Demonstrating the Use of Fish Oil as Fuel in a Large Stationary Diesel Engine

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ABSTRACT

Alaskan seafood processing operations produce approximately 8 million gallons of fish oil annually. Typically, about 2.8 million gallons of the total production volume is sold into domestic and international commodity markets, with the balance consumed on-site as boiler fuel. Inconsistent markets and difficult storage and transportation logistics often reduce the net value of the marketed oil to well below the cost of diesel fuel. The seafood processors and their associated communities generally are heavily dependent on diesel-fueled reciprocating engines for electric energy generation. The UniSea Fish Oil Demonstration Project is demonstrating the feasibility of using blends of fish oil and low-sulfur No. 2 diesel fuel in 2.3-megawatt, stationary medium-speed, two-cycle, engine-generator sets. The project entails assessments of the blended fuels' impacts on both engine exhaust emissions and engine operability and maintainability. Engine exhaust emissions resulting from the use of fuel blends ranging from 0 to 100 percent fish oil were measured at multiple engine loads. Results indicate up to 60 percent reduction in particulate matter, 33 percent reduction in carbon monoxide, and 78 percent reduction in sulfur dioxide emissions. These benefits are somewhat offset by an increase of up to 8 percent in nitrogen oxide emissions. Over a 10-month test period, the engines have operated normally in all respects utilizing a 50 percent fish oil fuel blend, to date consuming over 526,000 gallons of fish oil with no apparent adverse operational or maintenance impacts. Test program operations are anticipated to continue through October 2002.

KEYWORDS. Fish Oil, Diesel, Biodiesel, Biofuel, Alaska, Fairbanks Morse, Alternative Fuels

INTRODUCTION / BACKGROUND

The goal of the UniSea Fish Oil Demonstration Project (project) is to definitively evaluate the use of Alaska-produced fish oil as a practical supplemental fuel for a specific diesel-fueled engine-generator set in use for industrial energy production in rural Alaska. If the fish oil is found to be suitable as a supplemental fuel, it is anticipated that the practice may be adopted elsewhere in Alaska, which could result in substantial economic and environmental benefits both for the fish oil producers and for fuel consumers within the state.

UniSea, Inc., based in Redmond, Washington, owns and operates a large shore-based seafood processing facility (shown in Figure 01) located on Amaknak Island within the Unalaska/Dutch Harbor community in the Fox Island group of Alaska's Aleutian chain. Bering Sea pollock, one of several species processed by UniSea, yields a number of commercial products such as frozen fillets and surimi (a commodity fish protein product used in the manufacture of a variety of food products). The resulting processing wastes, e.g., the fish heads, skin, bones, and entrails, are directed to further on-site processing facilities to produce fishmeal, bone meal, and fish oil. Typically, Alaskan shore-based processors recover 3 to 5 percent of the raw landed weight of pollock as fish oil. Statewide, Alaskan seafood processors, both shore-based and afloat, produce approximately 8 million gallons of fish oil annually (Steigers 2002). Of the approximately 2.8 million gallons of fish oil shipped from Alaska to external markets, 2.7 million gallons are produced by UniSea and three other major shore-based seafood processors in and near Unalaska/Dutch Harbor and the nearby island community of Akutan.

Well over half of the fish oil produced in the state is consumed at the producing facilities as a boiler fuel, with the balance sold to customers outside Alaska, primarily for use in animal feed and aquaculture but also as a human dietary supplement and for the manufacture of cosmetics and pharmaceuticals. However, due to Unalaska/Dutch Harbor's remote location, limited transportation options, and the sometimes difficult logistical issues inherent in shipping fish oil, the economic challenges of marketing fish oil at times preclude even a break-even disposition of this commodity. In fact, the net market value of fish oil very often falls below that of diesel fuel. Accordingly, there is a desire on the part of UniSea and others to develop economically viable alternative uses for the fish oil. Use of fish oil as a locally consumed engine-generator fuel is a logical potential use that would likely benefit UniSea, both as a producer and as a consumer, as well as other fish oil producers and operators of diesel-fueled electrical generating units in the region.

Figure 01 - UniSea Seafood Processing Facility at Unalaska/Dutch Harbor, Alaska

The project's goal is to develop specific knowledge as to whether fish oil is an acceptable supplemental fuel, both with respect to the amount and type of air emissions generated and with respect to acceptable "durability" impacts on the engine. The project consisted primarily of a field demonstration conducted in two phases: engine emissions source testing while utilizing blended fuels and engine durability testing. Independent source-testing contractors conducted testing of engine emissions in October 2001 and July 2002. Multiple fuel blends, ranging from 100 percent low-sulfur diesel to 100 percent fish oil, were utilized in the test engine-generators at two or three operating loads. In addition to oxygen (O_2) and carbon dioxide (CO_2), the air pollutants nitrogen oxides (NO_x), carbon monoxide (CO), and particulate matter (PM) were evaluated. Sulfur dioxide (SO_2) is also a pollutant of interest, but those emissions were determined by mass balance calculations based on fuel sulfur content and fuel consumption rates and were not measured directly during source testing. The second portion of the project, durability testing, was intended to assess any impacts on the engines' operability and maintainability from long-term routine operation of the test engines utilizing a 50 percent diesel/fish oil fuel blend.

