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Best Practices Guide for Fuels with a High Cloud Point in Outside Tanks

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Introduction

The need to combat climate change has resulted in a shift toward the use of cleaner energy sources in many industries. The home heating industry faces such a shift as well. Various fuels have been investigated as lower greenhouse gas (GHG) alternatives to petroleum-sourced heating oil. Over the past 15 years, biodiesel has emerged as the most widely available and used of those alternatives. A number of heating oil marketers in the Northeast have already implemented the use of 20% biodiesel blend with heating oil (by volume, hereafter referred to as B20, and BXX for any other percentage of biodiesel) as standard. Some are exploring delivery blends up to B100 to select customers. This can be considered as a vast shift in the industry. Out of the reported 3.6 billion gallons of heating oil sold for space heating in the United States in 2018, 85% was consumed in the Northeast. Therefore, any changes in the Northeast will be strongly projected onto the national market.

While biodiesel has similarities to pure petroleum-based heating oil, it is chemically different. Biodiesel fuels generally crystallize ("wax" or "cloud") and freeze at temperatures greater than that of heating oil. A metric used to quantify cold flow properties is the cloud point, which is the temperature at which solid crystals start appearing upon cooling of the liquid. Pour point is also a common cold flow metric. Both of these are defined by ASTM standards. Table 1, below, provides typical values of the cloud point and pour point of biodiesel made from different types of vegetable oil [2]. This should be taken only for example. Fuel properties vary considerably and the biodiesel used in tests in this project has lower cloud and pour points than listed in this table with any feedstock. Also, biodiesel fuels now are commonly made with blends of vegetable oil types and not just one source.

Table 1: Typical Values of Cloud and Pour Points of Biodiesel Made from Different Vegetable Oil Feedstocks

Petroleum-Based Oil or Biodiesel Feedstock	*Cloud Point (°F)*	*Pour Point (°F)*
No. 2 Heating Oil	15	5
Kerosene	-35	-40
Soybean Oil	34	32
Canola Oil	32	16
Palm Oil	63	59
Jatropha Oil	46	43
Tallow	54-63	43

Because the cloud point of pure biodiesel is greater than that of pure petroleum heating oil, increasing blends of biodiesel in a mixture of the two will have increasing cloud points. A B20 blend made from a fuel oil sample with a cloud point of -20°F and a biodiesel sample with a cloud point of 35°F will have a cloud point somewhere between the two and closer to that of the fuel oil than that of the biodiesel. However, a B80 blend made from the same fuel oil and biodiesel samples will have a cloud point that is closer to that of the biodiesel portion.

The risk of gelling fuel in outdoor tanks then becomes greater, given the shift of the industry towards higher blends of biodiesel. The research performed in this study examined various methods as potential solutions to this concern. All tests included an external source of heat, while some, in addition, utilized insulating material. This report outlines these tests and suggests the most effective methods to keep fuels with high cloud point from freezing in outdoor tanks.

While there are different types of home heating oil tanks available on the market, the most common is the vertical, 275-gallon steel tank [3]. All work in this project focused on this type of tank. It should be noted that some 90% of home heating oil tanks are not outdoors and so this work only applies to the fraction which are outdoors and which cannot be practically moved indoors.

Experimental Setup

All tests were performed at the NORA lab facilities in Plainview, New York. In order to provide controlled cooling so the desired tests could be performed, an industrial walk-in cold chamber rated at 36,000 BTU/hr was rented from Polar Leasing Company for the duration of the test period. This cold chamber enabled cooling to various target temperatures.

Tanks, Heaters and Fuel System

Two Granby UL-142 steel tanks (275 gallons each) were installed inside the cold chamber. 250 gallons of B100 (nominal, testing found 94.5% biodiesel) was purchased from a local fuel marketer and pumped into the tanks – 200 gallons into one tank and 50 into the other. The fuel had a cloud and pour point of 26°F. The results of cold-flow and biodiesel content tests performed by Iowa Central Fuel Testing Laboratory for the test fuel is included as Attachment I to this report. A pump was set on a burner chassis along with piping to allow fuel to be transferred between the tanks. The fuel transfer could occur as a one-pipe or two-pipe flow to and from either tank. The piping was setup such that pressurized flow out of the pump could be returned to the supply tank or transferred to the other one at a flow rate of 1 gallon-per-hour (nominal). Return flow from the pump in two-pipe setup could also be directed to either or both tanks.

Figure 1 below shows the tank setup inside the cold chamber. The tank on the right (Tank A) was used as the main reservoir for all tests. The wooden box attached to that tank contains the burner and pump setup for transferring fuel to the on the left (Tank B). Insulated copper tubing was used to transfer the fuel to and from the pump. All tubing was covered in heat tape (not shown) and insulation in order to keep the fuel liquid when fuel transfer was required.

