DIAL STUDY EVALUATION
STORAGE TANK RESULTS
AND
MODEL EVALUATION

Prepared for:
Texas Commission on Environmental Quality
Air Quality Division

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Eastern Research Group, Inc.
and
The TGB Partnership

August 31, 2012
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Storage Tank Results
and
Model Evaluation

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1.0 EXECUTIVE SUMMARY

The purpose of this report is to provide an evaluation of the observations pertaining to storage tanks from a Differential Absorption LIDAR\(^1\) (DIAL) study conducted by the National Physical Laboratory (NPL), Middlesex, UK, at a petroleum refinery in the Houston Ship Channel area. The observations evaluated are from a City of Houston report (Houston), which includes the NPL report\(^2\) as an appendix.

Houston compared the DIAL results to other remote sensing technologies employed in the study, including the City of Houston’s mobile ambient air monitoring laboratory (MAAML), canister sampling, open-path Fourier transform infrared (FTIR), and ultraviolet differential absorption spectroscopy (UV DOAS). Houston reported similar patterns from DIAL and the other technologies, but insignificant correlations. While DIAL sometimes identified spikes that were confirmed by other technologies, Houston concluded “there appears to be no relationship between the DIAL emission rate and the concentration”\(^3\) measured using FTIR, and comparison between DIAL and MAAML was even worse.\(^4\) That is, the appearance of a spike in the DIAL readings was generally validated by the other methodologies, but the DIAL estimates of the emission rates for these spikes did not correlate with the other methodologies.

Houston identified many factors that may contribute to the lack of correlation between DIAL and the other technologies. These factors include “turbulent eddies, wind speed, varying detection limits, sample durations, shift in location”\(^5\) as well as the inability of DIAL to account for “temporal variations of the plume,”\(^6\) particularly with respect to molecular weight. In addition to these factors identified by Houston, there are other potentially contributing factors discussed in this report, most notably the failure of the DIAL study to reasonably characterize wind effects. Each of these factors potentially contributes to a lack of reliability in the emission rates predicted by DIAL.

Given the demonstrated unreliability of the emission rates predicted by DIAL, as well as the apparent absence of an attempt to estimate tank and time specific emission rates by Houston, the comparisons of “measured” to “estimated” emissions in Houston have no meaning. Statements that emission estimates were found to be “off by a factor of 132”\(^7\) are indefensible, given that the DIAL measurements failed to correlate with the other

\(^1\) LIDAR is an acronym for “Light Detection and Ranging.” It is similar in concept to RADAR, but whereas RADAR uses radio waves, LIDAR uses light (laser pulses).
\(^3\) Houston, page 78.
\(^4\) Houston, page 1.
\(^5\) Houston, page 79.
\(^6\) Houston, page 1.
\(^7\) Houston, page 1.
measurement technologies, and Houston does not appear to have applied emissions estimating methodologies to the conditions present at the time of the study.

Furthermore, guidance from remote sensing contractors indicates that the scan plane should be located at least 500 meters downwind of the target source in order for wind flow to be reasonably uniform, and that valid measurements may be obtained with the scan plane located up to 3 kilometers downwind of the source. Yet NPL does not seem to have recorded any emissions from storage tanks located in the 500 meters to 3 kilometers range upwind of the scan plane. Every measurable vapor concentration that NPL associated with a storage tank appears to be for scenarios where the scan plane was less than 500 meters from the storage tank. There is no explanation for the absence of measurable vapor concentrations from any storage tank located in the upwind range for which DIAL is claimed to be most valid.

Finally, Houston’s conclusions acknowledge that “the current DIAL costs may be prohibitively high.” DIAL is far more expensive than other available remote sensing technologies, and Houston concludes that only the pattern – and not the calculated magnitude – of the DIAL results were able to be validated.

The benefit of DIAL seems to have been limited to detecting apparent plumes, which could be achieved far more effectively with optical gas imaging cameras which allow actually viewing the plume and thereby positively identifying its source.