FISH OIL CHARACTERIZATION

The characteristics of fish oil are known to vary somewhat with the species of origin, the season, and the processor. The fish oil produced by UniSea is typical of that found in Alaska and is an amber to light orange-colored oil with a density of about 7.7 pounds per gallon, compared to No. 2 diesel fuel at about 7.1 pounds per gallon. A comparison of UniSea fish oil and No. 2 diesel conducted by Mr. Neil X. Blythe of the Fairbanks Morse Engine Division of BF Goodrich Company found that fish oil exhibits a substantially higher viscosity, is slightly more acidic, has a lower lubricity, and a higher flash point (Blythe 1996). Fish oil was reported to have a sulfur content of 0.004 percent by weight and a gross heat of combustion of 131,756 Btu per gallon. This may be compared to low-sulfur No. 2 diesel's 0.05 percent sulfur content and 137,000 Btu per gallon gross heat of combustion. Blythe's characterization of fish oil stated that it may be classed as a lipid, specifically a glyceride ester, and suggested that excessive hard deposits on exhaust gas path components and accelerated wear on components in contact with fuel may be a concern with sustained engine operation on fish oil blend fuels. Blythe's investigations, however, were not able to proceed for a sufficient period to be conclusive in this regard.

A recent analysis of a fish oil sample drawn from UniSea's July 2002 production run yielded a sulfur content of 0.0084 percent and a gross heat of combustion of 130,440 Btu per gallon (Intertek 2002). The flash point of the fish oil sample was determined to be in excess of 230°F. This recent analysis is considered most representative of the fish oil utilized in this project.

PROJECT DESCRIPTION / METHODS

Test Engines

UniSea owns and operates six Fairbanks Morse model 38TD8-1/8OP engines in its Dutch Harbor facility powerhouse. The UniSea engines were manufactured by the Fairbanks Morse Engine Division of BF Goodrich Company (Fairbanks Morse) and are shown in Figures 02 and 03. The engines are 12-cylinder/opposed-piston, two-cycle, water-cooled, series turbo and blower air charging (no bypass) and are equipped with Woodward Type EGB mechanical speed governors. The engines' primary fuel is low-sulfur (0.05 percent or less by weight) No. 2 diesel fuel. As directed by conditions of UniSea's air quality operating permit, all six engines' average fuel injection timing is set at no less than 41° (H.C.A.I.D.C.L.C.). Three of the six engines operate at 720 rpm and are rated and permitted at 3,160 hp and 2,152 kW maximum. The remaining three engines operate at 900 rpm and, while rated at 3,960 hp and 2,826 kW, are permitted for and operationally limited to 3,223 hp and 2,300 kW. Note that, for consistency in the following discussions, the engines' respective permitted capacity, rather than rated capacity, is regarded as "100 percent load."

Figure 02 - UniSea Powerhouse, Fairbanks Morse Engine-Generators Nos. 4 through 1 (l-r)

Fairbanks Morse engine-generator No. 6 (FM #6), a 720-rpm engine, was selected as the initial primary test unit for the October 2001 source testing and the October 2001 through October 2002 durability testing. The remaining five units were brought into the durability-testing program in June 2002 and, along with FM #6, will continue to operate on fish oil blend fuel through the end of the project testing in October 2002. FM #3 and FM #4, 900-rpm and 720-rpm, respectively, were source tested in July 2002.

Figure 03 – UniSea Powerhouse, Fairbanks Morse No. 6 Engine-Generator

Source Testing

In October 2001, FM #6 was source tested at the following conditions: fuel blends (expressed in diesel to fish oil percent by volume) of 100/0, 75/25, 50/50, and 25/75 were each tested at engine load conditions of 100 and 67 (±5) percent, with two 60-minute test runs at each condition. While useful information was obtained that is consistent with other tests, difficult test conditions attributable in large part to very adverse weather contributed to unusually variable results for the October testing. Accordingly, the October 2001 emission source test results are not further discussed in this report.

To gather a more conclusive emissions and operating data set and to support UniSea's anticipated air quality permitting initiatives, FM #3 and FM #4 were source tested in July 2002 at the following conditions: fuel blends of 100/0, 50/50, and 0/100 were each tested at engine load conditions of 100, 77, and 65 (±5) percent, with three 60-minute test runs at each condition. Emission measurements were taken for O_2, CO_2, NO_x, and CO for all runs. PM measurements were taken for all runs at all tested conditions except for the 50/50 and 0/100 fuel blends at 77 and 65 percent loads.

