WASTE OIL BURN-OFF
IN COAST GUARD POWERPLANTS
Waste Oil Fittering Systems and Diesel Engine Performances

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16. Abstract

This report documents two tasks of a continuing study to determine the feasibility of burning waste lubricating oils in Coast Guard powerplants. The first task evaluated the effectiveness of two treatment devices for the clean-up of waste lubricating oil. It was found that a commercially available diesel filter pack is more effective than an oily-water separator. In the second task, exhaust emissions and performance were measured with a GM6-71 diesel engine when mixtures of lube oil in fuel oil up to 10 percent were burned. No short-term degradation in emissions or performance were observed.

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PREFACE

An economical procedure for the disposal of waste lubricating oils in the Coast Guard fleet is to burn-off these oils in diesel engines and boilers. An initial study investigated the feasibility of adopting a lube oil burn-off program in the Coast Guard fleet. The work reported here is a follow-on to this feasibility study and documents the results of tests on waste oil clean-up devices and effects on diesel engines performance and emissions when burning mixtures of waste lube oil in fuel oil.

This work was performed under the auspices of the United States Coast Guard, Office of Research and Development, Pollution Prevention Projects Branch, Capt. D.B. Flanagan, Chief, and Lcdr. J. Sherrard, Ltjg. R. Skewes and William McKay, Project Officers.

Grateful acknowledgement is made for the assistance of the following people: Lcdr. L. Pichini and Lt. R. Huck, Coast Guard Office of Engineering; Mr. R. Roberts and C. Hoppen of TSC.

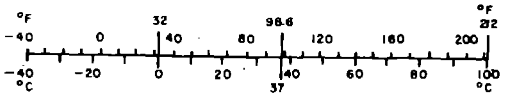
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. INTRODUCTION

In FY 75, TSC performed a study to determine the feasibility of burning waste oil (bilge and lubricating) in Coast Guard power plants (Reference 1).

In this earlier study, recommendations were solicited from diesel engine manufacturers; existing waste lube oil burn-off procedures were studied; fuel requirements and mix ratios of waste oil in fuel oil for Coast Guard diesel engines, boilers, and turbines were investigated, and candidate systems for the clean-up of waste oil were identified. The potential effects on performance and emissions in Coast Guard power plants were investigated. The study recommended areas for further evaluation before the Coast Guard adopt a waste oil burn-off program.

The work reported here documents the results from two of these recommended study areas;

1. Evaluation of waste oil filtering systems.
2. Short-term effects of burning waste oil on diesel engine emissions and performance.

A third study area, the long-term effects on diesel performance, is presently under investigation. A report will be published in the near future along with final recommendations to the Coast Guard on the adoption of a waste oil burn-off program.

1.1 SUMMARY

The objectives of this phase of a continuing study to determine the feasibility of burning waste lubricating oil mixed with fuel oil in Coast Guard powerplants have been achieved. These objectives were twofold:

1. Evaluate devices for the clean-up of waste lubricating oil;
2. Determine the short term effects on diesel engine emissions and performance when burning mixtures of waste lube oil and fuel oil.

Two devices were evaluated for the clean-up of waste lube oil. These devices were the oily water (bilge) separator and a commercially available diesel filter pack (Luber-Finer)*. The oily water separator has been developed by the Coast Guard for bilge treatment to meet EPA water discharge requirements. This device is being installed on all cutters and offered the advantages of being available at no additional cost and requiring minimum crew retraining. The diesel filter pack is a low-cost system used by commerical trucking fleets to clean waste lubricating oil.

The tests of emissions and performance were conducted on a two-stroke cycle GM6-71 diesel engine with mixtures of waste lube oil and fuel oil up to 1:10. This engine was selected because of its wide use in the Coast Guard fleet and also because of agreement among engine manufacturers that the two-stroke cycle engine would be a "worst case" condition for possible engine degradation (Reference 1).

Based upon the results of the lube oil analysis performed as part of the device evaluation, an effort was directed toward the final determination of the optimum mix ratios of lube oil and fuel oil for diesel engines, boilers, and gas turbines.

1.2 CONCLUSIONS

The following major conslusions have been reached as the result of the work reported herein:

1. The oily water separator effectively removes gross suspended particulate matter but further contaminates the filtered oil with water and insoluble material.
2. The commercially available filter pack is effective in removing gross suspended particulate matter, insolubles, and, to a lesser extent, water from lubricating oil.

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*Trade name of Luber-Finer Inc., a division of Rockwell International, Los Angeles, California.

3. Mixtures of filtered waste lube oil in fuel oil at ratios up to 1:10 produce no observable short term changes in diesel emissions and performance.
4. Mixtures of filtered waste lube oil in fuel oil at ratios of 1:100 can be burned in ship service and main propulsion boilers.
5. The soluble metallic content of waste lubricating oils can contribute to corrosion of turbine blades and would limit the safe mix ratio of lube oil in fuel oil on turbine equipped cutters to approximately 1:5000.

The final recommendations for adoption of lube oil burn-off program in the Coast Guard fleet will be included as part of a report, currently in preparation, on possible long term diesel engine effects when burning mixtures of lube oil in fuel oil.

2. FILTERING SYSTEMS DESCRIPTION

In the previous feasibility study, two types of systems were recommended for evaluation as methods to filter waste oil; bilge (oily) water separators and the Luber-Finer System. The later is used by several trucking companies to filter used crank-case oil from truck diesel engines for subsequent burn-off in the fuel oil. It was endorsed by Cummins Engine Company (Reference 2).

2.1 BILGE WATER SEPARATORS

The bilge water separator system is being installed on all Coast Guard ships over 65 feet in length and, if usable for filtering waste oil, would require a minimum of additional equipment and crew training. Two bilge water separators were evaluated in this study. One is a Separation and Recovery Systems, Inc. (SRS), five gallon-per-minute (gpm) unit. A flow diagram for this unit, as received from the manufacturer is shown in Figure 1. The other unit is a Cata-Sep 100 GPM unit. A flow diagram of this unit is shown in Figure 2. The SRS bilge water system consists of a pump, associated valves, and two coalescer units (pressure vessels) manufactured by SRS. The flow through these two coalescer units is from the inside of the cartridge to the outside. However, the Coast Guard is modifying the system so that the first pressure vessel is re-configured as a pre-filter with the flow from the outside of the filter cartridge to the inside (as shown in Figure 3). This modification was made for two reasons: (1) the pleated paper pre-filter cartridges, Fram #C-744, as used in the re-configured system, are only one-fifth as expensive as the all-glass coalescer cartridges, (2) the pleated paper cartridges constitute a larger surface area for filtering and therefore a larger filtering capacity and lower frequency of filter replacement. Figure 4 shows these bilge water separators installed for testing in the laboratory. This separator system was evaluated as received, that is, operating as two stages of coalescing (Mode I) and as modified, operating as pre-filter and coalescer (Mode II).

