FEROX LLC

Ferox Demonstration Procedure

Accurately and reliably measuring changes in efficiency

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Introduction

These instructions will guide you in conducting demonstrations in a way that produces positive reliable results. We have the benefit of having a product that works, so we don't have to fudge the numbers to make them look good. It is more important to get correct numbers than big numbers. Please read all the information presented here carefully and follow instructions. Be sure you understand everything so you know not only what to do, but why you are doing it. If you need any assistance or clarification, please email technical@feroxenergy.com at any time.

Background

Liquid fuel is usually measured by volume in liters or gallons. Fuel is full of energy trapped in chemical bonds, and the energy content of liquid fuel is often measured in BTU (British Thermal Unit) per gallon or liter. A BTU is a measure of energy equal to about 1055 Joules.

Getting the right data

When we are trying to measure energy or fuel efficiency, we need to collect the right data. We want to know how much energy went into a system and how much energy came out, not how quickly it went in and how quickly it came out. We can calculate "energy in" from the quantity of fuel consumed because the amount of energy in every liter of fuel should remain fairly constant for a single tank of fuel. Thus, we can measure "energy in" and "energy out" by measuring the quantity of fuel consumed and the quantity of energy coming out. This means we want meters that measure fuel in cumulative liters or gallons, not liters per hour or gallons per hour.

Gensets

When dealing with power generation, we need to make a distinction between power and energy. The difference can be difficult to grasp because you can't see a visible quantity of stuff. Energy is used to describe the *quantity* of work done and is measured in Joules, or kilowatt-hours. In contrast, Power describes how *fast* work is being done and is measured in Watts, or Joules per second. Therefore, Power is analogous to measuring liters per hour or gallons per hour, and energy is akin to measuring liters or gallons produced. I explain later when measuring power is important.

Boilers

In boilers, the energy or heat output is captured in steam, and used to perform some kind of useful work. When you add energy to water, its temperature rises. If you add the same amount of energy or heat to a large quantity of water and a small quantity of water, the small quantity will experience a greater rise in temperature. This means that when dealing with boilers, we are not only interested in steam quantity, but also the change in temperature between the feed water and the steam. We need to keep track of (1) the temperature of the water that is feeding the boiler, (2) the temperature of the steam, and (3) the quantity of steam produced. Quantity of steam and temperature of steam, when taken in isolation, are meaningless.

Measurement	Correct	Wrong
Fuel	Gallons, liters, tons	Anything “per hour”
Energy output	Joules, Kilowatt-hours	Kilowatts, Joules per hour
Steam output	Temp change & steam quantity	Steam temperature or quantity alone

