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AN EVALUATION OF WATER IN FUEL OIL EMULSIONS IN A SMALL PACKAGE BOILER

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DECEMBER 1979

ENERGY RESEARCH PROGRAM
ENERGY RESEARCH LABORATORIES
ERP/ERL 79-67(TR)

AN EVALUATION OF WATER IN FUEL OIL EMULSTIONS IN A SAMLL PACKAGE BOILER

by

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ABSTRACT

A series of tests to evaluate water in fuel oil emulsions were conducted in a small package boiler using No. 2 distillate and No. 6 residual fuel oils as reference fuels. During the tests, each of which were of at least 2 hours duration, SO_2, NO, and soot emission were measured along with relevant combustion performance parameters.

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INTRODUCTION

Widespread consumer interest in improved fuel efficiency and energy conservation has resulted in the marketing of various emulsification devices and numerous proprietary chemicals which claim to reduce oil consumption by minimizing smoke emissions and by removing soot deposits from boiler heat transfer surfaces.

To provide quantitative data on the role of water in combustion and heat transfers, a laboratory evaluation of water in fuel oil emulsions was carried out in a small packaged oil-fired boiler under combustion and operating conditions representative of those existing in industrial steam boilers. The evaluation was carried out as a component part of the CANMET Energy Research Program.

This report describes the facilities and procedures used to test the two types of water in fuel oil emulsion and gives an evaluation of the experimental data.

THE OIL-FIRED PACKAGED BOILER

The boiler used for this additive evaluation was a "Cyclotherm" fire-tube steam generator equipped with an axially-mounted, pressure-jet oil burner capable of burning either No. 2 or No. 6 fuel oil to provide a thermal input of 350,000 BTU/h (approximately 2 Igph of oil). Figure 1 shows a schematic illustration of the boiler and fuel supply system which was instrumented and tested in accordance with the American Society of Mechanical Engineers (ASME) Abbreviated Boiler Efficiency Test (PTC 4.1a - 1964). To provide a constant steam load throughout each test, the entire steam output was passed through an air-cooled heat exchanger. The condensate flow rate was measured routinely prior to discharge.

Fuel oil was supplied to the burner from a 45-gallon tank mounted on an electronic weigh scale. The tank contained electric heaters for preheating residual fuel oil and a mechanical blender for ensuring a uniform supply of either untreated or emulsified fuel oil. The emulsion was continously recirculated to provide a homogeneous stable fuel supply. To improve the stability of No. 2 fuel oil emulsions 4 volume % of a commercial emulsifier* was added.

The package boiler, although instrumented for automatic operation, was manually controlled throughout each combustion test to ensure that all control parameters were maintained within specified limits.

FUEL CHARACTERISTICS

The No. 2 and No. 6 fuel oils used for the emulsion evaluations were each supplied from single tanker shipments and the bunkered quantities of both fuels were in excess of that required to complete each test.

Representative analyses of the No. 2 and the No. 6 fuel oil from which the emulsions were made for each test were provided by the Petroleum and Gas Laboratory of the Energy Research Laboratories. These analyses are shown in Table 1.

EXPERIMENTAL PROCEDURES

The experimental conditions selected for the emulsion evaluations were essentially those conducted for the ASME abbreviated efficiency test. This procedure required 2 hours of operation under steady conditions before the necessary measurements for the efficiency determination were made.

Less than optimum combustion conditions were also selected because benefits from using emulsions are claimed to be greatest when the rates of smoke emission and soot deposition are high enough to reduce boiler efficiencies noticeably. Details of the different tests using No. 2 distillate and No. 6 residual fuel oils are summarized in Table 2, 3, 4, and 5.

The heat loss due to soot emissions was calculated by dividing the calorific value of the total carbon emitted by the calorific value of the total fuel burned.

To ensure that the boiler operation was typical of deteriorating or poor combustion conditions, the excess combustion air level was adjusted to a reproducible smoke spot index for all tests. Since it was desirable to

*Span 80 Atlas Chemical Co.

operate during the tests with higher than normal soot production it was not possible to use the standard Bacharach scale for control purposes. However, a reproducible smoke spot index was possible using the Bacharach instrument by reducing the sample volume abstracted by 90%.

Test Measurements

The following parameters of combustion performance were measured during each test at the locations shown in Figure 1.