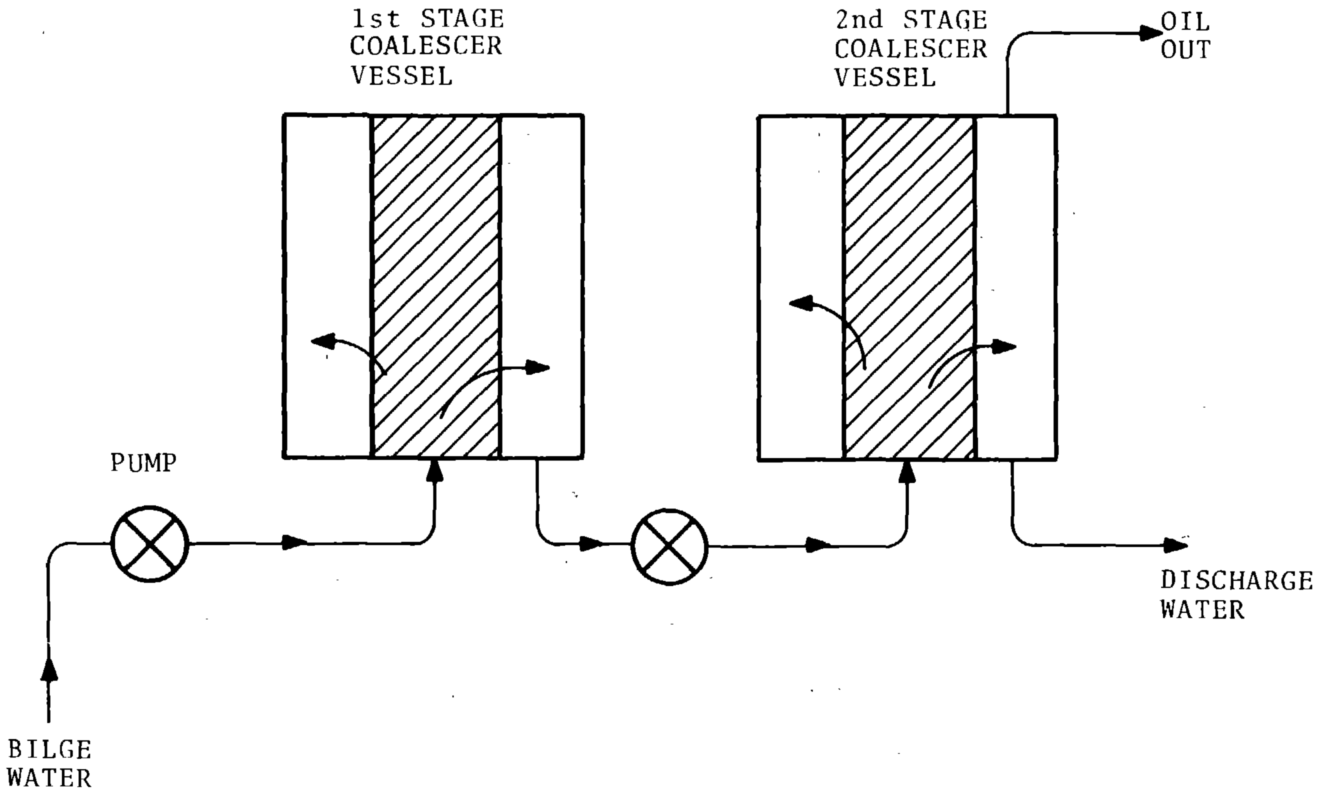


FIGURE 1. FLOW DIAGRAM FOR 5-GPM SRS BILGE WATER SEPARATOR AS RECEIVED FROM MANUFACTURER

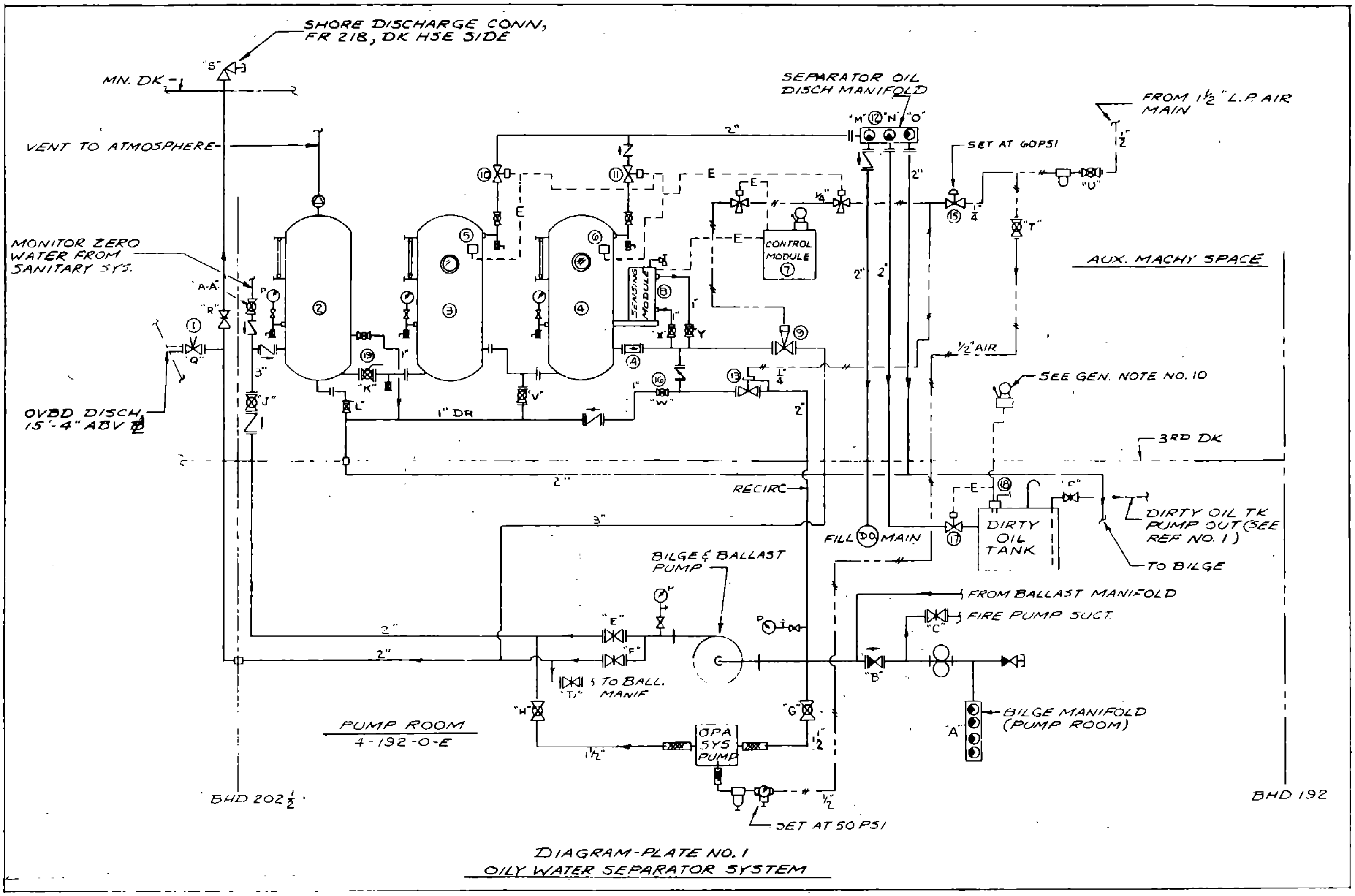
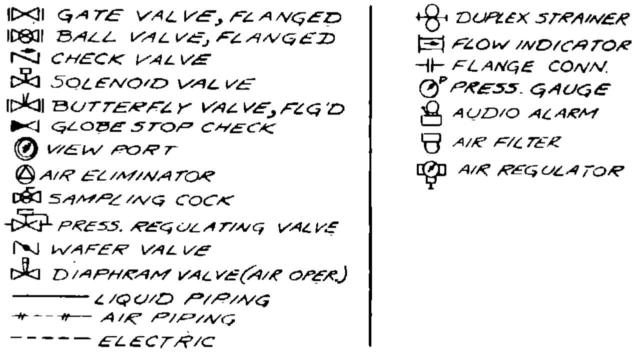


FIGURE 2. FLOW DIAGRAM 100-GPM CATA-SEP BILGE WATER SEPARATOR

LEGEND



COMPONENT KEY

① O.P.A SYSTEM OVBD DISCHARGE VALVE
② O.P.A. SYSTEM PRE-FILTER
③ OILY WATER SEPARATOR "A"
④ OILY WATER SEPARATOR "B"
⑤ 1ST STAGE LEVEL CONTROL
⑥ 2ND STAGE LEVEL CONTROL
⑦ CONTROL MODULE
⑧ SENSING MODULE
⑨ WATER DISCHARGE VALVE
⑩ 1ST STAGE OIL OUTLET VALVE
⑪ 2ND STAGE OIL OUTLET VALVE
⑫ OIL DISCHARGE MANIFOLD
⑬ RECIRCULATING VALVE
⑭ EFFLUENT FLOW INDICATOR
⑮ O.P.A. SYSTEM PRESS REGULATOR (AIR)
⑯ EFFLUENT DRAIN VALVE TO BILGE (NORMALLY CLOSED)
⑰ ELECTRICALLY OPERATED STOP VALVE
⑱ DIRTY OIL TANK LEVEL CONTROL
⑲ PREFILTER WATER OUTLET VALVE

MODES OF OPERATION

	VALVE																									
MODE	A	B	C	D	E	F	G	H		J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
HIGH RATE DEWATERING	○	○	●	●	●	○	●	●		●	●	●	●	●	●	●	○	●	●	●	●	●	●	●	●	●
DEBALLASTING	●	●	●	●	○	●	●	●		○	○	●	○	●	●	●	○	●	●	●	●	●	●	○	○	○
ROUTINE BILGE PUMPING	○	○	●	●	●	●	○	○		○	○	●	●	○	●	●	○	●	●	○	○	●	●	○	○	○
REMOVE WATER FROM TK BOT.	●	●	●	●	●	●	○	○		○	○	●	○	●	●	●	○	●	●	○	○	●	●	○	○	○

○ - VALVE OPEN ● - VALVE CLOSED

FOR OILY WATER SEPARATOR SYSTEM DIAGRAM - PLATE NO. 2

FIGURE 2. FLOW DIAGRAM 100-GPM CATA-SEP BILGE WATER SEPARATOR (CONT'D)

