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LP GAS MASS FLOW EMISSIONS THROUGH FIXED MAXIMUM LIQUID LEVEL GAUGES (FMLLG) DURING FORKLIFT CYLINDER REFILLING

I. Introduction & Objective

This project was to measure liquid phase and gas phase LP Gas mass flow rates through forklift cylinder FMLLG during cylinder refilling.

As LP Gas cylinders are filled, a FMLLG, also known as an “outage gauge” or “spitter valve”, is used to determine when liquid has reached the maximum fill level. The FMLLG is a valve with a 0.055” hole (# 54 drill size) flow restriction which is connected to a tube that extends into the tank to ~ the 80% full level (typically the maximum fill level for LP Gas). This valve is left open during filling, venting gas phase LP Gas until the liquid level reaches the bottom end of the FMLLG tube, at which point liquid LP Gas escapes through the 0.055” diameter opening. This escaping liquid produces a white cloud which indicates that filling should be stopped.

The 0.055” diameter restricted FMLLG is prevalent throughout the LP Gas industry. Thus, the mass emission rates measured through this protocol apply to the vast majority of LP Gas tanks (stationary or mobile) being refilled. Smaller flow restriction FMLLG’s are commercially available, but are rarely used.

II. Summary

On January 12, 2008, as part of work conducted for the California Air Resources Board (ARB) under the ICAT program, The ADEPT Group, Inc. (ADEPT) measured LP Gas mass flow emission rates through several forklift cylinder FMLLG’s. This work was conducted at Mutual Propane in Gardena, CA. ARB and the South Coast Air Quality Management District (SCAQMD) representatives were on-site to assist, witness, and comment on these tests.

The testing consisted of two parts: (1) gas phase emissions, and (2) liquid phase emissions. Gas phase releases were measured while the cylinder was filled with a pump, using a mass flow meter calibrated for propane. Liquid phase releases were measured by placing a full LP Gas cylinder on a scale and recording the drop in mass over a known period of time while liquid LP Gas is released through the FMLLG. These tests are described further in the below sections.

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. Sufficient 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 (36.3L)
2. LP Gas source tank (e.g. bobtail or stationary tank)
3. Shipping scale
4. Clock or stopwatch
5. Volumetric meter (optional) from LP Gas dispensing source tank

