Fish Oil as an Alternative Fuel for Conventional Combustors

Fernando Preto, Frank Zhang, and Jinsheng Wang

***Abstract*— Combustion tests for fish oil and its blends with fuel oils were performed in a pilot tunnel furnace and two residential boilers to evaluate fish oil as an alternative fuel for conventional boilers and furnaces. Droplet evaporation tests were also conducted as a complementary study of the combustion properties. Fish oil and the blends burned readily in the facilities. The emissions were generally lower than burning the pure fuel oil except that of NO, which was higher for blends with No. 6 residual fuel oil. With better quality No. 2 fuel oil the NO emission of the blends was at the same level as that of the pure oil. Overall fish oil showed good combustion properties and significant economic and environmental benefits are expected.**

***Key words*— Alternative fuel, Conventional combustors, Fish oil, Renewable energy.**

I. Introduction

FISH oil is produced in large quantity by fish-processing industry. In Alaska alone, eight million gallons of fish oil is produced annually [1]. This by-product has similar calorific value to petroleum distillates and is a renewable energy source. Active studies have been carried out for using fish oil as fuel for diesel engines [1-3]. However, there are circumstances where using fish oil as fuel for furnaces/boilers for heat/power generation is of greater interest. In this work, we assessed the combustion characteristics for fish oil and its blends with No.6 fuel oil and No.2 fuel oil respectively, and the potential for burning the blends in conventional furnace/boilers. Emission levels of gaseous pollutants and particulate matter (PM) were compared with those of burning the pure fuel oils. The stability of flame was also observed.

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II. Combustion of Blends of Fish Oil and Fuel Oil in a Tunnel Furnace

A. Facilities

The pilot-scale research tunnel furnace used for this study is a front-firing, horizontally-mounted, tunnel furnace (Fig. 1) which has a rated firing capacity of 0.7 MWt and can burn solid, gaseous and liquid fuels. It has a simple cylindrical configuration, 4.25 m long and 1 m internal diameter, to facilitate the study of combustion aerodynamics. The initial portion of the furnace is fitted with a 0.37 m long adiabatic quarl, which is refractory lined with a 35 ^{o} half-angle, and followed by a 0.90 m long, 0.81 m diameter, adiabatic cylindrical section. The next 2.4 m of the furnace has an internal diameter of 0.98 m and is divided into 28 segments that are separately cooled to provide a thermal load. The remaining 1.83 m of the furnace has a reduced diameter of 0.75 m and is lined with refractory before the 0.495 m diameter exit. All the cylindrical sections (adiabatic or cooled) are equipped with access slots for intrusive measurement probes. Combustion air is provided to an annulus around the burner, with adjustable swirl vanes. These vanes were set to 45^{o} for all tests.

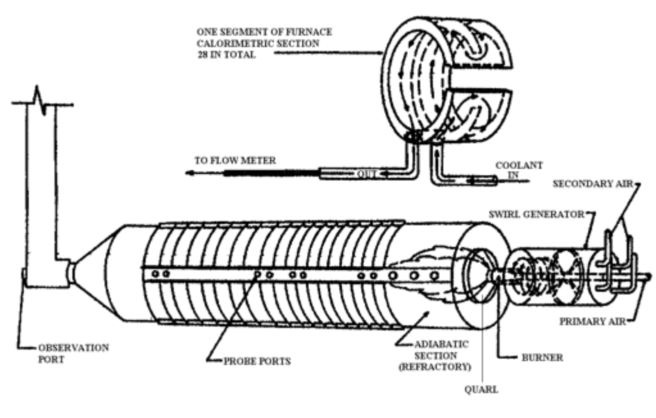

Fig. 1. Schematic of the tunnel furnace.

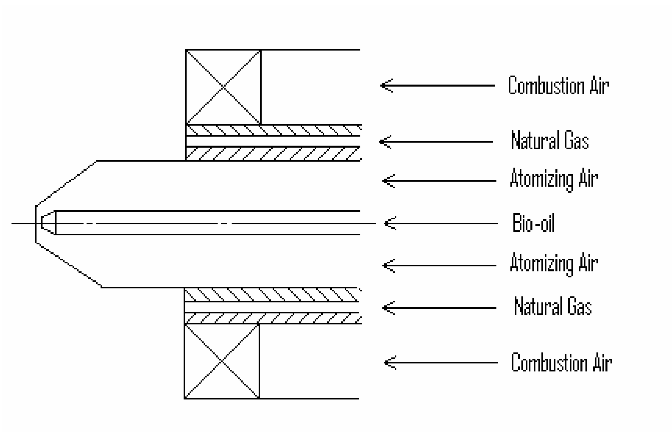

Fig.2. Schematic of the burner of the tunnel furnace.

