

# Cold flow operability testing

## Low temperature testing of biodiesel in common rail trucks reveals unexpected operability issues

Low temperature vehicle testing to monitor the effects of vehicle hardware changes on low temperature performance is almost a signature in the industry for Infineum. Recently Infineum has applied its expertise in order to better understand how fuels, biofuels and additives behave in the latest North American heavy-duty and medium-duty diesel common rail engines.

### Biodiesel use

The use of biodiesel blends with ultra low sulphur diesel (ULSD) is becoming more widespread in the industry for environmental, technical and political reasons. The addition of wax from biodiesel presents challenges to the cold flow additive supplier in terms of providing additive products that can give the required low temperature performance, whether used in 100% ULSD or in blends of biodiesel with ULSD. In North America some terminals and retail stations may offer both of these fuel types and often only have one additive available, which must be able to treat both. Depending on its source, a 5% blend of biodiesel into ULSD can provide in the order of an additional 2.5% wax, which needs to be treated for low temperature performance. Since typical North American ULSD contains only 2-2.5% paraffin wax 10°C (18°F) below the fuel cloud point then this additional wax from biodiesel is a major contributor to low temperature performance.

### Common rail systems

One of the hardware technologies being increasingly incorporated into modern engine designs is the common rail. The technology has been around since the 1960's, and today's 4th generation technology is now being applied to heavy-duty vehicles. Common rail technology allows engine manufacturers to combine the benefits of high pressure (~2000 bar) and fully flexible injection for optimised combustion across the engine speed range, which helps to reduce emissions, cut engine noise and maximise engine efficiency.

### Industry concerns

Some industry reports have suggested that the fuel filters in common rail engines are tighter (i.e. they are less porous) and that the new designs have very little fuel recirculation; both of which could impact low temperature performance.

These uncertainties prompted Infineum to evaluate how well current laboratory tests correlate with vehicle low temperature operability performance using ULSD and biofuels in common rail systems. Infineum selected three ULSD (15 ppm S) fuels for testing – the first contained no biodiesel (B0), the second

5% Soy (B5S) and the third 5% biodiesel made with a high cloud B100 (B5HC). Both the untreated fuels and those treated with a cold flow additive were tested in heavy-duty diesel (HDD) and medium-duty diesel (MDD) engines in a target temperature range of -20 to -30°C.

### Results

Cloud point, Cold Filter Plugging Point (CFPP) and Low Temperature Flow Test (LTFT) tests all underestimated the performance of the vehicles in this study. This is not surprising since they are first generation engine designs, which include fuel heating capabilities. In future designs the fuel delivery systems may change significantly to reduce costs if the systems provide unnecessary performance or if performance requirements change. These laboratory tests will be adequate performance predictors for the foreseeable future as none of the tests under-predicted performance, which would be a real issue in the field. It is likely to be many years before these and other new designs replace current on-road vehicles, which means the current HDD and MDD vehicle population is well served by these laboratory tests as demonstrated in recent CRC studies.



In general, B5 fuels exhibited poorer performance than B0, even though the basic low temperature properties of the fuels were not dissimilar. The addition of a cold flow additive resulted in a dramatic improvement in performance in the Soy B5, but less benefit was observed in the B5 made with a high cloud B100. In the additive treated fuels the CFPP came closer to estimating actual performance. However, based on Infineum's extensive experience of testing these types of fuels in these kinds of conditions, it is likely that these fuels would have failed in conventional HDD vehicles closer to the LTFT predictions.

As expected, the treated and untreated B0 fuels performed well in both vehicles. The treated and untreated B5 fuel blends operated to much lower temperatures than predicted by the cloud point, CFPP, or the LTFT tests due to the filter heating design. But in the case of the B5HC fuel the lowest operability was higher than the CFPP result. In all cases cold flow additives provided low temperature operability improvements, but the accepted laboratory tests could not adequately estimate their performance in these new common rail engines.

The addition of just 5% biodiesel had a much greater than expected negative impact on vehicle performance, considering the minor elevation of cloud point that

had been observed. Both untreated B5 blends behaved similarly, although the B5HC did not achieve the same low temperature operability as the B5S.

To interpret the results from low temperature vehicle testing it is essential to understand how cold flow additives improve low temperature performance and how the fuel delivery systems operate in these vehicles.

### Heavy-duty truck

While the fuel system design for the HDD vehicle used is arguably the more complicated of the two systems tested, it is in some ways reminiscent of older designs. It has three filters – the primary (10 µm) and secondary (3-5 µm) filters on the high pressure side of the pumps are used to move the fuel to the common rail. The third, a coarse 100 µm pre-filter, is located on the low pressure side, between the fuel tank and the low pressure pump.

In untreated fuels at low temperatures wax crystals with flat platelet shapes from 100 to 1000 µm tend to form. Fuel systems will continue to operate until a filter or line plugs with these crystals. Without cold flow additives or heat this failure generally occurs at or close to the cloud point of the fuel.

