# Diesel Fuel Flow Measurement –
# Avoiding Common Pitfalls

As the price of fuel increases and environmental regulations tighten, it is more important than ever to measure the amount of fuel used by diesel engines and standby power generation systems. However, accurate monitoring of diesel fuel consumption presents a significant challenge for end users in various industries.

The following white paper addresses a number of common pitfalls to help ensure the best flow measurement solution for diesel fuel applications.

**Background**

Diesel-powered engines are used in a wide variety of industrial and transportation-related applications, ranging from marine vessels and locomotives to off-road machinery and construction equipment.

Hospitals, factories and other industrial sites use diesel power for backup generation sets (gen-sets) that provide load leveling and emergency power during scheduled or unscheduled blackouts (See Fig. 1).

Figure 1


Exhaust emissions from diesel-powered engines and gen-sets include oxides of nitrogen (NOx), hydrocarbons (HC), carbon monoxide (CO), and particulate matter (PM). Diesel combustion occurs at very high temperatures and NOx is formed as a by-product. A standby diesel generator can produce up to 25-30 pounds of NOx per megawatt hour of power generated.

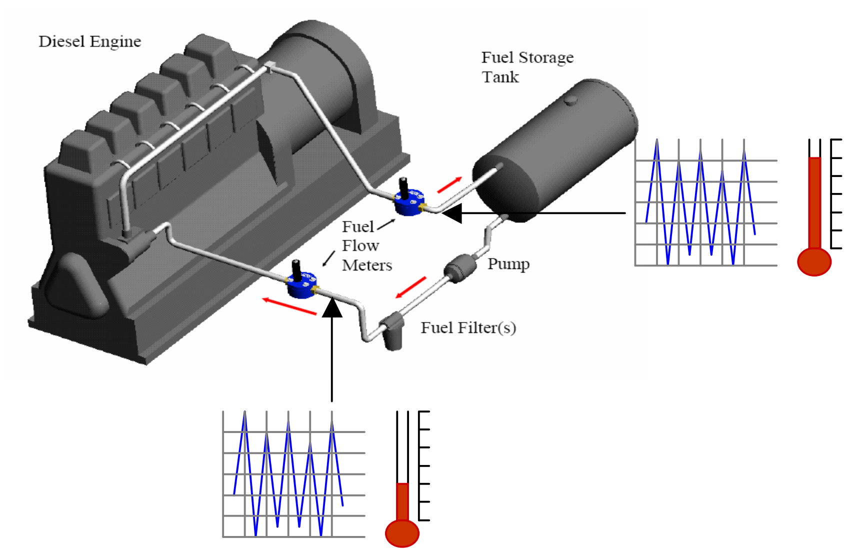
Current standards enacted by the U.S. Environmental Protection Agency (EPA) and various state agencies mandate significant reductions in diesel fuel pollutants—particularly NOx—in an effort to reduce impact on the environment and public health. As such, diesel-powered systems must be equipped with accurate flow measurement devices for monitoring and reporting total fuel usage and current fuel usage burn rate.

Due to today's rising fuel prices, diesel operators also need solutions for measuring the effectiveness of fuel-saving strategies, as well as obtaining fuel consumption data used for scheduling engine maintenance and creating ISO 14000 records.

**Fuel Metering Requirements**

In reciprocating diesel engines, fuel is pumped in a re-circulating loop at a higher volume than actually required by the engine. This serves to cool the injectors as well as powering the engine. Fuel unused is circulated back to the tank for reuse. Therefore, in order to measure the net fuel flow, a flow meter must be placed in the return line as well as the supply line; the difference being the amount consumed (See Fig. 2).

Figure 2




This operation sounds simple, but in fact introduces the possibility of significant error in measurement that is often overlooked by end users and specifying engineers. The supply and return line flows are being measured but it is the accuracy of the net fuel consumed by the engine that is important.

To illustrate this further, consider the following scenario. At close to full power, a diesel engine burns 400 Gallons Per Hour (GPH) with a supply of 900 GPH leaving a return flow of 500 GPH. The flow meters have an error of +/- 0.5% of reading (supply flow meter error is 900 GPH x 0.005 = +/- 4.5 GPH, and return flow meter error is 500 GPH x 0.005 = +/- 2.5 GPH).

Depending on whether the error is positive or negative on both flow meters, the total error is between 2 and 7 Gallons Per Hour (GPH). This relates to 0.5% to 1.75% error on the net burn of 400 GPM. The average system accuracy in this example is probably around the midpoint at approximately 1.1%—over twice the error of the individual flow meters.