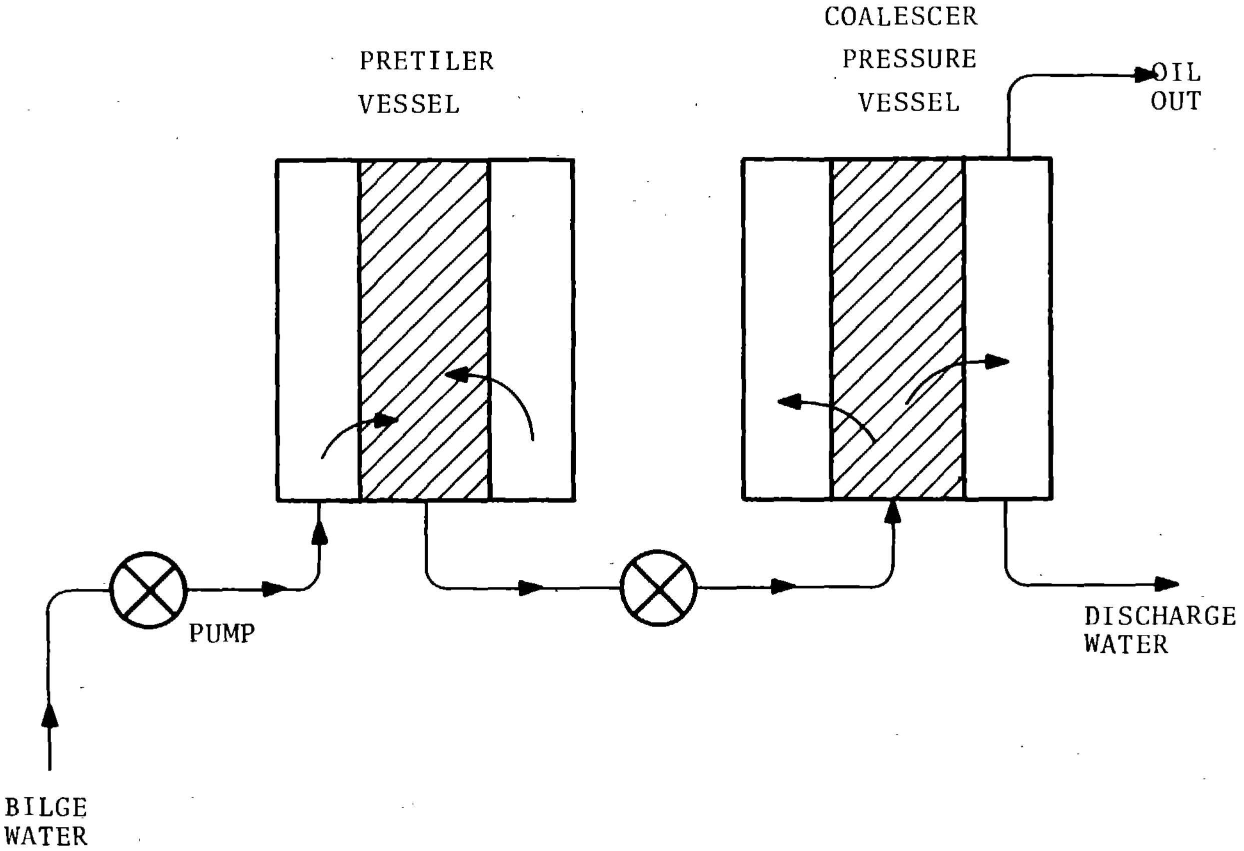


FIGURE 3. SRS 5-GPM BILGE WATER SEPARATOR AS RECONFIGURED BY COAST GUARD

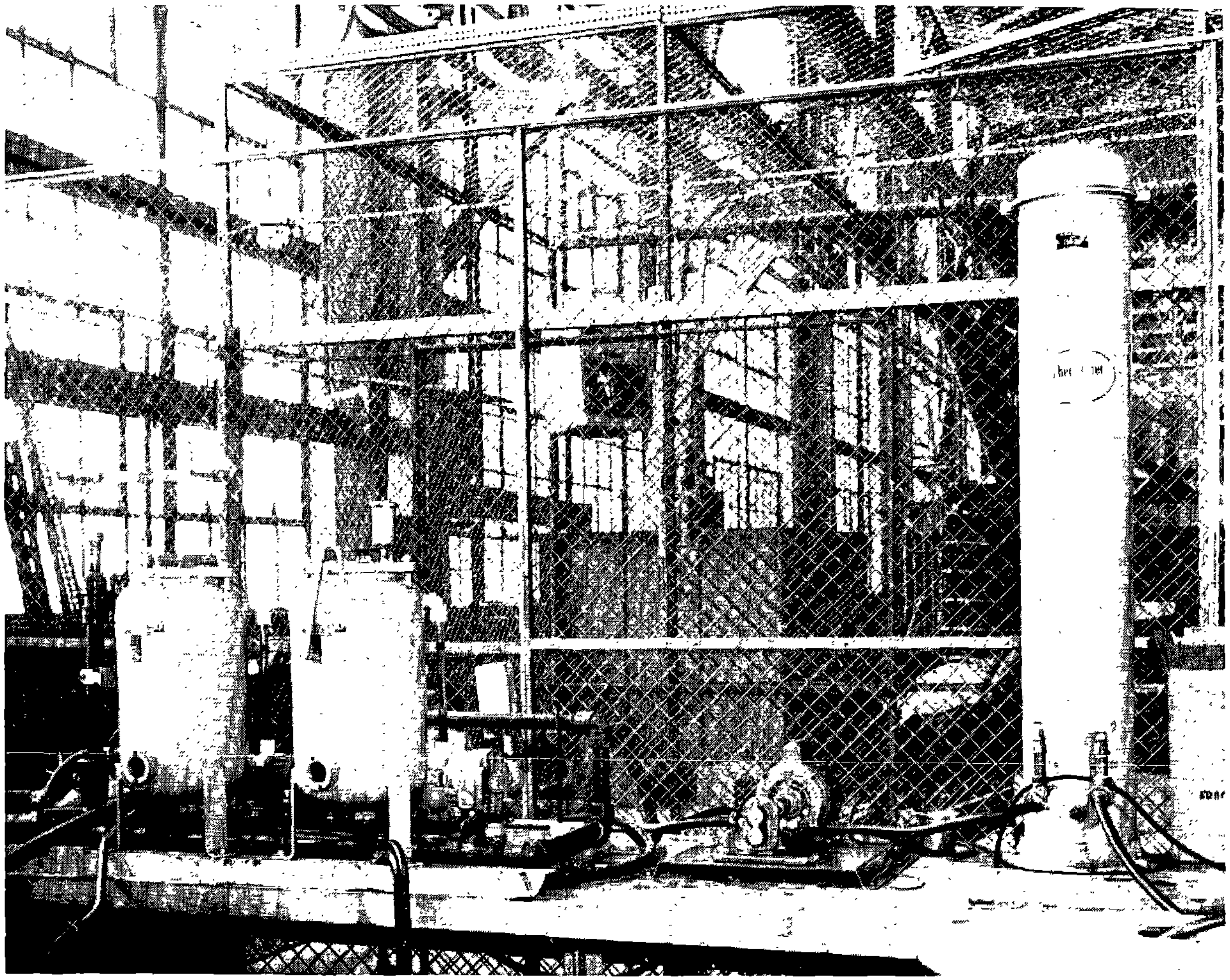


FIGURE 4. BILGE WATER SEPARATOR AND LUBER-FINER FILTER INSTALLED FOR TESTING IN THE LABORATORY

The Cata-Sep 100 gallon-per-minute separator (Figure 2) is a three stage unit consisting of a pre-filter and two coalescers. This unit was installed on the USCGC Hamilton and all testing was performed there.

2.2 LUBER-FINER FILTERING UNIT

The Luber-Finer unit (Rt - Figure 4) tested was a Model #750-3C consisting of a single pressure vessel containing three Luber-Finer Imperial Diesel Pak filters. A five gallon-per-minute rotary gear pump, operated by a 1/3 horsepower motor, was used to pump oil through the system (Figure 5).

