Performance of Thermo King Reefer with Yanmar 2010 2.1 L Engine on Refrigerated Trailer Using Fuel Saving Unit

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Project Summary

A new fuel savings unit for diesel engines has been developed. The unit implements the use of a heat exchanger and a fuel catalyst in a certain configuration to accommodate an increase in fuel efficiency. The focus of this study is to determine if the fuel savings unit performs as intended when installed on a Thermo King Reefer with a 2010 Yanmar 2.1 L engine, and to shed light on the ideal working conditions of the unit. This study focused primarily on fuel consumption data but also includes data external to the system such as time of day, ambient temperatures, and humidity. It is noted that the conditions external to the system have an impact on its relative efficiency. The test results show that the system experienced an overall fuel efficiency increase of 13.28% with a range between 9.24-22.13% depending on factors such as time of day, ambient temperature, and humidity.

1. Objective:

The principal objective of the proposed testing is to determine the changes in the fuel consumption of Thermo King Reefer with a 2010 Yanmar Engine for 53’ Refrigerated Trailer owned by Cool Carriers, INC using a Vapster-Diesel RV-3300. The goal is to improve the fuel efficiency of the Reefer Engine used in the Refrigerated Trailer.

2. Technical Approach:

The performance of the Vapster-Diesel RV-3300 Fuel Saving Unit (Retrofit System) installed on the Yanmar Reefer Engine of Refrigerated Trailer is tested in this study. All the proposed tests are performed off site at Delray Beach. The goal is determine the changes in engine fuel consumption using this new Fuel Saving technology. To reach this goal, we are proposing:

2.1 Protocol for engine testing:

In order to decrease the possibility of a bias between the base runs and test runs the protocol for engine testing was kept identical for each.

2.1.1 Test without Fuel Savings Device- Baseline measurements

(a) Number of tests = 5

(b) Duration for each test = 0.5-1 hour

2.1.2 Repeat the same tests with the Fuel saving device

(a) Number of tests = 8

(b) Duration for each test = 1 hour

2.1.3 Repeat the same test with only heat exchanger, without fuel catalyst

(a) Number of test = 1

(b) Duration of test = 1 hour

2.2 Refrigerated Trailer, Reefer Engine and Fuel Saving Unit

The 53’ refrigerated Trailer (ThermoKing 200B Cooling Unit) and the Thermo King Yanmar Reefer Engine (4 cylinders) with the Fuel Saving Unit are shown in the figure below.

2.3 Fuel Consumption Measurements

In order to keep this study as consistent as possible the fuel consumption procedures were kept identical for each of the tests. The principle of the test was to measure the initial and final weights of a fuel tank that could be attached and reattached to the engine, shown below. The difference of these two readings would be the total fuel consumed by the engine during a set period of time. As stated above the time period was identical for both the baseline and test runs allowing comparison of the two. To ensure that the weight of the tank was measured correctly the Ohaus Floor Scale was correctly calibrated and leveled before use. Also in order to simulate the operation of the trailer a fan was kept blowing on the fuel tank in all tests. Because the testing took place in the period of two days each time the engine would be left alone for a long period of time the following set-up procedure was followed.

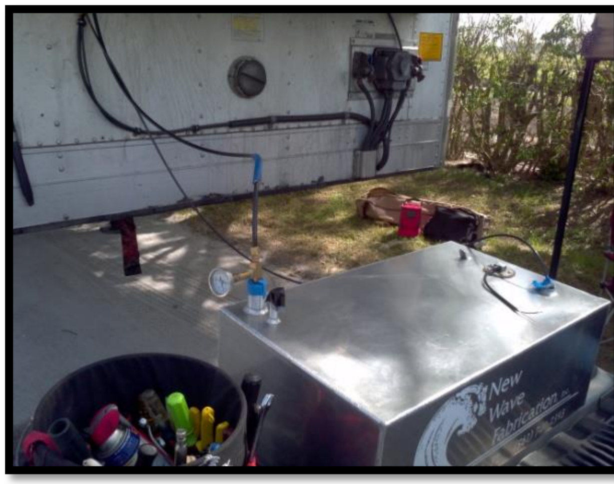
<u>Set-up Procedure</u>:

1) Engine was turned on, let run on its own fuel for twenty minutes in order to allow it to reach operating temperatures.
2) The Ohaus Floor Scale was leveled and tared.