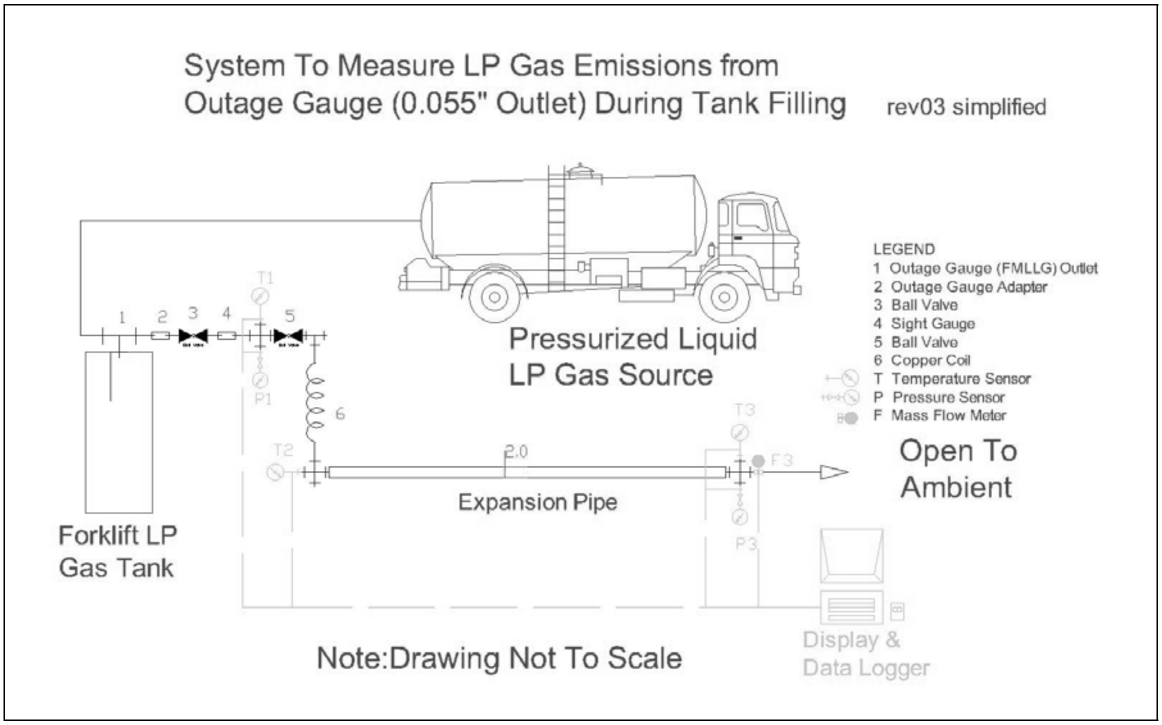

Figure 1: Equipment Setup Schematic

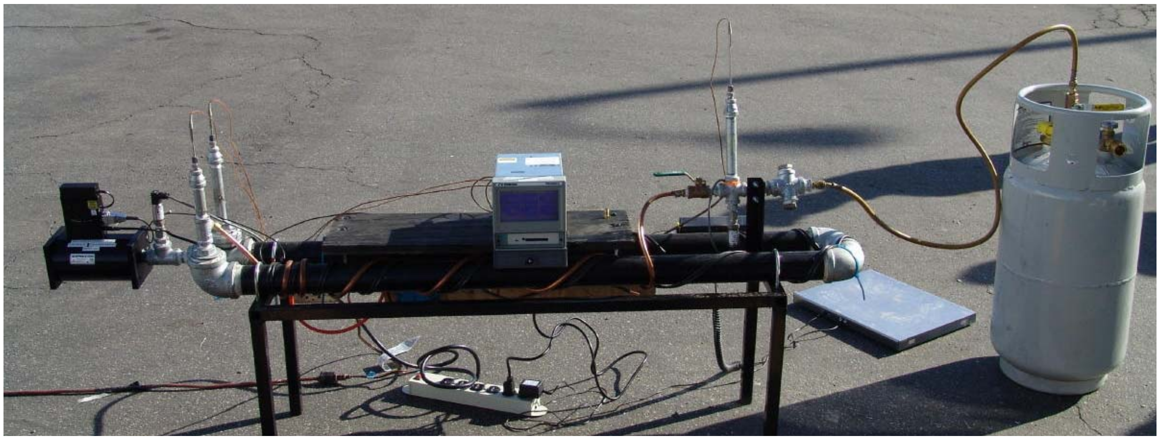

Figure 2: Emissions Test Equipment Setup

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 is a necessary step 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. Start pumping liquid LP Gas 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

C. Liquid Phase Measurement

1. Turn on power to scale and verify scale is on
2. Place full LP Gas cylinder with attached outage gauge adapter and ball valve on scale
3. Record initial weight of full cylinder
4. Zero stopwatch
5. Open ball valve to release liquid LP Gas and start stopwatch
6. Record cylinder weight at regular time intervals
7. Close ball valve to shut off flow after ~3 minutes

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

Figure 4: (a) Sight glass and instruments at 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 started, LP Gas flow rate gradually increased over approximately 10-20 seconds until reaching a relatively steady rate; then increased sharply once liquid phase LP Gas was released through the FMLLG. 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. For the first two tests there is no pressure data as the transducers were not receiving power.

The filling pump flow rate was not constant for each test. After the first test (which was at the maximum pumping rate), the pumping rate was decreased from full flow. This is apparent in the amount of time passed from the start of filling to the time to reach the maximum liquid level in the tank (Figures 7 through 10). These adjustments in the pump rate served two purposes: (1) provide variability to test whether the pumping flow rate had any significant effect on the mass flow rate through the FMLLG; and (2) allow for a longer period of steady gas flow through the FMLLG before the cylinder was filled.