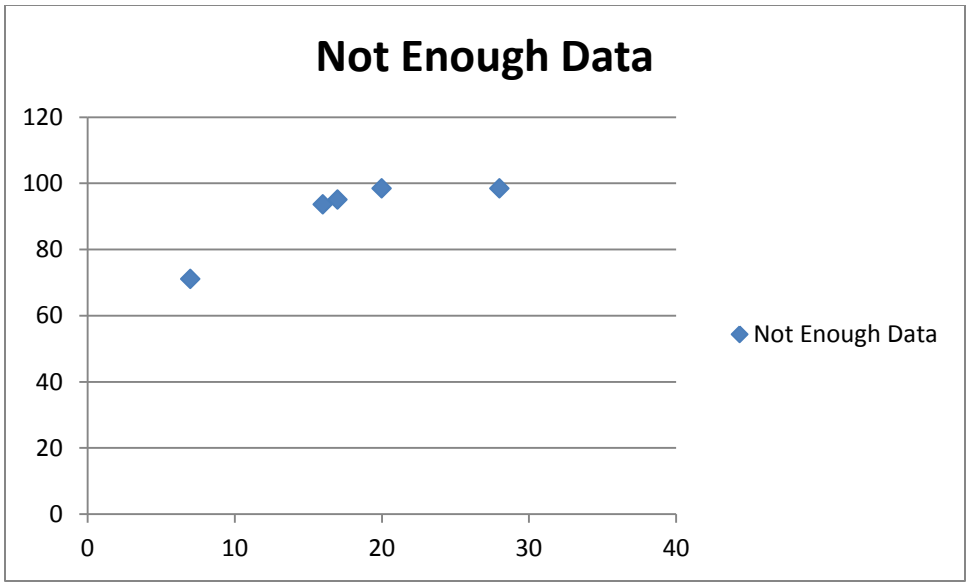
The importance of load

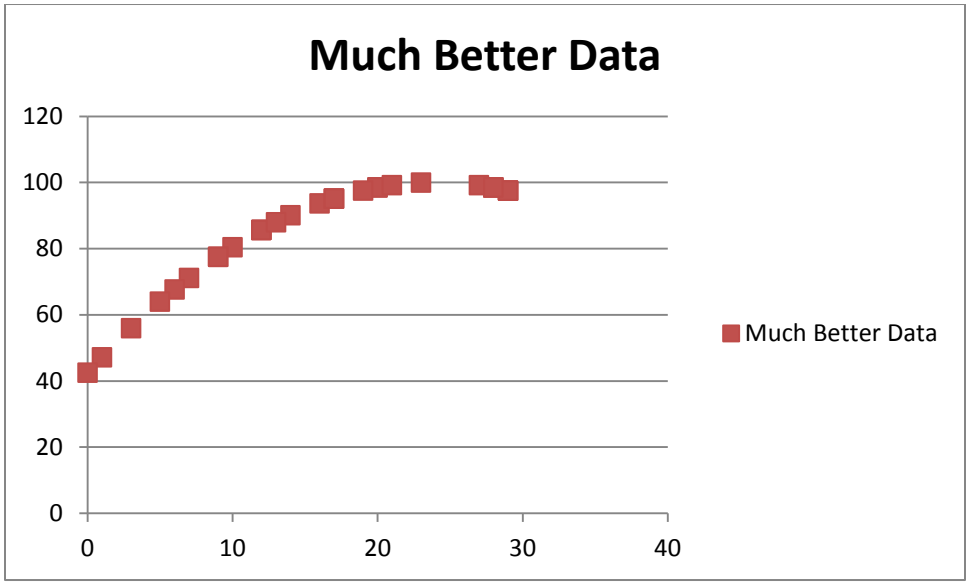
The main purpose of gathering data on fuel consumption and energy production at short intervals is to get an idea of how efficiency changes with load on the particular machine we are testing. Every machine is different, so you can make no assumptions. Efficiency changes with load to a much greater degree than it does with Ferox treatment, so you must eliminate load related efficiency changes as a variable to make certain that the changes in efficiency that you see are primarily attributable to the use of Ferox. If you don’t account for changes in efficiency attributable to changes in load, or eliminate changes in load altogether, the numbers you get are useless

Getting enough data

We must also make sure we collect enough data. Let me try to define “enough.” When you take a single measurement of some value, you don’t really know what to expect if you take another measurement. But the more measurements you make, the better you can predict the range where your next measurement will fall. So “enough data” means that you don’t expect numbers you won’t see, and you don’t see numbers you didn’t expect. The more data you collect, the closer you get to this ideal.

Another way to define “enough” with regard to genset and boiler data is whatever gives you a solid idea of the machine’s efficiency curve. Efficiency of gensets and boilers can vary dramatically with load. This means that if you take 5 measurements, they could come back drastically different from one another because the load has changed from one moment to the next. Therefore you must make multiple measurements at short intervals, which allows you to paint a complete picture of where the efficiency lies at each point on the load scale. Look at the two examples below:





The above examples illustrate how taking more measurements gives you a better idea of how efficient the genset or boiler is at various loads. The above examples also illustrate why you must get just as much data for the baseline as you do for the product demonstration. If you imagine the blue as the baseline and the red as the demo, can you tell if any improvement has been made? You can't because you don't know what your baseline looks like. You'll never be able to see a change unless you know what it looked like before changing.

Setup and Preparation

On both gensets and boilers fired by diesel fuel, there is usually a fuel feed line and a fuel return line. In order to determine the amount of fuel consumed, you must subtract the amount of fuel sent back through the fuel return line from the amount of fuel sent through the fuel feed line. This means that you may need two flow meters in order to determine fuel consumption. However, you may be able to get away with just one.

Using only one meter

The amount of fuel sent by the fuel pump through the fuel feed line should be fairly constant and whatever doesn't get injected and consumed will flow back through the fuel return line. This means that the amount of fuel passed back through the fuel return line is a much better indicator of how much fuel is being consumed than the amount of fuel passed through the fuel feed line. So if we are only going to use one meter, we should attach it where it gives us the most useful information. Somewhat counterintuitively, this ends up being on the return line.

In order to know if we can get away with just one flow meter, we have to determine how steady the flow rate is on the fuel feed line. This is the only time when we are concerned with *flow rate* rather than *flow quantity.* However, we are interested in *average* flow rate over 15-30 minute intervals, so we will still measure quantity in each interval and divide out the time length to get average flow rate. Note that these are the same measurements we will take for the actual demonstration, but the math done on them is different.