1. Carbon dioxide and carbon monoxide continuously by non-dispersive infrared analyzers, Station C.
2. Oxygen continuously by paramagnetic analyzer, Station C.
3. Nitrogen oxides continuously by chemiluminescent analyzer, Station C.
4. Sulpher oxides intermittently twice daily by modified Shell-Thornton Method, Station B.
5. Smoke spot index, intermittently at least hourly by Bacharach Smoke Tester, Station A.
6. Particulate loading intermittently every four hours by isokinetic dust sampler, Station B.
7. a) Flue gas temperature by thermocouple at Station A.
   b) Combustion air temperature by thermocouple at the combustion air fan inlet.
   c) Oil temperature by thermocouple in oil line immediately before burner.
8. Oil flow rate continuously by electronic weighing of the bunker.

In addition to the critical combustion parameters, a number of supplementary measurements were taken to provide an immediate indication of any discrete changes in boiler operating conditions. These measurements included steam pressure, steam and supply water temperatures, water flow rate to the boiler, burner windbox pressure, furnace draft and oil pressure.

EXPERIMENTAL DATA AND DISCUSSION

The experimental data for steady-state combustion are summarized in Table 2, 3, 4, and 5. The influence of increasing water content of both fuels is shown in Figure 2.

Efficiency levels in the boiler deteriorates at high water content, but there is slight evidence of an optimum water content at low levels of water addition. These results confirm earlier findings at CCRL on residential heating systems (1,2). Any changes in soot emissions were negligible.

CONCLUSIONS

The addition of water to form emulsions of No. 2 and No. 6 fuel oils have shown no significant changes in the generation of soot and fuel efficiency was shown to deteriorate with increasing water content during closely controlled tests in a small packaged boiler.

The baseline conditions used for comparison were typical of poorly operated boilers and provided an ideal environment for emulsions to reduce smoke emissions and to remove existing soot deposits thereby improving heat transfer. Gas-borne soot values were essentially unaffected by the use of emulsions and any catalytic reactions due to the water are considered negligible. In the particular boiler system at CCRL it does not appear that water in fuel oil emulsions are a viable energy conservation or emissions control strategy.

ACKNOWLEDGEMENTS

Thanks are due to D.M. Desjardins, H.P. Raghunandan, F.L. Wigglesworth and D.H.J. McLaughlin who were responsible for various aspects of the sampling program

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2. Whaley, H., and Braaten, R.W., "An evaluation of water-in-oil emulsions in oil fired residential hot water furnace"; ERP/ERL 78-100(TR); Dec. 1978.

Table 1 -- Fuel oil analyses (1)

Fuel analyses	No. 2 oil	No. 6 oil
Specific gravity, 60/60 F	0.849	0.955
Gross calorific value BTU/lb	19,337	18,412
Carbon, wt %	86.97	86.66
Hydrogen, wt %	12.75	10.67
Nitrogen, wt %	0.01	0.22
Sulpher, wt %	0.50	1.86

(1) Analyses performed by the Petroleum and Gas Laboratory, Energy Research Laboratories, CANMET, Department of Energy, Mines and Resources, Ottawa, Canada.

Table 2 - Summary of boiler operating data; water in No. 2 fuel oil

Test No.	1	2	3	4	5	6	7	8	9	10
Water content, vol. %	0	0.8	1.8	2.2	4.5	6.9	11.9	16.4	18.4	22.2
Test duration h	2.2	5	4	2	4	5	5	4	5	5
Steam conditions										
Pressure, psig	5.6	5.3	5.6	7.1	6.4	6.8	7.6	6.8	7.7	6.8
Temperature, F	216.5	215.7	219.6	221.3	220.2	222.5	222.2	169.3	222.5	223.8
Water conditions										
Supply temperature, F	66	66	61	61	61	61	57	61	58	58
Condensation return, F	80	87	93	96	93	90	92	91	92	92
Make-up, Igph	10.9	10.4	11.2	11.5	12.1	10.9	10.7	10.5	11.0	10.4
Oil conditions										
Pressure, psig	203.8	195.0	203.6	209.3	197.8	196.0	201.8	198.8	195.8	194.9
Temperature, F	-	-	-	-	-	91	84	65	62	62
Flow rate, lb/h*	15.5	16.1	17.2	15.8	15.5	16.3	15.2	13.8	17.0	17.5
Furnace draft, in WG	0.04	0.08	0.06	0.06	0.06	0.06	0.03	0.07	0.06	0.06
Windboy pressure, in WG	5.25	3.86	4.08	3.92	3.60	3.5	4.2	2.9	3.4	4.4

