Technical Support Note

Title: LPG Exhaust Gas Emissions - Regulatory Agency Requirements and Maintenance Factors
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Guidelines for Exhaust Gas Emissions Requirements of LPG Fueled Equipment

1. Federal and State OSHA Requirements:

The current Federal (and therefore States) requirement is that CO levels in breathing air in the work environment be less than 50 ppm for 8 hours exposure. To give you a comparison, the 0.50% CO found in well-tuned forklift engine exhaust is 5,000 ppm. Our analyzers measure the source of CO (forklift exhaust), NOT its result in the ambient air of the work environment.

The 50 ppm limit is historical in nature, and is predicated on human response to CO, which disables hemoglobin (the blood component that takes oxygen from the lungs to the cells) by strongly attaching to it to make CarboHemoglobin - thereby not allowing it to be used to transport oxygen to the cells. In essence, it looks to the body as if there is less oxygen available when there are small amounts of Carbon Monoxide present.

The ambient concentration safety level of CO is set at a point that will produce less than 10% COHb Saturation - the clinical limit of CarboHemoglobin that has been found to indicate the onset of CO poisoning. (By the way - this is determined by a blood test run to determine if there has been CO poisoning - and warehouse managers should know that there is a well defined and accepted blood test for CO poisoning that will tell if employee symptoms are caused by CO.) Symptoms generally show up at the 10%-20% COHb saturation level - so the 50 ppm limit for 8 hours exposure is a pretty conservative and safe standard.

OSHA requirements have to do with human body response to CO in breathing air - not CO emissions in warehouse equipment. In essence, you can have much higher tailpipe concentrations as long as the employees are not exposed to more than 50 ppm for 8 hours when it is diluted into the air they breathe. This requirement is also Time Weighted Average - or TWA. This means that there can be a momentary peak in CO gas levels in the warehouse air - as long as the 8 hour average is less than 50 ppm. The peak level is generally accepted to be 200 ppm for 15 minutes or up to 2000 ppm instantaneous (30

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seconds) level. If the CO stays under this limit, AND the TWA in 8 hours is less than 50 ppm - the breathing air is OK. Some states are now going to 35 ppm for 8 hours TWA - so this limit is migrating to smaller levels.

The ambient level of CO in the warehouse breathing air is a function of how much CO is being generated in the warehouse, the volume of the warehouse air, and how rapidly the warehouse air is being exchanged with clean outside air. In order to guarantee that the breathing air is safe, ambient air monitors must be used by employees and/or fixed site monitors.

2. Physiological Effects - CO Uptake and Release:

The human body takes 4 or 5 hours to uptake CO or to release it, so while the CO level is critical the human body response to it is very slow. That is why it can accommodate short (15 minute) increases in CO well above the TWA level. OSHA ambient air analyzers and exhaust gas analyzers respond within seconds - so there is potential for thinking that there is a problem when there is not. The OSHA or equivalent ambient air meter must be set to TWA mode - where it averages the CO level with respect to the time of exposure. In this way, instantaneous or short-term CO excursions can be eliminated as a source of error and a cause for concern.

Also - the breathing air in the vicinity of the worker is what must be measured - not in the vicinity of the material handling equipment tailpipe (unless, of course, a worker is always in that vicinity). The OSHA regulations do NOT regulate tailpipe gas. They regulate employee breathing air. It is important to make this distinction when considering tailpipe emissions vs OSHA regulations. The Federal OSHA regulations are very simple: less than 50 ppm CO for 8 hours TWA, and less than 200 ppm CO for 15 minutes TWA.

3. Indoor Ambient Air Gas Exchange:

Commonly, internal combustion engines are the primary source of CO in working environments. Typical levels of CO in the exhaust of a well-maintained LPG fueled forklift are 0.20% to 1.00% - (2,000 to 10,000 ppm) depending on the state of tune and the power being produced. However, the tailpipe gas very rapidly dissipates into the warehouse air - so the ambient air CO concentration is generally hundreds of times lower than the tailpipe gas concentration. Typical values are 200 to 1000 to one - depending on the size of the warehouse, the number of forklifts and how much power (therefore, exhaust gas volume) the are producing, and the air exchange rate of the warehouse. When the weather gets warm, the air exchange rate goes up dramatically as the warehouse doors are opened - and conversely, as the weather gets colder, the heating bill goes up if the warehouse doors are opened - so air exchange rate is lowered to control heating costs. Thus – during cold weather the CO level in warehouse breathing gas is

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inversely proportional to the heating bill. To keep the heating bill under control, the warehouse manager tends to reduce air exchange, which increases ambient CO level in the warehouse. Due to this effect, forklift tuning becomes more critical in cold weather. In fact, some forklift maintenance technicians tune the forklifts lean in the fall (to reduce CO emissions at the expense of raw power) - and then tune them richer to restore power in the spring - when there is better air exchange, the doors are open, and material movement increases.

