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Services at the interface of energy, economics and environment

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LP GAS MASS FLOW EMISSIONS FACTORS THROUGH FIXED MAXIMUM LIQUID LEVEL GAUGES DURING FORKLIFT CYLINDER REFILLING – PART II: GRAVITY FILLS

I. Introduction & Objective

LP Gas tank "gravity fills" are conducted without the help of a pump. This refueling practice is quite common for fork lift cylinders. Throughout California, it is significantly more popular than pump assisted re-fills of fork lift cylinders.

Measurements were made on a specifically designed test rig to quantify gas phase LP Gas mass flow rates emitted through forklift cylinder Fixed Maximum Liquid Level Gauges (FMLLG) while these cylinders are "gravity filled".

As LP Gas cylinders are filled, a fixed maximum liquid level gauge, also known as an "outage gauge" or "spitter valve", is used to signal when liquid LP Gas has reached the maximum safe fill level. An outage gauge is a valve with a 0.055" diameter hole (#54 drill size) flow restriction within. This valve is connected to a tube that extends downward into the tank to the ~80% full level (the usual maximum fill level for LP Gas tanks). This gauge is typically left fully open during filling, venting gas phase LP Gas until liquid rises to the bottom of the outage gauge tube, at which point liquid LP Gas is observed to escape through the top of the outage gauge. The emitted white cloud of mixed liquid and vapor LP Gas signals that the filling must be stopped.

There are smaller than 0.055" diameter outage gauges, but such gauges have little commercial acceptance. Smaller than 0.055" diameter restriction outage gauges cannot be mass produced due to machining equipment limitations. If and when such smaller restricted outage gauges were used, they would only eliminate a portion of such emissions.

A 0.055" diameter restricted outage gauge is prevalent throughout the LP Gas industry. Thus, the mass emission rates measured through the protocol described in this report apply to the vast majority of LP Gas tanks (stationary or mobile) that are refilled.

II. Summary

On November 4, 2008, The ADEPT Group, Inc. (ADEPT) engineers measured the gas phase LP Gas emissions released through forklift cylinder outage gauges. This work was conducted at Mutual Propane in Gardena, CA. Three engineers from the South Coast Air Quality Management District (SCAQMD) were on-site to assist, witness, and comment on these tests. The SCAQMD

engineers also conducted their own emissions tests during the same session using alternative tests methods. SCAQMD will report separately the results of its tests.

ADEPT tested gas phase emissions while forklift cylinders were being gravity filled from a vertical 420-lb. tank, using a mass flow meter calibrated for propane.

III. Materials and Equipment Setup

The testing apparatus (Figures 1 & 2) consists of:

1. An outage gauge adaptor assembly having a #54 drill hole and allowing for threaded connection to 1/8" pipe; and a ball valve to open and close the outage gauge
2. Pipe and tubing to allow for liquid phase LP Gas to fully expand
    a. Piping includes a sight glass to observe state of LP Gas (i.e. liquid or gas phase) released through outage gauge (Figure 4a)
    b. Heat tape to reduce effects of cooling in the expansion tube
3. A mass flowmeter, calibrated for propane, placed at the outlet of the system (downstream of all expansion piping) (Figure 5)
4. Thermocouples installed to measure temperature at:
    a. Immediately after the sight glass (Figure 4a)
    b. the flowmeter (Figure 5), and
    c. an intermediate point in the system (Figure 5)
5. Transducers installed to measure pressure:
    a. Immediately after the sight glass (Figure 4a)
    b. At the flowmeter (Figure 5)
6. Data recorder for simultaneous flow, temperature, and pressure vs. time measurements (Figure 6)

Other equipment:

1. Forklift cylinders
2. LP Gas source tank (420-lb tank)
3. Shipping scale
4. Clock or stopwatch
5. Volumetric meter (optional) from LP Gas dispensing source tank