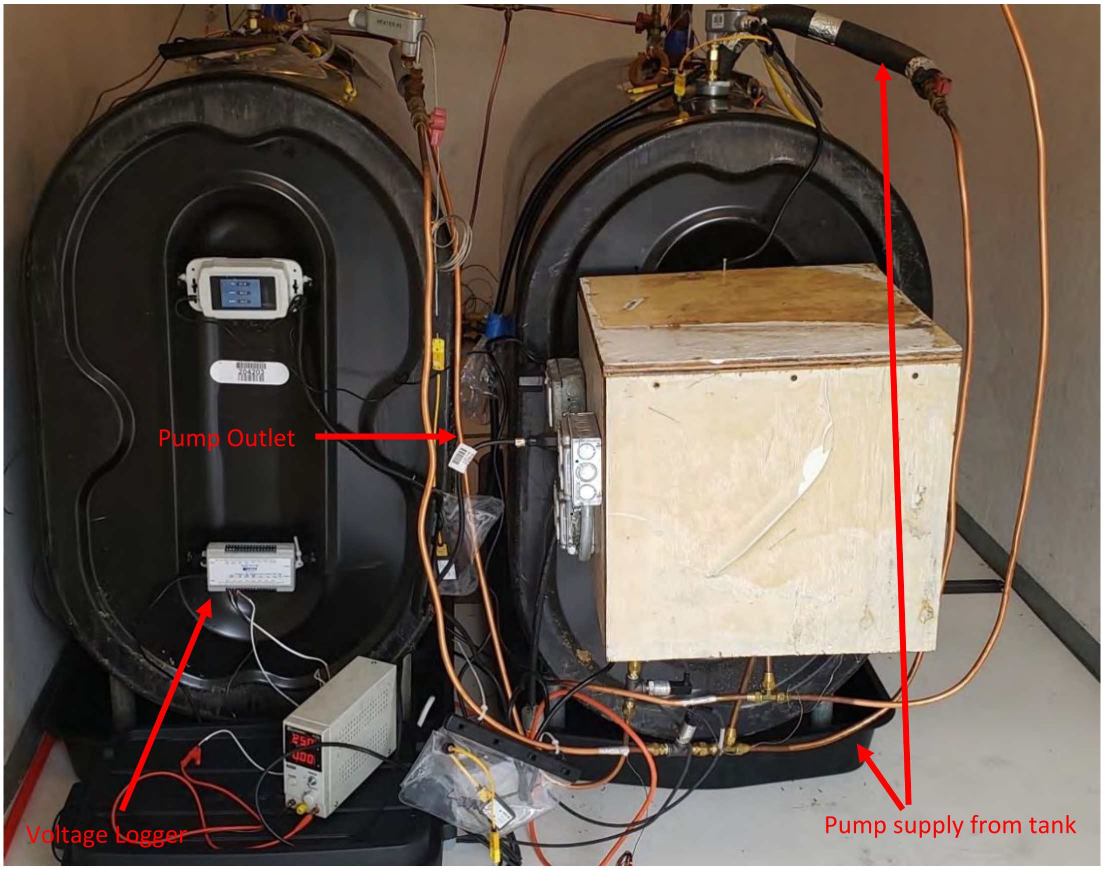


Figure 1: Tank, piping, and data acquisition setup

Thermocouples were setup for temperature measurements at various points in the tank. The tank configuration is shown in *Figure 2*, prior to installation in the cold chamber, with the 5 threaded holes (referred to hereafter as bungs) for fittings labeled. Bung 3 is always reserved for the fill alarm and was only utilized for taking pictures of the inside of the tank since it provided the best view of the fuel condition. The other bungs were all equipped with double tapped bushings to allow insertion of other hardware. Various in-tank rod heaters were tested, all manufactured by a Rollie Products, Inc. Each heater was inserted into bung 1 for testing. The first style of rod heaters used was entirely vertical, as shown in *Figure 3*. The heating element in these heaters was contained in the bottom 8 inches of the heater rod, which reached down to ~4 inches from the bottom of the tank. The copper tube for fuel draw from the tank was placed in the same bung for tests involving this type of heater. In some cases, the heater and fuel supply tube were enclosed by a long steel tube. The other kind of heater, shown in *Figure 4* contains an 8-inch horizontal portion at the bottom end of the vertical section. The fuel supply tube did not fit in the same bung with this heater, so it was moved to bung 2.

Figure 2: Field picture of steel tank used in the study with the various bungs labeled