Nevertheless, while a careful reading of Houston shows DIAL to be an expensive and inconclusive way of detecting emissions, the observance of notably higher concentrations of volatile organic compounds (VOCs) downwind of some tanks than others invites explanation. This report reviews potential scenarios which may result in a given storage tank exhibiting higher than average emission rates.

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8 Houston, page 99.
2.0 INTRODUCTION

The purpose of this report is to provide an evaluation of the observations pertaining to storage tanks from a Differential Absorption LIDAR (DIAL) study conducted by the National Physical Laboratory (NPL), Middlesex, UK, at a petroleum refinery (the Refinery) in the Houston Ship Channel area. The observations evaluated are from a City of Houston report\(^9\) (Houston), which includes the NPL report\(^{10}\) as an appendix.

This report has three major sections. First is a discussion of the DIAL technology and its limitations. Next is an overview of the Houston study, with an evaluation of the DIAL results. Finally, there is a discussion of issues to consider in an investigation of a storage tank that appears to be exhibiting higher than average emission rates.

2.1 DIAL OVERVIEW

2.1.1 DIAL Technology

DIAL is a technology for measuring range-resolved concentrations of selected gases in a two-dimensional field. This technology permits mapping of vapor concentrations in the plane of the scan (scan plane), thereby allowing plume shape and height to be estimated, as illustrated in Figure 2-1.\(^{11}\)

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\(^9\) Loren Raun and Dan W. Hoyt, Measurement and Analysis of Benzene and VOC Emissions in the Houston Ship Channel Area and Selected Surrounding Major Stationary Sources Using DIAL (Differential Absorption Light Detection and Ranging) Technology to Support Ambient HAP Concentrations Reductions in the Community (DIAL Project), City of Houston Bureau of Pollution Control and Prevention, July 20, 2011.


The LIDAR used in DIAL is an acronym for “Light Detection and Ranging.” It is similar in concept to RADAR, but whereas RADAR uses radio waves, LIDAR uses light in the form of pulsed laser beams. Some of the pulsed laser beam is absorbed by the gas to be measured, and some is reflected back to and detected by the DIAL equipment. The concentration of the measured gas and its distance from the light source are determined from the amount of light that is reflected back and the time that it takes for the light to return.  

The DIAL equipment is housed in a large truck, such as shown in Figure 2-2.  

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A meteorological station is attached to the truck, and other meteorological stations may be deployed in or near the scan plane.

The DIAL equipment measures concentrations of gases in the scan plane, and the meteorological stations measure the wind speed and direction. The rate of air movement perpendicular to the scan plane is calculated from the wind speed and direction, and the rate at which the measured gases are moving through the scan plane is then calculated from the rate of air movement and the concentration of the measured gases. The accuracy of this calculation is subject to variation in wind speed and direction within the plume during the period of measurement. 14 Wind movement is obviously more readily characterized in an open plain than it is downwind of buildings or other structures that interfere with the wind pattern.

### 2.1.2 DIAL Limitations

The results of DIAL studies are sometimes characterized as measured emission rates but, as noted above, DIAL measures only vapor concentrations. In order to translate these measurements of concentration to an emission rate from a target source, other parameters must be accounted for, including wind speed and direction, any contribution from other upwind sources, how the response of the DIAL technology to the actual vapors present may differ from its response to the gases to which it was calibrated, and any temporal variation in the site conditions.

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2.1.3 Wind Characterization.

Wind speed and direction must be characterized in order to determine a flux, or rate of vapor movement perpendicular to the scan plane, associated with each DIAL scan. In order to account for wind speed and direction, one or more meteorological stations are established at the site during the time of the DIAL study. A meteorological station is typically located at the truck containing the DIAL equipment, and additional stations may be located within the plane of the DIAL measurement. One DIAL contractor’s description of their procedure for meteorological measurements includes the statement that “remote anemometers and wind vanes are deployed along the DIAL scan plane at various heights.”