*emulsion flow rate

Table 3 - Summary of combustion conditions; in No. 2 fuel oil

Test	3	4	5	6	7	8	9	10		
Water content, vol. %	0	0.8	1.8	2.2	4.5	6.9	11.9	16.4	18.4	22.2
Test duration, h	2.2	5	4	2	4	5	5	4	5	5
Flue gas analyses										
CO_2, % vol.	9.2	10.4	8.5	8.4	8.7	8.2	8.1	8.3	7.9	8.9
O_2, % vol.	9.5	10.0	9.8	10.3	11.8	10.4	10.6	10.4	10.8	10.0
CO, ppm vol.	343.	553.	644.	513.	570.	502.	582.	752.	618.	717.
NO, ppm vol.	33.3	30.5	29.2	31.3	29.8	29.2	30.8	24.6	26.2	29.3
SO_2, ppm vol.	40	54	69	67	71	73	69	80	85	88
Soot loading, mg/sm^3	97	105	111	120	112	107	97	111	98	98
Flue gas temp, F	435.	435.	475.	496.	502.	518.	496.	599.	550	579.
Combustion air temp, F	68.	79.	90.	91.	86.	86.	86.	84.	86.	88.
ASME heat balance										
Dry flue gas loss %	10.7	9.2	12.1	12.9	12.5	14.1	13.6	16.6	15.7	14.8
Hydrogen loss %	7.3	7.2	7.2	7.3	7.3	7.4	7.3	7.6	7.5	7.5
CO loss %	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Unburnt carbon loss %	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Water in fuel loss %	0.0	0.1	0.1	0.2	0.4	0.5	0.9	1.5	1.7	2.2
Indirect efficiency %	81.7	83.1	80.2	79.2	79.4	77.6	77.8	73.9	74.7	75.1

Table 4 - Summary of boiler operating data; water in No. 6 fuel oil

Test No.	1	2	3	4	5	6	7	8
Fuel								
H_2O % vol.	0.0	0.4	0.8	2.9	3.3	10.1	18.5	30.1
Test duration, h	5.5	3.0	5.5	3.0	4.0	4.0	4.5	3.5
Steam conditions								
Pressure, psig	6.3	5.7	6.3	7.6	5.1	5.6	4.7	5.0
Temperature, F	218	213	215	221	214	215	215	215
Water conditions								
Supply temperature, F	53	52	48	48	48	48	48	48
Condensation return, F	81	80	76	83	81	77	82	82
Make-up, Igph	19.4	19.4	19.5	15.7	17.2	15.1	13.4	10.5
Oil conditions								
Pressure, psig	280	263	227	203	207	202	201	203
Temperature, F	239	251	252	247	251	237	248	239
Flow rate, lb/h*	22.5	22.9	18.8	19.0	19.0	18.5	17.2	18.3
Furnace draft, in WG	0.06	0.20	0.16	0.06	0.09	0.05	0.05	0.09
Windowbox pressure, in WG	6.9	7.4	6.8	6.7	6.5	5.8	4.6	3.1

*emulsion flow rate

Table 5 - Summary of combustion conditions; water in No. 6 fuel oil

Test	1	2	3	4	5	6	7	8
H_2O, % vol.	0.0	0.4	0.8	2.9	3.3	10.1	18.5	30.1
Test duration, h	5.5	3.0	5.5	3.0	2.0	2.0	4.5	3.5
Flue gas analyses								
CO_2, % vol.	8.5	8.7	10.1	9.0	8.4	7.8	6.8	5.4
O_2, % vol.	10.3	10.1	9.4	10.2	10.6	11.4	12.3	11.0
CO, % vol.	0.09	0.12	0.11	0.07	0.05	0.03	0.04	0.04
NO, ppm vol.	104	108	112	107	108	95	79	36
SO_2, ppm vol.	377	397	383	388	341	371	389	364
Soot loading, mg/sm^3	290	281	285	281	305	344	319	308
Flue gas temp, F	669	643	601	582	567	547	523	498
Combustion air temp, F	77	76	72	77	78	79	81	71
ASME heat balance,								
Dry flue gas loss, %	19.6	18.4	14.8	15.8	16.4	16.8	18.2	22.0
Hydrogen loss, %	6.9	6.8	6.7	6.6	6.6	6.5	6.5	6.5
CO loss, %	0.3	0.3	0.3	0.2	0.2	0.1	0.1	0.1
Unburnt carbon loss, %	0.6	0.5	0.5	0.5	0.6	0.7	0.7	0.9
Water in fuel loss, %	0.0	0.1	0.1	0.2	0.2	0.8	1.6	3.0
Indirect efficiency, %	72.6	73.9	77.6	76.7	76.0	75.1	72.9	67.5