Unfortunately, the aforementioned example is the best-case scenario. With the engine running at idle, for example, the net fuel used is much lower with most of the supplied fuel being returned.

To illustrate this further, let's look at the same engine at idle. The engine burns 30 GPH with a supply of 900 GPH, leaving a return flow of 870 GPH (supply flow meter error is 900 GPH x 0.005 = +/- 4.5 GPH, and return flow meter error is 870 GPH x 0.005 = +/- 4.35 GPH). Here the total error is best-case 0.15 GPH and worst case 8.85 GPH, giving a range of 0.5% to 29.5% error on the net burn of 30 GPH and a nominal system error of about 15%. Clearly, this would be an unacceptable error in most diesel fuel measurement applications.

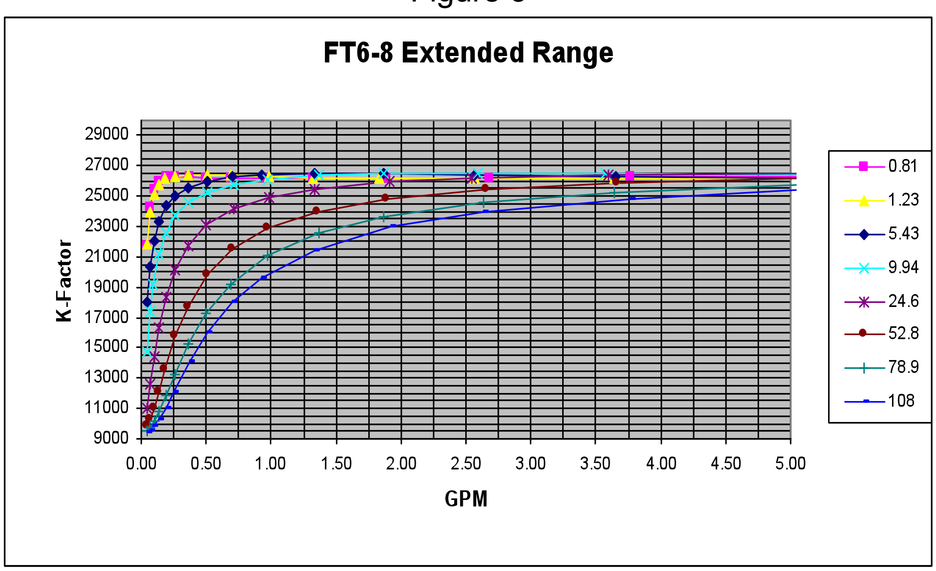
The other key takeaways are:

1. It really depends on how long the engine spends at reduced load during its duty cycle
2. The accuracy of the flow meters is critically important. Even meters with accuracy of 0.5% of reading are not good enough in many fuel flow applications as demonstrated above.

Now let's tackle these two issues starting with flow meter accuracy. Let's take a highly accurate meter with a calibration accuracy of +/-0.05% of reading, a repeatability of +/-0.05% of reading and linearity of +/-0.1% reading. The overall accuracy can be stated using the root mean square of all three, and this works out to +/- 0.12% of reading.

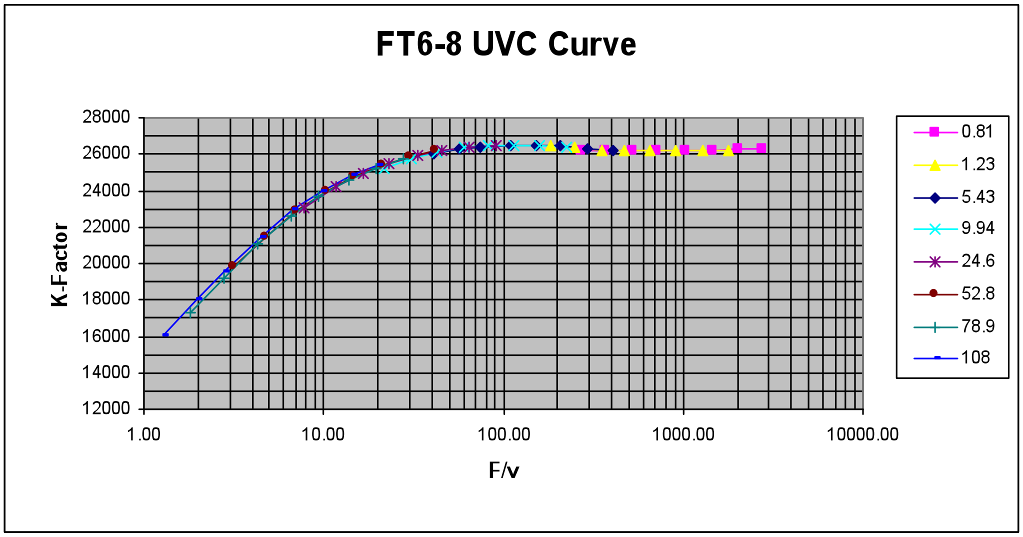
Unfortunately, another factor that can seriously affect the accuracy of diesel fuel measurement is the changing viscosity of the fuel with temperature. Diesel fuel has a viscosity of 5.8 centistokes (cSt). at 0° C and a viscosity of 2.6 cSt. at 35° C. This viscosity shift causes a significant change in the k factor or number of pulses per gallon outputted by the flow meter electronics. Errors in excess of 10% are not uncommon (See Fig. 3).