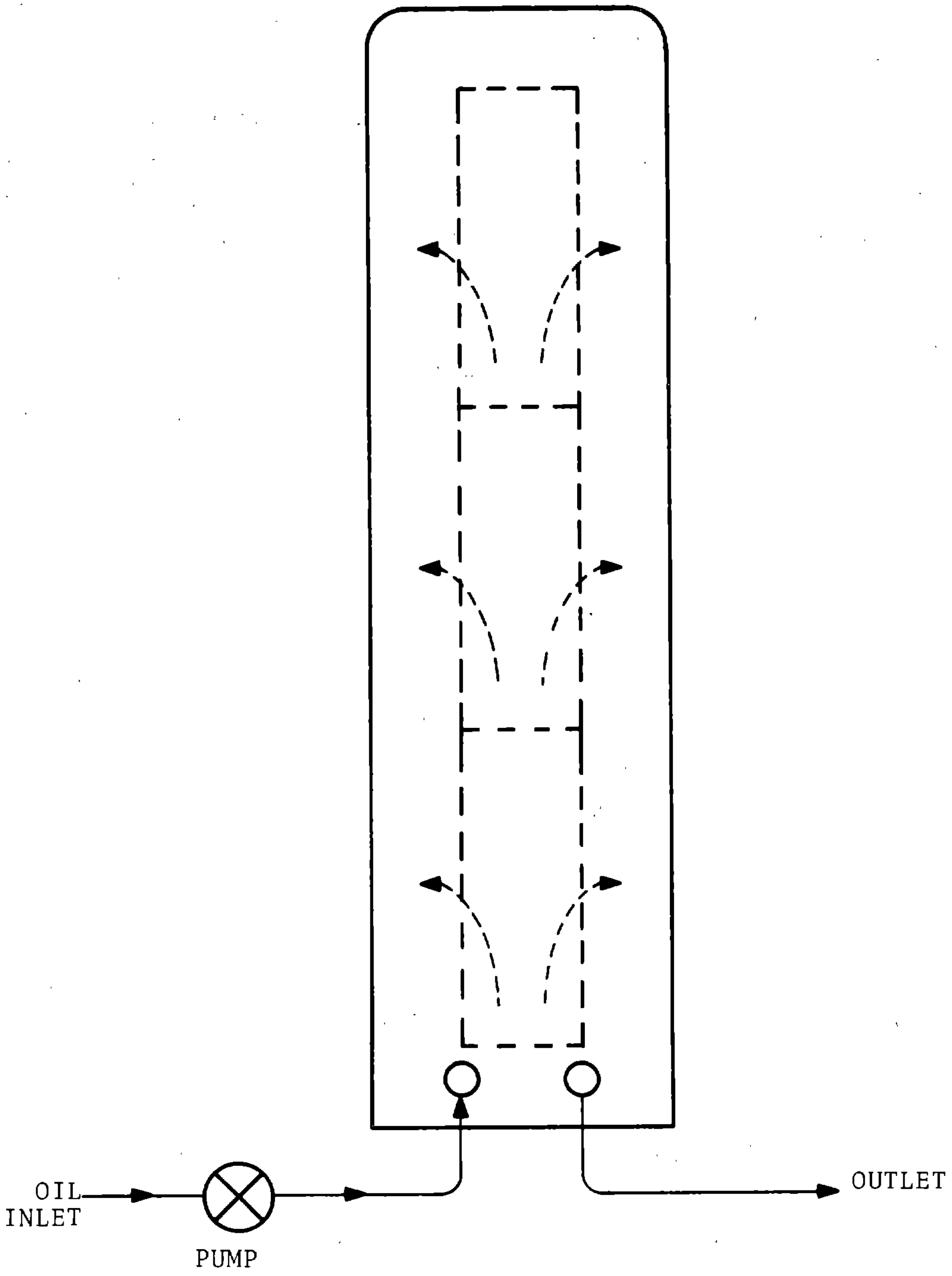


FIGURE 5. LUBER-FINER 730-3C FILTERING UNIT

3. FILTERING SYSTEMS EVALUATION

Numerous tests were performed with oil from various sources including bilge oil, bilge oil-water mixtures, and diesel engine crankcase oil. In all tests, oil analysis was performed on the samples as received and after various treatment procedures.

3.1 OIL ANALYSIS

Analyses of the oil samples were performed by Oil International Labs, Inc., Houston, Texas. The samples were analyzed for the following:

a. Insolubles

b. Trace metals

c. Water content

d. Sulfur

e. Particulates on 3 μm and 5 μm filters.

Ash content could not be determined because of the high amount of fuel oil and water in various samples. Total sulfur was not measured in all the samples because of the high trace metal content.

Samples of the oils were analyzed as received, analyzed after one pass through the treatment system, and generally analyzed again after multi-passes over a time period of up to one hour.

3.2 BILGE WATER SEPARATORS

Tests of filtering efficiency were made using the SRS 5-GPM unit on waste oil as received and with dilution of the waste oil with No. 2 diesel fuel before filtering through the unit. Similar tests were performed using the 100 GPM Cata-Sep bilge water separator in the USCGC Hamilton.

3.2.1 SRS 5-GPM Bilge Water Separator

Several drums of used oil were obtained from the USCG Support Center Boston. The origin of this oil is unknown; however, it is believed some of the oil came from ships bilges since much sea water was included. These samples were labeled B-1, D-1, and E-1. Samples of each were analyzed (Table 1).

Sample E-1 was processed through the unit in Mode I, i.e., two stages of coalescing. Sample E-2 was the first cut taken from the top of the second stage coalescer. After all the oil and water mixture was processed through the unit, the filtered oil was recirculated for one hour and sample E-3 was taken from the top of the second stage coalescer. The data for these samples is also shown in Table 1.

At this time the SRS-5 GPM unit was reconfigured so that the first stage unit operated as a pre-filter. Samples of oily water from barrels B-1 and D-1 were run through the unit and the separated oil samples were taken off the top of the first stage coalescer (second vessel). These samples were analyzed and the data also reported in Table 1 as B-2 and D-2.

Although not reflected in the data of Table 1, the bilge water separator removed considerable amounts of large particulate matter, as evidenced by subsequent examination of the coalescer cartridges. Because of the large amount of water in the samples a complete analysis was not possible on any of these samples. As can be seen in Table 1, the amount of water in the oil samples increased after passing through the bilge water separator. This increase in the water content is caused by the two factors: first, when large amounts of water and oil are being introduced and the first stage is being used as a pre-filter there is no oil/water separation and all of the oil/water mixture passes into the first stage coalescer (second vessel). Second, in the 5-GPM unit the volume of the pressure vessels is small and the oil-water separation is not complete when large quantities of oil are handled. In

TABLE 1. ANALYSIS OF USED OIL SAMPLES FILTERED BY THE SRS 5-GPM BILGE WATER SEPARATOR

		Trace Metals (ppm)																								
Sample	% H_2O	Fe	Ti	V	Pb	Cu	Sn	In	Sb	Cr	B	Na	Al	Si	Ag	Mo	Ba	Ca	Zn	P	K	Cd	Ni	Mg	Mn	Co
E-1	3.0	46.2	4.6	0	276.9	13.4	20.9	0	1.7	13.5	34.1	362.2	9.8	6.7	2.1	0	45	3975	449	279	0	1.7	0	80.2	2.8	0
E-2	5.0	40.3	3.1	1	270.2	11.9	23.9	0	0	13.4	25.6	225.1	11.6	5.7	1.2	1	38	2904	410	273	0	4.7	0.6	67.8	2.6	0
E-3	5.0	39.1	2.3	0	240.1	11.4	18.6	0	0	10.4	27.1	220.8	6.3	5.7	0.3	0	35	2842	367	178	0	1.7	0	66.1	2.3	0
B-1	12.0	74.6	0	0	13.2	9.5	20	0	0	3.6	26.7	244.3	0.6	7.3	0	0	9	3729	299	110	0.8	0	0	53.1	4.0	0
B-2	15.0	77.1	1.8	0	35.5	20.5	18.5	0	0	17.8	12.2	338.4	9.1	10.6	0.7	0	11	1984	327	129	0	0.5	0	83.7	2.0	0
D-1	6.0	53.0	2.0	0	12.2	20.7	13.8	0	0	21.4	8.4	395.8	7.4	7.8	1.3	0	8	2644	337	171	0	0	0	64.2	1.1	0
D-2	20.0	64.3	3.6	0	112.8	20.7	16	0	0	18.1	6.1	245.2	9.5	9.9	0.6	0	17	2019	321	128	0	0.9	0	65.2	1.5	0

this situation the oil is removed from the top of the first stage coalescer (second vessel) before complete separation has occurred and hence the oil is contaminated with water.

As can be seen from Table 1, the presence of bilge water is also evident from the large quantities of sodium and magnesium. In addition, sample E-1 shows a high lead content probably from lubricating oil from a gasoline powered engine. Two measures were proposed to eliminate the amount of water withdrawn with the oil from the top of the first stage coalescer (second vessel). First, the water-oil interface in the first stage coalescer should be pushed to the bottom of the pressure vessel before any oil is drawn off the top. This would allow more time for the coalescing action to take place and permit better oil/water separation. Second, dilution of the waste lube oil with #2 diesel fuel would lower the viscosity of the mixture, permit separation of the lube oil/fuel oil mix from the water, improve filtration, and increase the speed of the entire filtering process. A 1:1 to a 3:1 dilution of the used oil with fuel oil would be sufficient to permit better oil separation.

Fuel oil dilution and lowering of the oil/water interface was tested using the 5-GPM SRS System. Approximately 50 gallons of used crankcase oil was taken from the No. 2 main diesel engine (Fairbanks Morse 38TD81/8) of the USCGC Sherman. This was labeled sample S-2-1, diluted 3:1 with #2 diesel fuel, and run through the 5-GPM SRS unit with the oil/water interface at the bottom of the second stage pressure vessel; three barrels of 3:1 lube oil/fuel oil mixture were taken from the top of the first stage coalescer. Samples from these three barrels were designated S-2-2, S-2-3, and S-2-4. The data for these tests are shown in Table 2.

Table 2 indicates that dilution of the used oil at 3:1 with fuel oil and holding the oil/water interface at the bottom of the first stage coalescer (2nd vessel) did not prevent water contamination. The water content increased from an immeasurably small amount in the as-received used oil to 1.5 percent, 2.0 percent and 0.3 percent respectively in the three samples. An increase

TABLE 2. ANALYSIS OF USED OIL/FUEL MIXTURES FILTERED THROUGH THE SRS 5-GPM BILGE WATER SEPARATOR

				Trace Metals (ppm)																								
Sample	% H_2O	%Oil	%Ins.	Fe	Ti	V	Pb	Cu	Sn	In	Sb	Cr	B	Na	Al	Si	Ag	Mo	Ba	Ca	Zn	P	K	Cd	Ni	Mg	Mn	Co
S-2-1	0	100	0.2	29	0	0	12	17	22	0	0	25	3	275	4	4	0	0	407	4540	519	282	0	0	0	18	1	0
S-2-2	1.5	38	1.0	8	3	2	5	6	8	0	0	9	1	93	6	1	2	0	135	980	165	0	9	0	1	7	0	2
S-2-3	2.0	34.5	0.1	5	3	2	1	6	8	0	0	9	1	68	7	1	2	0	118	890	165	0	6	0	2	6	0	2
S-2-4	0.3	31.4	0.1	6	2	2	1	7	10	0	0	7	1	84	7	2	2	0	180	1300	204	0	7	0	3	6	0	3

in insolubles in sample S-2-2 is probably caused by the "washout" of previously entrapped small particles. As the system purges itself of entrapped water and particulate matter, the percentages of water and insolubles decrease in sample S-2-4 to 0.3 percent and 0.1 percent, respectively. This water content is still higher than that of the original lube oil (S-2-1).