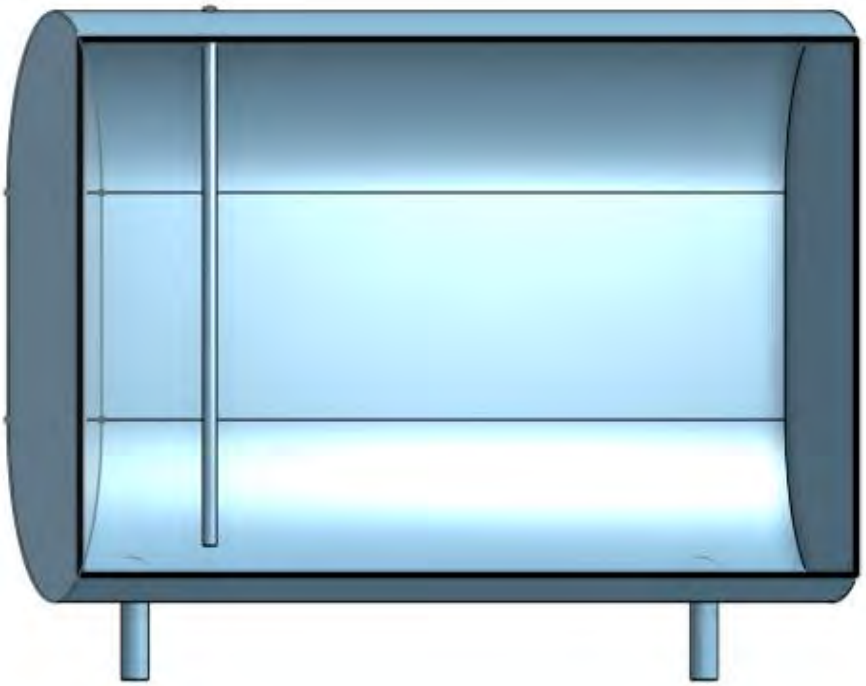


Figure 3: Cross-sectional drawing of tank to show in-tank vertical rod heater

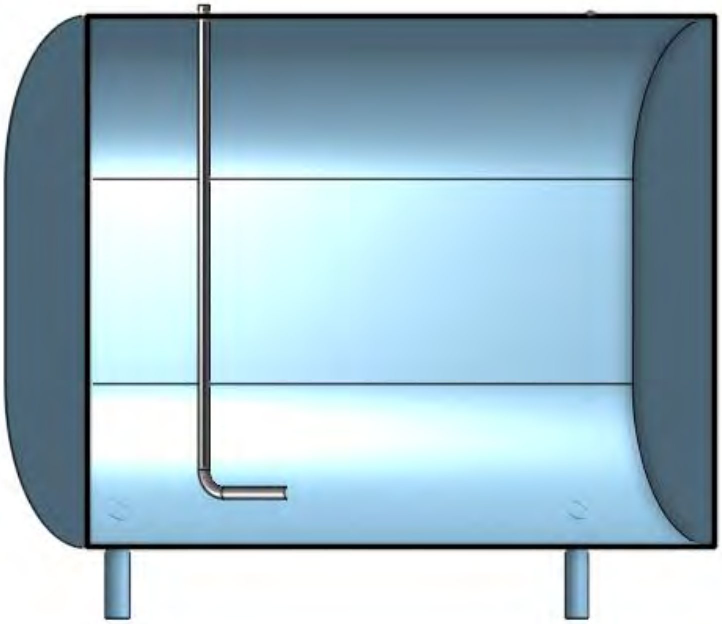


Figure 4: Cross-sectional drawing of tank to show in-tank rod heater with horizontal heating element

Data Acquisition

For temperature measurement inside the tank, 48-inch long thermocouple probes, reaching ~5 inches above the bottom of the tank were installed in bungs 2, 4 and 5. These probes were ~12, 24 and 36 inches away horizontally from the heater, respectively. An adhesive “stick-on” thermocouple probe was attached to the pump supply line immediately after its exit point from the tank. Other adhesive thermocouple probes were installed on the supply and nozzle exit lines close to the pump.

All thermocouple probes were of K-type and were connected to Thermoworks TC101A temperature loggers, which were set to record temperature measurements once every 30 seconds. These loggers also measured their surrounding ambient temperatures, providing data on the actual temperature inside of the cold chamber. The loggers were stored inside protective waterproof pouches (from Thermoworks) with K-type compatible thermocouple probe leads to prevent moisture damage. Pressure on the pump outlet and vacuum on pump inlet was measured using TDC31 transducers from Transducers Direct. The output voltage from the transducers was measured using a DI-2108 voltage logger from DATAQ Instruments. The logger was set to record data every 100 ms. During tests where the fuel was transferred from one tank to the other, these pressures were useful indicators of the presence of flow blockages, caused by gelled fuel.

In addition to the thermocouple in-tank sensors, a set of 3 RTDs, each connected to wires of varying lengths on a vertical probe, provided temperature readings on an external display. This setup was installed close to the heater in the tank so that live vertical temperature profiles could be measured to observe the state of heating and cooling of the fuel in the tank.

Other Heaters and Hardware

For one set of tests, the entire tank was covered with 1-inch thick insulation rated at R4, which is based on NBR/PVC elastomers. This insulation is manufactured by K-Flex. Pieces of various sizes were joined together and installed on Tank A with duct tape, the setup of which is shown on the left side of *Figure 5*. Another set of tests was performed with an enclosure formed by creating outer "walls" using R5 per inch insulation from Foamular, which totaled to R15 at a thickness of 3 inches of the finished enclosure. This setup provided an air gap between the tank wall and insulation and is show in the right side of Figure 5.