Figure 3



The solution, then, is to calibrate the flow meter at two or more viscosities, compute frequency over viscosity to line up the curves, continually monitor the temperature of the fuel and program the electronics with all the data so that it can compensate quickly for temperature and viscosity variation and give the correct number of pulses per gallon output. Using this method can ensure the best system accuracy by compensating for temperature/viscosity variations (See Fig. 4).

Figure 4




Let's now consider the duty cycle of a diesel engine in a marine workboat. Figure 5 shows the supply, return and burn rates at 5% (idle) through full power.

Figure 5

| Power Setting | Supply Flow | Return Flow | Burn |
|---|---|---|---|
| idle - 5% | 900 | 870 | 30 |
| 20% | 900 | 808 | 92 |
| 40% | 900 | 716 | 184 |
| 60% | 900 | 624 | 276 |
| 80% | 900 | 532 | 368 |
| 100% | 900 | 440 | 460 |

Now, consider the approximate amount of time the engine spends at each power setting and using the high accuracy flow meters with temperature compensation (See Fig. 6).

Figure 6

| With worse case error +0.1% on supply and -0.1% on return | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Supply** | **Return** | **Diff.** | **Flow Error** | **% Error** | **Time Ratio** | **Mean Accuracy** |
| **Idle - 5%** | **900.9** | **869.1** | **31.8** | **1.8** | **5.9%** | **0.1** | **0.59%** |
| **20%** | **900.9** | **807.2** | **93.7** | **1.7** | **1.9%** | **0.05** | **0.09%** |
| **40%** | **900.9** | **715.3** | **185.6** | **1.6** | **0.9%** | **0.05** | **0.04%** |
| **60%** | **900.9** | **623.4** | **277.5** | **1.5** | **0.6%** | **0.2** | **0.11%** |
| **80%** | **900.9** | **531.5** | **369.4** | **1.4** | **0.4%** | **0.3** | **0.12%** |
| **100%** | **900.9** | **439.6** | **461.3** | **1.3** | **0.3%** | **0.3** | **0.09%** |
| | | | | | | **1** | **1.04%** |

In this example, worst-case system error is approximately 1% of reading, which is very acceptable in all diesel fuel measurement applications. Obviously, if the engine spends more time at lower load then this accuracy will not be achieved but could still be acceptable (remember, the above is worst-case).

**Flow Meter Selection**

When it comes to choosing a flow measurement device, some end-users assume "one size fits all." In reality, there are significant differences between flow meter types, and each design has its unique "pros and cons." The basis of proper meter selection is a general awareness of flow measurement science—and a clear understanding of your specific application requirements.

All flow meter users should have a basic understanding of fluid viscosity (i.e., fluid's resistance to flow). Kinematic viscosity is the ratio of the absolute viscosity to the specific gravity, usually expressed in centistokes, where the resistance to flow is measured in square millimeters per second ($mm^2/s$). Fluid viscosity sometimes fluctuates during a given measurement period. Viscosity and density also vary due to a physical change in the mixture of the fluid. In most cases, however, these changes are due to variations in the operating temperature of the fluid itself.

Also, users should consider pressure drop when specifying a flow measurement instrument. Pressure drop is the decrease in pressure from an upstream to a downstream point in an application. In order to achieve a lower pressure drop, some users end up choosing a larger meter than originally planned—significantly increasing costs and impacting their measurable low-end flow range.

In diesel fuel applications, the chosen flow meter must withstand vibration and pulsating flow; it must be compact in order to fit easily into fuel lines; and, ideally, it should fail open instead of closed so that in the unlikely event of a meter failure, the engine is not starved of fuel. Cost is also an important consideration, since there are two sets of meters per engine requiring two sets of electronics.

Some flow meter technologies suffer from inaccuracy at engine idle, when very small amounts of diesel fuel are being consumed. Meters generally become more accurate when the engine is running at 80-100% of load. Thus, measurement of fuel consumption requires that the user estimate the amount of time the engine spends in idle, and then factor in the time ratio when calculating overall system accuracy.