The lowering of the soluble trace metals can be attributed in most cases to the 3:1 dilution. The trace metals Ti, V, K, Ni and Co show slight increases. These increases may be caused by the fuel oil acting as a solvent for some of the previously insoluble trapped material in the filter.

3.2.2 Cata-Sep 100 GPM Bilge Water Separator

During the tests of the 5-GPM bilge water separator, some water was inevitably introduced into the oil effluent from the system water residue. Even using the two techniques discussed at the end of Section 3.2.1, the amount of water in the oil effluent increased from a trace to a maximum of 2 percent (Table 2). Since the pressure tanks on the 100 GPM Cata-Sep Units are about ten times the capacity of the SRS unit, tests were performed to determine if this larger volume permitted better water/oil separation.

Initially, an evaluation of oil samples from the normal operation of the Cata-Sep 100 GPM bilge water separator on the USCG Hamilton was performed to ascertain the effectiveness of the separator when operating on bilge suction. A sample (H-1) of oil found in the bilges of the Hamilton was taken and then the separator operated on these bilges. Sample H-2 was then removed from the top of the first stage coalescer. The analysis of these samples is given in Table 3.

Next, fuel oil dilution and lowering of the oil/water interface were studied using the Cata-Sep unit. Six gallons of lube oil was drained from the #2 main engine of the USCGC Sherman (Sample S-2-1, Table 3), diluted 1:1 with #2 fuel oil and placed in the strainer inlet of the Cata-Sep 100-GPM separator on the USCGC Hamilton. This procedure eliminated the possibility that

TABLE 3. ANALYSIS OF USED OIL SAMPLES FILTERED BY THE CATA-SEP 100 GPM BILGE WATER SEPARATOR

			Trace Metals (ppm)																									
Sample	%H_2O	%Ins.	Fe	Ti	V	Pb	Cu	Sn	In	Sb	Cr	B	Na	Al	Si	Ag	Mo	Ba	Ca	Zn	P	K	Cd	Ni	Mg	Mn	Co
S-2-1	0.1	0.2	29	0	0	12	17	22	0	0	25	3	275	4	4	0	0	407	4540	519	282	0	0	0	18	11	0
H-1	0.1	0.2	0	0	0	0	13	5	0	0	3	1	28	0	0	1	0	4	693	29	0	0	0	0	3	0	0
H-2	0.1	0.5	13	0	0	0	14	3	0	0	4	1	50	0	0	0	0	6	1323	47	0	0	0	3	0	8	0
H-3	1.5	0.5	12	1	0	4	11	8	0	0	5	8	90	5	2	1	0	20	1636	215	0	17	0	0	7	0	0
H-4	1.5	1.0	12	1	0	5	11	8	0	0	5	8	50	6	2	2	0	9	1412	43	0	10	0	1	5	0	0

any water from the bilges could contaminate the sample. However, water was still present in the separator tanks and filters from previous usage. Twelve gallons of the oil/fuel-oil mixture was taken from the top of the first stage coalescer (2nd vessel). As the twelve gallons was mixed and introduced six gallons at a time, two samples (one for each six gallons) were taken and analyzed. The results are labeled H-3 and H-4 in Table 3.

As previously mentioned, Sample H-1 was skimmed from the top of the bilge of the USCGC Hamilton. At this time, the bilges contained very little water, considerable diesel fuel oil from a broken fuel transfer pump and small amounts of lube oil. The sample analysis shows less than 0.1 percent H_2O (trace) and 0.2 percent insolubles. The rest of the analysis shows small amounts of sodium due to sea water, calcium from the calcium phenate or calcium sulphonate detergents, and some zinc from the zinc amide dispersents in the lube oil. Sample H-2 was taken from the top of the first stage coalescer (2nd vessel) of the 100-GPM separator. This sample shows 0.5 percent insolubles and increased sodium, calcium and zinc. This increase in insolubles and trace metals can be attributed to two factors: First, sample H-1 was taken from top of the bilge while sample H-2 was drawn from the bottom of the bilge, where a large quantity of smaller sized particles had settled and were not removed by the separation, and second, previously trapped small particles and residual oil in the filters were washed out by the fuel oil.

Sample S-2-1, oil from the No. 2 main diesel engine of the USCGC Sherman, shows high calcium, barium, zinc, phosphorus, and sodium; a trace of H_2O and only 0.2 percent insolubles. As previously mentioned, twelve gallons of this used oil (sample S-2-1) were diluted with an equal volume of #2 diesel fuel and placed in the strainer inlet. The oil/fuel samples, H-3 and H-4, taken off the top of the 1st stage coalescer (2nd vessel) show a 64 percent reduction of calcium, a 50 percent reduction of Zn, removal of all phosphorous, and a 73 percent reduction of sodium. As with the tests of the 5-GPM unit, most of these trace metal reductions can be attributed to the 1:1 fuel oil dilution. However, as in previous tests, these samples show a marked increase in water and insolubles. As all the oil/fuel oil mixture passes through the pre-filter, previously trapped particulate matter and heavier oils are "washed out" along with some of the trapped water. These increases in water and insolubles are evident in Table 3. Eventually these contaminants will be cleaned out of the system as was evident in the tests performed with the 5-GPM unit. However, in the tests performed with the 100-GPM unit, not enough fuel oil/lube oil mixture was run through the unit to precipitate clean-up. It is probable that at least 100 gallons of this mixture would be needed before the trends evident in Table 3 are reversed.

3.3 LUBER-FINER UNIT

The other treatment system evaluated was the Luber-Finer unit used by trucking companies to filter used oil for burn-off with #2 disel fuel. The unit used for this test contained three Luber-Finer Imperial Diesel-Pak filter elements.

Fifty gallons of used crankcase oil from the No. 1 main diesel engine of the USCGC Sherman (Sample S-1-1) was filtered through the Luber-Finer unit. One sample of the initial filtered effluent (S-1-2) was taken and another sample (S-1-3) was taken after 1/2 hour of continuous filtering. After 50 gallons of the oil had been processed through the filter once, approximately five gallons of the filtered oil was recirculated through the filter for 1-1/2 hours and a sample (S-1-4) taken (Table 4). Fifty gallons of used oil from the #2 main diesel engine of the USCGC Chase was also processed by the Luber-Finer unit (Sample C-1). In order to minimize carryover, the filter elements in the system were replaced. Sample C-2 was taken after 1/2 hour (approx. 25 gal.) of filtering. When all the oil (approximately 50 gallons) had been filtered once, Sample C-3 was taken. Approximately five gallons of the filtered oil was then recirculated through the filter system for 1-1/2 hours and a sample C-4 was taken. These samples were also analyzed and the data are included in Table 4.

TABLE 4. ANALYSIS OF USED OIL FILTERED THROUGH THE LUBER-FINER OIL FILTERING UNIT

			Trace Metals (ppm)																									
Sample	$\%H_2O$	% Ins*	Fe	Ti	V	Pb	Cu	Sn	In	Sb	Cr	B	Na	Al	Si	Ag	Mo	Ba	Ca	Zn	P	K	Cd	Ni	Mg	Mn	Co	
S-1-1	0.5	1.5	33	1	0	19	15	22	0	0	27	3	199	8	4	1	0	174	4385	485	265	0	2	0	21	1	0	
S-1-2	0.1	0.3	16	0	0	12	16	16	0	0	24	2	201	7	3	0	0	161	3956	442	183	0	2	0	17	1	0	
S-1-3	0.1	0.3	18	0	0	14	14	22	0	0	26	2	232	9	4	1	0	158	4212	455	208	0	1	0	17	1	0	
S-1-4	0.1	0.2	18	0	0	17	16	18	0	0	26	2	208	5	5	0	0	164	4186	458	230	0	2	0	21	3	0	
C-1	<0.1	<0.1	15	2	2	3	9	29	0	0	16	10	213	10	6	2	0	34	4812	527	363	14	0	2	15	1	0	
C-2	<0.1	<0.1	14	2	1	2	9	26	0	0	16	9	207	10	4	2	0	32	4621	524	318	15	0	2	14	1	0	
C-3	<0.1	<0.1	15	1	1	2	9	26	0	0	16	9	224	10	4	2	0	33	4894	530	322	15	0	1	16	1	0	
C-4	<0.1	<0.1	13	1	0	0	10	25	0	0	17	8	201	11	4	2	0	33	4719	540	276	16	0	1	16	1	0	

The data of Table 4 indicates that filtration by the Luber-Finer filtering system lowered the water in samples S-1-2, S-1-3, and S-1-4 to the trace level (the lower limit of detection) and lowered the insolubles in sample S-1-1 by 80 percent while not permitting the insolubles to increase above the trace level in samples C-2, C-3 and C-4. In addition, a test of filterable solids on 3 μm and 5 μm filter paper was performed on samples C-1, through C-4. In samples C-2, C-3 and C-4 these results indicate a decrease in particulate matter on 3 μm filters ranging from 22 percent to 5 percent and on 5 μm filters from 45 percent to 27 percent.

As can be seen from Table 4, the Luber-Finer System did not reduce the trace metal content of the oil. Most of the additives containing zinc, barium, calcium, and phosphorous were highly dispersed and could not be filtered out. Except for the presence of the wear metals (iron, copper, tin, chromium, and aluminum) and the contaminants from sea water (sodium and magnesium) the oil has a typical trace metal content for MIL-L-9000G lube oil. (See Table 5.)

