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Maximus™ Stop-Fill Instrument Demonstration
Final Report

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ABSTRACT

This project was to adapt and develop an acoustic sensing instrument that could significantly reduce the amount of hydrocarbon emissions during LP Gas cylinder refills. During the course of the project, different acoustic sensing methods were developed to cope with the particular challenge of determining liquid position while filling. The project included extensive work to measure and determines gas and liquid phase LP Gas emissions through a fixed maximum liquid level gauge which typically are released to ambient during filling of LP Gas cylinders. Finally, the project included field testing and collection of feedback from LP Gas filling personnel and the LP Gas industry to make the product user-friendly and commercially viable.

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INTRODUCTION

This report is the final element of ICAT Grant 06-11 to develop and demonstrate the Maximus™ Stop-Fill Instrument (SFI) acoustic sensing technology to reduce LP Gas outage gauge emissions while refilling tanks.

INNOVATIVE TECHNOLOGY

Summary

The Maximus™ (SFI) is an innovative stop-fill instrument using cutting-edge acoustic sensing to reduce emissions and conserve valuable energy resources during the filling of LP Gas tanks. This solution gives the LP Gas industry a cost-effective, simple-to-use and reliable tool that will improve the way tanks are filled. This technology can also be applied in other industries that fill pressurized vessels with liquids (such as anhydrous ammonia) which is vented while filling.

The Maximus™ technology grew out of work done at Los Alamos National Laboratory (LANL), to measure liquid levels of hazardous liquids. Adept Science & Technologies, LLC (ASCENT) adapted the technology to develop and utilize a proprietary acoustic method to non-invasively detect the presence of either liquid or gas at a specific point in an LP Gas tank. (US: 6,286,370 B1). As liquid reaches a predetermined maximum fill point, the acoustic signal received by the sensor changes indicating the presence of liquid on the other side of the tank wall and that refueling should be stopped.

Whereas the Maximus™ SFI uses acoustic sensing methods to be used outside the tank, existing products use invasive methods that require that they are inserted inside the tank. The LP Gas industry has been slow to accept the widespread use invasive devices in such a volatile and dangerous environment. By sensing the LP Gas level from *outside* the tank, the Maximus™ SFI does not jeopardize tank integrity, nor is it difficult or costly to maintain or replace.

Emission Benefits to California

The LP Gas industry (and other industries using pressurized cylinders) currently rely on fixed maximum liquid level gauges (FMLLGs - also known as “outage gauges” or “spitter valves”) to prevent overfilling. The maximum fill level is noted when a white vapor cloud sprays out, indicating it’s time to stop filling. Public health concerns and economic loss due to evaporative emissions through FMLLGs are a growing concern for air quality regulators and the LP Gas industry (regulated VOC’s are released every time a residential LP Gas tank is re-filled.) It should be noted that although industry training calls for the outage gauge to be opened only periodically during fills, observation of field practices indicates that the outage gauge is often left open for the entire duration of the fill.

Figure 1: Outage Gauge (FMLLG) Dip Tube Internals

Figure 2: LP Gas Emissions from Bus Tank Outage Gauge

These significant emissions present both environmental and economic challenges. On top of the negative environmental impact, end-users charged for a product never get to use it and a valuable clean energy resource is lost to the atmosphere. Until the development of the Maximus™ SFI no safe, cost-effective and reliable means has been available to replace the practice of filling using the outage gauge. The Maximus™ SFI is expected to bring about significant VOC reductions, energy savings, and lower safety risks.

Prior to the start of this project, hydrocarbon emission rates from LP Gas tanks during filling were conservatively calculated to be 4.2 grams/second in liquid phase and 1.2 g/s in gas phase (ADEPT 2005). It was also is estimated that ~50 tons/day of LP Gas are currently emitted from filling LP Gas tanks throughout California (ADEPT 2005). During the course of the project, outage gauge emissions during refilling of cylinders were measured to be about 10 g/s in liquid phase and 2.53 to 2.96 g/s in gas phase. In California, forklift cylinder fills and stationary tanks alone would account for 13.4-15.6 tons/day and 23 – 26.8 tons/day respectively of LP Gas emissions.

In summary, the Maximus™ SFI can provide significant environmental benefits to California by ending the need to open the outage gauge and eliminating ~98% of LP Gas emissions generated while refueling tanks, while enhancing health, safety and economic well-being. Additionally, the pre-project sale price of the Maximus™ SFI was projected to be considerably higher than the current expected sale price in high volume, thus making the emissions reductions substantially more cost effective than previously estimated.