There was no apparent correlation between the pumping rate and the mass flow rate through the FMLLG. However, because total emissions are a function of the FMLLG emissions rate (mass flow rate) and the total filling time (assuming the FMLLG is closed immediately after filling), a reduction in the filling time (i.e. increasing the pumping rate) may result in lower total emissions.

The below results are calculated by averaging mass flow rate for a stable ten second interval centered around the point where flow rate beings to stabilize and the point just prior to liquid LP Gas being released. This averaging period is shown in an orange box in Figures 7 through 10. This interval was used to exclude from calculations the initial readings as the expansion volume was filled prior to a steady state being reached. The average mass flow rate for four cylinders was 2.96 g/s (Table 1).

The composition of LP Gas was analyzed (per ASTM D2163) (Table 2) to determine if corrections were needed to the initial propane-calibrated mass flow readings. Based on this 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	10 s Average Mass Flow Rate (g/s)
Test 1	3.13
Test 2	3.05
Test 3	2.62
Test 4	3.04
Average	2.96

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:

$\square$ = 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.

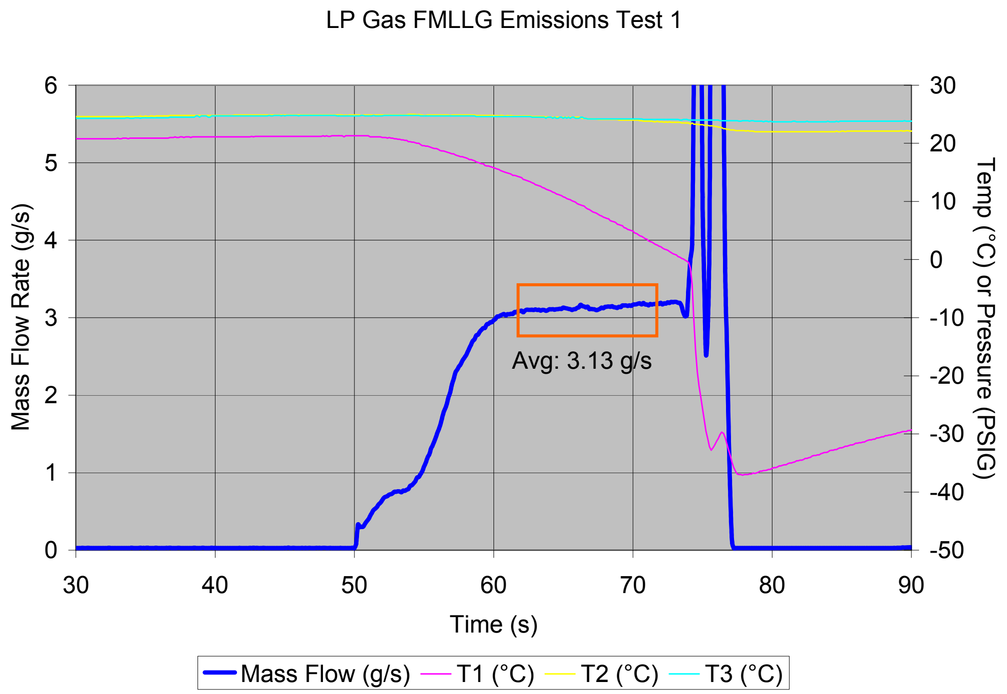

Figure 7: LP Gas Mass Flow Rate through Outage Gauge While Filling - Test #1

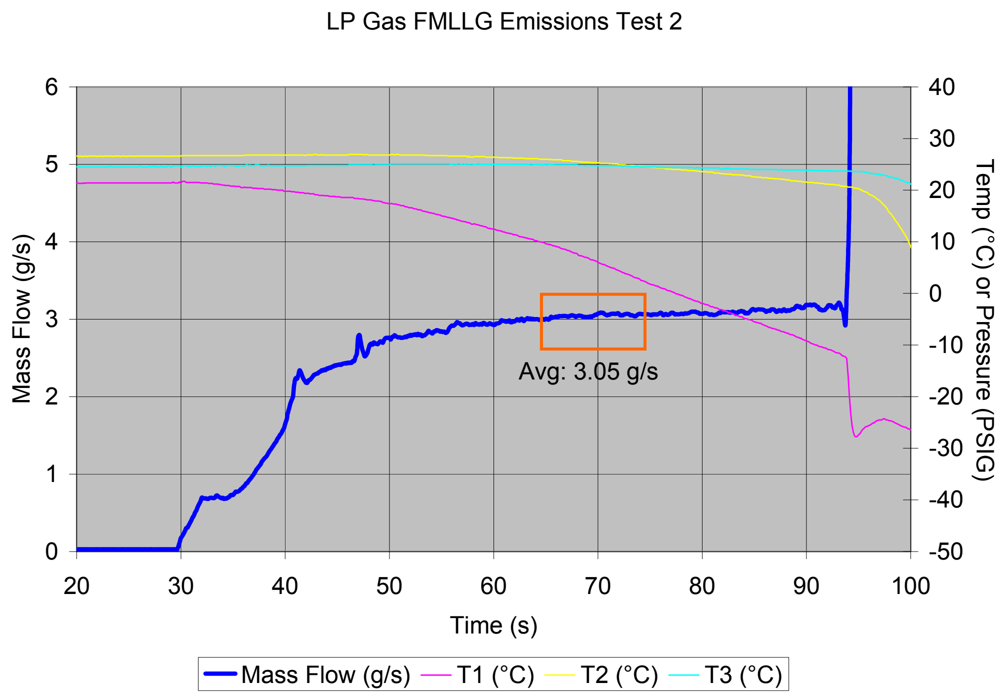

Figure 8: LP Gas Mass Flow Rate through Outage Gauge While Filling - Test #2

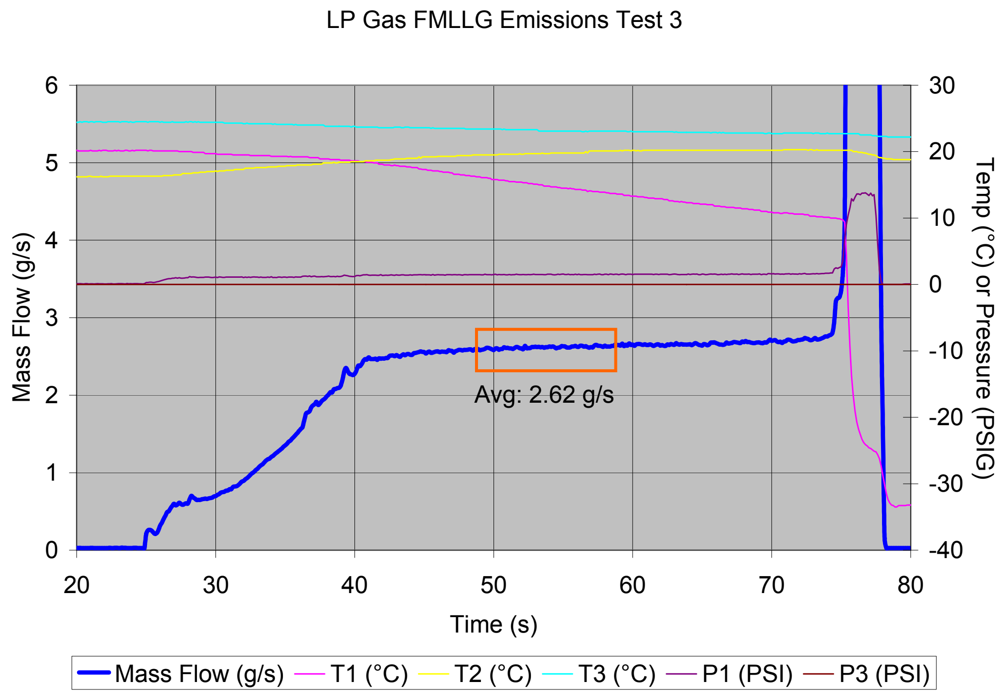

Figure 9: LP Gas Mass Flow Rate through Outage Gauge While Filling - Test #3

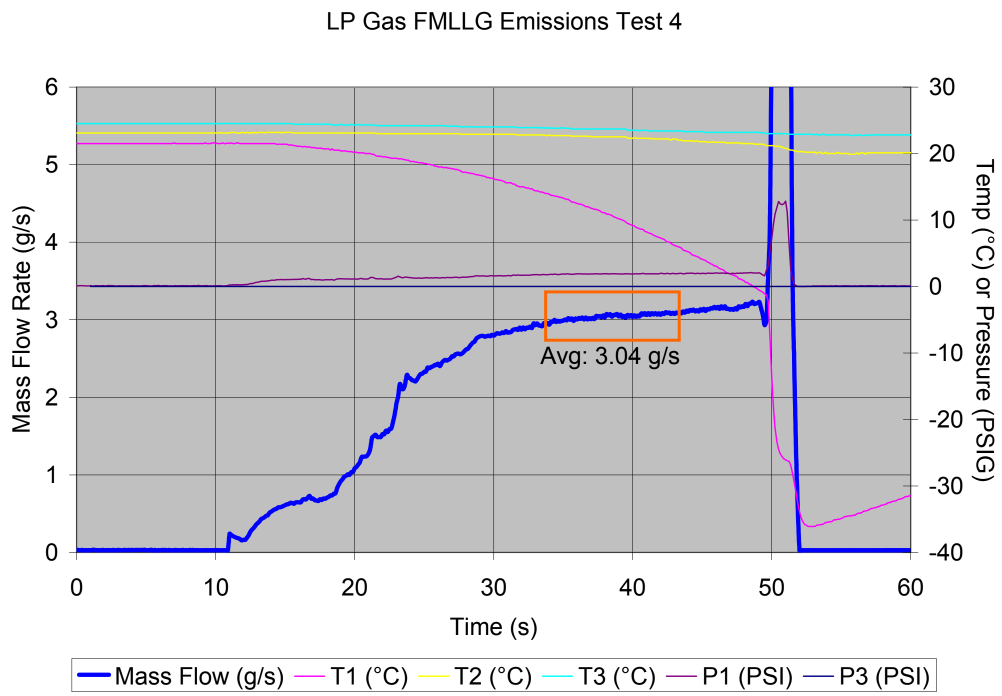

Figure 10: LP Gas Mass Flow Rate through Outage Gauge While Filling - Test #4

Figure 11: Liquid phase emissions measurement using scale

B. Liquid Phase Emissions

Results from the liquid phase tests are shown in Table 4 below. More tests were conducted on May 8, 2008 after the scale used was recalibrated as a check on the previous results (Table 5).

Table 4: Average Liquid Phase Mass Flow Rate

Test Number	Mass Flow Rate (g/s)
Cylinder 2	9.8
Cylinder 3	10.6
Cylinder 4	9.6
Average	10.0

Table 5: Liquid Phase Mass Flow Rate Validation (Recalibrated Scale)

Test Number	Mass Flow Rate (g/s)
Cylinder A	10.9

VII. Conclusions

The vast majority of LP Gas tanks (stationary, mobile, forklift cylinder) are equipped with FMLLG's. With the exception of vehicles in air quality sensitive areas, all these FMLLG's are used from fully open to barely open during every filling event. Such refill events can last from a few seconds to over 10 minutes. This is a loss of fuel as well as an undesirable air quality and safety occurrence.

The measured gas phase mass flow rate (emissions rate) was 2.96 g/s.
The measured liquid phase mass flow rate (emissions rate) was 10.0 g/s. These measurements turned out to be quite close (and slightly higher) to pre-project estimates (2.9 g/s and 8.1 g/s respectively).