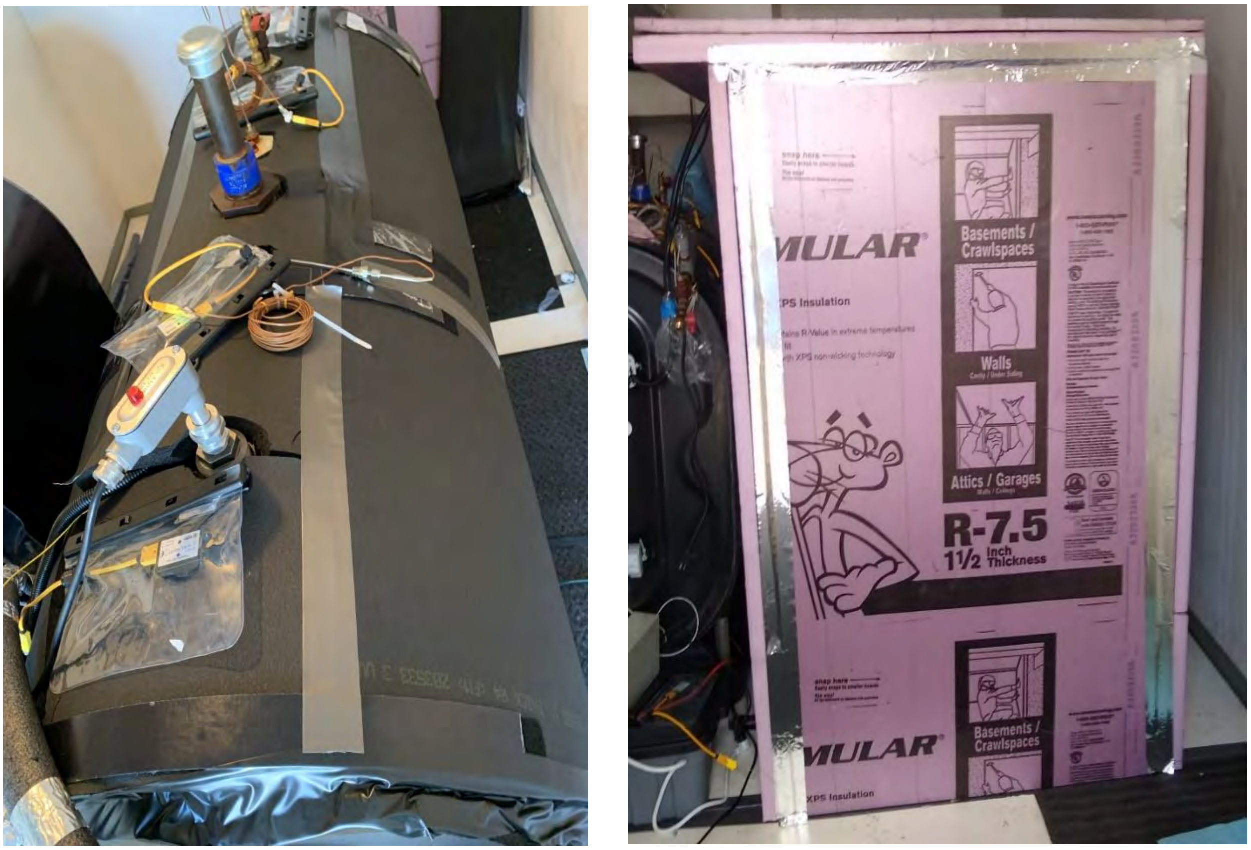


Figure 5: R4 insulation wrapping entire tank (left) and R15 enclosure for tank (right)

Another form of enclosure used was a storage shed purchased from Home Depot. The inside of the shed was insulated with the same Foamular insulation as the one shown above.

With the enclosures, pad or "mat" heaters that are mainly used to heat plants that are grown indoors were used. For one of the test methods, two of these heaters were suspended in the air inside the enclosure setup shown above (Figure 5, right side). A plate style heater with an aluminum enclosure was also used in a different test, where it was secured onto the bottom of the tank with straps. This heater was manufactured by the same company that provided the rod heaters.

List of Tests

A number of tests were performed for this study but not all of them will be discussed in this report. The tests that provided insight into possible solutions to the problem of fuels freezing in outdoor tanks were chosen for detailed discussion. *Table 1* below briefly outlines the tests in which only a rod heater with no added insulation is used. All tests initially began with cooling provided by the cold chamber. The heating period was started after a certain amount of cooling in all tests except number 8. In all cases, cooling of the cold chamber continued throughout the test period, including the portion during which the tank heater was powered.