3.4 DISCUSSION

During the work described in the preceeding section, observations of the bilge water separator used in its normal operating manner indicated it is an effective filter for particulate matter in the used lubricating oil, but would probably increase the cartridge failure rate due to clogging. In addition, more water and insoluble material (until the units are thoroughly flushed) are introduced than already present in the used oil. If the bilge water separator is to be used for clean-up one of the following two procedures would have to be adopted. In the first procedure, the bilge water separator would be drained and the filter elements replaced with new ones. The lube oil would then be pumped directly from the engine, diluted approximately 3:1 with #2 oil, and processed through the bilge water separator. The filtered oil that is removed from the top of the first stage coalescer could then be

TABLE 5. ANALYSIS OF USED OIL FILTERED BY THE CATA-SEP 100 GPM BILGE WATER SEPARATOR AND ANALYSIS OF THE FILTERED OIL WITH DIESEL FUEL OIL AND USED IN THE EMISSIONS TESTING

(Navy Symbol 9250.)

Characteristic	Value
Viscosity @ 210°F	
Centistokes	11.9-14.5 min.
Saybolt Sec., Universal	66-75
Flash Point °F, Min.	390
Pour Point, °F Max.	10
Ash, Sulfated, %	1.5-2.0 (3)
Contamination (mg/gal) Max.	10
Zinc	0.039% (3)
Phosphorous	0.036% (3)
Barium	- (3)
Calcium	0.49% (3)
Magnesium	- (3)
Chlorine	- (3)
Sulphur	0.22% (3)

directed to the appropriate fuel tank. It may be helpful to have a single-element in-line filter, such as Luber-Finer 750-C unit, to remove any trace water before going to the fuel tank. This procedure would best be undertaken at the time the bilge water separator requires element change. After filtration of the used lubricating oil, the system could then be used for normal bilge water clean-up using new elements.

The second procedure would be to use the separator as is for treatment of the waste lube oil. The used oil should be diluted approximately 3:1 with fuel oil and pumped to the separator. The water/oil interface on the first stage coalescer (second unit) should be pushed to the bottom of that pressure vessel. As the filtering process begins, the initial effluent (equal to the gallon capacity of the system) of oil should be diverted back to the bilges or the dirty oil tank because it contains the residual water and insolubles from the separator. The remaining dirty oil can then be filtered and piped to the fuel tanks for burn-off. Again, an in-line filter such as a Luber-Finer 750-C should be placed between the separator and the fuel system to remove any water or insolubles.

Both of these procedures present operational problems. Also, it is inefficient to contaminate the used oil with water and insoluble material from the bilge water separator and to clean it subsequently with another filtering system. It would be simpler, and more effective, if a Luber-Finer or similar filtering system were used exclusively instead of the bilge water separator. The Luber-Finer system would require additional expense for the filter unit (approximately $300) and for the pump and plumbing (approximately $200).

The filtered lube oil from the Luber-Finer unit and samples low in water from the bilge separators would be an acceptable fuel for diesel engines when diluted with fuel oil at the recommended 1:100 ratio (Reference 1) as reflected in Table 6. However, it should be stressed that the introduction of the water and insolubles from the separator is not good operational practice. Bilge

TABLE 6. ANALYSIS OF MIXTURES OF 1% TREATED, USED LUBRICATING OIL IN NO. 2 DIESEL FUEL*

			Trace Metals (ppm)																									
Sample	%H_2O	%Ins.	Fe	TI	V	Pb	Cu	Sn	In	Sb	Cr	B	Na	Al	Si	Ag	Mo	Ba	Ca	Zn	P	K	Cd	Ni	Mg	Mo	Co
S-2-2	0.1	0.2	0.2	0	0	0	0.15	0.2	0	0	0.2	0	2.4	0.1	0	0	0	3.6	25.8	4.3	0	0.2	0	0	0.2	0	0
S-2-3	0.1	0.1	0.2	0	0	0	0.17	0.2	0	0	0.2	0	2.0	0.1	0	0	0	3.4	25.8	4.3	0	0.2	0	0	0.2	0	0
S-2-4	0.1	0.1	0.2	0	0	0	0.18	0.3	0	0	0.2	0	2.7	0.1	0	0	0	5.7	41.4	6.5	0	0.2	0	0	0.2	0	0
H-2	0.1	0.1	0.5	0	0	0	0.5	0	0	0	0.2	0	1.9	0	0	0	0	0.2	49.9	1.8	0	0	0	0.1	0	0.3	0
H-3	0.1	0.1	0.2	0	0	0	0.2	0.1	0	0	0.1	0	1.5	0.1	0	0	0	0.3	28.0	3.7	0	0.3	0	0	0.1	0	0
H-4	0.1	0.1	0.3	0	0	0	0.3	0.2	0	0	0.1	0	1.2	0.1	0	0	0	0.2	33.6	1.0	0	0.2	0	0	0.1	0	0
S-1-2	0.1	0.1	0.2	0	0	0.1	0.2	0.2	0	0	0.1	0	2.0	0	0	0	0	1.6	39.6	4.4	1.8	0	0	0	0.2	0	0
S-1-3	0.1	0.1	0.2	0	0	0.1	0.1	0.2	0	0	0.3	0	2.3	0.1	0	0	0	1.6	42.1	4.6	2.0	0	0	0	0.2	0	0
S-1-4	0.1	0.1	0.2	0	0	0.2	0.2	0.2	0	0	0.3	0	2.1	0.1	0	0	0	1.6	41.9	4.6	2.3	0	0	0	0.2	0	0
C-2	0.1	0.1	0.1	0	0	0	0.1	0.3	0	0	0.2	0	2.1	0.1	0	0	0	0.3	46.2	5.2	3.2	0.2	0	0	0.1	0	0
C-3	0.1	0.1	0.2	0	0	0	0.1	0.3	0	0	0.2	0	2.2	0.1	0	0	0	0.3	48.9	5.3	3.2	0.2	0	0	0.2	0	0
C-4	0.1	0.1	0.1	0	0	0	0.1	0.3	0	0	0.2	0	2.0	0.1	0	0	0	0.3	47.2	5.4	2.8	0.2	0	0	0.2	0	0

*Calculations based on data taken from Tables 2., 3., and 4.

oil when run through the separator is also an acceptable diesel fuel when low in water content (Sample H-2). The increased trace metal content in all samples would contribute to ash buildup, but this is not considered a problem when these fuels are only used on a periodic basis as would be the case in Coast Guard operations. All of the lube oil/fuel mixtures shown in Table 6 would be an acceptable fuel for main and ship service boilers. (For more detailed discussions, see Reference 1). None of the filtering units tested here however, would provide a filtered oil which would make a suitable gas turbine fuel at the 1:100 recommended mix ratio. Table 7 gives the Pratt and Whitney gas turbine fuel requirements (Reference 3). As can be seen by comparing Tables 6 and 7, turbine fuel requirements of the soluble trace metals calcium and sodium are exceeded in the 1:100 lube oil/fuel oil mixture. As previously mentioned, calcium and sodium originate as detergent additives and some sodium comes from sea water contamination in the waste oil. The calcium would form an ash deposit on the turbine blades and could combine with the sulfur in the fuel to form calcium sulfate which causes sulfidation corrosion of the blades. At present, there are no simple filtering systems that can remove the trace metals from oil. However, Pratt and Whitney (P&W) has developed a new adsorption-absorption fuel filtering system which is reported to be capable of lowering the trace metals from the levels shown in Table 6 to acceptable levels (Reference 4). The addition of such a fuel filtering system on turbine powered cutters (378' WHEC and 210' A WMEC) could not be justified on a cost basis. This new P & W system, being installed on the Polar-class of icebreakers, along with the improved blade coatings and air supply on the FT4A-12 turbine, should minimize the trace metal corrosion problems on these new icebrakers. As the gas turbines draw fuel from the same tanks as the diesel engines, the mix ratio of used lube oil in fuel oil would have to be lowered to 1:5000, in order to meet the Pratt and Whitney fuel requirements; therefore, only 50 gallons of lube oil could be evenly distributed throughout the full fuel load (250,000 gallons) of the 378' WHEC. As the 50 gallons of lube oil would be mixed at the proper ratio in each of the twenty fuel tanks of varying capacities, this would seem to present an operational problem. Any lube oil produced in excess of the 50 gallons would have to be stored for future use. (The lube oil capacity of the 38D81/8 engine is 340 gallons.)

TABLE 7. PRATT AND WHITNEY FT4A GAS TURBINE FUEL REQUIREMENTS PWA-527 (Reference 3)

Characteristics	Value
Sulphur	1.0% by weight
Carbon Residue (10%) bottoms)	0.1% by weight
Ash	0.005 by weight
V	0.1 ppm
Na + K	0.2 ppm
Ca	0.1 ppm
Pb	0.1 ppm
Cu	0.02 ppm

4. EFFECTS OF BURNING WASTE LUBE OIL IN FUEL OIL ON DIESEL ENGINES

As the majority of the fuel used in the Coast Guard fleet is burned by diesel engines, this section addresses the short-term effects on emissions and performance when mixtures of waste lube oil and fuel oil are burned in these engines. Long term effects on engine wear are being determined by Southwest Research Institute (SWRI) and will be covered in a future report.