ICAT PROJECT

Purpose, Goals, and Accomplishments

Prior to the ICAT project, field tests proved one sensing aspect of the Maximus™ technology (i.e. its ability to detect the presence of liquid or gas on the other side of the cylinder wall) to work effectively in bus fleet re-filling applications. Commercialization of the Maximus™ for this purpose was underway. One of the main goals of the ICAT project was to convert this bus fleet targeted technology to stationary tank applications. Another goal was to show the Maximus™ device's effectiveness to the targeted end-users through hands-on demonstrations and to educate the industry and the public about this technology.

Figure 3: Early Stage Prototype of Maximus™ Electronics

Figure 4: Testing of Maximus™ Acoustic Sensing on Bus Tanks

Part of the original plan for the project was to see 15 Maximus™ prototypes adapted for stationary tank applications and used as part of a field trial. In this plan, the work was to take place at two LP Gas distributor sites: (1) Delta Liquid Energy in Central California; and (2) Expo Propane in Southern California. Both firms are considered to be "technology leaders" by the North American LP Gas industry. Bobtail operators from these distributors were to be trained and monitored in the use of the Maximus™ instruments in actual field conditions.

The planned development work included reduction in the size of the circuitry, modifications to the sensors, the driving voltages, and lowering of power use. Design of the instrument was to be intrinsically safe and to be ready for certification by CSA and UL.

Figure 5: Early Stage Lab Tests for Development of Maximus™

Figure 6: Early Stage Lab Tests for Development of Maximus™ for Stationary Tanks

Early on in the technology development stages of the project, lab and field tests determined that the original single acoustic sensing method being used for the Maximus™ SFI could not alone determine when the liquid reached the fill level under normal filling conditions (i.e. while the tank was being filled). This was an unexpected challenge that required a reassessment of the project plan.

Figure 7: Early Field Tests of First Maximus™ Acoustic Approach

Figure 8: Early Field Tests of First Maximus™ Acoustic Approach

In addition to the first sensing method, an entirely new acoustic sensing method had to be developed to cope with this challenge. Implementation of this second technique required considerable new design and experimentation work. Because of the redesign, resources that would have otherwise been used earlier on for commercialization activities were rededicated to additional R & D work.

Figure 9: Sensor Development

Figure 10: Testing of Multi-Sensor Approach

With the fundamentals of the two acoustic sensing techniques approach functional, work began to refine the device and develop it for beta prototype and pre-manufacture field testing and commercialization.

Figure 11: Field Tests of Beta-Prototype Maximus™ SFI Incorporating New Sensing Methods

Figure 12: Field Tests of Beta-Prototype Maximus™ SFI Incorporating New Sensing Methods

Figure 13: Field Test of Pre-Manufacture Maximus™ SFI Showing Outage Gauge Emissions

Figure 14: Field Test of Pre-Manufacture Maximus™ SFI

During field tests, the LP Gas distributors, including LP Gas bobtail drivers (who refill the tanks and would be the eventual end-users of product) were consulted to determine what improvements could be made in the way the Maximus™ SFI functioned and would create the least disruption to their filling practices.

During the course of field tests, it was found that there was a significant need for the Maximus™ SFI to be used in vertical stationary tank applications, which was previously not considered to be a major sector of the residential tank market. Because of the way the sensors were developed and aligned for the horizontal tank Maximus™ SFI, the same embodiment could not be used to address this larger than expected and burgeoning vertical tank market.

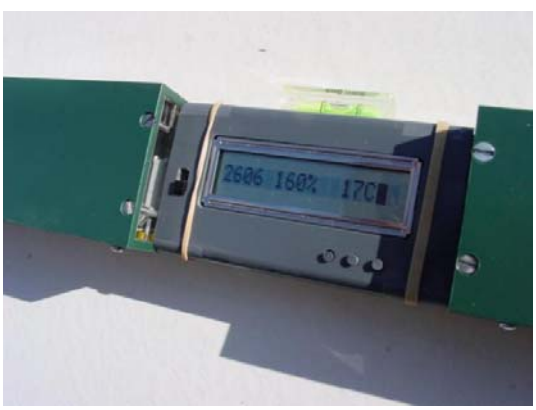
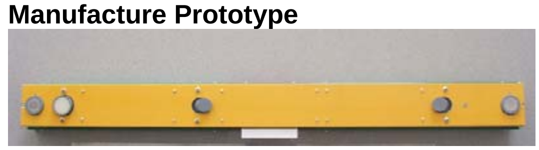