Durability Testing

UniSea's Dutch Harbor powerhouse typically operates one to three FM engine-generators, depending on the level of the facility's seafood processing; each base-loaded at approximately 77 percent of full load (two smaller engine-generators located elsewhere in the facility provide a load-following function). For the period October 2001 through June 2002, FM #6 was operated 4,376 hours, consuming 221,400 gallons of fish oil blended 50/50 with low-sulfur No. 2 diesel fuel. Prior to start of testing in October 2001 and again in April 2002, technical representatives of Fairbanks Morse performed detailed inspections of FM #6 to first establish its baseline condition and then to assess any effects on the engine from operating with fish oil blend fuel. A number of less formal inspections were also conducted by UniSea operating staff when suitable opportunities arose. A final inspection of FM #6 will occur in November 2002 after the test program has concluded.

Starting in July 2002, the scope of the durability-testing program was expanded, with FM #1 through FM #5 being operated on the 50/50 fuel blend as well. Total fish oil consumption among the six powerhouse engines is currently 4,500 to 5,000 gallons per 24-hour day, seven days per week. Test operations are anticipated to continue through October 2002 by which time a total of 550,000 to 650,000 gallons of fish oil will have been consumed by the powerhouse engines in the course of project testing.

Fuel Logistics and Operations

Test fuels were blended on a batch basis in a dedicated 5,000-gallon mixing tank. Diesel fuel and fish oil were metered in from their respective storage tanks simultaneously in the appropriate volume ratios. Upon filling, the blend tank was recirculated with both a closed loop pump and a centrifugal fuel purifier to assure uniform mixing of the blended fuel prior to its use. The fuel purifier incorporates a fuel heater to raise the fuel blend temperature to about 90°F to increase the effectiveness of its oil/water/sediment separation. As-used fuel temperatures were not closely monitored by the project, and, while generally above 85°F, fuel blend temperature did drop as low as an estimated 40°F on occasion.

RESULTS

The emission and engine operating data obtained from the July 2002 source testing of FM #3 and FM #4 are summarized in Tables 1 and 2, respectively (AST 2002).

Engine Operations

Both the 720-rpm and 900-rpm engines have operated routinely in all respects without apparent difficulty on all tested fuel blends. As anticipated due to the lower thermal energy content of fish oil relative to diesel, fuel consumption increased at higher fish oil contents but remained comfortably within the governor and fuel systems' range of control. Fuel consumption rates for FM #3 and FM #4 as load and fish oil fuel content were varied are illustrated in Figures 04 and 05, respectively.

Starting the engines from either a warm or cold condition using the fish oil blend fuels was accomplished without difficulty. In fact, engine operators made the observation that the engines seemed to start slightly easier with fish oil than with diesel. Engine shutdowns (and subsequent restarts) were also accomplished without difficulty while utilizing fish oil blend fuels.

While detailed long-term trending has not yet been completed, unusual engine operating conditions have not been observed in the course of operations on blended fuels. An increase in the engines' fuel rack position due to the lower thermal content of the blended fuels was observed, as were higher engine-mounted fuel filter pressure differentials due to the higher viscosity of blended fuels.

Table 1 - UniSea FM #3 (900-rpm) Test Data

	Runs	10-12	13-15	16-19	46-48	49-51	42-54	37-39	40-42	43-45
Fuel blend	[diesel/fish oil]	100/0	100/0	100/0	50/50	50/50	50/50	0/100	0/100	0/100
engine load	[kW]	2,274	1,778	1,493	2,266	1,791	1,502	2,267	1,789	1,475
engine load	[% full load]	98.9%	77.3%	64.9%	98.5%	77.9%	65.3%	98.6%	77.8%	64.1%
fuel use	[gph]	196.7	165.8	147.9	235.0	196.3	176.1	257.8	222.8	197.1
stack flow	[acfm]	30,301	26,682	24,224	29,387	26,641	24,173	29,002	25,642	22,886
Exit velocity	[fps]	160.8	141.6	128.5	155.9	141.3	128.2	153.9	136.0	121.4
stack temp	[ºF]	572.3	550.0	526.7	582.0	559.7	537.7	570.0	545.0	530.0
O_2	[%volume]	15.1	15.5	15.8	14.9	15.3	15.6	15.0	15.3	15.7
CO_2	[%volume]	4.4	4.1	3.9	4.6	4.3	4.1	4.6	4.4	4.1
NO_x	[g/bhp-hr]	10.2	9.5	8.9	10.4	9.8	9.4	10.8	9.9	9.5
CO	[g/bhp-hr]	0.363	0.404	0.445	0.346	0.412	0.475	0.328	0.399	0.514
PM	[g/bhp-hr]	0.181	0.256	0.255	0.149			0.132		
***NO_x**	[lbs/hr]	71.8	51.9	40.8	73.0	54.4	43.6	75.7	54.8	43.3
***CO**	[lbs/hr]	2.55	2.22	2.05	2.42	2.28	2.21	2.30	2.21	2.34
***PM**	[lbs/hr]	1.27	1.41	1.17	1.04			0.92		
NO_x	[lbs/gal]	0.365	0.313	0.276	0.311	0.277	0.248	0.294	0.246	0.220
CO	[lbs/gal]	0.013	0.013	0.014	0.010	0.012	0.013	0.009	0.010	0.012
PM	[lbs/gal]	0.0065	0.0085	0.0079	0.0044			0.0036		

*** normalized to 100% load basis**

FM #3 (900-rpm) Emissions As illustrated in Figure 06, as fish oil content of the fuel blend increased, NO_x emissions, on a grams per brake horsepower-hour (g/bhp-hr) basis, increased on the order of 2 to 7 percent across the tested load range. Figure 07 illustrates that FM #3 CO emissions did not vary significantly with fish oil fuel content. PM emissions decreased dramatically, however, with increased fish oil use. Figure 08 illustrates the observed 40 to 60 percent drop in PM emissions.