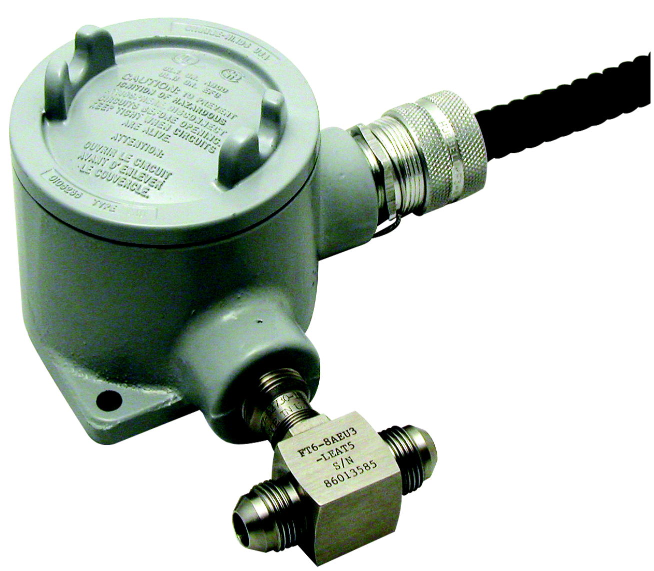
Coriolis flow meters are a very popular flow measurement device throughout many industries, but in most cases, they are too large and costly to be used in diesel fuel applications. In addition, Coriolis meters often require larger sizing in order to handle pressure drop caused by high fluid viscosity. As a result, the user must sacrifice performance on low-end flow rates.

Positive Displacement (PD) flow meters are commonly used for diesel fuel measurement, but because of their tight gear tolerances, they have a greater likelihood of locking up and failing closed. PD meters also have high pressure drop.

**Turbine Meter Solution**

Turbine flow meters are gaining recognition as the meter-of-choice for diesel fuel measurement, offering compact size, fast speed of response, low voltage and power requirements, and a wide turndown ratio. Properly calibrated with temperature compensation, these instruments can achieve the high accuracy required for diesel fuel applications. Turbine flow meters have a low pressure drop, fail open, and are highly reliable due to the fuel naturally lubricating the meter bearings (See Fig. 7).

Figure 7




The turbine meter design incorporates a freely suspended rotor turned by fluid flow through the meter body. Since the flow passage is fixed, the rotor’s rotational speed is a true representation of the volumetric flow rate. The rotation produces a train of electrical pulses, which are sensed by an external pickoff and then counted and totalized. The number of pulses counted for a given period of time is directly proportional to flow volume.

Turbine flow meters provide real-time fuel measurements with National Institute of Standards & Technology (NIST) traceable flow data. However, users should only consider a meter with an overall error of less that 0.125% reading for this application. A quality turbine meter can achieve 0.1% accuracy, ensuring precise overall flow readings at all engine load levels. Thanks to the proven turbine design, there are no impediments to the flow of diesel fuel in the event of a meter failure.

Regardless of the chosen flow meter technology, overall system accuracy can be no greater than the equipment used to perform the meter calibration. The most precise flow calibration systems in use today are based on a positive displacement design. Calibrators of this style can be directly traceable to NIST via water draw validation. Their total accuracy is conservatively specified at 0.05%.

**Additional Consideration**

Flow meter users should keep in mind one other important consideration, which is the display of flow data. The simplest way is to use a local digital panel meter display with two pulse or analog inputs that has the ability to subtract one input from the other to compute and display the net burn rate and also the total burn. The output from this panel meter can then go to a printer or central control system for further analysis. Alternatively, outputs from the flow meter can go directly to the control system and the calculations can be performed there (See Fig. 8).

Figure 8


Some displays can get more sophisticated depending on individual market requirements. For example, marine vessel operators may want to display various parameters for multiple engines and generators on the vessel. These parameters could include fuel flow, total, engine RPM and engine efficiency for each engine and for the vessel. They may also want to record data for further analysis so that they can make educated decisions on how to operate the vessel more efficiently. Computerized displays are available for this purpose (See Fig. 9).

Figure 9

**Conclusion**

Accurate diesel fuel flow measurement is much more challenging than it appears on the surface. That is why end-users should purchase the most precise, cost-effective flow meter available—one that is designed to handle the environmental conditions and pressure drop requirements of fuel metering applications.

Flow Technology is highly experienced in this field and can help with your specific application. Please contact us at (480) 240 3400 or visit www.ftimeters.com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