The furnace was pre-heated with natural gas for 2 or 3 hours to bring the refractory to operating temperature. Then the oil blend was introduced in the presence of some natural gas. The natural gas was shut off when the flame was stable at the specified rate for the test. Upon the completion of the test, No.2 fuel oil was introduced for a short time to purge the system.

The nozzle is an external mix air assist atomizer. The fuel is injected through a central pipe with a slight contraction at the tip allowing for a slight pressure build-up to aid atomization. The atomizing air is introduced through a concentric annulus. The air tip is sharply convergent. The atomizing air cools the fuel line and tip. The drawing of CLM nozzle and the burner is shown in Fig. 2.

Radiative heat flux in the furnace is measured by an ellipsoidal radiometer, as a function of the distance from the burner. The radiometer consists of an ellipsoidal cavity which has an aperture at one end of its principal axis and a hemispherical radiation detector at the other. The surface of the cavity is highly reflective so that radiation passing through the aperture is reflected onto the detector which is mounted on a stainless steel rod and acts as a simple heat flow plug. Canstantan wires are welded to both ends of this rod to form a differential thermocouple to measure the heat flow down the rod.

B. Results with Blends of Fish Oil and No. 6 Fuel Oil

The fuel analysis data of No.6 fuel oil, fish oil and a blend at 10% fish oil are shown in Table 1. Compared with No. 6 fuel oil, the fish oil has lower content of carbon and slightly higher content of hydrogen. The fish oil also has higher flash point and pour point but much lower kinematic viscosity. As a result, the viscosity of the blend is much lower than that of the No.6 oil. This could reduce the requirement for preheating the fuel to make it flow easily, and reduce pump demands and improve the atomization at the burner.

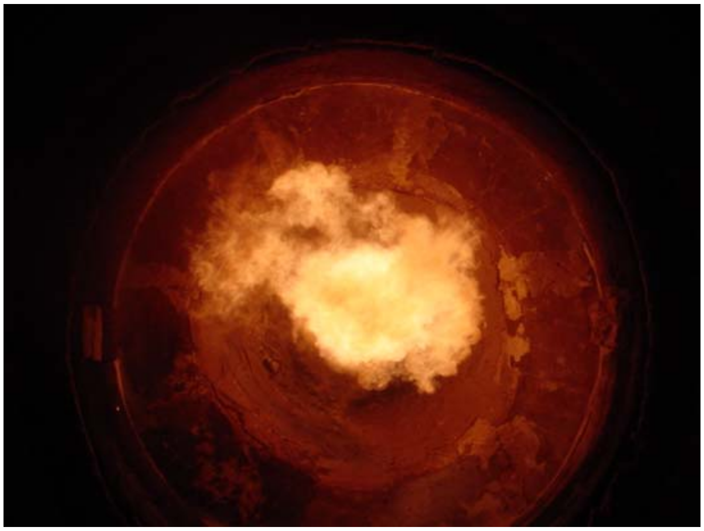

Fig. 3. The flame of No.6 fuel oil.

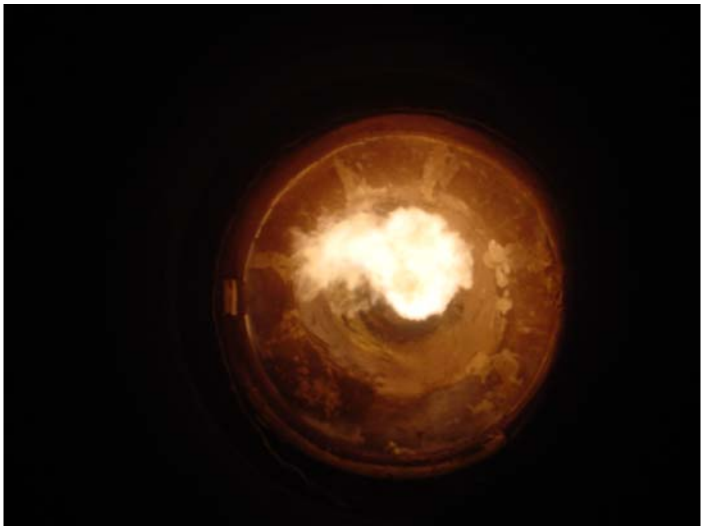

Fig. 4. The flame of the blend of 10% fish oil.