4.1 ENGINE EMISSIONS AND PERFORMANCE

The effects of burning waste lube oil in fuel oil on engine emissions and performance were determined using a boat-size diesel engine mounted on a test stand in the TSC Marine Engine Test cell.

4.1.1 Experimental

The engine used for these tests was a GM (Detroit Diesel) 6-71, rated 200 hp at 2000 rpm. The engine was on loan from the USCG Support Center Boston and in its marine configuration could be considered typical of the two-stroke cycle engine used as main propulsion in boats and auxiliary power on some classes of cutters. The engine had recently been rebuilt by the CG and was equipped with type HV-70 injectors. The engine had been run-in at the CG base dynamometer facility and in emissions tests at TSC.

The engine was coupled to a water brake type dynamometer for power absorption (Figure 6). The marine engine test cell and its associated instrumentation have been described in detail in previous reports (Reference 5).

The test engine was operated over a power-prop loading curve typical of marine use. This curve is given by the equation:

$$P = KS^e$$

where P is the engine power, S the engine speed, and K and e are constants depending on engine and hull design. For purposes of these tests e = 2.8 (planning hull) and K calculated at the rated

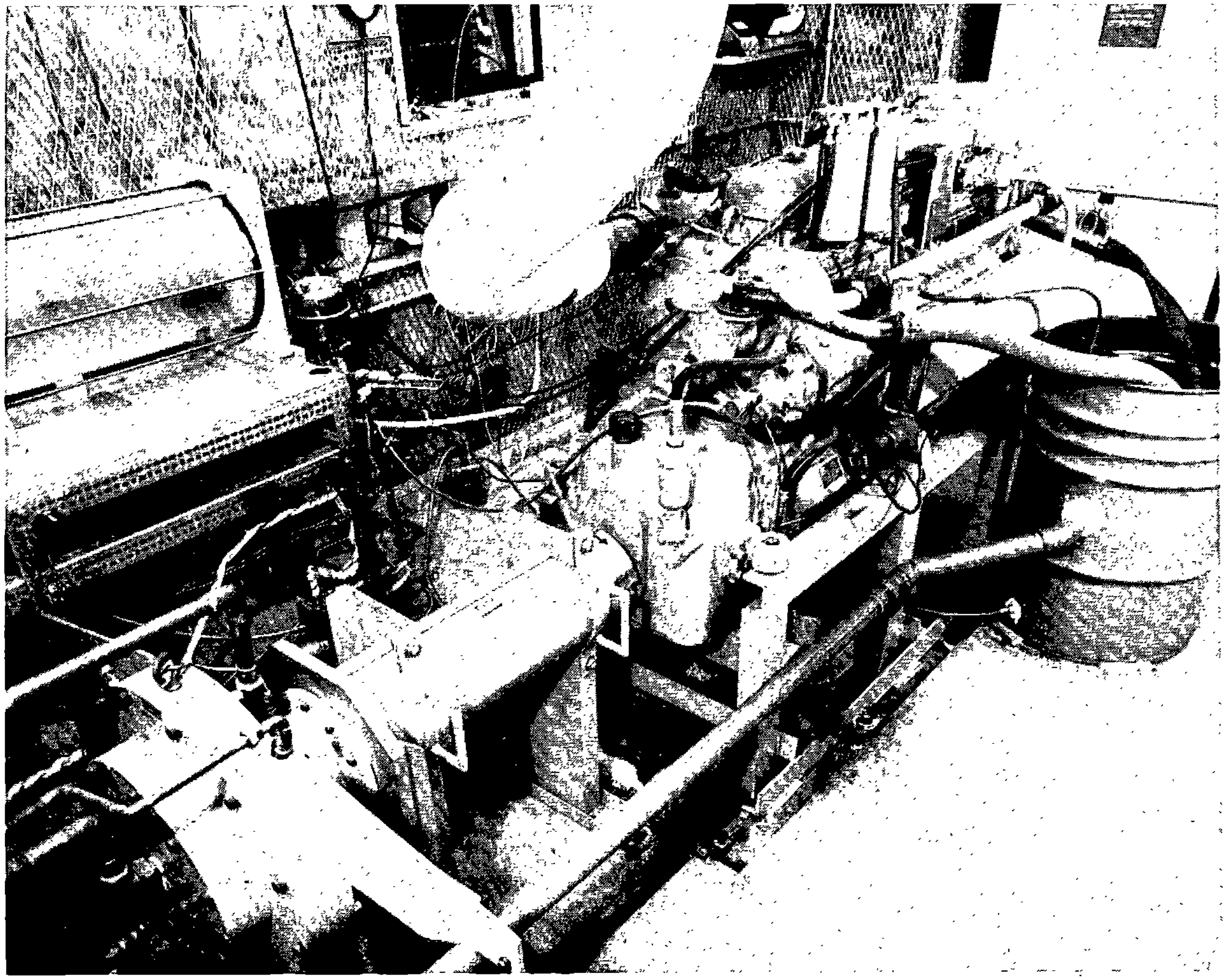


FIGURE 6. ENGINE COUPLED TO WATER BRAKE - DYNAMOMETER FOR POWER ABSORPTION

speed and power of the engine is used to calculate P at other engine speeds. The load curve using this K and e is given in Figure 7. Measurements were performed over this load curve at test points (Modes) from idle to 2000 rpm at 200 rpm intervals as listed in Table 8. Exhaust gas constituents in ppmV were measured on a continuous basis at each of the modes by the techniques listed in Table 9. The exhaust gas constituents were converted from a concentration basis (ppmV) to a mass basis (g/hr) using appropriate computer programs. The percent exhaust smoke opacity was continuously measured by an in-line opacity meter (Figure 8).

Other engine parameters continuously measured were engine rpm, shaft rpm, torque, water temperature, lube oil temperature and pressure, drive oil pressure, crankcase pressure and blower box pressure. A fuel flow meter, Flowtron Model 24-B, continuously measured fuel consumption. This meter was periodically checked against a gravimetric, i.e., direct weighing method.

The engine was brought to operating temperature before a load was applied, and sequentially ran through each test mode from idle to full power. Each test mode was held long enough for all test parameters to stabilize and to obtain a representative exhaust gas measurement (usually about 15 minutes). All test parameters were recorded on log sheets and strip-chart recorders for subsequent computer analysis.

The drained crankcase oil from the main engines of the USCGC Sherman was mixed with fuel oil in these tests. This oil was processed through the Cata-Sep bilge water separator on the USCGC Hamilton. (H-3 and H-4 in Table 10.) The samples were then mixed by volume with #2 diesel fuel to dilutions of 1:100, 3:100, 6:100, and 1:10 lube oil to fuel oil. These samples are designated L-1 through L-4 in Table 10. Subsequent measurements of specific gravity gave these mixtures to be 1:100, 3.5:100, 7:100, and 1.15:10. For simplification these mixtures will hereafter be referred to as 1 percent, 3 percent, 6 percent and 10 percent, respectively.