Figure 15: Field Test with Close-Up of First Pre-Manufacture Developmental Interface

Figure 16: Front View of Revised Pre-Manufacture Maximus™ SFI Prototype Showing New User Interface

Figure 17: Back View of Revised Pre-Manufacture Prototype



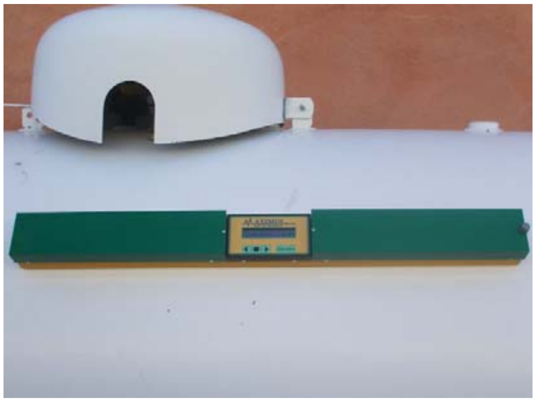


Figure 18: Most Recent Maximus™ SFI Field Tests with Improved Interface

Figure 19: Programming of Maximus™ SFI During Most Recent Field Tests

Figure 20: Operator Feedback Was Integral to Development of Maximus™ SFI

Figure 21: Operator Filling Tank with Maximus™ Shown to Tank Attached during Most Recent Field Tests

The project plan was again revised to incorporate development of the Maximus™ acoustic sensors for this large and important market. This development, however, was more difficult than initially expected as it began to take significantly more resources than were allocated for the project. Concomitantly, another approach to the preventing outage gauge emissions to the atmosphere (through the use of a vapor return mechanism) was designed to fill the role of the Maximus™ SFI for vertical as well as horizontal tanks. Development is in progress for this vapor return system, which is expected to meet the needs of both markets. The completion of this aspect of the project, however, could not be completed under the budget and timeframe for ICAT project. Further work to develop and commercialize this technology will continue.

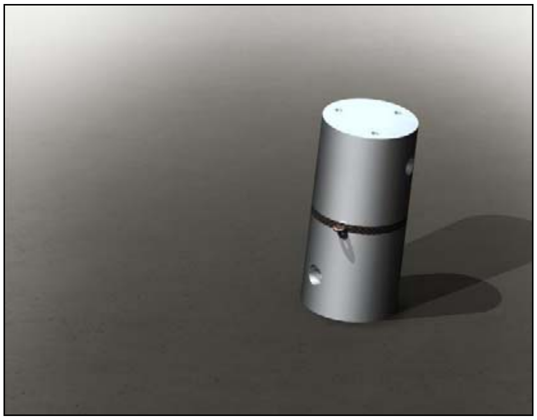


Figure 22: Rendering of Recently Designed Vapor Return Stop-Fill System Applicable for Vertical and Horizontal Tanks

Field testing at the pre-manufacture stage alone was conducted on a total of 25 tanks in the Greater Los Angeles Area. These field tests are in addition to all field tests conducted at earlier developmental stages as well as extensive lab testing of the latest instrument revisions. Based on analysis of field test results and dialogue with LP Gas distributors and delivery personnel during the course of these field tests, modifications were made to Maximus™ SFI. Apart from the SFI development engineer, two others operated the device during fills. The final version of the SFI was functional in detecting the presence of liquid during filling at a predetermined point in all test cases. One important lesson learned from these tests, however, was that knowledge and correct operator application of the instrument based on specific tank characteristics is critical in the ability of the SFI to work correctly. For this reason, making the device as easy to use in all tank applications is essential for a commercially successful product. Instruments are now ready for sale and work is underway to prepare for larger scale manufacturing and sales.

Results of Emissions Tests

An important aspect of the ICAT funding was to measure liquid phase and gas phase LP Gas mass flow rates through forklift cylinder FMLLGs during cylinder refilling.

As described briefly above, when 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 the protocol developed by ADEPT 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. Further, they cost more to implement for an LP Gas distributor than using the SFI.