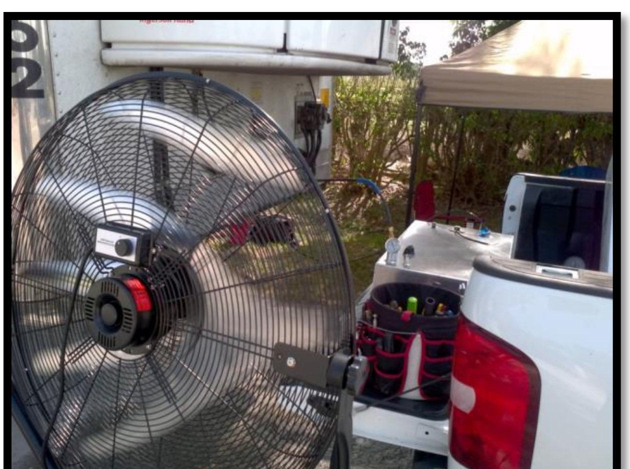
3) Fuel saving unit would be installed or uninstalled depending on the tests to be run. Air that entered the system during installation was ejected using the engine's priming pump.
4) Fan was put in place and switched on - regular testing procedure was followed.

Testing Procedure:

1) Initial weight of the separable tank filled with fuel was taken using a scale (tared).
2) Fuel tank was reconnected to engine using a feed and return line (fan turned on).
3) The Thermo King Yanmar was started and the back doors of the trailer would remain open. This would ensure that the thermostat would not control the speed of the engine and create an additional variable in the study. With the trailer door open the engine would run on low speed for two minutes and then run on high speed for the remainder of the test run. Test run time was taken using stop watches.



4) During the test run the ambient temperature and humidity was taken. Also at twenty and forty minutes the fuel temperature was recorded using the feed line thermometer. The time of day was also recorded.



5) After allowing the engine to run for the exact testing time (for most runs 1 hour), the engine was shut off.
6) Removed the fuel feed and return lines.
7) Allowed the tank to cool for ten minutes.
8) Final weight of the separable tank was recorded using the tared and balanced scale shown below. The

difference between the initial and final weight reading represented the fuel consumed during the run.

9) The tank was then reconnected to the engine using the fuel feed and return lines and the next test run was ready to begin.

2.4 Temperature measurements:

The temperature of the fuel tank was taken ever at twenty and forty minutes into each of the runs. This temperature was taken using a thermometer attached to the fuel feed line and can be seen in the photographs above. Also the ambient temperature and humidity was taken using the Weather Channel app for the Delray Beach, FL area.

3. Results

The following table shows the fuel usage data for all fourteen test runs taken during the two day period of testing.

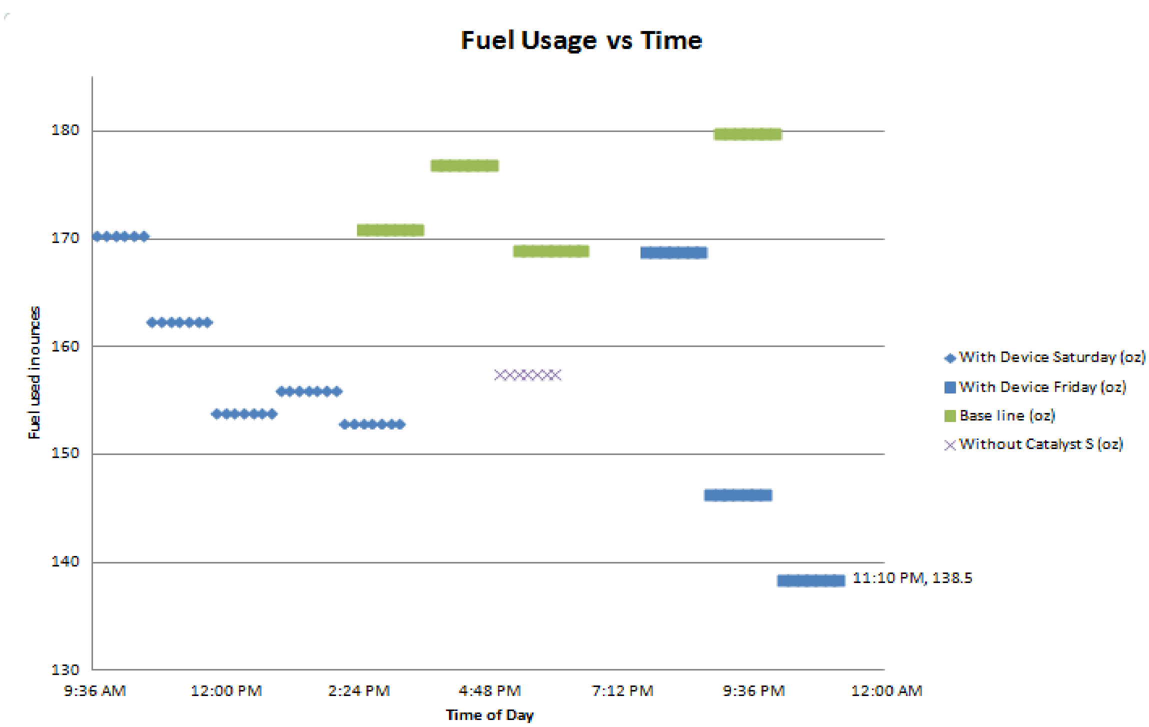
1B= first baseline run
1F= first run with fuel saving unit
1C= Run without fuel Catalyst