Table 2 – UniSea FM #4 (720-rpm) Test Data

	run	1-3	4-6	7-9	19-21	22-24	25-27	28-30	31-33	34-36
fuel blend	[diesel/fish oil]	100/0	100/0	100/0	50/50	50/50	50/50	0/100	0/100	0/100
engine load	[kW]	2,218	1,740	1,471	2,211	1,766	1,481	2,269	1,748	1,470
engine load	[% full load]	96.4%	75.7%	64.0%	96.1%	76.8%	64.4%	98.7%	76.0%	63.9%
fuel use	[gph]	175.8	145.3	126.7	204.6	174.2	151.8	221.8	189.2	167.2
stack flow	[acfm]	23,117	19,393	17,356	22,476	19,061	16,992	21,946	18,965	15,866
exit velocity	[fps]	122.6	102.9	92.1	119.2	101.1	90.1	116.4	100.6	84.2
stack temp	[ºF]	647.7	621.3	597.3	646.7	624.7	598.0	650.3	618.3	581.0
O_2	[%volume]	15.1	15.5	15.8	14.9	15.3	15.6	15.0	15.3	15.7
CO_2	[%volume]	4.4	4.1	3.9	4.6	4.3	4.1	4.6	4.4	4.1
NO_x	[g/bhp-hr]	11.4	10.2	9.4	11.7	11.0	10.0	11.6	11.4	9.9
CO	[g/bhp-hr]	0.813	0.985	0.956	0.647	0.815	0.804	0.587	0.750	0.640
PM	[g/bhp-hr]	0.215	0.233	0.240	0.130			0.085		
$*NO_x$	[lbs/hr]	76.2	53.8	41.6	78.3	59.0	44.9	79.8	60.5	44.1
***CO**	[lbs/hr]	5.45	5.19	4.25	4.33	4.35	3.60	4.03	3.96	2.85
***PM**	[lbs/hr]	1.44	1.23	1.07	0.87			0.58		
NO_x	[lbs/gal]	0.434	0.370	0.329	0.383	0.339	0.296	0.360	0.320	0.264
CO	[lbs/gal]	0.031	0.036	0.034	0.021	0.025	0.024	0.018	0.021	0.017
PM	[lbs/gal]	0.0082	0.0084	0.0084	0.0043			0.0026		

*** normalized to 100% load basis**

FM #4 (720-rpm) Emissions As illustrated in Figure 09, as fish oil content of the fuel blend increased, NO_x emissions, on a g/bhp-hr basis, increased on the order of 2 to 8 percent across the tested load range. Figure 10 illustrates that CO emissions decreased by 16 to 33 percent as fish oil fuel content was increased. PM emissions decreased 17 to 27 percent with increased fish oil content, as illustrated in Figure 11.

SO_2 Emissions Fish oil produced by UniSea has sulfur content between 0.004 percent (Blythe 1996) and 0.0084 percent (Intertek 2002) by weight. Based on the as-tested fuel consumption rates and on diesel fuel and fish oil sulfur contents of 0.05 percent and 0.0084 percent, respectively, reductions in engine SO_2 emissions of 30 to 78 percent were realized through the use of fish oil as engine fuel.

Fuel Operations

The powerhouse was generally able to utilize fish oil as received from UniSea's on-site fishmeal plant without further processing being necessary. On occasion, however, transient operating conditions in the final fish oil polishing stages of the fishmeal plant resulted in brief incidents of a higher-than-normal content of suspended non-soluble proteins in the delivered fish oil. At those times, the powerhouse experienced difficulty with fuel purifiers and filters unable to handle the increased protein load. An additional purifier for the fishmeal plant operation is currently being procured to address this issue. Most Alaskan fish oil producers have typically based their fish oil quality control standards and practices on the needs of their fish oil customers (largely animal feed and aquaculture operations) and of their boilers' fuel quality requirements. These standards and practices may not be adequate for fish oil intended for use as engine fuel. Accordingly, it would seem advisable that, for any large-scale use of fish oil as engine fuel, it is likely advisable for the consuming facility to have dedicated fish oil centrifugal fuel purifiers and/or suitable filtration equipment to ensure that any incidence of entrained water and insoluble protein or sediment in delivered fish oil does not create or contribute to adverse operating and maintenance conditions.