The wind characterization issue was addressed in presentations at a 2009 Remote Sensing workshop hosted by Houston Advanced Research Center (HARC 2009). One presentation explained: “The measurements are typically conducted at 0.5 – 3.0 km distance from the sources. The assumption is then that the plume is distributed from the ground up to several hundred meters height and that the wind varies little with height.” This presentation further discussed how a physical obstruction disturbs and alters the wind pattern. While it is readily evident that the wind speed is appreciably less on the leeward side of an obstruction than it is in an open area, this presentation illustrated how wind in a plane close to an obstruction could have eddying characteristics that could result in the same vapor molecules passing through the scan plane multiple times, as shown in Figure 2-3.

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16 “Remote Sensing VOCs and GHGs,” hosted by Alex Cuclis, Houston Advanced Research Center, December 7, 2009 (HARC 2009).
17 Johan Mellqvist and Jerker Samuelsson, “VOC Measurements by the Solar Occultation Flux (SOF) Method and mobile extractive FTIR (meFTIR),” Chalmers University of Technology, Gothenburg, Sweden, presented at HARC 2009.
18 Mellqvist and Samuelsson.
Another HARC 2009 presentation illustrated DIAL validation testing, with the qualifier that the validation program was for scan planes greater than 500 meters downwind of the source. A third presenter confirmed the effective range for DIAL to be up to 3 kilometers downwind of the source. The consensus of these remote sensing contractors, then, is that the DIAL scan plane should be at least 0.5 kilometers downwind from the source (and other obstructions) in order to be located in reasonably uniform wind flow, and that DIAL can obtain valid measurements up to 3 kilometers downwind of the source.

**Upwind Contributions**

Upwind measurements are taken in order to account for contributions from other sources to the vapor concentrations measured downwind of a target source. A typical DIAL configuration, however, does not accommodate taking these upwind measurements simultaneously with downwind measurements. A DIAL unit is housed in a large mobile facility that takes some time to re-site and set up, and thus the ratio of upwind to downwind scans tends to be small if both the upwind and downwind sides of a source cannot be scanned from the same location.

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20 Rod Robinson, “NPL DIAL – Applications to VOCs and GHG emissions measurements,” National Physical Laboratory (NPL), presented at HARC 2009.
As noted above, DIAL contractors claim the technology to be capable of measuring concentrations from sources as much as 3 kilometers upwind of the scan plane. When using DIAL at an extensive industrial facility comprising myriad sources of emissions, there are likely numerous upwind sources, with different sources being aligned with the target source with each shift of wind direction. The contribution of upwind sources to a given scan in such a setting can be reasonably known only if upwind scans are conducted concurrently with the downwind scans.

**Correction Factors**

As with all remote sensing technologies, measurements should be corrected to account for differences in the sensitivity of the technology to different gases. DIAL studies typically involve collection of air samples to determine the gases present in the atmosphere to be measured, in order to develop an appropriate correction (response) factor.

Such sampling and analysis can be used to reasonably develop a response factor when the emitted gas is a single chemical. In a complex petroleum refining and chemical manufacturing facility, however, there are hundreds of different chemicals being emitted, with different process units emitting different combinations of chemicals.

**Temporal Variation in Site Conditions**

DIAL studies have historically tended to collect measurements from a given location over a relatively brief period of time and only during daylight hours. This practice does not accommodate evaluation of the longer term emission rates for sources that may have varying or cyclical emission patterns or which have diurnal variations in their emission patterns. Storage tanks have numerous temporal factors that affect emission rates at any given point in time, including the level of the liquid in the tank, whether filling or emptying is taking place, the speed and direction of the wind, the temperature inside the tank, and the time of day.

It is not surprising, then, that DIAL studies typically report no detectable vapor concentration for many tanks, while reporting vapor plumes for certain other tanks.