In most cases the combustion test for each fuel were carried out under three different excess air conditions: 3.5%, 5% and 7.5% oxygen in the flue gas at the stack. The test results are shown in Table 2. Compared with the No.6 oil, the 10% fish oil blend showed lower emissions of CO and SO_2 but noticeably higher emission of NO. This will be discussed together with the effect of excess combustion air on the emissions.

Fig. 3 and Fig. 4 are the pictures of the flame of No.6 fuel oil and 10% fish oil blend taking from the observation port, respectively. Comparison of these pictures shows no significant differences, except that the blend seems to have a somewhat higher flame temperature which may be related to its higher hydrogen content. No difficulty occurred in burning the blend.

C. The Effect of Excess Combustion Air on Emissions

Table 2 indicates that CO and SO_2 emissions do not change significantly with the level of excess combustion air. However, there is a constant tendency of increased NO emission with increased excess air, as shown in Fig. 5. Similar tendency has been reported for other fuels [4, 5]. As the blend has lower nitrogen content than that of No.6 fuel oil, clearly the increased NO is not from the fish oil. In general, biodiesel is known to produce more NO_x emissions than petrodiesel in diesel engines, and it was postulated that higher cetane rating and higher oxygen content of the fuel resulted in rapid conversion of nitrogen from the atmosphere to NO_x. The viewpoint of higher oxygen content is not likely to be applicable in the present case, as will be shown later that the blends of fish oil and No. 2 fuel oil did not exhibit increased NO_x emission. Moreover, at least for the current blend, significant increase of oxygen content in the fuel by only 10% fish oil is not plausible.

A blend of 50% fish oil was also tested with regard to the effect of fish oil fraction. The fuel analysis is shown in Table 3 and the test results are shown in Table 4. It can be seen that NO emission was lower than in the case of the 10% blend. The fuel analysis indicates that the nitrogen content in the 50% blend was substantially lower than that in the 10% blend (0.147 % vs. 0.45%). This appears to suggest that the NO emission in burning the blends was dependent on the fuel nitrogen. With decreased fuel nitrogen content, the effect of fish oil on NO emission would decrease.

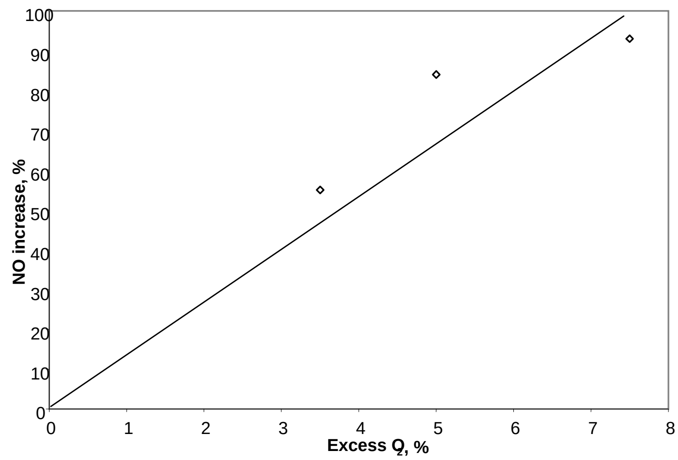

Fig. 5. Increased NO emission as a function of excess air when burning the blend of 10% fish oil.