No problems were observed or experienced due to the higher viscosity of fish oil compared with diesel. At the UniSea powerhouse, fish oil is held in an uninsulated 25,000-gallon-capacity external storage tank and, thus, is subjected to cold winter temperatures. In practice, however, the fish oil is delivered from the fishmeal plant somewhat warm, and turnover of the stored oil is such that fish oil never fell to temperatures that created adverse conditions. A heater-equipped centrifugal fuel purifier is available to recirculate the main fish oil storage tank if low fish oil temperature were to become an issue.

The batch blending of diesel and fish oil to achieve targeted blend ratios was found at times to be cumbersome and somewhat labor intensive, especially if achieving some degree of uniform mixing requires confirmation for operational or regulatory purposes. Potentially suitable commercially available adjustable-ratio in-line blenders are available and should be considered for use in this application.

Durability Impacts

The assessment of any impacts on the engines' operability and maintainability will not be completed until after test operations conclude in October 2002. Results to date have been very encouraging, however, with no apparent adverse effects on the engines.

Through August 2002, the UniSea's six Fairbanks Morse engines have logged over 7,920 hours of routine operations on a 50/50 blend fuel, 4,850 hours on FM #6 alone, consuming over 526,000 gallons of fish oil while generating nearly 14,000 MWh. Inspections of fuel injectors and engine-mounted fuel pumps, likely candidates for accelerated wear, reveal no unusual wear patterns or rates. Visual inspections of exhaust gas path components such as piston ring seating grooves, exhaust ports, and exhaust turbine inlet rings, show no evidence of any unusual type or rate of hard deposits. The engines' crankcase lubricating oil has been monitored closely and evaluated for lubricity at no less than 24-hour intervals, with no unusual conditions or consumption rates observed.

CONCLUSIONS

Based on the strong to-date project results, fish oil produced from wastes generated by the processing of Bering Sea pollock may be regarded as suitable as a displacement or supplementary fuel for the Fairbanks Morse model 38TD8-1/8OP and similar engines in a stationary electric-generation application when and where favorable economic, operating, and air quality permitting conditions exist.

Overall, dramatic decreases in CO, PM, and SO_2 are seen in exhaust gas emissions as fish oil content of the fuel blend increases, with an offsetting increase in NO_x. In terms of absolute magnitude, the changes in pollutant emissions are largely a wash with the tons of CO, PM, and SO_2 reduced approximately equal to the tons of NO_x increased. In identifying specific potential benefits of the use of fish oil as engine fuel, the pollutants of particular concern for the prospective consuming facility and its air quality environment would bear close consideration. As a case in point, the Unalaska/Dutch Harbor community within which UniSea is located has been identified as being of special concern for high ambient SO_2 levels by air quality regulatory authorities and a substantial reduction in SO_2 emissions may be deemed a desirable achievement even with a accompanying marginal increase in NO_x. Furthermore, in the case where a prospective consuming facility utilizes a higher sulfur diesel fuel than does UniSea (0.5 percent sulfur fuel is in common use in Alaska), the reductions realized in SO_2 (in excess of 95 percent) would far exceed the increase in NO_x emissions.

Any consideration of the use of fish oil as engine fuel should be done in the context of the prospective consuming facility's air quality permitting and overall regulatory environment. The Alaska Department of Environmental Conservation (ADEC) has air and water quality regulatory jurisdiction over UniSea's Unalaska/Dutch Harbor facility and has been supportive of the project's efforts; increasingly so as higher-confidence emissions and operating data become available. Furthermore, fish oil, unlike diesel and other petroleum products, does not present the same adverse environmental impacts if spilled and is thus treated accordingly by regulatory authorities. This suggests a possible application for use as engine fuel in remote and environmentally sensitive locales, especially those with sub-optimal fuel storage and handling facilities.

Engines similar to UniSea's serving in stationary electric-generation applications are relatively rare in Alaska, and, thus, the general applicability of this project's results may be limited. In recognition of this consideration, the Alaska Energy Authority and Steigers Corporation are currently engaged in identifying potential Alaskan partners to conduct a fish oil demonstration project similar to that of this report but targeting an engine type with a larger installed inventory base. Of particular interest are engines in wide use among electric generators in smaller rural Alaskan communities.

Acknowledgements

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funding and technical support, and continues to serve in the role of project manager. Further valued technical contributions were provided to the project by: Mr. Neil X. Blythe, Manager of Engine Design/Research and Development for Fairbanks Morse Engine Division of BF Goodrich Company in Beloit, Wisconsin; Mr. Peter Crimp, Development Specialist for Alaska Energy Authority in Anchorage, Alaska; and Dr. Charles Peterson, Professor of Biological and Agricultural Engineering for the University of Idaho at Moscow, Idaho. Photographs are by the author.

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REFERENCES

1. Alaska Source Testing (AST), LLC 2002. *Summary Report – UniSea Dutch Harbor Seafood Processing Facility Source Emissions Testing.*

2. Blythe, Neil X. 1996. *Fish Oil as an Alternative Fuel for Internal Combustion Engines.* Fairbanks Morse Engine Division of BF Goodrich Company, Beloit, Wisconsin.