Remember, though, that there will be 200 to 1000 to one exhaust gas CO concentration to warehouse breathing gas concentration. That is why you want to keep OSHA inspectors (with their 50 ppm limit) away from direct forklift exhaust gas. They are to measure the average breathing gas concentration in the warehouse to accommodate the exhaust gas dilution effect and get to the average gas that the typical warehouse employee is breathing for 8 hours. On the other hand, if you are expecting 0.50% CO in the forklift exhaust and you see 8.00% (this has happened, by the way - it is not a hypothetical), you are bound to get in trouble. What the OSHA inspector wants to see is that you are keeping the forklifts under a regular inspection and maintenance schedule, and that you are cognizant of the facts of the matter and seeking to maintain ambient air levels of CO at under the OSHA TWA limit. To do this, you really have to measure and maintain the source of CO (forklift exhaust gas) and ambient air levels of CO (a wall-mounted ambient air CO monitor). If you have both of these, OSHA will generally be happy. If you let OSHA measure your air, and you maintain your forklifts - OSHA will still generally be happy - but make sure that the ambient air CO is measured correctly by OSHA. No fair checking the ambient air at the back of a running forklift unless you constantly have people there too.

4. The Federal EPA:

The Federal Environmental Protection Agency is now requiring manufacturers of LPG fueled material handling equipment to meet strict regulations for CO, HC, and NOx emissions. This is to protect the environment, not the same as OSHA at all. However, to meet the EPA requirements required the manufacturers to add fuel mixture controls and catalytic converters on the forklifts - which greatly reduces tailpipe emissions of all of the regulated gases. CO emissions are down by a factor of about 10 from non-controlled material handling equipment - and the closed-loop control system on the new forklifts helps to keep them under control as components age.

It is very difficult to relate the EPA emission regulations - which are written as grams of gas per horsepower-hour when operated to a carefully controlled power regimen to the concentrations of gas measured in the forklift. We have generally described the exhaust gas concentrations in closed loop forklifts in Bridge TSN-12 - and if you compare them to the emission levels in open-loop forklifts in this document, you can see how much

improvement you expect to see in these newer (2004 and later) forklifts. CO levels are so low in these new forklifts that you should see no OSHA problem with any of them. However, keeping them working correctly requires the same diligence as before. There is no way to tell just how much emissions are in the exhaust gas without direct measurement. The new forklifts have some On Board Diagnostics (OBD) capability - but these systems do not physically measure exhaust gases (even though some of them have 'O2" sensors for fuel mixture control - these sensors do NOT measure oxygen. They toggle back and forth at lambda = 1.000 and are used for fuel mixture control only - not emissions level testing.) To make sure the closed loop system is are working correctly, you still should measure the constituents of exhaust gas as well as lambda and combustion efficiency. There is more gas testing to do, not less - as they are 10 times better than open loop systems, and this means the gas oxidation and reduction processes have to be in 10 times better control.

While the open loop (conventional, not catalytic converter equipped) forklifts perform directly as a state of maintenance and tune, the closed loop (2004 and later) forklifts have to be watched carefully, as they automatically adjust and control the mixture. In essence, the open loop systems had a technician in the loop, and the closed loop systems tend to take him out of it. Replacing an experienced but periodic technician with a full-time but limited microprocessor is not necessarily a good thing. A real person should periodically make sure the closed loop system is operating correctly - and the easiest way to do this is to query the OBD codes and measure the tailpipe gases.

5. Air Dilution, Catalytic Converters, and the benefits of direct port gas sampling:

Forklifts without catalytic converters have exhaust gas levels conventionally measured by tailpipe gas measurement. There is a problem with air dilution using this method – as full probe insertion is not always possible. This is indicated by excessively high Oxygen values combined with excessively low CO2 values. (The gas being delivered to the gas analyzer is a mix of ambient air – containing 20.6% O2 and exhaust gas, containing about 13.0% CO2.) This situation will result in reported CO levels substantially lower than those which exist in pure forklift exhaust – making the technician thinking that the forklift is producing less CO than it actually is. Catalytic converter-equipped forklifts have this problem as well, and the catalytic converter also prevents the technician from evaluating the fuel control and combustion efficiency in the engine. Both of these issues may be avoided by installing a direct gas sampling port in the exhaust system ahead of the muffler or catalytic converter.

If installed upstream from the tailpipe, air dilution of exhaust gas is prevented, making ‘true tailpipe exhaust gas’ easier to obtain. The best location for the port is between the header collector and the muffler for accessing true tailpipe gas.

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If the forklift is equipped with a catalytic converter, engine out gas can be accessed by installing a port prior to the catalytic converter. By analyzing this intermediate gas, the technician can assure himself that the engine is delivering the proper exhaust gas mix to the catalytic converter, thereby being assured that fuel control and combustion efficiency are both under control.

For the purposes outlined above, Bridge manufactures a 6MM port installation tool that can create a gas-port at an accessible location in the exhaust stream, and has flexible lines and adapters to ensure a tight, leak free attachment to the port and proper delivery to the gas analyzer. In this way, the technician can be assured of the location and quality of the gas being analyzed. Once the port is installed, it remains in the equipment permanently for later periodic maintenance purposes.