**Summary of DIAL Limitations**

DIAL estimations of emission rates are entirely dependent on the accuracy with which the wind flow through the scan plane is characterized. The DIAL scan plane should preferably be located at least 500 meters downwind of the target source, and the wind speed and direction should be measured at multiple locations in the scan plane.
DIAL estimations of emission rates from a target source are further dependent on accurately quantifying any contribution from upwind sources, which would preferably be accounted for by conducting upwind scans concurrently with downwind scans.

DIAL estimations of emissions rates are additionally dependent on the accuracy with which correction is made for the differing response of the sensor to different chemicals present in the scan plane, which would preferably involve obtaining vapor samples from the plume being observed in the scan plane.

Actual emission rates from storage tanks vary significantly with variations in temporal factors. Any comparison of DIAL results to expected emissions from a storage tanks is only meaningful if the pertinent temporal variables are fully accounted for.

The conditions that are preferable in order to mitigate these DIAL limitations are generally not practical to achieve at a complex industrial facility with many sources of emissions, numerous obstacles to wind flow, hundreds of different chemicals being emitted, and constant change in the temporal variables.

2.2 HOUSTON STUDY

2.2.1 NPL Protocol

The NPL report includes some discussion of the protocol followed for the Houston study, as well as summaries of the results.

Wind Measurements.

NPL indicates that, for all of the storage tank scan locations except one, wind speed was measured at a fixed mast on site, which was as much as two miles from where DIAL scans were conducted. Furthermore, this fixed mast was located in an open area away from the storage tanks and other obstructions to the wind. This fixed-mast, then, was not located in the scan plane, nor was it located immediately leeward of a storage tank.

In light of the dependency of DIAL results on the proper characterization of the wind, and the guidance given by another DIAL contractor that multiple anemometers and wind vanes should be deployed along the DIAL scan plane at various heights, the NPL protocol appears to be inadequate for properly characterizing wind speed.

Scan Plane Locations

It is apparent from the NPL plot plans of scan lines and target tanks that the scan plane was typically located much less than 500 meters from the target tank. NPL indicates that wind direction was measured at a mast attached to the DIAL truck which, while being located at the origin of the scan, was not actually in the scan plane.
As noted above, the scan plane should preferably be at least 500 meters downwind of the target source or other obstructions. The wind immediately leeward of an obstruction will not only be at a lower speed than in an open area, it is also likely to exhibit turbulent eddies that would result in significant variation in wind direction in the scan plane. In that DIAL calculations of mass flux depend on uniform wind flow and accurate measurement of wind speed and direction, the location of the scan plans in the NPL protocol appear to be incompatible with the conditions required for reasonably estimating mass flux.

NPL does not explain why results for storage tanks are reported only for those tanks for which the scan plane may have been in the eddy zone on the leeward side of the tank, and no emissions are reported from the dozens of storage tanks which were located in the 0.5 to 3 kilometer range upwind of the scan planes.

**Other Upwind Sources**

The NPL plot plans typically show numerous other emissions sources upwind of the storage tanks for which results are reported, but the NPL protocol did not include concurrent upwind scans in order to account for any contribution to measured vapor concentrations from these upwind sources. When upwind scans were conducted, they were at different times from the downwind scans, and thus subject to differences in the temporal variables. Most notably, a shift in wind direction between the times of the upwind and downwind scans would change the wind-directed alignment of upwind sources relative to the target source. For example, a stack or vent that was not aligned directly upwind of the target source during the upwind scan may have become directly aligned due to a change in wind direction by the time of the downwind scan. Furthermore, NPL did not record any upwind scan at all for many of the scan locations.

The potential for results to be skewed by the inadequate determination of upwind contributions is illustrated by NPL scan location SDP32 on March 22. NPL reported the emissions downwind of tank D-379 as 0.9 lb/hr (LOS3) and upwind of tank D-379 as 5.1 lb/hr (LOS1), implying that tank D-379’s emissions were -4.2 lb/hr.

The NPL protocol does not appear to have adequately accounted for potential upwind contributions when reporting results for targeted sources.