3. Intertek Testing Services/Caleb Brett 2002. *Report of Analysis, Fish Oil Sample* (Sample Reference No. SF 02-18597).

4. Steigers Corporation, Alaska Energy Authority 2002. *Alaska Fish Oil Demonstration Project – Fish Oil Resource Report.*

FIGURE 04 - UniSea FM #3 (900-rpm) Fuel Use

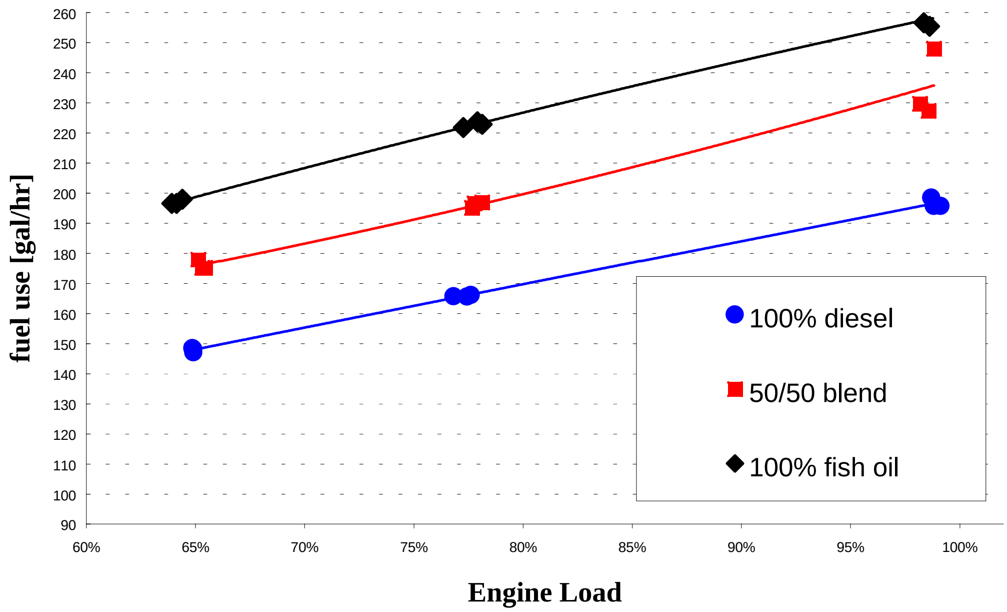

FIGURE 05 - UniSea FM #4 (720-rpm) Fuel Use

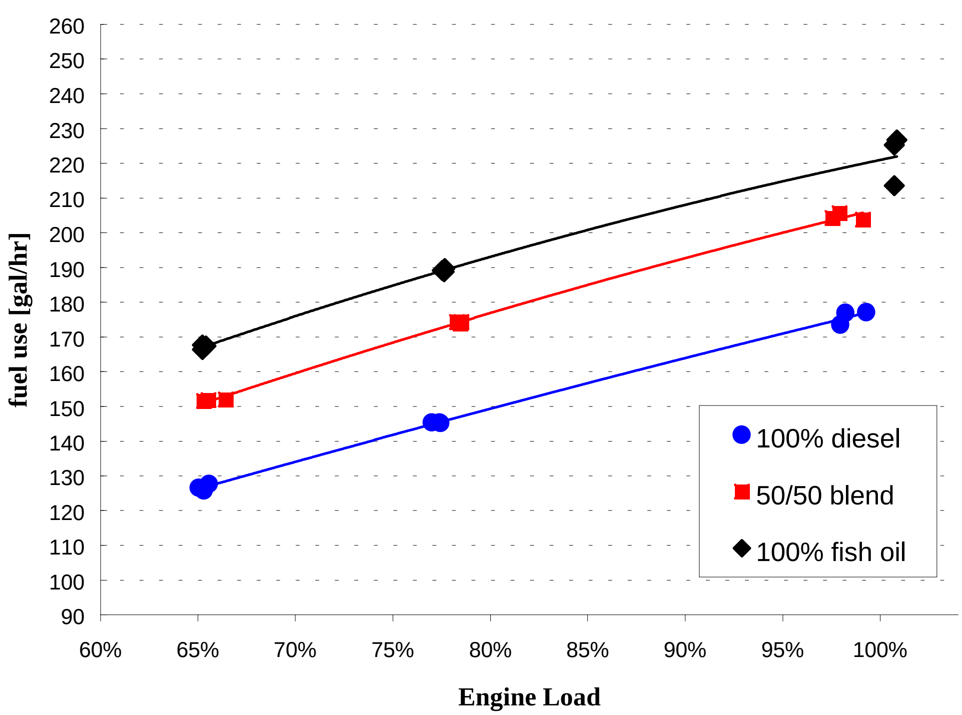

FIGURE 06 - UniSea FM #3 (900-rpm) NO_x Emissions

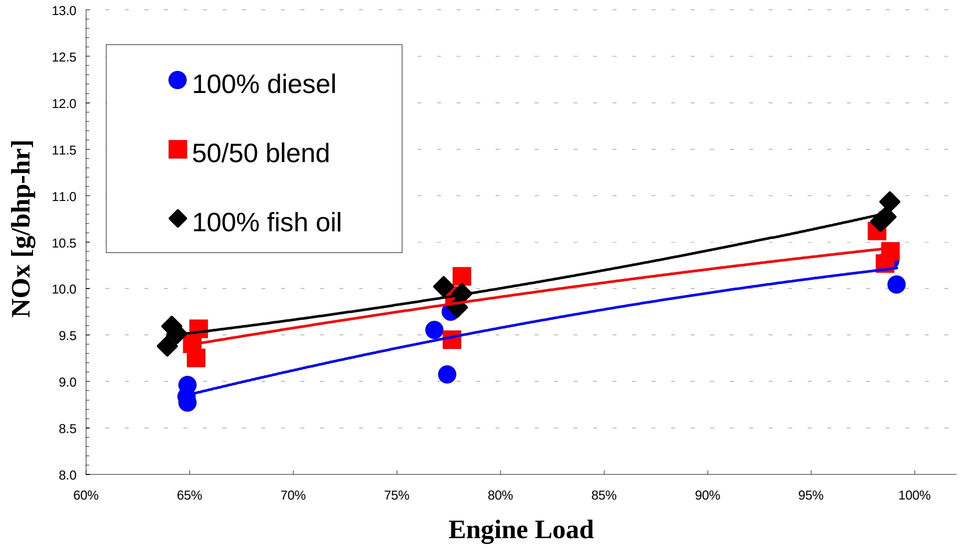

FIGURE 07 - UniSea FM #3 (900-rpm) CO Emissions

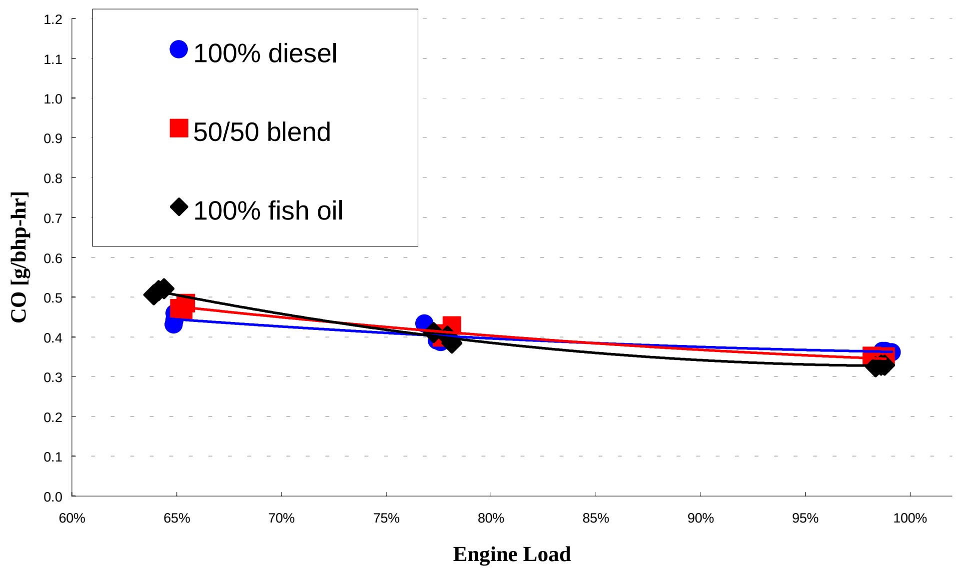