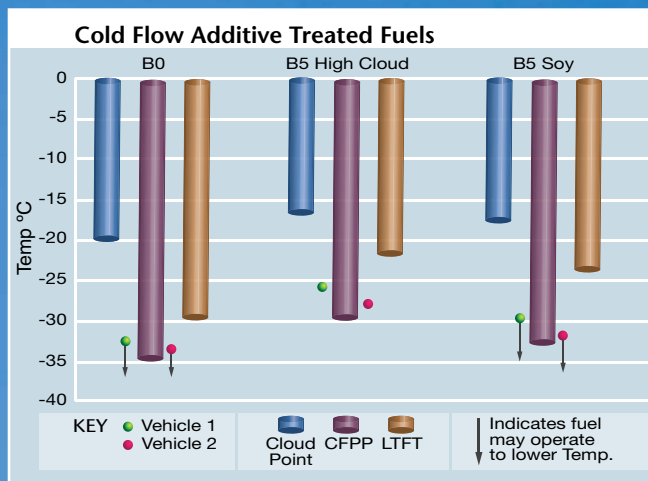
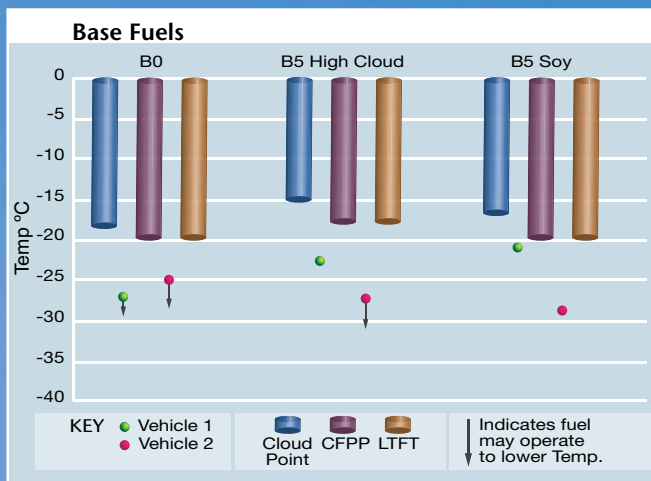
Cold flow additives modify the size and shape of wax crystals so that they can either pass through the filter or form a porous 'wax cake' on its surface.

The cake allows sufficient liquid fuel to pass through until the engine and fuel system warm up adequately to melt any wax build up – the smaller the crystals the faster they melt since they are more readily suspended in the fuel. For the wax to melt, the fuel in the tank must warm up either through the recirculation of hot fuel from the engine or by using some type of heating system. The HDD truck used in this test program employs a coolant heater on the fuel returning to the fuel tank.

The longer it takes to warm the fuel the higher the chance that wax will settle in the fuel tank and the more likely there will be a delay in melting of the wax, potentially leading to operability problems.

The primary filter tends to become blocked because it is usually located on the low pressure side of the lift pump. But even in cases where filters are only on the high pressure side of the pump it is the primary filter that tends to block. Due to the unique design of the fuel system in the truck used in the tests, where multiple bypass and re-circulation loops are included, the engine can keep operating with minimal fuel. However, because tests only run for 1-1.5 hours, it is not yet known if operating under these minimal fuel supply conditions for prolonged periods will be detrimental to the life of the equipment.





Cold flow additives provide significant low temperature performance improvements in the B0 and both B5 fuels

## Medium-duty box truck

The fuel delivery system here is similar to many recent designs, with the primary filter (10 µm) on the low pressure side of the pump and the secondary 4 µm filter on the high pressure side. However, there is one major difference: the primary filter is fitted with a 150 W electric heater to melt any wax that forms. While the heater works well, in some instances the pressure at the primary filter remained high throughout the test. This suggests the heater is able to melt just enough wax to keep the engine running.

The high primary filter pressure throughout most of the tests translates into slow recovery or elevation of fuel tank temperature. This suggests that the vehicle is operating on a minimal amount of fuel, which again raises the question of the durability of the fuel delivery components when operating at such a state for prolonged periods of time. While only few vehicle failures were observed it is likely that the drop in

pressure observed just after acceleration to steady state speed at 80 kph may be a prelude to failure.

The fact that the fuel tank temperature did not rise significantly in most test runs indicates minimal fuel return in most cases. This echoes the concern that a lack of fuel re-circulating to the tank may increase vehicle operability severity. If vehicles travel at high speeds for several hours in low temperatures and the return fuel does not warm the fuel tank then the fuel can theoretically get colder and eventually produce enough wax to starve the engine, which means the vehicle could lose power and speed even though the engine is hot.

## Conclusion

Cloud point, CFPP and LTFT tests underestimated the low temperature performance of B0 and B5 fuels in the common rail vehicles used in this test program.

The results obtained leave questions around the durability of these designs if they operate under maximum pressure/vacuum conditions for long periods.

The use of 5% biodiesel resulted in a significant loss of low temperature performance - much more than would have been expected from the small impact on cloud point.

Cold flow additives provide significant low temperature performance improvements in the B0 and in both B5 fuels. Although the laboratory tests underestimated their performance, they are still a safe indicator of low temperature performance for the current HDD and MDD vehicle population.

It is clear that more work must be carried out by the engine and truck builders, fuel providers and additive suppliers to determine how to protect these newer engine developments without sacrificing the protection of older equipment now that biodiesel and common rail use is growing.



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