Before beginning a demonstration, determine your maximum margin of error on the flow rate in the fuel feed line by following the procedure outlined below:

Determining deviation of fuel feed line flow rate

1. Attach your flow meter that measures gallons or liters (not gallons or liters *per hour*) to the **fuel feed line**. You may need the assistance of the engineer on-site for ideal location. For this task, you need not attach a meter to the return line.
2. Attach your energy meter that measures kilowatt-hours or joules to the electrical output on the genset. You may need the assistance of the engineer on-site for ideal location.
   Note: Although we are only concerned with the flow rate on the fuel feed line, we need to track load on the output as well so we can be certain that the flow rate on the feed line remains constant even under changing load conditions.
3. Record the values from the flow meter and energy meter at the same interval you plan on for the entire demonstration. This should be every 15 – 30 minutes. Be sure to record time, fuel, and energy within a few seconds of each other to ensure that all measurements are on the same interval of time.
4. Make enough recordings to get a solid idea of the amount of fuel that flows through the fuel feed line at a variety of load conditions.
5. Once you have determined that your fuel flow measurements were taken in a variety of load conditions, calculate average flow rate for each time period by taking each measurement of fuel flow and dividing out the time interval over which it was measured.

6. Finally, determine the deviation from average by following the equations below. If the flow rate deviates from average less than 2%, you can assume the flow is constant on the fuel feed line. If this is the case, you may measure flow only on the fuel return line during the entire demonstration and subtract that value from the constant value you determined here in order to get actual fuel consumption.

$$avg\ flow\ rate = \frac{total\ fuel\ used}{total\ time}$$

$$max\ deviation = maximum\ of$$
$$|avg\ flow\ rate - \max flow\ rate|$$
$$or$$
$$|avg\ flow\ rate - \min flow\ rate|$$

$$max\ deviation\ \% = \frac{\max deviation}{avg\ flow\ rate} \times 100$$

Properly Mixing Ferox Powder

Ferox Powder is designed to dissolve rapidly in diesel fuel, petrol, gasoline, bunker fuels, heating oil, heavy fuel oil, residual fuels, and even alcohol. Time to completely dissolve varies depending on fuel type, temperature, dosing rate, and agitation. Ferox has done dissolution tests on tablets at 180-200 times the recommended dosing rate with zero stirring or agitation, and the product goes into complete solution within minutes. Dissolution of Ferox products is simply not a concern, but there are several things you can do to minimize the time required to dissolve:

1) Always follow recommended dosing rates – increased dosages take longer to dissolve
2) Mix with warm fuel when possible – warmer temperatures reduce dissolve time
3) Add Ferox product before refilling – the agitation produced by adding fuel aids dissolution
4) Mix after adding – shaking, stirring, and sloshing aids dissolution
5) Premix – at room temperature, several hundred times the correct dosage can be mixed with a small amount of the target fuel with enough agitation, shaking or stirring. The resulting liquid will mix with fuel immediately. Be sure to recalculate your dosing rate.

As always, if you have any questions about mixing or proper dosing, please contact technical@feroxenergy.com.

Special considerations for O2 trim systems

In the real world, 100% complete combustion doesn't occur because the world just doesn't work that way. There will be some small amount of uncombusted fuel and oxygen in the exhaust. However, we can still optimize the system by providing enough oxygen to balance efficiency and emissions.

Boiler tuning

There is a certain amount of oxygen required to completely combust a given amount of fuel. Air is about 21% oxygen, so boilers are set to supply the volume of air that contains enough oxygen to optimize combustion. If there is not enough oxygen to burn the fuel, efficiency drops and pollution increases. If there is too much oxygen, the excess air absorbs heat from the combustion process and passes it out the exhaust rather than into the steam, reducing efficiency.

The benefit of O2 trim

Although, you can tune your air intake to optimize combustion, changes in humidity, temperature, and barometric pressure change how much oxygen in present in a given volume of air. O2 trim systems automatically make adjustments to compensate for these changes and keep the boiler in tune.

To ensure optimum efficiency, boilers are typically tuned to provide about 10% excess air. This tends to provide enough available oxygen to maximize combustion of the fuel without having so much excess air that efficiency is lost. Boiler controls can often only be set up to supply a fixed volume of air for a given volume of fuel.

O2 trim systems address this problem by reading the amount of excess oxygen after combustion. If the O2 level is too high, it will automatically reduce the airflow. Likewise, if excess O2 levels are too low, the O2 trim system will increase airflow. O2 trim systems still need to be calibrated to maximize efficiency but they can automatically correct for changes in available O2 and stay properly tuned as environmental conditions change.