**Other Upwind Storage Tanks**

NPL typically reported results for only a few storage tanks located immediately upwind of the scan plane, even when there were numerous additional storage tanks located in the 0.5 to 3 kilometer upwind range of DIAL capability. NPL apparently omitted these tanks from the reported results on the basis that no emissions were detected from them.
It is grossly misleading, however, to neglect low-emitting emission points when making comparisons of study results to estimated emissions.

Emission estimates are intended to represent the average of a large population of emission points within which actual emissions are understood to vary. When measuring VOC concentrations downwind from a group of tanks, it would be expected that some tanks will have higher emissions than others. An example of this would be if one tank in a group of fixed-roof tanks is being filled while the others are not. It would be expected in such a scenario that most of the emissions at that point in time would be from the tank being filled.

It is misleading to base a comparison of emissions estimates upon only the higher emitting tank or tanks. Rather, a comparison of estimated emissions should account for all of the tanks that are in a reasonably close proximity upwind of the plane of the DIAL scan. The practice of neglecting tanks for which no plume is detected limits the comparison to the higher emitting tanks, thereby imposing a grossly misleading upward bias on the so-called measured emissions per tank. NPL appears to have followed this misleading methodology by making comparisons only to selected tanks within upwind groups.

Response Factor

NPL conducted a DIAL measurement of an “unknown propane mixture,” but it appears that the unknown variable was only the concentration of the propane. In that this release was apparently of a single, known chemical, it would not address the concern of varying response factors for varying mixtures of different gases. NPL does not appear to have conducted any controlled release measurements of unknown mixtures of gases that might be representative of the gases emitted at the facility, and thus does not appear to have adequately evaluated the impact of variable response factors on the DIAL results.

Temporal Variables

As noted above, there are numerous temporal factors that may affect emission rates from storage tanks. NPL typically conducted scans at a given location for only an hour or two during the middle of the day, and thus does not appear to have accounted for the potential impact of temporal factors. It cannot be known from the NPL report whether the emission rate from a given tank at the time of a DIAL scan was near the high or low end of the range of emission rates that may be typical for that tank.

In one case where scans were taken along the same line of sight on different days, the results varied considerably. DIAL estimated the benzene emissions downwind of Tanks T-OL911, T-OL912, T-OL913, and T-OL920 on February 8 (location SDP24 line of site LOS1) as averaging 6.2 lb/hr, on February 10 (location SDP26 line of site LOS1) as
averaging 4.5 lb/hr, and on March 22 (location SDP33 line of sight LOS1) as averaging 24.9 lb/hr. The NPL protocol does not appear to involve sufficient scans at a given location to adequately evaluate variability in emission rates due to temporal factors.

2.3 Houston Report

Houston evaluates the DIAL results in comparison to other remote sensing technologies used in the study, and reports comparisons to estimated emissions.

DIAL Emission Rates Not Validated By Other Technologies

Houston acknowledged many of the issues noted above concerning DIAL limitations. In particular, Houston cited “turbulent eddies, wind speed, varying detection limits, sample durations, shift in location” and “temporal variations” as contributing factors to the absence of correlation between the DIAL results and the other remote sensing measurements taken during the study.

The Houston conclusions included the following:

“While the FTIR could not be used to statistically validate the DIAL measurements, in almost every instance when the DIAL detected emission events (used in the sense of a transient plume, not in the context of the regulatory definition of an event), the FTIR also detected the event in the same location and at the same time.” 21

Thus spikes identified by DIAL were generally verified by FTIR (as well as by MAAML), but the estimated emission rates were not.

Houston concluded, “DIAL was shown to be an effective technology for the measurement of mass flux from fugitive, non-point emissions sources.” It should be kept in mind, however, that this statement is apparently meant to refer to the capability of DIAL to detect spikes in emissions, and not to any validation of DIAL as a reliable tool for determining actual emission rates. It should further be understood that DIAL does not actually measure mass flux, but rather measures concentration. DIAL then calculates an estimated mass flux based on the assumed characterization of the wind. As noted above, however, there were numerous deficiencies in the characterization of wind in this study.

