem	FO	Natural Gas	Y	
13	PCU 5578.1	5-3-06	1053	Plug	FO	94% propylene 6% propane	N	Off D124B, bubbles visible
14	PCU 5620	5-3-06	1102	Valve Stem	FO	Propylene	Y	Dump line off D124B
15	PCU 9762.1	5-3-06	1104	Plug	FO	Propylene	Y	Dump line off D124B
16	PCU 9608.1	5-3-06	1143	Plug	FO		N	D126A inlet, very large leak
17	PCU 3824.1	5-3-06	1148	Plug	FO	99% propylene	Y	D126A
18	PCU	5-3-06	1202	Plug	FO	94%	N	From D122A

	1371.1					propylene		
19	PCU 2069.1	5-3-06	1223	Plug	FO	99% propylene	Y	From D152 outlet
20	PCU 1882	5-3-06	1234	Valve Stem	FO	Mix	N	E-122 shell side
21	BPU 855.1	5-3-06	1432	Plug	FO	Butene	Y	P274A from T272A bottoms
22	BPU Near 1648	5-3-06	~1500	Sample line	-	Butene	N	Valve closed and leak stopped
23	BPU Not in program	5-3-06	~1550	From under insulation	FO		Y	
24	PFU 2827	5-3-06	1620	Valve Stem	FO	Xylene	N	
25	CMPR 1267- 1269	5-4-06	0940	Under insulation, many potential sources	FO		N	"Refrig" tag
26	CMPR 1242	5-4-06	0947	Vessel Flange	99,000	Propane	Y	D-205A end
27	CMPR 1191	5-4-06	0952	Valve Bonnet	50,000	Ethylene	Y	"Refrig" D109
28	SRP/BR	5-4-06	1338	Covered & Sealed Drain	23,000		Y	Sewer drain in front of T-520

NRU = Naphtha Rerun Unit

TDU = Toluene Disproportionation Unit

PAU = Paraxylene Adsorption Unit

PCU = Propylene Concentration Unit

BPU = Butenes Processing Unit

PFU = Paraxylene Feed Unit

CMPR = Compressor Section (Butyl Polymers)

SRP/BR = Solvent Replacement Process - Bromination Section (Butyl Polymers)

**Table 3: Summary of Aliphatic Compound Mass Emission Results**

Leak Number	2	10	11	12	14	15	17	19	21	23	26	27	28
Tag Number	15029	7675	6614.1	PCF338CV	5620	9762.1	3824.1	2069.1	855.1	No Tag	1242	1191	Drain
Compound	Mass Emission Rates in grams/hour												
Methane	ND	ND	ND	3.5	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ethane/C2	ND	ND	ND	0.2	ND	ND	ND	ND	ND	ND	ND	61.2	ND
Propylene	ND	47.0	68.5	ND	64.2	84.7	77.4	23.8	ND	ND	ND	ND	ND
Propane/C3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	4.7	ND	ND
Butane/C4	ND	ND	ND	ND	ND	ND	ND	ND	10.6	67.1	0.05	ND	ND
<Pentane <sup>1</sup>	46.4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
>Pentane	1.9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	54.6
Other VOC as Heptane	20.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Total Hydrocarbons	68.7	47.0	68.5	3.7	64.2	84.7	77.4	23.8	10.6	67.1	4.7	61.2	54.6

**Table 4: Summary of Aromatic Compound Mass Emission Results**

Leak Number	1	5	9
Tag Number	1347.1	10531	2930
Compound	Mass Emission Rates in grams/hour		
Benzene	0.02	1.7	ND
Toluene	0.6	50.2	0.1
Ethyl benzene	3.1	0.1	0.003
Diethylbenzene (DEB)	ND	ND	1.1
Xylene	14.0	0.3	0.01
Total Hydrocarbons	17.8	51.3	1.2

**Table 5: Demonstrated Detection Limits from Bagging Leaks**

(Below 60 grams/hour)

CHEMICAL SPECIES	LOWEST DETECTION DEMONSTRATED (grams/hour)	LEAK ID
Methane	3.7	12
Propane	4.7	26
Butane	10.6	21
Propylene	23.8	19
Toluene	50.2	5
Xylene (17% EB)	17.8	1

**Table 6: Components Monitored Per Hour**

DATE	TIME	START TIME	STOP TIME	TOTAL MONITORING TME (minutes)	APPROXIMATE NUMBER OF COMPONENTS MONITORED (LDAR Tags)	COMPONENTS MONITORED PER HOUR
Monday May 1, 2006	AM	09:40	12:05	145	80% of 5,900	1,953
Monday May 1, 2006	PM	13:20	16:30	190	70% of 23,000	5,084
Tuesday May 2, 2006	AM	08:30	10:00	90	30% of 23,000	4,600
		11:05	12:35	90	5,800	3,867
Tuesday May 2, 2006	PM	14:30	16:40	130	50% of 10,000	2,308
Wednesday May 3, 2006	AM	08:50	12:35	225	15,000	4,000
Wednesday May 3, 2006	PM	14:05	15:50	105	66% of 10,400	3,922
Thursday May 4, 2006	AM	08:45	11:15	150	8562	3,425
Thursday May 4, 2006	PM	13:05	14:20	75	50% of 8581	3,432

**Table 7: Comparison to Published Laboratory Detection Limits**

SPECIES		CHEMICAL PLANT TEST	WIND TUNNEL TESTS
GROUP	CHEMICAL		
ALKANES	Methane	3.7	3.96 - 49* ; 0.3 - 11**
	Propane	4.7	0.76 - 19.1* ; 0.4 - 9.3**
	Butane	10.6	0.72 - 15.9* ; 0.4 - 13**
OLEFINS	Propylene	23.8	4.37 - 59.8* ; 2.9 - 35**
AROMATICS	Toulene	50.2	22.6 - >75.3* ; 3.8 - 14.3**
	Xylene	17.8 (17% EB)	15.1 - >75.3* ; 1.9 - 18.9**

\* Panek et al., 2006

\*\* Benson et al., 2006