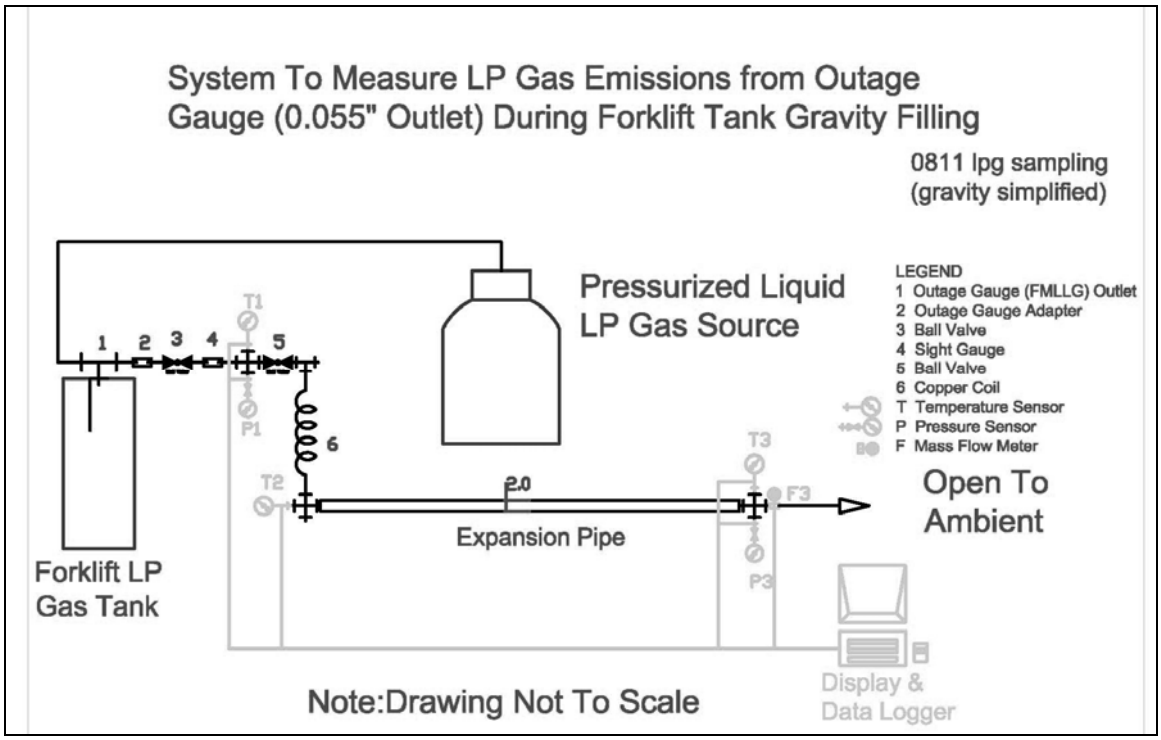

Figure 1: Equipment Setup Schematic

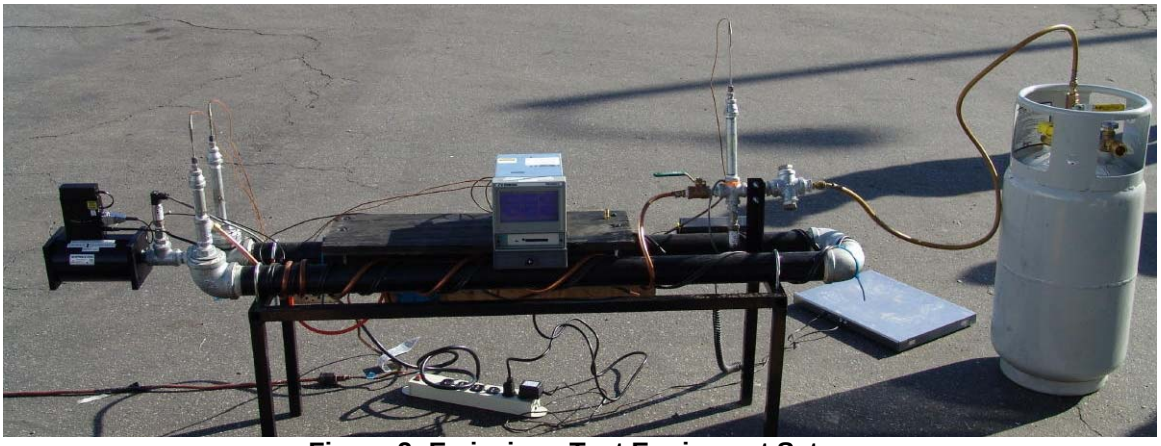

Figure 2: Emissions Test Equipment Setup

IV. Pre-Test Check

Prior to conducting the emissions tests, the system was tested to ensure that:

1. There was sufficient piping (expansion volume) to allow for complete vaporization of the emitted liquid LP Gas
2. Instruments and data recorder are properly set-up and functional; and
3. Measurements are within operational range of instruments used.

After this pre-test check, some adjustments were made in the setup of the data recorder, but no major equipment changes were necessary.