Table 2: Brief Description of Tests with Rod Heaters Only

Test Number	*Heater Setup*	*Description of Test*
1	• 100W in-tank rod heater • Supply line and heater enclosed in a 2-inch tube inserted in bung 1	• Cold chamber set to maintain temperature between 30°F and 35°F • Heater turned on after fuel temperature stabilized and tracked chamber setpoint • After some heating, fuel was transferred from tank A to tank B (while still heating fuel)
2	• Same as test 1	• Same initial conditions as test 1 • Fuel draw in cycles of 5 min on and 5 min off
3	• Same as test 1	• Cold chamber set to maintain temperature between 15°F and 20°F • Heater turned on after fuel cooled to chamber setpoint • After 2 days of heating, fuel draw was started
4	• Same as test 1	• Cold chamber set to maintain temperature between 5°F and 10°F • Heater turned on after fuel cooled to chamber setpoint • After a few hours of heating, fuel draw was started
5	• Same as test 1	• Cold chamber set to maintain temperature between -5°F and 0°F • Heater kept on during cooling period until steady state was reached, after which fuel flow was started
6	• Two in-tank rod heaters installed • 200W heater and supply line in bung 1, not inside tube • 100W heater in bung 5	• Same cold chamber temperature settings as test 5 • Heater turned on after fuel cooled and frozen • Fuel draw started after 22 hours of heating
7	• 350W in-tank rod heater with horizontal element • Supply line in bung 2	• Same cold chamber temperature settings as test 5 • Heater turned on after fuel had completely frozen • Fuel draw initiated after 7 hours of heating
8	• 225W in-tank rod heater with horizontal element • Supply line in bung 2	• Same cold chamber temperature settings as test 5 • Heater and cold chamber started at the same time to observe condition of fuel as cooling occurred

Table 2 below outlines and briefly describes tests where an insulating method was added along with some form of heating.

Table 3: Brief Description of Tests with Insulation and Heating

Test Number	*Heater/Insulation Setup*	*Description of Test*
9	• Enclosure made of R15 foam insulation installed around tank • 100W in-tank rod heater	• Fuel warmed to ~55°F before cooling • Same cold chamber temperature settings as test 5 • Fuel cooled without heating for 70 hours • Heating provided for 30 hours after
10	• Same enclosure as test 9 • Two 100W heaters mats suspended in the air using strings	• Same cold chamber temperature settings as test 5 • Two phases in the test with varying height of heaters from the ground: o 2 feet o 7 inches
11	• R4 insulation wrapped around entire tank, as shown in *Figure 5* • 350W in-tank rod heater with horizontal element	• Same cold chamber temperature settings as test 5 • Heater turned on after fuel had completely frozen • Fuel draw initiated after 7 hours of heating
12	• Same insulation as test 11 • 225W in-tank rod heater with horizontal element	• Same cold chamber temperature settings as test 5 • Heater and cold chamber started at the same time to observe condition of fuel as cooling occurred

Results and Discussion

The 12 tests chosen above provide the basis for discussion of the various solutions to freezing of low cloud point fuels in outdoor tanks. As a reminder, the cloud and pour points of the fuel used for this test were 26°F. References to temperature differences between the cloud point and the on-setting for the ambient cold chamber temperature will be made when discussing a particular test [note: the control in the cold chamber used has an on- and off-setting. On rising temperature in the chamber, the "on-setting" is the temperature at which the chamber cooling system is energized to begin cooling] This is because the temperature in close proximity (within a few feet of it) of the tank almost always tracked close to the on-setting temperature, which is a result of the position of the temperature sensor relative to the tank. For example, the ambient temperature parameter for test 2 will be described as "10°F below the cloud point of the fuel". The purpose of such terminology is to provide a clear understanding of which potential solution best fits the particular fuel used by someone seeking to use the results of this study. Furthermore, the temperature measurement points that are 12, 24 and 36 inches away horizontally from the bottom of the rod heater position in bung 1 will be referred to as MP1, MP2 and MP3, respectively.

Each of the first 5 tests listed above were simulating cold conditions following a power outage, where the heater performed recovery for a few hours before the burner was started. The purpose of tests 1 and 2 was to determine if, under the same conditions, the supply output would be different for an intermittent fuel draw (test 1) as compared to a continuous one (test 2). No advantage was found for one circumstance over the other given that the difference between the average supply temperatures for each was less than 1°F.

The tests after first two, up to test 5, were performed to determine how low a temperature below the cloud point of the fuel a 100W heater would work. For ambient conditions of 5°F below cloud point on average (test 3), the heater was able to provide 18.5 hours of continuous draw with an average supply temperature of 50.84°F. The draw was started after 6 hours of heating. In the case where cold chamber setpoint temperatures were 15°F below the cloud point on average (test 4), 6 hours of fuel supply was provided at an average supply temperature of 52.94°F. Test 5 was the most extreme of these cases, where cold chamber setpoint temperatures were 25°F below the cloud point on average. For this test, no specific draw period was set, and the burner pump was allowed to operate until failure. This is a situation where the boiler would have to operate continuously to recover heat lost after an extended period of power outage. The result was that the rate of fuel draw under these conditions was too great and the heater could not stop the freezing of more fuel over time. Shown in *Figure 6* below are the tank conditions at the start of the fuel draw and just before failure.