Comparison of DIAL to Estimated Emissions

Houston presented comparisons of DIAL to “emission factor estimates.” These comparisons would seem to be meaningless, however, given that the study failed to validate the DIAL emission rates. Furthermore, EPA has no published emission factors

21 Houston, page 97.
for estimating storage tank emissions on an hourly basis, and thus it is not apparent how these so-called emission factor estimates were determined. It is also not apparent how, or whether, actual conditions at the given point in time were accounted for. And it is not apparent whether all upwind tanks for a given scan location were included in the emission factor estimates, or the comparison was skewed by neglecting the tanks that were not reported by NPL to have detectable emissions. Finally, Houston compares the emission factor estimate, which is intended as an estimate of an average or mean value, to the “Upper 95th Confidence Limit of the Mean” of the DIAL results. This appears to be a comparison of the middle of the range from one method to the expected top end of the range from another method, which further seems to render the comparison meaningless.

POTENTIAL CAUSES OF HIGHER THAN AVERAGE EMISSION RATES

While the study failed to validate the emission rates estimated by DIAL, it did verify a pattern of higher vapor concentrations downwind from certain storage tanks than from other tanks. There are numerous factors that may contribute to a storage tank exhibiting higher than average emissions at a given point in time. Many of those factors are addressed in EPA’s emission factors and equations in AP-42, such as whether or not a tank is being filled or whether a floating roof is landed. There are other potentially contributing factors, however, that are not incorporated into the AP-42 methodology, some of which are discussed below.

Inappropriate TANKS Defaults

An additional issue with respect to estimating emissions from storage tanks is the use of default values from EPA’s TANKS program. For the case of crude oil storage tanks, a particular concern is the use of the default value given in TANKS for Reid vapor pressure (RVP). TANKS contains default physical properties for crude oil which include an RVP value of 5 pounds per square inch (psi). However, actual values for the RVP of crude oil vary substantially from this default value. For example, a review of RVP data from one refinery (not the refinery in this DIAL study) over a period of one year showed values that varied from 0.93 psi to 12.80 psi. The effect of RVP on estimated emissions is in the P* vapor pressure function, which is calculated from the true vapor pressure (TVP) of the stock. The TVP, in turn, may be calculated from the RVP. It is apparent from Table 2-1 that the observed range in crude oil RVP at one refinery would result in estimated emissions that range by a factor of about 60 (it is only coincidental that the calculations were based on an assumed temperature of 60 degrees Fahrenheit).
Table 2-1. Variation in Reid vapor pressure (RVP) and True vapor pressure (TVP)

<table>
<thead>
<tr>
<th>RVP (psi)</th>
<th>TVP (@ 60 F)</th>
<th>P* (dimensionless)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.93</td>
<td>0.29</td>
<td>0.005</td>
</tr>
<tr>
<td>5</td>
<td>2.90</td>
<td>0.055</td>
</tr>
<tr>
<td>12.80</td>
<td>10.5</td>
<td>0.304</td>
</tr>
</tbody>
</table>

Another example is the TANKS default for Residual Oil No. 6 (No. 6 Oil). TANKS contains default values of TVP for No. 6 Oil at 10 degree Fahrenheit increments, from 40 to 100 degrees Fahrenheit. There are a couple of evident problems with these default values, however. One problem is that No. 6 Oil is typically a mixture of a straight residual stream blended with a cutter stock. The cutter stock is may be a light distillate such as Diesel, and may constitute about 25 percent of the mixture. As shown in Table 2-2, the partial pressure of the Diesel cutter stock is considerably higher at 100°F than the TANKS default for No. 6 Oil. This problem is then exacerbated by the fact that No. 6 Oil is typically stored in heated tanks, but TANKS does not extrapolate the default TVP for temperatures above 100°F. Thus TANKS gives the same value of TVP at 200°F as at 100°F. The net result is that the TVP of No. 6 Oil would be estimated 300 times higher on the basis of the partial pressure of the Diesel cutter stock than the default value given by TANKS at 200°F.