Fuel Usage			
Test Run	Fuel Used (oz)	Run Time (hr)	Burn Rate (gal/hr)
1B	171	1	1.3359375
2B	177	1	1.3828125
3B	169	1	1.3203125
4B	154.5	1	1.20703125
5B	91.5	0.5	1.4296875
1F	169	1	1.3203125
2F	146.5	1	1.14453125
3F	138.5	1	1.08203125
4F	170.5	1	1.33203125
5F	162.5	1	1.26953125
6F	154	1	1.203125
7F	156	1	1.21875
8F	153	1	1.1953125
1C	157.5	1	1.23046875

The following chart also offers an understanding of the fuel usage (oz) in relation to the time of day and therefore ambient conditions.

It must be noted that baseline run ‘4B’ is not included in the chart above. This test run was not considered accurate because it was performed after a series of test runs with the fuel saving unit attached. The fuel savings unit raises the temperature of the tank to above 115 degrees Fahrenheit whereas the basline runs all were recorded to be near the 105 degrees Fahrenheit range. Immediately before trail ‘4B’ the tank was not given enough time to cool. For this reason the last baseline run ‘5B’ was done after ‘4B’ but the tank was allowed to cool to close to 100 degrees Fahrenheit. Because it was late at night and after an entire day of testing this test was only run for half an hour not an hour. It is reasonable to presume that the fuel usage of a half hour run can be projected out to an hour run. This is what is shown in the table above. Also test runs ‘1F’ and ‘4F’ are not included in the following analysis because these tests were the first tests with the Fuel Savings Unit and the Designer believes that his system had not yet achieve operating temperatures.

If the table above is inspected the following can be deduced. First, the baseline runs all fall between 169-180 oz/hr range and the test runs with the fuel saving unit falls between the 138-162.5 oz/hr range. Second, the fuel usage of the fuel savings unit does not show much of an improvement from the baseline for the first test of the day, but as the time of



the day (therefore number of runs) progresses the efficiencies increase. Third, there seems to be some correlation between the time of day and the highest achievable efficiency. In other words, the highest efficiency of 138.5 oz/hr achieved by test run '3F' was completed in the middle of the night, when temperatures dropped and humidity increased. There are several ways of viewing the data and they will be portrayed below. First the Overall fuel efficiency data is computed below.

Over-all Baseline Average Fuel Consumption:

$$\frac{171 + 177 + 169 + 183}{4} = 175\ oz/hr$$

Over-all Fuel Savings Unit Average Consumption:

$$\frac{146.5 + 138.5 + 162.5 + 154 + 156 + 153}{6} = 151.75\ oz/hr$$

Overal Fuel Saving Percent Increase:

$$\frac{(175 - 151.75)\ oz/hr}{175\ oz/hr} * 100 = 13.28\%$$

A second way of viewing the data is making note of the large difference between daytime and nighttime relative efficiencies. Calculations are shown below. Daytime is considered before sunset at 7pm and nighttime is considered after 7pm.

Daytime Baseline Average:

$$\frac{171 + 177 + 169}{3} = 172.33\ oz/hr$$

Daytime Fuel Savings Unit Average:

$$\frac{162.5 + 154 + 156 + 153}{4} = 156.4\ oz/hr$$

Daytime Fuel Savings Percentage Increase:

$$\frac{(172.33 - 156.4)\ oz/hr}{172.33\ oz/hr} * 100 = 9.24\%$$

Nighttime Baseline Average: Because run '4B' is not being used there is only one reading for baseline, '5B' at 183 oz/hr.