Ferox and O2 trim

Ferox powder catalyzes the combustion process, meaning it causes more of the available fuel to combine with the available oxygen. This has the effect of reducing both unburned fuel and excess O2 in the exhaust stream. The result is that using Ferox changes the optimum level of excess O2 for the system. When Ferox is used on a boiler equipped with O2 trim, the trim system will sense a reduction in excess O2, and increase the airflow. If this extra air is not needed, it absorbs heat from the combustion process and passes it out the exhaust, reducing efficiency. Although the effect is small, the O2 trim system will typically have a negative effect on the efficiency results when using Ferox. Therefore, in order to get the most accurate results from a demonstration, we recommend that you recalibrate the O2 trim system after adding Ferox. The other option is to disable the O2 trim system for both the baseline and treatment periods.

Demonstration

Once you are prepared to deal with O2 trim and have decided how many flow meters to use on the fuel lines, you can then move to establishing a baseline. This is data that will be used to calculate results, so it must be done correctly.

Don't use historical records for a baseline

You must establish a new baseline. The reason you must always establish a new baseline is because in order for measurements to be comparable to each other, they must be measured by the same method. Using a different method is like asking a different question. For example, if you assess your financial situation by counting the cash in your bank account, you'll likely get a different result than if you also consider the bills to pay and incoming deposits. Both methods generate useful information, but if you use one method one month and another method the next, you can't really say you've improved because you didn't really ask the same question both times. The baseline and treatment periods must both be measured by the same method.

Baseline and Ferox treatment

1. Attach a flow meter to the fuel return line on the genset. Depending on what you determined in the previous section, you may also need to attach a flow meter to the fuel feed line. Your flow meter must report the quantity of fuel , not the flow rate.
2. Failure to connect the meters in the correct place, where they are isolated from the influence of other machinery, will result in poor accuracy. Different flow meter technologies are susceptible to different types of interference, so follow the flow meter manufacturer's instructions for optimal placement.

   For Gensets

   Make sure the power meter is attached to the power output of the genset. It must be attached at a location that gets power only from the genset being used for the demonstration.

   For Boilers

   Make sure you can measure (1) the temperature of the boiler's feed water, (2) the temperature of the steam produced, and (3) the quantity of steam produced. Make sure the steam temperature and quantity are measured where they are only influenced by the boiler running the demonstration. Often more than one boiler will be connected to the same steam system.

   * If you are using a data logger, you can skip steps 3 and 4. Make sure all the meters are properly connected to their inputs, and properly grounded. Make sure there is a sufficient power supply, and the logger is powered on.

3. Take measurements every 15-30 minutes. The shorter the time interval the more accurate your results will be, but remember the law of diminishing returns and use your time wisely.
4. Record your measurements in the Ferox Demo Form spreadsheet. It will perform most calculations for you, but you must supply the correct raw data. Fuel is recorded as the amount used since the last measurement. Energy output is recorded cumulatively, like a car odometer.
5. Run the baseline long enough to get a full picture of the load cycle that the equipment experiences during normal use. Typically one day is enough, but in certain situations, more or less time may be required. Contact technical@feroxenergy.com if you have any questions about this.
6. Add Ferox powder to the fuel supply and repeat steps 1-5. Make sure that if the fuel tank is refilled during testing, The correct amount of Ferox powder is also added.
7. Be sure to fill out the background information on the Ferox Demo Form so we can distinguish this test from other tests. The more information you get about the equipment, fuel, and facilities, the easier it will be to find answers if questions arise.

Followup

Submit your completed Ferox Demo Form as an attachment to technical@feroxenergy.com . Make sure that all available data is filled in, including background data. If you are using the data logger, return the entire unit to Ferox and email the Ferox Demo Form with just the background data filled in. Note on the form that a data logger was used to gather the necessary data.

If you followed these directions closely, you should get positive results from your data. If you cut corners, you might still get positive numbers, but the results will be inconclusive and you have wasted your time. It's better to do it correctly from the beginning. If there is any ambiguity in these instructions such that you don't understand exactly what you are supposed to do, or why, please contact technical@feroxenergy.com .

Additional Tips and Tricks

This section gives additional information to help deal with difficulties in accurately measuring fuel consumption over short time intervals.

Reducing compound error with multiple meters

In situations where the fuel feed line flow rate deviates more than 2%, you will have to continuously measure flow on the fuel feed line and the fuel return line. This statement assumes that your flow meter was connected correctly and fluctuations represent actual changes in flow rather than inaccuracies of the meter due to improper placement or choosing the wrong meter for the application. Taking two measurements and subtracting them to get the actual fuel consumption presents a problem of compounding error. If your meters have a repeatability (precision) rating of 1%, that tiny 1% error is

compounded by the ratio of fuel flowed versus fuel consumed. The difference between these is highest at idle and becomes smaller as loads increase. Below is an example of what could happen at low loads.