TABLE 1
FUEL ANALYSES (WET BASIS) FOR 10% FISH OIL BLEND AND THE PARENT OILS

Components	No. 6 Fuel Oil	10% fish oil blend	Fish oil
Density (15°C), kg/m^3	990.1	977.4	880.1
Calorific value, MJ/kg	41.74	42.48	40.07
Flash point, °C	126.2	128.2	178.5
Pour point, °C	-44.0	-	4.0
Kinematic viscosity, cSt			
40°C	-	-	4.250
60°C	303.26	105.54	-
80°C	103.73	51.14	-
Water, wt %	2.6	0.05	<0.1
Carbon, wt %	85.38	87.15	77.47
Hydrogen, wt %	10.44	10.28	11.91
Suplhur, wt %	1.65	1.43	<15ppm
Nitrogen, wt %	0.50	0.45	0.001
Ash, wt %	0.033	0.028	<0.001

TABLE 2
COMBUSTION RESULTS FOR NO.6 FUEL OIL AND 10% FISH OIL BLEND

	3.5% O_2		**5.0% O_2**		**7.5% O_2**	
	No.6 oil	**Blend**	**No.6 oil**	**Blend**	**No.6 oil**	**Blend**
Feed rate	28	28.2	28	28.2	28	28.2
Atomising air (kg/h)	40	40	40	40	40	40
Combustion air (kg/h)	628.3	640.9	688.3	705.4	825.9	846.5
Exit flue gas temperature(°C)	538	534	543	542	535	533
Refractory temperature, (°C)	730	758	734	755	741	752
Stack gas analyses						
CO_2 (%)	12.9	13.0	11.8	11.9	9.9	10.1
CO* (ppm)	23	20	21	21	22	22
NO* (ppm)	163	252	157	289	152	294
SO_2*(ppm)	793	759	791	758	776	753
Particulates (mg/Nm^3)	74	55				

*Results for 5.0 and 7.5% O_2 have been corrected to 3.5% O_2 for comparison.

TABLE 3
FUEL ANALYSES FOR THE 50% FISH OIL BLEND AND THE PARENT OILS
TABLE 4

	Fish oil	**No. 6 fuel oil**	**Fish oil/No.6 oil 50/50 blend**
Moisture, wt%	0.05	0.05	0.17
Ultimate analyses, wt% (wet)			
C	77.17	89.1	84.26
H	12.38	10.75	11.48
N	0.005	0.305	0.147
S	0.001	0.29	0.167
Ash	< 0.001	0.024	0.012
O (by difference)	10.39	0.00	3.75
Calorific value, MJ/kg	39.71	43.19	41.50
Density at 15 °C, kg/m^3	875.3	984.8	925.8
Specific gravity, 60 / 60 F	0.876	0.9857	0.9267
Kinematic viscosity, cSt			
at 25 °C	5.76	5689.7	43.97
at 40 °C	4.36	602.24	18.97
at 80 °C	ND	52.14	6.06
at 100 °C	ND	26.17	4.21
Flash point, °C	156	109	119
Pour point, °C	4	-64	-6
Cloud point, °C	5.2	ND	-5.7

COMBUSTION RESULTS OF THE BLEND OF 50% FISH OIL

		3.5 % O_2	5.0% O_2	7.5% O_2
Fuel flow rate, kg/h		28.96	28.96	28.96
Atomizing air flow, kg/h		34	34	42
Combustion air flow, kg/h		564	623	736
Exit flue gas temperature, °C		492	496	526
Flue gas analyses				
CO_2	%	12.1	10.7	8.6
CO*	ppm	30	33	34
NO*	ppm	174	163	215
SO_2*	ppm	100	100	91

*Results for 5.0 and 7.5% O_2 have been corrected to 3.5% O_2 for comparison.

TABLE 5
ANALYSES (WET BASIS) OF BLENDS OF FISH OIL AND NO. 2 FUEL OIL

Components	No. 2 Fuel oil	20% fish oil blend	50% fish oil blend	100% fish oil
Density (15°C), kg/m^3	846.5	852.1	860.1	875.4
Calorific value, MJ/kg	45.49	44.55	43.04	40.21
Flash point, °C	61.0	65.0	68.0	100
Pour point, °C	-46.0	-32.0	-10.0	2.0
Cloud point, °C	-16.0	-14.2	-8.7	3.2
Kinematic viscosity, cSt				
at 25°C	3.238	3.518	3.902	5.083
at 40°C	2.484	2.714	3.018	3.883
Water by distillation, wt %	<0.01	<0.01	0.02	0.06
Carbon, wt %	86.26	84.34	82.06	76.99
Hydrogen, wt %	12.86	12.65	12.36	11.94
Suplhur, wt %	0.21	0.17	0.11	0.0077
Nitrogen, wt %	0.009	0.008	0.006	0.003
Ash, wt %	<0.001	<0.001	<0.001	<0.001