V. Test Procedure

A. Pre-Fill Setup

1. Connect #54 hole outage gauge adaptor with ball valve assembly to forklift cylinder
2. Connect cylinder to LP Gas source tank (Figure 3)
3. If necessary, purge cylinder with LP Gas (this step is needed if the cylinder was previously filled with air rather than LP Gas)
4. Close ball valve
5. Connect cylinder to measurement apparatus
6. Place cylinder on scale
7. Record cylinder weight
8. Determine approximate cylinder weight when filling is to be stopped

B. Filling and Measurement

9. Turn on power supplies to instruments and verify that instruments are on
10. Start recording instrument data
11. Zero meter at pump (if applicable)
12. Begin filling
    a. Allow liquid LP Gas to flow into forklift cylinder, and
    b. Open outage gauge ball valve
13. Monitor temperature, pressure, flow, and cylinder weight
    a. Record time of any sudden change in temperature, pressure, or flow rate
    b. Record time when liquid phase LP Gas is first observed
14. Stop filling when liquid LP Gas is visible through sight glass
15. Record time filling is stopped
16. Close ball valve
17. Allow system to vent entirely
18. Stop recording when flow has stopped
19. Disconnect forklift cylinder from apparatus
20. Review and store instrument data
21. Repeat for additional forklift cylinders

Figure 3: Connection of LP Gas source to forklift cylinder fill port

Figure 4: (a) Sight glass and instruments at gas inlet; (b) Cylinder scale display

Figure 5: Flow, temperature, & pressure sensors mounted at expansion pipe outlet

Figure 6: Data recorder display

VI. Results and Discussion

A. Gas Phase Emissions

Once filling of the forklift tank was started, LP Gas flow rate gradually increased over approximately 25-40 seconds until reaching a relatively steady rate; then increased sharply once liquid phase LP Gas started to flow through the outage

gauge. The inlet temperature decreased gradually until liquid LP Gas was released at which point it decreased sharply. Temperature at the midpoint of the test apparatus was relatively stable as was the temperature at the outlet, which only decreased slightly from the initial temperature. Inlet pressure was stable throughout the measurement until liquid was released at which point it peaked sharply. Outlet pressure remained constant at 0 psig. It should be noted that ambient temperature was slightly higher when the second test was conducted.

In both tests the valve from the source tank fully opened. The flow rates of LP Gas into the forklift cylinder for the two tests were 1.66 gal/min (0.054 kg/s) and 1.86 gal/min (0.060 kg/s) respectively.

The below results were calculated by averaging flow rate for a stable fifteen second time interval centered around the approximate point where the flow rate begins to stabilize and the point just prior to liquid LP Gas released. This averaging period is noted by an orange box in Figures 7 and 8. This interval excludes from calculations the initial readings as the expansion volume was filled prior to a steady state being reached. The average gas phase flow rate of LP Gas through the outage gauge for two cylinders was 2.53 g/s (Table 1).

ADEPT did not take an LP Gas sample during these tests as the SCAQMD engineers did that. For this study, it was assumed that the composition of the LP Gas was similar to the samples analyzed in earlier tests. At that time, the LP Gas composition was analyzed per ASTM D2163 (Table 2) to determine if any corrections were needed to the initial propane-calibrated mass flow readings. Based on this composition analysis, the flow meter manufacturer provided the K-factor and density to be used for the calculations (Table 3 & Equation 1).

Table 1: Average Gas Phase Mass Flow Rate

Test Number	15 s Average Mass Flow Rate (g/s)
Test 1	2.45
Test 2	2.60
Average	2.53

Table 2: LP Gas Compostition Analysis

Composition	Volume %	Weight %	Volume % for 4-gas K-factor calculations
Ethane	0.42	0.30	0.42
Propane	96.88	96.73	96.88
Propylene	0.13	0.13	0.13
Isobutane	2.48	2.75	2.57
n-Butane	0.05	0.05	
1-Butene	0.01	0.01	
Isobutylene	0.01	0.01	

trans-2-Butene	0.01	0.01	
Isopentane	0.01	0.01	

Table 3: Density and K-factor for Propane and LP Gas Mixture

	Density (g/L)	K-factor relative to N_2
Propane	1.967	0.35
LP Gas Mixture	2.04	0.3366

Equation 1: Calculation of LP Gas Mass Flow Rate

$$\square_{LP\ Gas} = \rho_{LP\ Gas} \cdot Q_{propane} \cdot (K_{LP\ Gas} / K_{propane})$$

Where:

□ = mass flow rate

ρ = density

Q = volumetric flow rate

Results from each of the tests are shown below. The time axis indicates time of data recording. The start of filling is indicated by the initial rise in flow rate.