6. Maintenance factor effects on exhaust gas levels:

Oil has little effect on emissions. However, a forklift that burns oil may have higher than normal emissions due to the same wear that causes the oil to burn reducing the combustion efficiency of the engine. Old oil has no real effect on emissions - but certainly increases engine wear. We have seen blue smoke in engine exhaust, and it does not effect the exhaust gas readings much, but does make the filters short lived. The engine wear that causes blue smoke may be an indicator of poor engine performance and increased emissions, though.

Degraded air filters may increase emissions if they cause the engine to go out of tune. Dirty, and therefore more restrictive air filters reduce air flow into the engine. This means the operator has to open the throttle more to get the same power - which means he is operating at a different point on the power curve - more throttle opening than normal. This may change the tuning to a higher power state (depending on the details of the carburetion system) and may richen the mixture. If the carburetion were perfect, there would be no perceptible change due to a dirty air filter, but nothing is perfect and this effect may be apparent. A dirty air filter may effect the pressure reference of the carburetor, and if it biases to the rich side, CO will rapidly increase. The technician should always check the air filter and make sure it is clean when he checks emissions or tunes the forklift.

General maintenance has an effect too, of course. As the engine wears, it is more difficult to keep it in the correct state of tune. This has to do with combustion efficiency and mechanical efficiency, as it is related to how well the engine operates as a pump (taking in a fresh charge, compressing it for ignition, allowing it to expand and exhausting it), how well the combustion gas is measured and mixed, how well it is ignited, and how well the engine converts the thermal energy from the burning gas charge to mechanical power. Older engines get difficult to tune for power, and the error is always on the rich side - as this is more power conservative. However, emissions,

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especially CO emissions, are highly sensitive to rich-side running, so there is always a balancing act here. The fresher the engine is, the better the balancing act is. The older the engine is, the harder it is to tune for power and low emissions. The longer between tuning intervals - the more the engine can drift off tune - and the operators will not generally complain until power goes off (meaning poor combustion efficiency or lean-side tuning), not excessive CO emissions, as these are caused mainly by rich-side tuning, and this effect has no effect on perceived power - in fact it may be better. (Performance tuners go to the rich side to guarantee maximum performance - motorcycles are generally tuned for 3.00% to 4.00% CO!) Unless you periodically measure exhaust emissions, you really do not know the state of tune of the engine.

7. Fuel Savings:

Mixture - Lambda (AFR) Effects:

The ratio of excess CO to excess fuel usage is about 3:1. This means that every 1.00% CO in excess of an acceptable level means you are burning 3% more propane than you should. So – for example, if you see 3.0 % excess CO, it means your fuel usage is up almost 10%.

Clearly, the better the state of tune of the engine, the better the combustion efficiency and the lower the fuel use. Fuel economy is strictly a measure of how well the fuel is being used to generate power – and this simply cannot be done if there is not enough oxygen (air) to burn all the fuel. Oxygen available means Lambda – so you get a degradation of fuel economy in direct proportion to it – 10% rich means 10% more fuel per horsepower-hour than stoichiometric – perfect combustion ratio of air and fuel.

Compression, timing and Ignition -Combustion Efficiency Effects:

The degree of Oxygen availabel that is being used to generate power is combustion efficiency, and a combustion efficiency value of 90.0% means you are wasting 10% of the fuel. So – these two factors – Lambda (AFR) and Combustion Efficiency are related and tell you how well the engine is producing power for the fuel it is consuming.

To give you a feel for it, if the engine is running well, but produces 3.50% CO, it means that the engine is tuned rich, with a Lambda of about 0.900 - or 10% rich. If the engine is tuned right at a stoichiometric air/fuel ratio (Lambda = 1.000), but has only 90% combustion efficiency, you are still wasting 10% of the fuel.

To optimize fuel economy, you have to get BOTH values right – both the correct Air/Fuel mixture, and combustion efficiency – which is a function of timing, valve adjustments, spark intensity, etc.

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8. The Bottom Line:

You will not be able to keep indoor open loop equipment in the state of tune you need to for both personnel safety and economic reasons without doing periodic (every 6 months) emission testing and tuning. You should also verify that closed loop emission equipment in their intended state of tune with periodic inspection too - as although the underlying technology is based on gasoline-fueled vehicles and is seasoned, its application to LPG fueled equipment is relatively new.

If you are operating equipment out of doors, things are a great deal easier, as OSHA will leave you alone, and you only have to worry about the EPA - and in fact you don't even have to worry about them. The equipment design and implementation is certified to the EPA by the manufacturer, and is also warranted for longevity. However, remember that indoor-operated equipment is critical more to OSHA than the EPA – and is NOT certified or warranted by the OSHA - as their purview is employee safety, not environmental protection. While the emissions levels are indeed better because of the EPA rules, the EPA rules specifically do not address OSHA concerns. The EPA rules are written to control mass emission standards (similar to automobiles), not indoor concentration standards, which is what OSHA is concerned about.

At the end of the day, periodic testing of actual engine exhaust is necessary to ensure compliance with OSHA ambient breathing air regulations – whether the equipment is designed and certified to meet EPA standards or not.

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