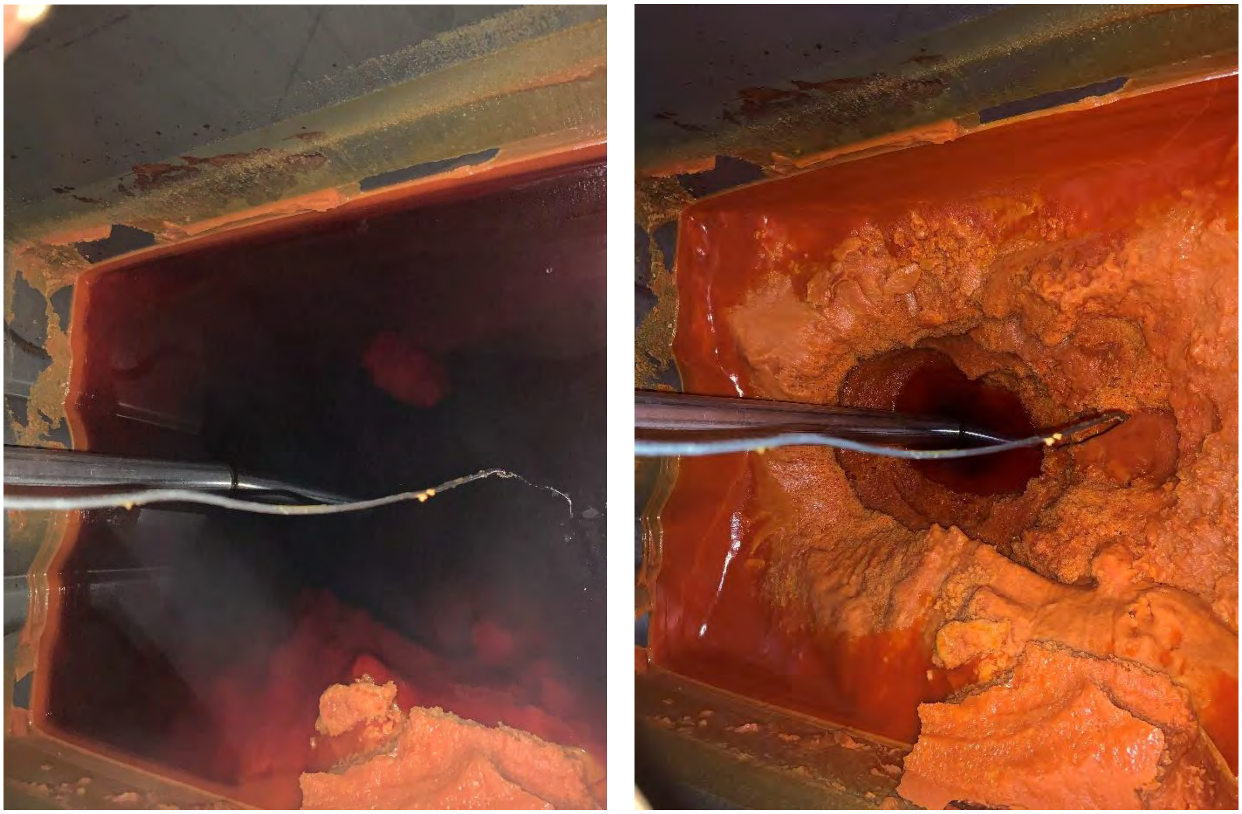


Figure 6: Condition of fuel close to heater during test 5 at start of draw period (left) and 23 hours into draw period just before failure (right)

Based on the above, it can be established that a 100W heater may not suffice when temperatures drop to 25°F below the cloud point. Another point also established from the above set of tests is that the use of a 2-inch tube to enclose the heater and supply line restricts the flow of heat to the rest of the tank. This is observed from the data which shows almost no rise in the fuel temperature at MP1 while temperatures inside the 2-inch tube rise to 20-40°F (depending on the height) above the cloud point. Furthermore, visual observation showed that fuel that was beyond 24 inches of horizontal distance away from the heater was frozen to the top even when temperatures were only 5°F below the cloud point. Based on these observations, it was decided that the 2-inch tube surrounding the heating element would not be utilized in the remaining tests.

In order to tackle the problem of heat distribution in temperatures 25°F below cloud point, test 6 was performed by using a stronger primary heater (rated at 200W) close to the supply line and adding a secondary heater (100W) to the opposite end of the tank. This method allowed not only more heat to remain in the tank, but also better flow across the fuel within it. This was shown by a constant rise in temperature at MP1. The temperature at that measurement point rose above the cloud point of the fuel and settled to 3°F above it, whereas in tests 3, 4 and 5, there was little to no rise. This demonstrates the effectiveness of the higher heating power level. *Figure* 7 below shows that temperature for test 6 during the heating and draw periods, along with a line representing the cloud point of the fuel.