In 2008, as part of two separate tests conducted under the ICAT program, gas and liquid phase LP Gas emissions through the outage gauge were measured during pump-assisted and gravity fed (without the use of a pump) filling of forklift cylinders. Representatives from ARB and the South Coast Air Quality Management District (SCAQMD) were on-site to assist, witness, and comment on these tests. In the case of the gravity fill tests, SCAQMD engineers also conducted independent measurements of the emissions during the same session. Their tests corroborated the results of the ADEPT tests.

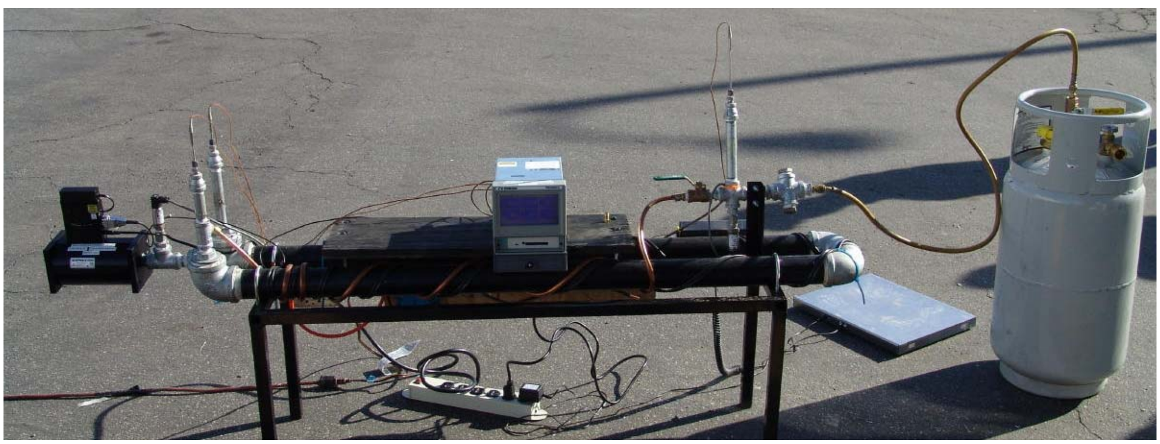


Figure 23: Emissions Test Equipment Setup

Figure 24: Flow, temperature, & pressure sensors mounted at expansion pipe outlet

Figure 25: Data recorder display

The below results are calculated by averaging mass flow rate around a time interval centered at the point where flow rate beings to stabilize and the point just prior to liquid LP Gas being released. For pump-assisted filling tests, the average mass flow rate was 2.96 g/s (Table 1). For gravity fills, the average gas phase flow rate of LP Gas through the outage gauge for two cylinders was 2.53 g/s (Table 2).

Table 1: Average Gas Phase Mass Flow Rate (Pump-Assisted Fill)

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: Average Gas Phase Mass Flow Rate (Gravity Fill)

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

Figure 26: Liquid phase emissions measurement using scale

Results from the liquid phase tests are shown in Table 3 below. Tests were conducted again after the scale used was recalibrated as a check on the previous results (Table 4).

Table 3: 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 4: Liquid Phase Mass Flow Rate Validation (Recalibrated Scale)

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

As the vast majority of LP Gas tanks (stationary, mobile, forklift cylinder) are equipped with FMLLG's which are open during every filling event which may last from a few seconds to over 10 minutes, these practices result in a substantial loss of fuel as well as undesirable VOC emissions.

STATUS OF THE TECHNOLOGY

The technology is now at the point where it can be commercially manufactured. However, there are still several key milestones to be achieved before the product can be widely accepted in the marketplace.

One milestone will be the actual UL/CSA certification of the device. The instrument was developed in consultation with appropriate certification entities; however the process is not complete. Secondly, the incorporation of end-user suggestions during field testing into the interface will make the instrument safer, more user-friendly, and more marketable. Finally, the continued development and prototyping of a product that functions in the vertical tank sector will substantially increase the marketability of the product.

A key part of the commercialization plan was to conduct promotional and educational activities. These included participation in industry meetings with the Texas Propane Gas Association and the Western Propane Gas Association; as well as attending the annual conventions and key conferences of the National Propane Gas Association and World LP Gas Association. These meetings helped educate the LP Gas distribution industry on the negative impacts of current practices on air quality as well as to present the Maximus™ SFI as one possible solution. The reception by industry at these meetings has been mixed. Some feedback was supportive of this technology to help the industry advance; while others are reluctant to change current practices.

The ICAT project had a major impact in helping to bring the technology from the early developmental stage to a commercially ready and viable product that can bring about significant benefits to California air quality.