D. Radiation Features

Fig. 6 shows the measured radiative heat flux along the distance from the burner of the tunnel furnace. The radiation of the blend appears to be stronger near the burner than that of the pure No.6 oil while somehow weaker at longer distance from the burner. As the heat value of the two fuels are very close (Table 1), the results suggest that the blend burned more readily than No. 6 fuel oil. This can also be expected from the much lower viscosity of the blend (Table 1), as lower viscosity can lead to better atomization and smaller-size droplets, which burn closer to the burner.

Results of the radiation measurements with the 50% fish oil blend (Fig. 7) suggest that increasing excess oxygen from 3.5% to 5% results in very limited increase in the radiation near the burner, whereas further increasing the oxygen to 7.5 % decreases the radiation significantly. Taking into account that NO emission may also be increase with excess oxygen (Fig. 5), there is no apparent benefit in increasing excess oxygen.

E. Results with Blends of Fish Oil and No.2 Fuel Oil

Blends of varied fractions of fish oil and No. 2 fuel oil were tested. The fuel analyses are shown in Table 5. Compared with No. 6 oil, No. 2 oil is closer to fish oil in composition and physical properties, particularly in density, specific gravity and viscosity. As a result, the difference between the blends and No. 2 oil looks very small.

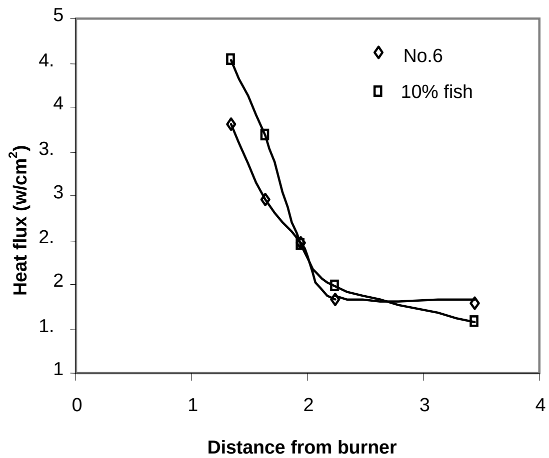

Fig. 6. Radiation in the furnace when burning the blend of 10% fish oil (O_2=3.5%).

The results of combustion tests are shown in Table 6. SO_2 emission appears to decrease with increasing fraction of fish oil, whereas NO emission does not appear to vary significantly with the fraction of fish oil. On the other hand, an overall examination of the data for blends with both (Nos. 2 and 6) fuel oils suggests that the NO emission reduces with decreasing nitrogen content of the blends. As shown in Fig. 8 by the relative emission level (the ratio of NO emission of the blends to that of the pure fuel oils), for lower fuel nitrogen content, NO emission is not higher than that of pure fuel oils.

TABLE 6
COMBUSTION RESULTS OF BLENDS OF FISH OIL AND NO. 2 FUEL OIL

	No. 2 fuel oil		20% fish oil blend		50% fish oil blend		100% fish oil	
	3.5% O_2	9.0% O_2	3.5% O_2	9.0% O_2	3.5% O_2	9.0% O_2	3.5% O_2	9.0%O_2
Fuel flow rate, kg/h	25.10	25.10	25.66	25.66	26.76	26.76	28.09	28.09
Atomizing air flow rate, kg/h	42	42	41	41	42	42	40	40
Combustion air flow rate, kg/h	520	796	495	739	488	729	466	703
Exit flue gas temperature, ^oC	499	517	495	520	496	535	495	535
Flue gas analyses								
CO_2 %	12.3	8.3	13.2	8.9	12.7	8.7	12.6	8.8
CO ppm	17	15	13	10	20	10	13	11
NO ppm	146	61	148	81	143	87	139	97
SO_2 ppm	102	70	95	65	62	41	4	3

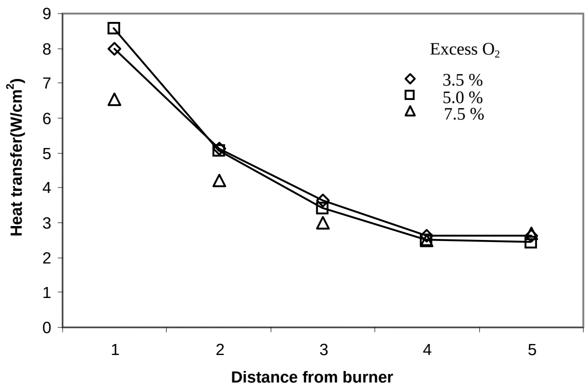

Fig. 7. Radiation in the furnace when burning the blend of 50 % fish oil.