Nighttime Fuel Saving Unit Average:

$$\frac{146.5 + 138.5}{2} = 142.5\ oz/hr$$

Nighttime Fuel Saving Percentage Increase:

$$\frac{(183 - 142.5)\ oz/hr}{183\ oz/hr} * 100 = 22.13\%$$

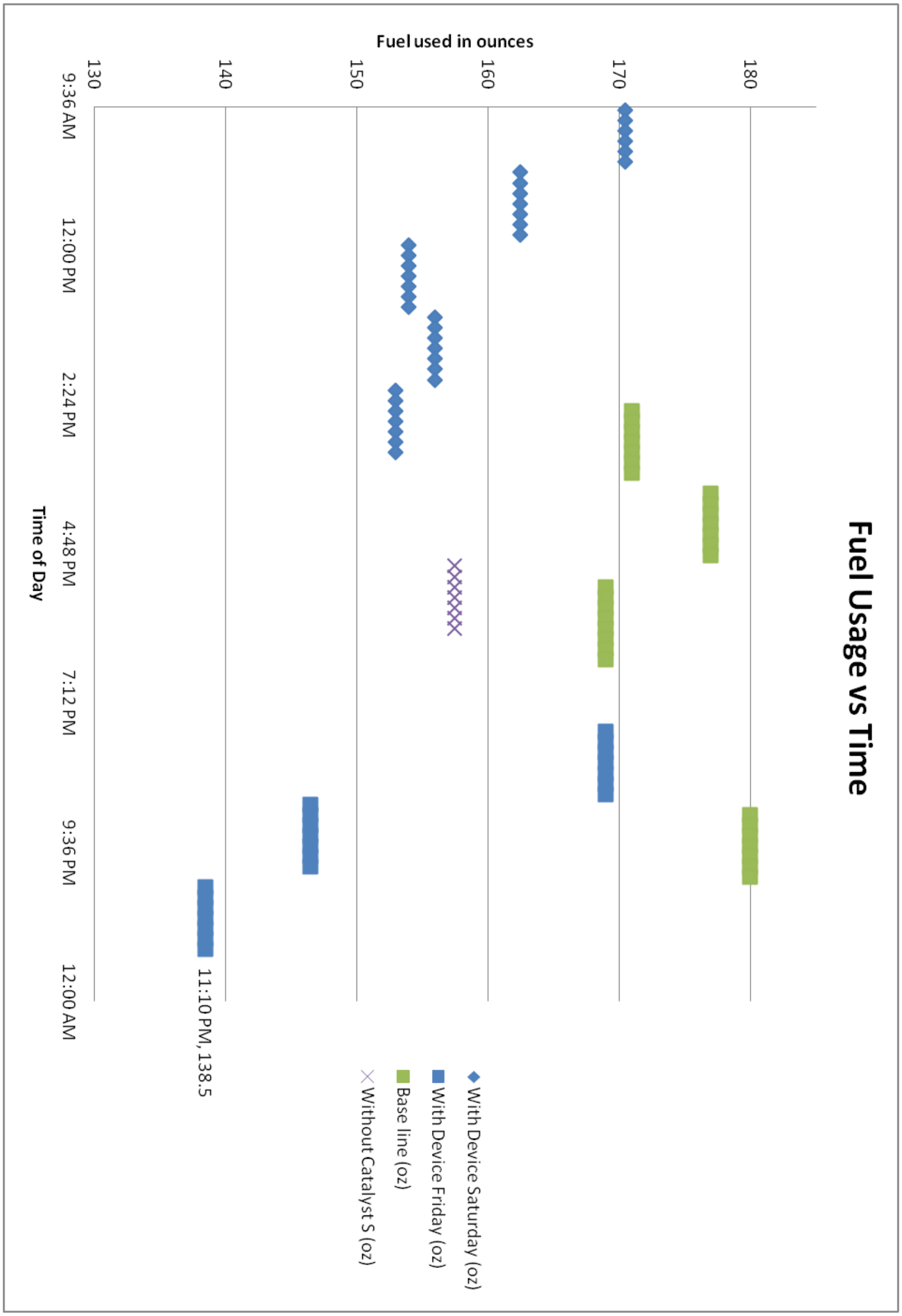
With these calculations in mind it can be said that the Fuel Savings Unit during these test showed a range of efficiencies between 9.24-22.13% increase from daytime to nighttime runs, and an over-all average fuel efficiency increase of 13.28%. Additional data including the ambient temperatures and tank temperatures for each run can be viewed in the appendix sections.