Table 2-2. Comparison of TVP for No. 6 Oil (TANKS default) and 25% Diesel Blend

<table>
<thead>
<tr>
<th>TVP (psia) at given Temperature</th>
<th>100°F</th>
<th>150°F</th>
<th>200°F</th>
<th>300°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>TANKS default</td>
<td>0.0002</td>
<td>0.0002</td>
<td>0.0002</td>
<td>0.0002</td>
</tr>
<tr>
<td>as 25percent Diesel</td>
<td>0.006</td>
<td>0.020</td>
<td>0.062</td>
<td>0.364</td>
</tr>
</tbody>
</table>

Gross Errors in the Determination of TVP

The examples above illustrate the potential magnitude of error that may occur in the estimated emissions of Crude Oil and No. 6 Oil. Both of these examples are rooted in gross errors in the determination of the true vapor pressure (TVP) of the liquid stored in the tank. The problems in these examples arose from inappropriate defaults and other issues with EPA’s TANKS software, but problems in the determination of TVP may also occur due to erroneous data for the stored liquid or for the temperature in the tank.

Erroneous data for the stored liquid is particularly a problem for heavier streams such as distillates and residuals. The volatility of these stocks is below the lower threshold of
applicability for the Reid vapor pressure (RVP) test method, which is the test method commonly used in the petroleum industry. There is another ASTM test method available for these heavier stocks, ASTM D 2879, but it has not been widely used. In the absence of suitable testing, a facility may be relying on sources such as a material safety data sheet (MSDS) for vapor pressure information, and the information available may be grossly erroneous.

In that TVP is a function of temperature, storage tank emissions will be underestimated if the temperature of the stored liquid is understated. Emission estimates would be improved by the use of actual measured temperatures, rather than defaulting to an assumption that the contents of the tank are in equilibrium with ambient meteorological conditions.

2.4 Large Rim Seal Gaps

The emission factors in EPA’s AP-42 Chapter 7.1 for floating roof rim seals were derived from the testing of leak rates past rim seals with varying degrees of gaps between the rim seal and the tank shell. The emission factors were then based on an assumed distribution of seal gaps for a typical tank population, based on historical records of seal gap measurements. This variation in the fit of the floating roof rim seals corresponds to variation in the rim seal emissions. The higher emissions due to larger rim seal gaps, while taken into account in the average rim seal emission factor, can partially explain why tanks with the same estimated level of emissions may have different actual levels of emissions.

This variation in emissions due to rim seal gaps can be quantified by evaluating the test results for the larger gap cases from the study that determined the average rim seal emission factors. Table 2-3 compares emission factors for the larger gap cases to the emission factors based on the weighted average (which is the basis for the EPA emission factors). The comparisons shown are for external floating-roof tanks (EFRTs) at a wind speed of 10 miles per hour.

<table>
<thead>
<tr>
<th>Type of Primary Seal</th>
<th>Type of Secondary Seal</th>
<th>Average Fit</th>
<th>Large Gaps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical-Shoe</td>
<td>None</td>
<td>43.6</td>
<td>83.2</td>
</tr>
<tr>
<td>Mechanical-Shoe</td>
<td>Rim-Mounted</td>
<td>4.6</td>
<td>46.1</td>
</tr>
</tbody>
</table>

It is apparent that rim seal emissions from an external floating-roof tank with relatively large rim seal gaps can be 10 times greater than estimated using the emission factors for average fitting rim seals. This does not mean that the average factors are incorrect, but rather illustrates the range of variability that may be expected within the storage tank population.