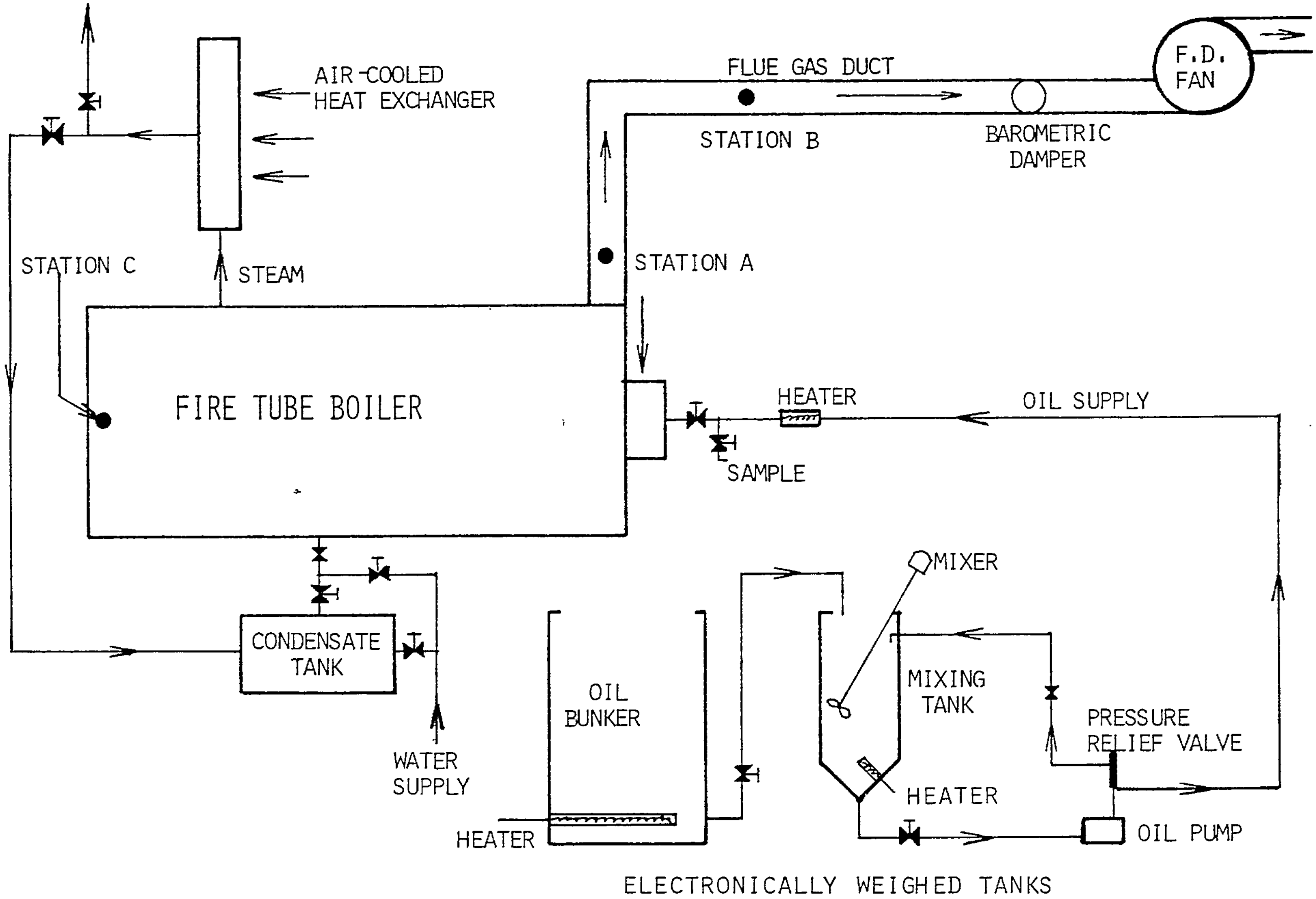

Figure 1. Schematic illustration of the packaged oil-fired boiler; water-in-oil emulsion tests.