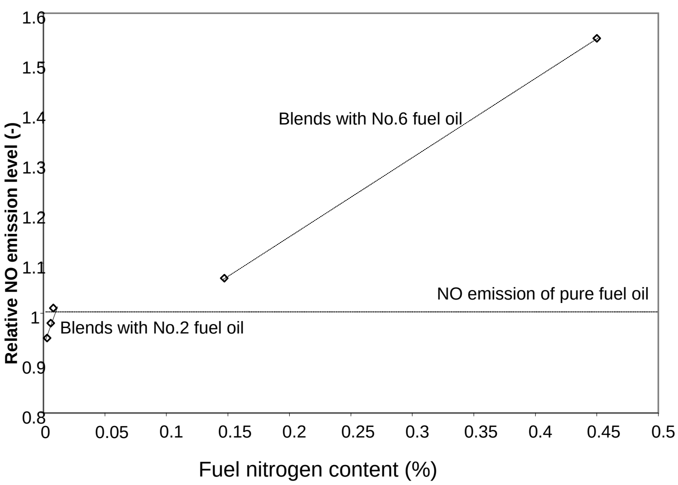

Fig. 8. Correlation of NO emission with nitrogen content in the blend.

Another possible factor for lower NO emission of the blend with No. 2 fuel oil are similar physical properties of fish oil and the No. 2 oil, which lead to practically unchanged ejection properties, such as the droplet size. As a result, the combustion conditions did not change much with the variations in fish oil content, and the rate of NO formation remained in the same level.

Results of radiation measurements show that the variation with fish oil fraction was not significant (Fig. 9), suggesting that fish oil can be burned with No. 2 fuel oil with any fractions and give the same thermal effect as that of burning the No. 2 oil.

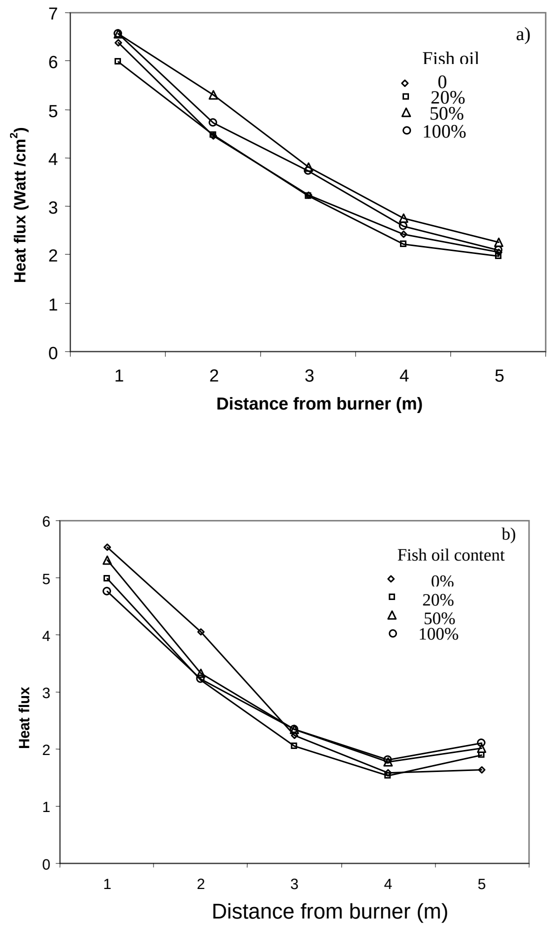

Fig. 9. Radiation in the furnace with burning blends of fish oil and No. 2 fuel oil. a) with 3.5 % excess oxygen; b) with 9 % excess oxygen.