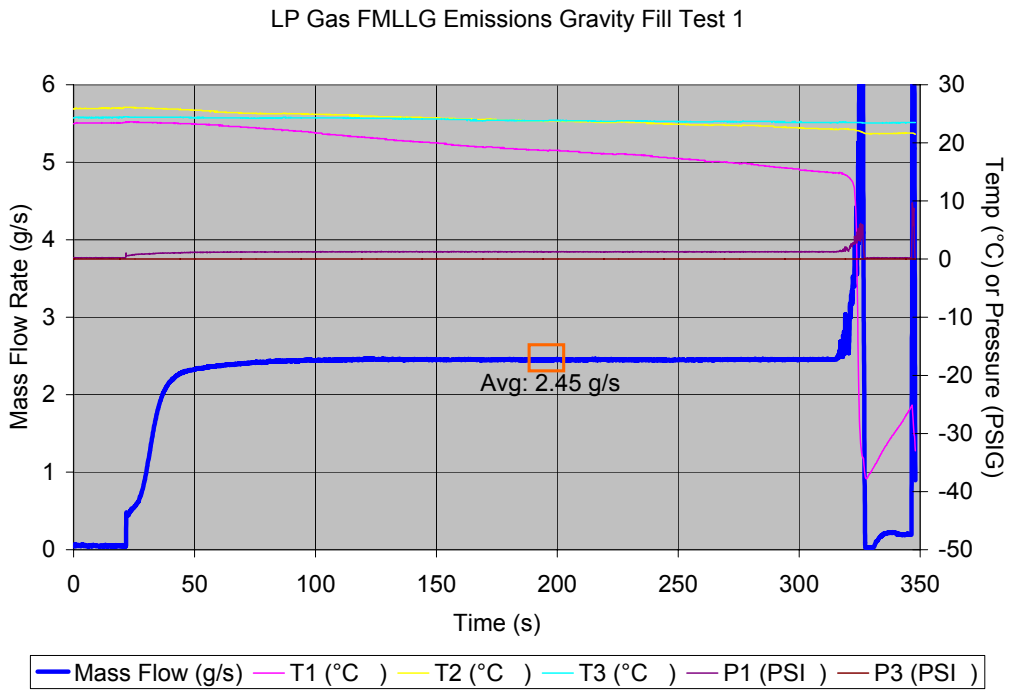

Figure 7: LP Gas Mass Flow Rate through Outage Gauge While Gravity Filling - Test #1

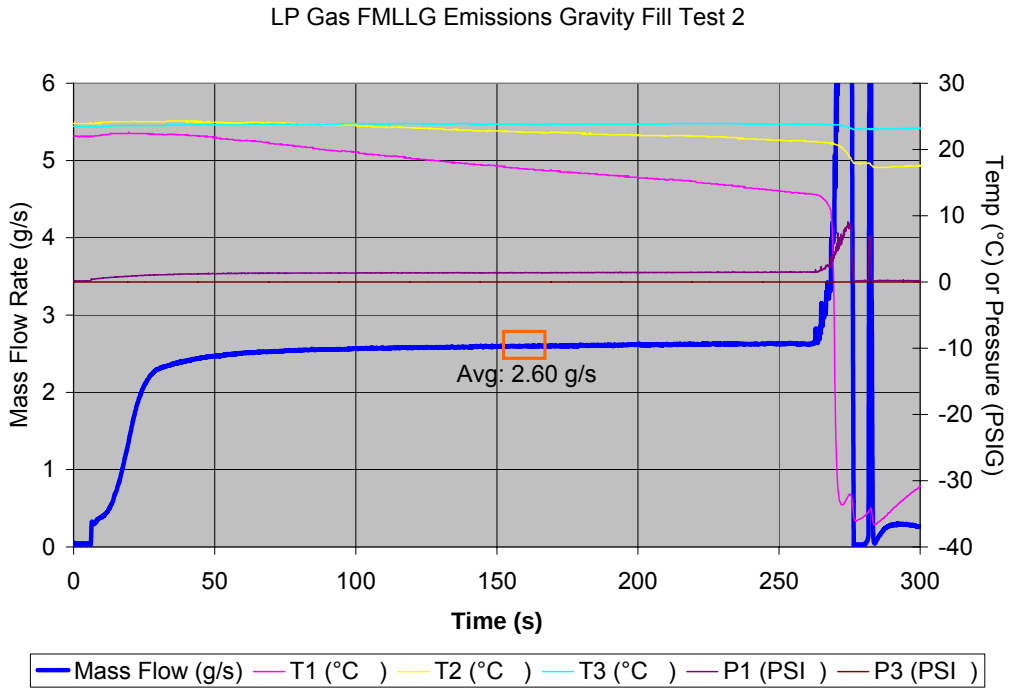

Figure 8: LP Gas Mass Flow Rate through Outage Gauge While Gravity Filling - Test #2

B. Liquid Phase Emissions

ADEPT did not measure liquid phase emissions during this testing session; however SCAQMD did measure liquid phase emissions and will report these results separately. In May of 2008 ADEPT measured and reported liquid phase emissions during pump fills to be ~10.0 g/s.

VII. Conclusions

A. The gas phase emissions for gravity fills averaged 2.53 g/s. Prior tests on pump-assisted fills using the same measurement equipment averaged 2.96 g/s.

B. All LP Gas tanks (stationary, mobile, and forklift cylinder) are equipped with outage gauges which are typically used during every filling event. Given that large number of LP Gas forklift cylinders are “gravity filled” every day, such outage gauge emissions currently account for significant releases of VOC and greenhouse gases to the atmosphere.