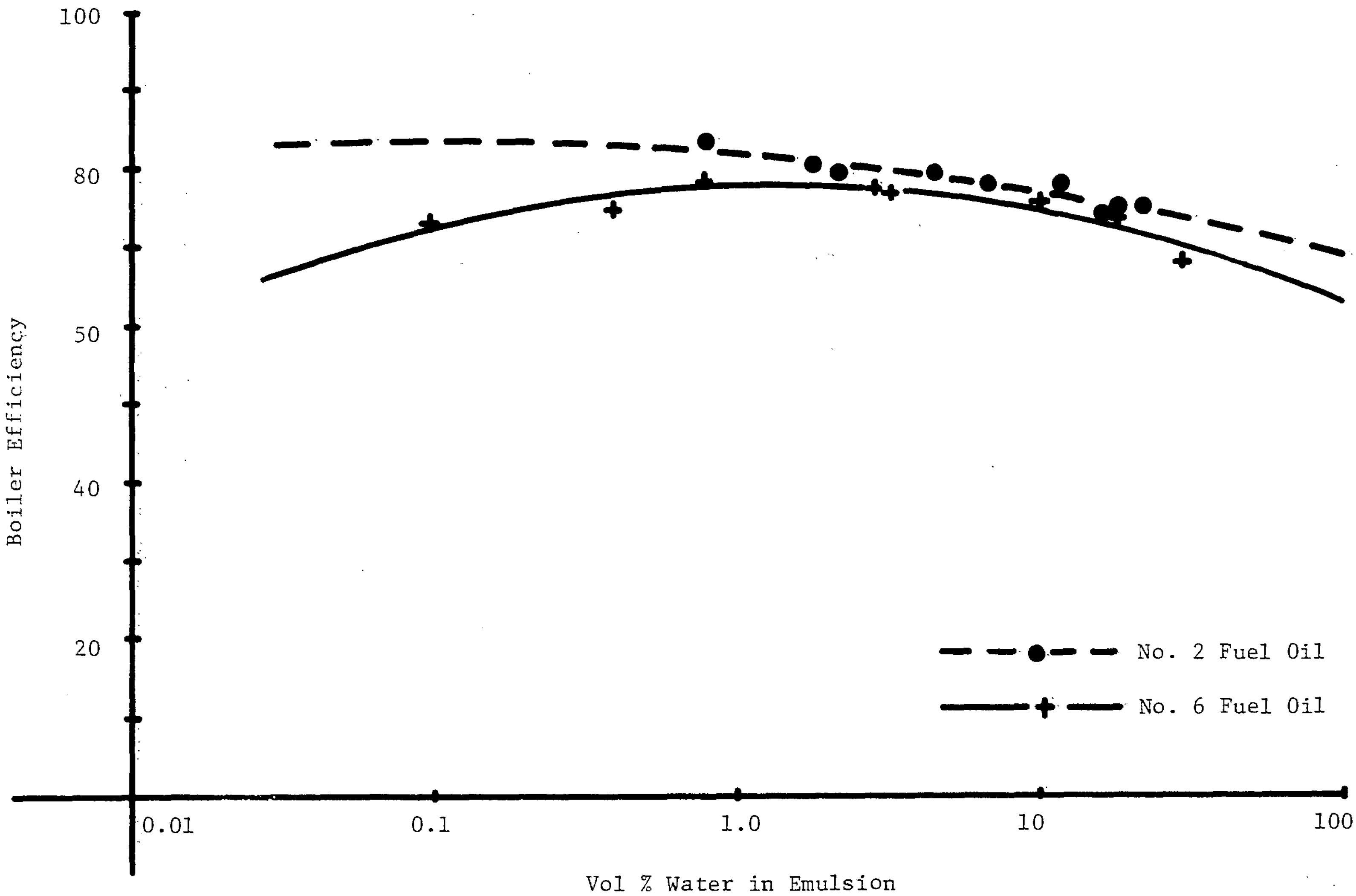

Figure 2. Variation of boiler efficiency with water content; No. 6 fuel oil emusion.