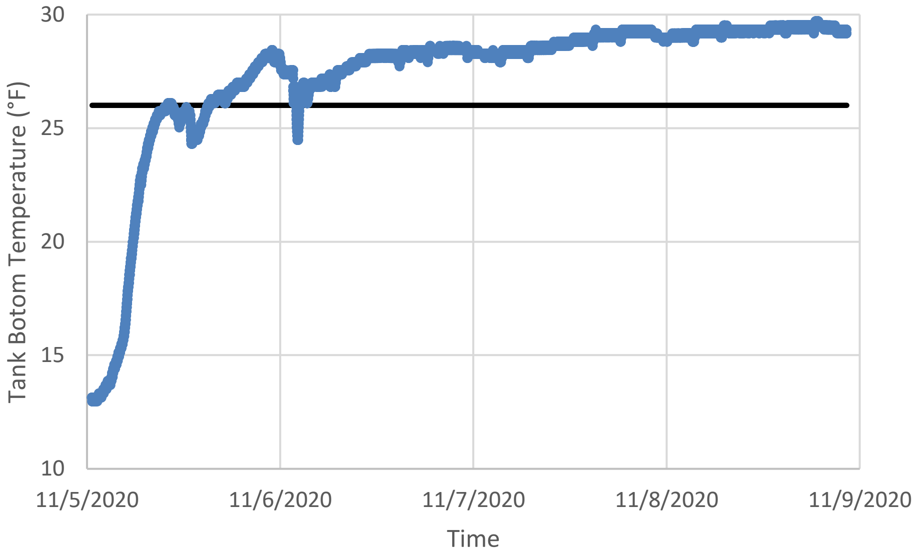


Figure 7: Tank bottom temperature 24 inches away from primary heater for test 6

The only negative outcome of this test was that after 69 hours of continuous draw, the transducer data indicates a drop in outlet pressure from the pump. While the pressure eventually increased back to that of normal operation, the drop was indicative of frozen fuel particles being drawn by the pump. This can be verified by a drop in fuel temperature very close to the supply point.

The setup for test 7 only included a 350W rod heater. The horizontal heating element at the bottom of this heater was intended to solve the problem of the bottom of the tank remaining frozen. That was not achieved, as the three bottom temperature measurement points all showed no rise in temperature throughout the heating period. The heat did, however, melt all fuel on top of the tank. The initially observed melting of fuel close to the heater during the heating period continued even after fuel was continuously drawn out of the tank. As a comparison to this, test 11 was performed to emulate these conditions as closely as possible, along with the addition of an R4 insulating material covering the whole tank. The average supply temperature for this test was 32.10°F, which was greater than the value of 30.3°F for test 7. The insulated system also allowed bottom fuel at MP1 to melt and then increase in temperature beyond the cloud point. The measurement point 24 inches away horizontally from the heater also showed an increase but did not reach the cloud point by the end of the test.

A more compelling point for using the insulation can be made using the differences in heater performance between tests 8 (without insulation) and 12 (with insulation). For these two tests, the same horizontal style heater as tests 7 and 11 was used, except the power rating was cut down to 225W using a Variac voltage transformer. The starting fuel temperature for both tests 8 and 12 are almost the same. The fuel volume in the tank was also kept constant between the tests. This was done in order to ensure the comparison made between temperature measurements was independent of factors other than the heater and cold chamber. *Figure 8* below shows the temperature of the fuel at MP1 during tests 8 and 12, and a reference line for the cloud point of the fuel in orange. In the figure, hour 0 is the start time of each test.

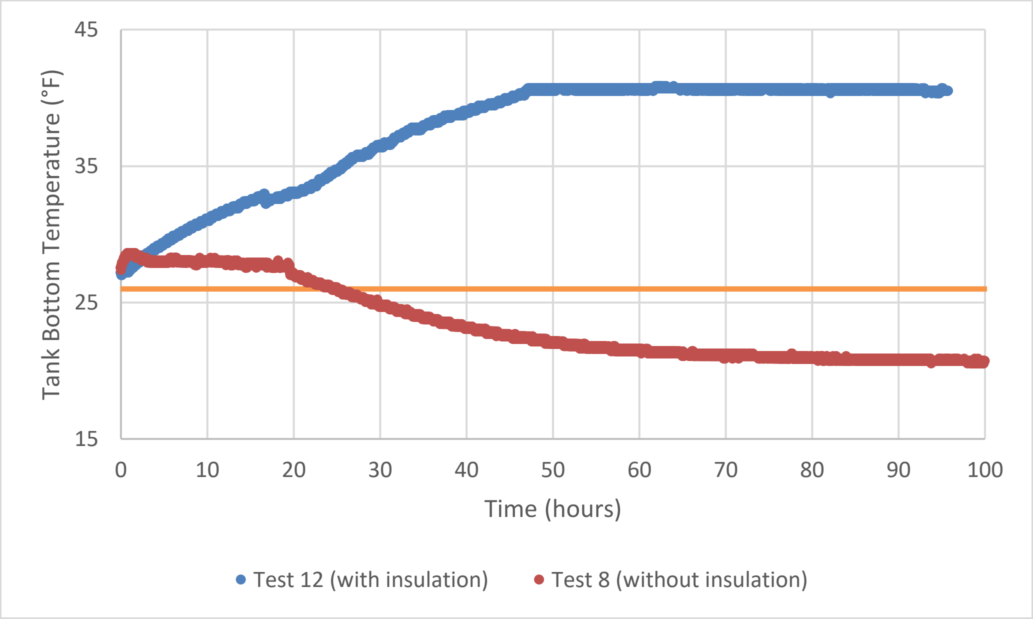


Figure 8: Tank bottom temperature 12 inches away from primary heater for tests 8 and 12

The comparison shown in the figure above clearly demonstrates the advantage provided by the insulation. This suggests that the presence of the insulation allowed heat flow rate out of the tank to slow down enough to allow the flow of heat internally via convection. On the other hand, the setup without insulation is unable to achieve the same because the heat loss to the surroundings is too great.