**Loss of Light Ends from Crude Oil**

One consideration with respect to receiving crude oil is the potential for the crude oil to contain light ends that flash out of solution when the crude oil enters an atmospheric tank. It is generally assumed that crude oil is stable by the time that it arrives at the refinery, but if there were, in fact, unstable light ends present, these could result in temporarily higher emissions during tank filling.

Another consideration with respect to receiving crude oil into a floating-roof tank is that the estimation method includes a product factor, $KC$, of 0.4 for crude oil. This product factor may be due in part to the potential for crude oil to weather at the surface, which refers to the loss of light ends even if those light ends do not have the flash potential discussed above. That is, the vapor pressure of the liquid at the surface is lowered as light ends evaporate, unless those light ends are replaced by diffusion from the lower portions of the liquid at a rate equal to the rate of evaporation from the surface. This replacement by diffusion readily occurs with most refined stocks, and thus refined stocks have a product factor of 1.0 (i.e., no reduction). Crude oil, on the other hand, has a product factor of 0.4, which means that the estimated emissions are reduced by 60%.

If the product factor reduction is largely attributable to weathering, but the filling process were to result in mixing such that the weathered layer at the liquid surface were replaced with fresh crude oil, then the reduction would not take effect until after the initial evaporation of light ends from the region near the liquid surface. This would suggest that crude oil emissions would be higher than estimated immediately after filling, even if the light ends are stable (i.e., do not flash), but would then decrease as the layer of crude oil near the surface is weathered. Another consideration, if weathering is the phenomenon supporting the product factor, is that stock would not be expected to experience weathering if a mixer is used, in that the mixer would cause constant replacement of the liquid at the surface. Similarly, weathering would be less likely to occur in a tank that has frequent turnovers or frequent flow through the tank.
3.0 CONCLUSIONS

The Houston study involved the use of multiple remote sensing technologies in an evaluation of emissions at a petroleum refinery in the Houston Ship Channel area. Houston was unable to validate the DIAL emission rates, but a similar pattern was observed in the results from the various technologies. Specifically, spikes observed in the DIAL results were verified by the other technologies.

Houston identified numerous limitations to DIAL that may have contributed to the absence of correlation between the DIAL results and the other measurements, and additional limitations have been identified and discussed in this report. These include:

- Inadequate characterization of the wind,
- Turbulent eddies and other wind anomalies due to the scan plane being too close to the target,
- Inadequate evaluation of the contribution of emissions from other upwind sources,
- Neglecting non-detect storage tanks in the evaluation of storage tank emission rates,
- Inadequate accounting for the variation in response of DIAL to different chemical mixtures, and
- Inadequate accounting for variation in temporal factors.

Despite the inability to validate the DIAL emission rates, Houston compared the DIAL results to emission factor estimates. However, EPA has no published short-term (pound per hour) emission factors for storage tanks, so it is not apparent how Houston determined these emission factor estimates. It is also not apparent how, or whether, actual conditions at the given point in time were accounted for. And it is not apparent whether all upwind tanks for a given scan location were included in the emission factor estimates, or whether the comparison was skewed by neglecting the tanks that were not reported by NPL to have detectable emissions. Finally, Houston compares the emission factor estimate, which is intended as an estimate of an average or mean value, to the “Upper 95th Confidence Limit of the Mean” of the DIAL results. This appears to be a comparison of the middle of the range from one method to the expected top end of the range from another method, which further seems to render the comparison meaningless.

Nevertheless, the pattern of some tanks apparently having higher-than-average emissions is an issue that warrants investigation and explanation. The published EPA emission factors account for some temporal and operational factors that are expected to result in significant variation in the emission rate from a given storage tank. These include whether the tank is being emptied or filled, the speed and direction of the wind, and the temperature in the tank. Additional factors that may result in a given storage
tank exhibiting higher than estimated emissions are identified and discussed in the report, including inappropriate defaults in EPA’s TANKS software tool, erroneous determination of the stock TVP, large gaps between the rim seal of a floating roof and the wall of the tank, and unaccounted for evaporation of light ends from crude oil.