	Fuel Flow	Error	% error
Actual Fuel Feed	100 lpm	NA	NA
Actual Fuel Return	90 lpm	NA	NA
Actual Fuel consumed	10 lpm	NA	NA
Measured Feed	101 lpm	+-1 lpm	1%
Measured Return	89 lpm	+- 0.89 lpm	1%
Calculated Consumed	12 lpm	+- 1.89 lpm	15%

As you can see, when the amount of fuel flow is merely 10 times more than the fuel consumed, the error in your calculated value of fuel consumed is inflated to 15%, despite your equipment having independent error rates of 1%. The error in your measurement could completely account for changes in efficiency less than 15%!

Clearly, you can't rely on data with an error rate of 15%. Changes in efficiency from using Ferox will often be less than that. There are three ways you can deal with this problem: (1) get better meters, (2) minimize error of the meters you have, or (3) figure out a way to use fewer meters.

Getting better meters

Anybody who is truly concerned with increasing their efficiency must be willing to permanently install equipment that allows them to track efficiency. There's just no way of knowing that you've changed something that you can't or won't measure. It is possible to get flow meters with a repeatability spec of 0.1% or less. The smaller this number gets, the better your data will be. The problem is that these high-precision meters get very expensive. Therefore, high-precision meters might only be feasible for companies that stand to save large amounts of money through increased efficiency.

Minimizing error on less precise meters

If cost constraints prevent the use of high-precision meters, you can still minimize the compounding effect of cheaper meters by monitoring load. At lower loads, the compound error is quite large, but at high loads, it is significantly diminished. If you monitor and control loads on the generator such that the overall average load remains high, they the overall error introduced by the two flow meters is minimized. At the very least, you should be able to calculate what your weighted average error is based on the changes in fuel consumption and amount of time spent at each consumption rate. This will at least give you some measure of the accuracy of your measured values. Contact technical@feroxenergy for help with processing these numbers.

Using Fewer meters

If you must use two meters, you might still be able to get away with using one. However, this solution should only be attempted with the assistance of an expert who can account for and minimize the inherent risks. The most significant risk comes from the fact that diesel systems use fuel flow to cool and

lubricate the injectors. Implementing the following method can have a significant effect on the temperature of the fuel and its cooling ability.

> WARNING: THIS METHOD CAN DAMAGE YOUR ENGINE IF DONE IMPROPERLY. CONSULT AN EXPERT.

That said, let's talk about using just one meter. The fuel return and fuel feed lines can be rearranged so that there is a single connection to the fuel tank. This means that the fuel return line would T into the fuel feed line, recirculating unused fuel back to the engine rather than back to the fuel tank. This allows a single meter to be placed between the fuel tank and the return T, which will only measure fuel that is actually consumed. The danger is that under normal conditions, fresh fuel is pulled straight from the tank. This fuel is cooler than what just came from the engine, and therefore more effective at cooling the injectors. Recirculating hot fuel that just came from the engine increases the risk of seriously damaging your equipment if it isn't done carefully and properly. Counterintuitively, the risk is not necessarily lower at low loads because less fuel is being consumed and less fresh cool fuel is being pulled into the recirculation system. The risk of overheating and damage depends on a variety of factors. When using this method, adequate cooling must be maintained and verified under the all possible load conditions. Ferox will take no responsibility for the damage that results from improper fuel recirculation.

Advanced math

It might be that you simply cannot measure fuel consumption accurately on a 15-30 minute time scale. If you have thoroughly consulted with technical@feroxenergy.com and confirmed that there is no way to take the necessary measurements and received authorization, then you can try the Trinity Method.

Trinity Method

Take measurements of the baseline without Ferox for 7 days. For each day, measure the total fuel consumption for that day, the total energy produced in kilowatt-hours, and the load at 15 minute intervals or less. Load may be measured using a kilowatt meter with data logging capability, so you don't have to be there with pen and paper every moment of every day for what will certainly seem like eternity. On the eighth and ninth days, add Ferox to the fuel in the correct dosing rate, and take the same measurements you did before. Send all the data to Ferox and we will work some magic to find the percentage improvement.

The Trinity Method is somewhat experimental and should only be used as a last resort. Consult with technical@feroxenergy.com closely throughout the process as last minute adjustments may be required.