III. Combustion of Blends of Fish Oil and No. 2 Fuel Oil in Two Residential Boilers

Combustion tests were also carried out using two oil-firing residential boilers for two blends, which had 5% and 10% fish oil fraction respectively. The fuel analysis data are given in Table 7. The combustion was trouble-free and no modifications to the combustion and fuel delivery systems were made.

Emission results for the tests with the smaller boiler (30 kW) are shown in Table 8. No. 2 fuel oil and the 5% fish oil blend showed very similar stack emissions. A slight reduction (about 5%) in SO_2 emission was noted for the 5% fish oil blend. No appreciable difference in NO_x emission was

TABLE 7
PROPERTIES OF THE FUELS TESTED IN THE BOILERS

	Fish oil	No.2 oil	5% Fish oil	10% Fish oil
Density (15°C), kg/m^3	880.1	840.2	842.3	844.1
Kineatic viscosity (40°C), cSt	4.25	2.13	2.20	2.28
Cloud point, °C	6.5	-14.9	-14.7	-13.4
Ultimate Analysis (wt%)				
Carbon	77.47	86.82	86.66	85.97
Hydrogen	11.91	12.84	13.0	13.08
Nitrogen	<0.01	0.01	<0.01	<0.01
Sulphur	<0.002	0.217	0.205	0.192
Ash	<0.001	<0.001	<0.001	<0.001

TABLE 8
COMPARISON OF EMISSIONS FOR COMBUSTION OF NO. 2 FUEL OIL AND 5% FISH OIL BLEND IN THE 30 KW BOILER

Fuel	No. 2 oil	5% fish oil blend
CO_2, %	13.3	13.3
CO, ppm	20.6	21.1
NO_x, ppm	108	107
SO_2, ppm	114	109

TABLE 9
COMPARISION OF EMISSIONS FOR COMBUSTION OF NO. 2 FUEL OIL AND TWO FISH OIL BLENDS IN THE 150 KW BOILER

Fuel	No. 2 oil	5% fish oil	10% fish oil
CO_2, %	13.3	13.4	13.3
CO, ppm	22	21	20
NO_x, ppm	104	4	99
SO_2, ppm	113	106	100

observed. With the larger boiler (150 kW), the 5% fish oil blend appeared to give about 6.2% reduction in SO_2 than No. 2 fuel while a 9.7% reduction was observed for the 10% fish oil blend (Table 9). The combustion of the 5% fish oil blend in the 30 kW oil-fired boiler emitted particulate emissions that are smaller than 2.5 micrometer, i.e., $PM_{2.5}$ materials, and the results are shown in Table 10 as a comparison of $PM_{2.5}$ emissions for the two tested fuels. The data appear to suggest a reduction of PM emission when burning the blend, as is also consistent to the observation that biodiesel can reduce emission of particulates.

TABLE 10
COMPARISON OF PARTICULATE EMISSIONS FOR COMBUSTION OF NO.2 FUEL OIL AND 5% FISH OIL BLEND IN THE 30KW BOILER

Sample No.	$PM_{2.5}$ emissions (mg/m^3)	
	No.2 fuel oil	**5% fish oil blend**
1	11.5	11.9
2	12.0	11.7
3	11.6	11.5
4	11.2	10.8
5	11.8	11.1
6	11.3	11.0
7		11.4
8		11.0
9		9.9
Average	11.6	11.1

IV. CONCLUSIONS

Blends of fish oil and fuel oils burn easily in the furnace and the boilers, up to 100% fish oil content. Fish oil could reduce effectively the viscosity of the residual (No. 6) fuel oil and the blends burned more readily. The emission was generally lower than the pure fuel oil except that of NO. The NO emission was somehow higher when burning the 10% fish oil blend with No. 6 fuel oil, but at lower fuel nitrogen content the emission reduced and for blends with low nitrogen content (No. 2) fuel oil, the emission of NO was at the same level as that of pure fuel oil. The emission of NO increased with increasing excess air, while emissions of CO and SO_2 did not show appreciable dependence on excess air. The droplet of fish oil evaporated faster than No. 2 fuel oil at 500ºC, whereas the temperature dependence of the evaporation rate looked quite weak. Overall, fish oil showed good properties for combustion in conventional furnace/boilers.

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