Another insulation setup examined was the R15 enclosure. Test 9 was performed to determine if a 100W heater accompanied with this setup will provide a substantial advantage. For the first phase of this test, the heater was not turned on, and the fuel was warmed to 60°F as measured at MP1. As expected, the enclosure slowed down the cooling of the tank. Once cooled just under the cloud point, the heater was turned on. Despite the presence of the enclosure, the heater was not able to provide sufficient heating to MP1, MP2 and MP3 and the fuel in those regions remained frozen. This is the result of the air temperature inside the enclosure decreasing down to the setpoint temperature of the cold chamber, at which point the rate of heat transfer out of the tank is expected to be the same as it would be if there was no enclosure.

Because of this failure, the idea of heating the air inside the enclosure was proposed. This was performed in test 10. The first phase of this test was deemed a failure because the heating mats were placed too high up from the floor, which resulted in the heat only affecting the top of half the tank and escaping through the top of the enclosure while leaving the bottom half of the tank unheated. This was fixed by lowering the position of the heaters to within a few inches of the floor. This changed the results dramatically by raising the temperature of the fuel in MP1 and MP3 to the cloud point and keeping them above it throughout.

Best Practices Guide

Based on the results of the tests discussed in this report, a list of possible solutions was made for the general problem of issues with freezing fuels in outside tanks. They are the following:

- Installing a rod heater is possibly the simplest way to tackle the issue of freezing tanks. A 100W rod heater is sufficient in regions where the temperature does not drop to more than 15°F below the cloud point.
- If temperatures are expected to be lower than 15°F below the cloud point, it is recommended that the power of the heater be increased. For example, a 350W heater will should suffice for temperatures as low as 25°F below the cloud point. It is possible this will work to a lower temperature, but there is not enough data to suggest that.
- In order to ensure more portions of the bottom of a tank are kept liquid, the heating power should be divided between a primary and secondary rod heater. Here, the primary heater should be more powerful and close to the supply tube while the secondary should be on the opposite end of the tank.
- Use of an insulated enclosure is only effective if the air inside of the enclosure (between tank wall and inner wall of insulated enclosure is kept warm using a heater. For purposes of recovery from a power outage situation, an internal rod heater can be added inside the tank.
- Adding insulation to cover the entire tank can make the rod heater substantially effective and even lower the power rating of the heater required. This is highly recommended to

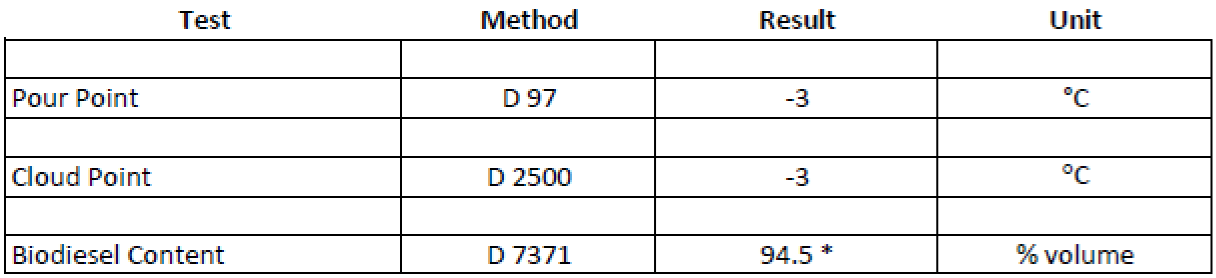
use, but there is no existing product in the market. There is a concern that any insulation covering will trap moisture and contribute to corrosion of the tank,

- A control method for power heaters on and off based on fuel temperature is highly suggested to decrease power consumption.

References

[1] “Heating oil explained: Use of Heating Oil.” U.S. Energy Information Administration. www.eia.gov.
[2] Knothe, G., Krahl, J., and Van Gerpen, J. “The Biodiesel Handbook” (2nd Edition). AOCS Press, Urbana, 2010.
[3] Donohue, J., Levey, J. "Advanced Heating Fuel Storage Tanks”. National Oilheat Research Alliance. 2020. www.noraweb.org/advanced-study-manuals.

Attachment I – Cold Flow Property Test Results of Fuel



Test	Method	Result	Unit
Pour Point	D 97	-3	°C
Cloud Point	D 2500	-3	°C
Biodiesel Content	D 7371	94.5 *	% volume