4. Conclusions and Recommendations

The conclusion that can be drawn from the tests perform over the two day period for this study is that there is a fuel efficiency increase with this configuration of the fuel savings unit and diesel engine. As noted above the relative fuel efficiency increases can be viewed over-all, in which case the engine sees a 13.28% fuel efficiency increase. It can also be broken into daytime and nighttime efficiencies of 9.24% and 22.13% increase, respectively. It is also noted that the time of day and therefore ambient temperatures and humidities play a role in the system's efficiency. This is what is believed to cause the 9.24-22.13% range of efficiencies.

With these conclusions in mind there are the following recommendations for future testing. It is recommendated that in future testing the ambient temperature and humidity should be recorded using onsite instruments, which would be more accurate than those taken during this study. It is also recommended that a long period test run should be completed with and without the fuel savings, each an entire day at a time. Therefore this study has resulted in fuel efficiency increases described above but it must be noted that tests were only performed over a two day period and contain only eight fuel savings units data points and four usable baseline data points. For these reasons additional testing is recommended.

5. Appendix


Fuel Usage vs Time
Fuel used in ounces
130
140
150
160
170
180
9:36 AM
12:00 PM
2:24 PM
4:48 PM
7:12 PM
9:36 PM
12:00 AM
Time of Day
11:10 PM, 138.5
With Device Saturday (oz)
With Device Friday (oz)
Base line (oz)
Without Catalyst S (oz)

Test Runs								
		Time	Notes	Total Weight (oz)	Fuel Used (oz)	Tank Temperature (F)	Ambient Temperature (F)	Humidity
Friday	1	7:40pm	After the end of the base runs the heat exchanger and catalyst were installed. We then let the engine run for 20 minutes using it's own tank in order to purge any air in the system and to allow the exchanger and catalyst to operating temperature. We then attached our seperate tank and continued with our 60 minute run.	initial 1860 final 1691	169	110 @ 20 min, 120 @ 40 min	84	
	2	9:25pm		1544.5	146.5	125 @ 20 min, 129 @ 40 min	84	
	3	10:30pm	This was our last run for Friday.	1406	138.5	125 @ 20 min, 130 @ 40 min	84	
		12:00am	Locked up and left					
Saturday	1	9:30am	Arrived, setup, enginer warm up for 20 minutes, took initial tank weight at 1406 oz and continued our test runs	initial 1406 final 1235.5	170.5	120 @ 20 min, 130 @ 40 min	84	66%
	2	10:50am		1073	162.5	132 @ 20 min 135 @ 40 min	87	66%
	3	12:30pm	Had to refill tank with gas	initial 2201.5 final 2047.5	154	110 @ 20 min 120 @ 40 min	89	57%
	4	2:00pm	Nox Reading were taken	1891.5	156	125 @ 20 min 130 @ 40 min	89	60%
	5	4:20pm		1738.5	153	125 @ 20 min 125 @ 40 min	89	60%
		5:55pm	WITHOUT CATALYST	1581	157.5	120 @ 20 min 125 @ 40 min	88	58%

Base Runs								
		Time	Notes	Total Weight (oz)	Fuel Used (oz)	Tank Temperature (F)	Ambient Temperature (F)	Humidity
Friday	1	2:34pm	Arrived at 2pm. We let the engine warm up using it's own tank for 20 minutes. Then weighed our separate tank at 2377oz, connected it to the trailer and began the first run. When it was finished we weight the tank again and recorded following weight	2206	171	90 @ 20 min, 105 @ 40 min	90	
	2	3:45pm		2029	177	115@ 20 min, 112@ 40 min	90	
	3	5:25pm		1860	169	115 @ 20 min, 115 @ 40 min	90	
Saturday		7:20pm	Saturday night base run was done immediately after the last Test run. I believe that this run was scewed because the tank was not allowed to cool down before we began. For this reason I convinced Gerald to run another base line for 30 minutes after cooling down the tank to aprx 100 degrees NOx RUN	initial 1581 final 1426.5	154.5	115 @ 20 min, 115 @ 40 min	87	61%
		9:00pm	HALF HOUR RUN	1335	91.5	105 @ 15 min	85	68%