FIGURE 08 - UniSea FM #3 (900-rpm) PM Emissions

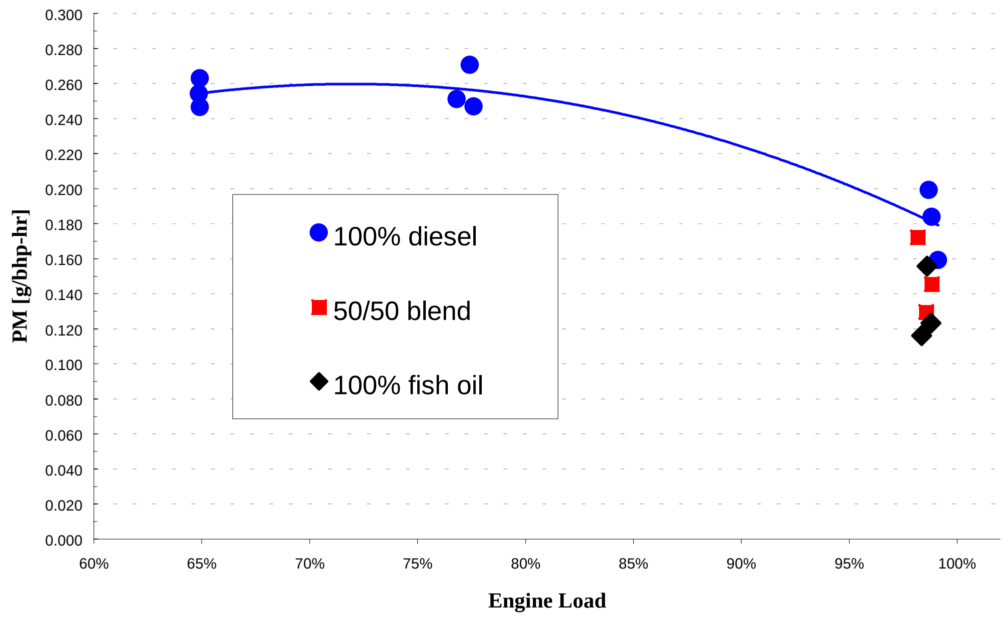

FIGURE 09 - UniSea FM #4 (720-rpm) NO_x Emissions

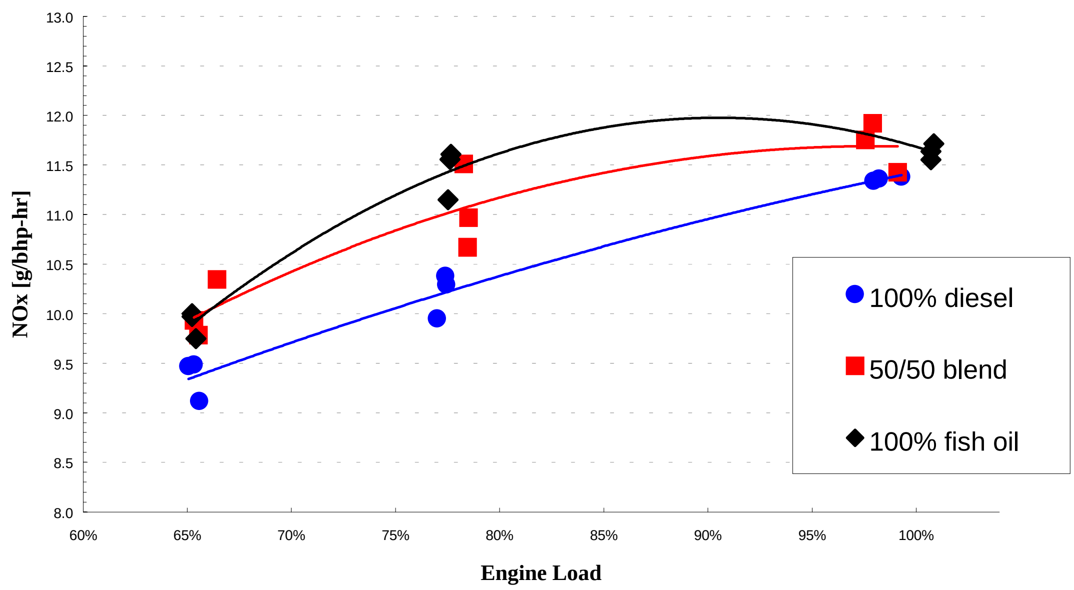

FIGURE 10 - UniSea FM #4 (720-rpm) CO Emissions

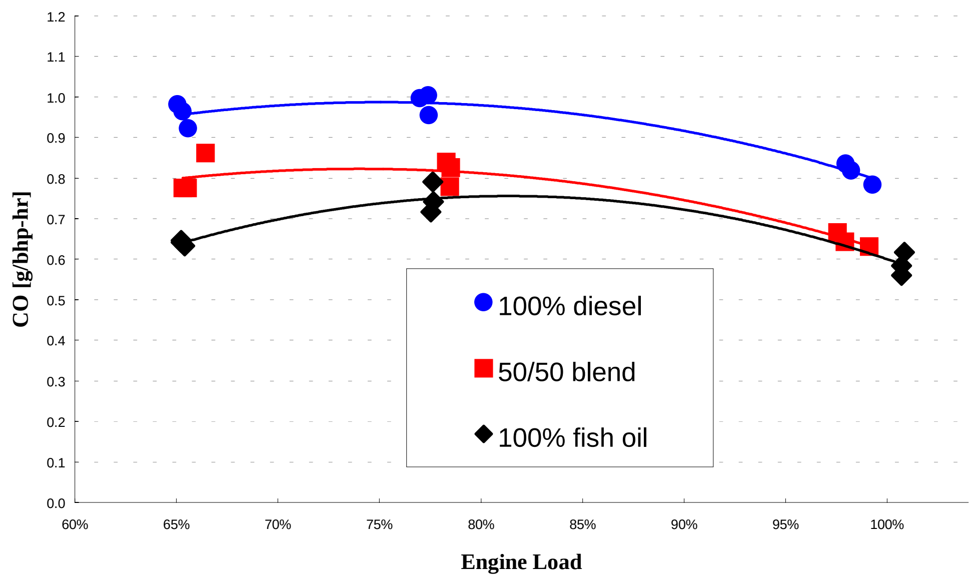

FIGURE 11 - UniSea FM #4 (720-rpm) PM Emissions