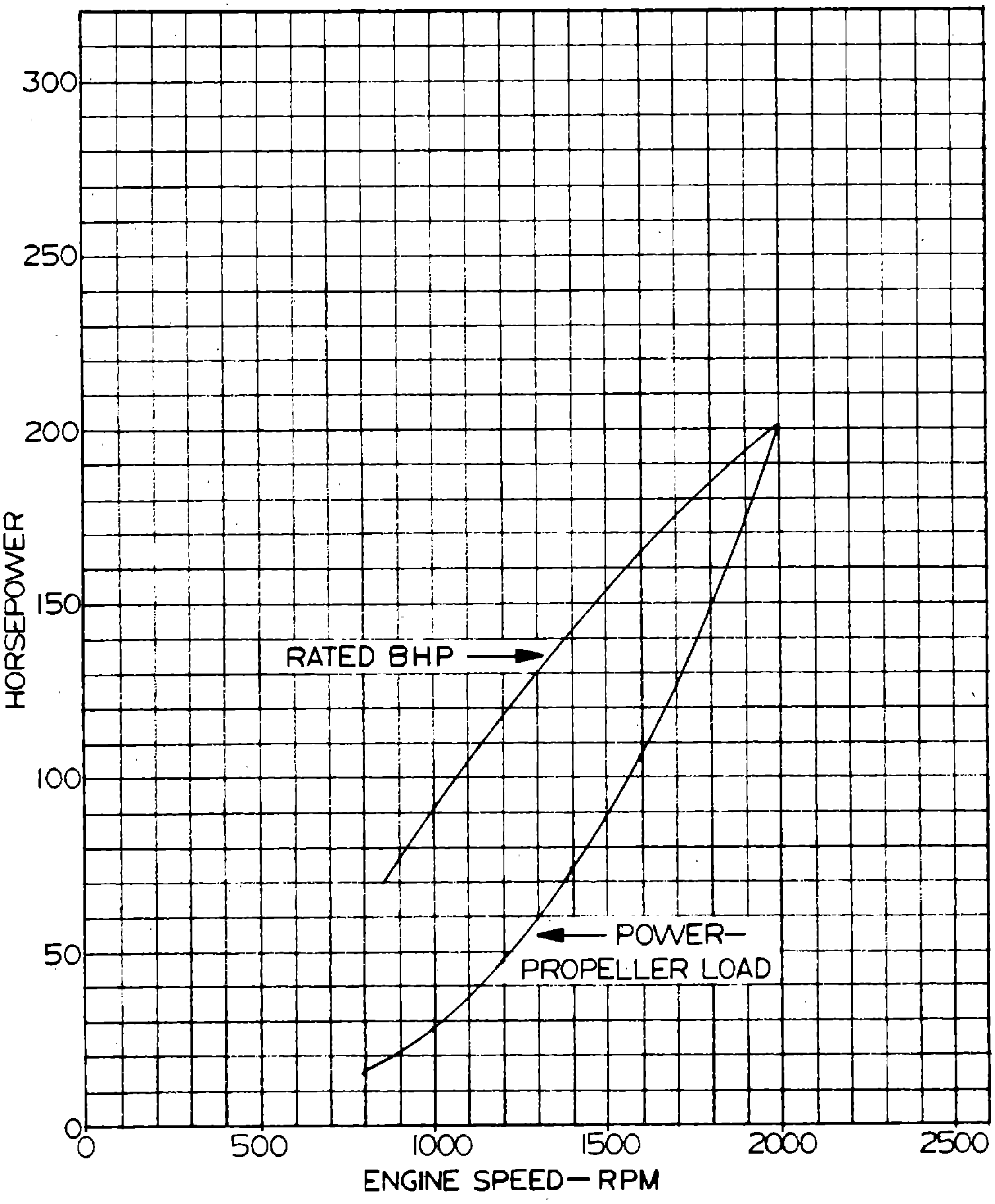


FIGURE 7. LOAD CURVE FOR 200 BHP, 2000 RPM GM 6-71 DIESEL ENGINE

TABLE 8. ENGINE TEST MODES

MODE	HP	RPM
1	idle	700
2	15.4	800
3	28.7	1000
4	47.8	1200
5	73.7	1400
6	107.1	1600
7	148.9	1800
8	200.0	2000

TABLE 9. ENGINE TEST TECHNIQUES

GAS SPECIES	MEAS. TECHNIQUE
CO	NDIR
CO_2	NDIR
NO	Chemiluminescence
NO_x	Chemiluminescence
THC	Flame Ionization
O_2	Paramagnetic

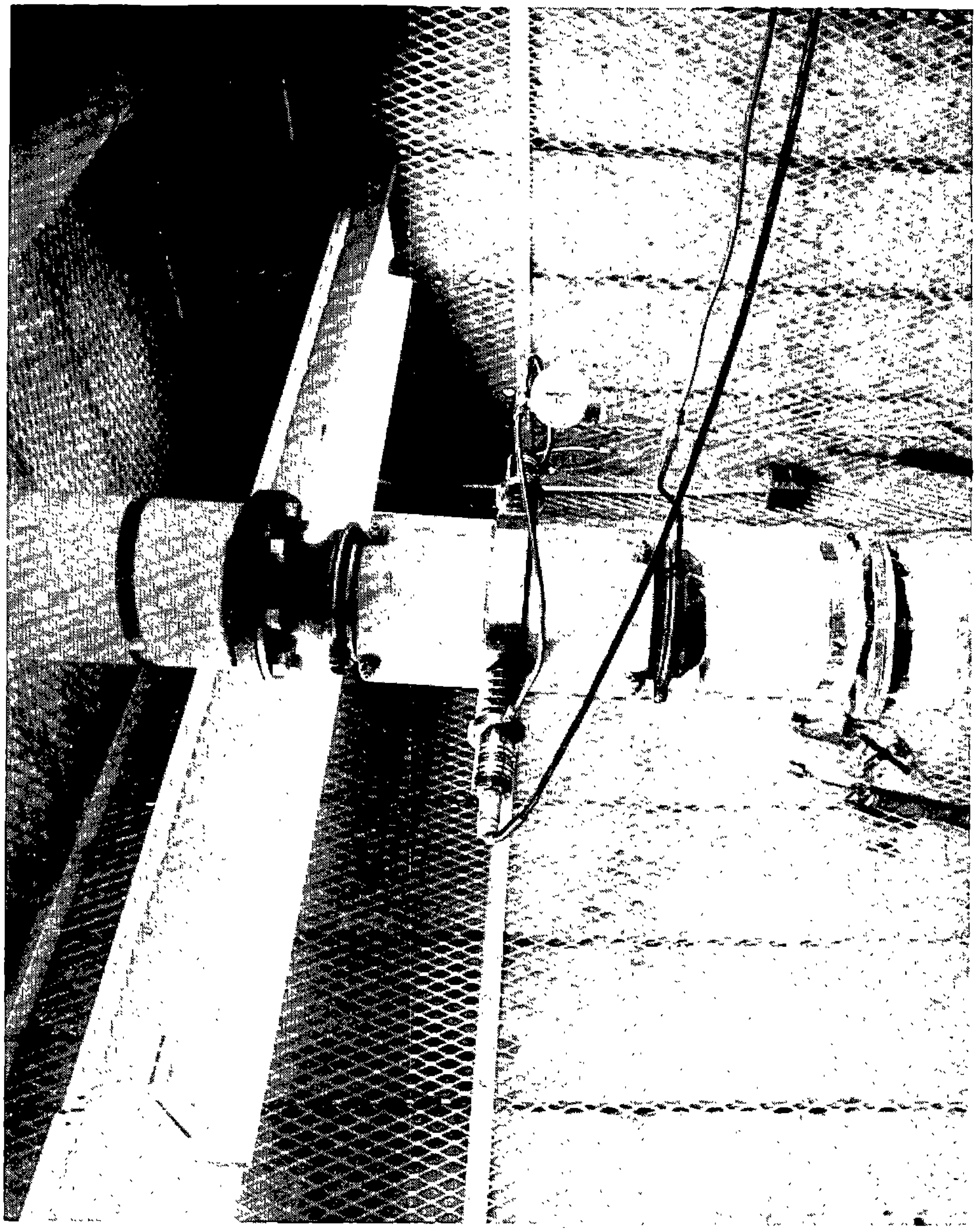


FIGURE 8. OPACITY METER

TABLE 10. ANALYSIS OF USED OIL FILTERED BY THE CATA-SEP 100GPM BILGE WATER SEPARATOR AND ANALYSIS OF THE FILTERED OIL MIXED WITH DIESEL FUEL OIL AND USED IN THE EMISSIONS TESTING

			Trace Metals (ppm)																								
Sample	$\%H_2O$	% Ins	Fe	Ti	V	Pb	Cu	Sn	In	Sb	Cr	B	Na	Al	Si	Ag	Mo	Ba	Ca	Zn	P	K	Cd	Ni	Mg	Mn	Co	% Oil
H-3	1.5	0.5	12	1	0	4	11	8	0	0	5	8	90	5	2	1	0	20	1636	215	0	17	0	0	7	0	0	58.5
H-4	1.5	1.0	12	1	0	5	11	8	0	0	5	8	50	6	2	2	0	9	1412	43	0	10	0	1	5	0	0	42.0
L-1	<0.1	<0.1	0	2	0	0	1	4	0	0	1	2	3	6	0	2	0	3	39	1	0	0	0	2	0	0	0	1.0
L-2	<0.1	<0.1	0	1	0	0	2	0	0	0	0	3	5	2	0	1	0	2	145	12	0	0	0	0	1	0	0	3.0
L-3	<0.1	<0.1	0	1	0	0	2	2	0	0	1	3	9	3	0	1	0	2	190	14	0	0	0	0	1	0	0	6.0
L-4	<0.1	<0.1	1	2	0	0	4	5	0	0	1	4	8	4	0	2	0	3	266	20	0	0	0	1	1	0	0	10.0

Baseline tests using diesel fuel only were run before and after the series of tests with the lube oil/fuel oil mixtures. At the end of each baseline and mixed fuel test the engine was disconnected from the fuel supply and allowed to run until shut-down occurred from lack of fuel. The engine was then cranked over several times and the fuel drained from the return lines and fuel meter. The new fuel mixture was then connected to the supply and return lines and the engine primed and started. This process minimized any possible carryover contamination from the preceding mixture.

4.1.2 Experimental Results

Figures 9 through 12 give the mass emission rates for CO, CO_2, NO_x and THC. CO_2 is included here as a indicator of engine operating performance. Results indicate no statistically meaningful difference in emissions between "before" and "after" baseline tests and when burning mixtures of lube oil in fuel oil up to 1:10. Tables 11 through 16 give the mass emission rates, the percent opacity as well as the specific fuel consumption in lbs/hp/hr (SFC). As with the gaseous emissions, the smoke opacity shows no meaningful changes when burning waste lube oil. Although the plot of SFC given in Figure 13 seems to indicate an upward trend in fuel consumption with an increase in the percentage of lube oil in fuel oil, the limited data base and experimental errors do not permit a firm conclusion to be drawn. These SFC trends are being studied further by SWRI. Large variations in smoke opacity and CO emissions are noted at the full load condition. This is attributed to the fact that the engine could not reach full rated load and speed (200 hp @ 2000 rpm), and that maximum loading and speed varied somewhat (usually between 180 and 190 bhp at 1900 to 2000 rpm). Both opacity and CO emissions were extremely sensitive to small changes in speed or load at these high power conditions.

Engine performance, as indicated by CO_2 and NO_x readings as well as various engine temperatures and pressure readings, was unaffected by burning mixtures of lube and fuel oil. These results verify tests performed for TSC at Bartlesville Energy Research Center using a Caterpillar D333-C engine run over the

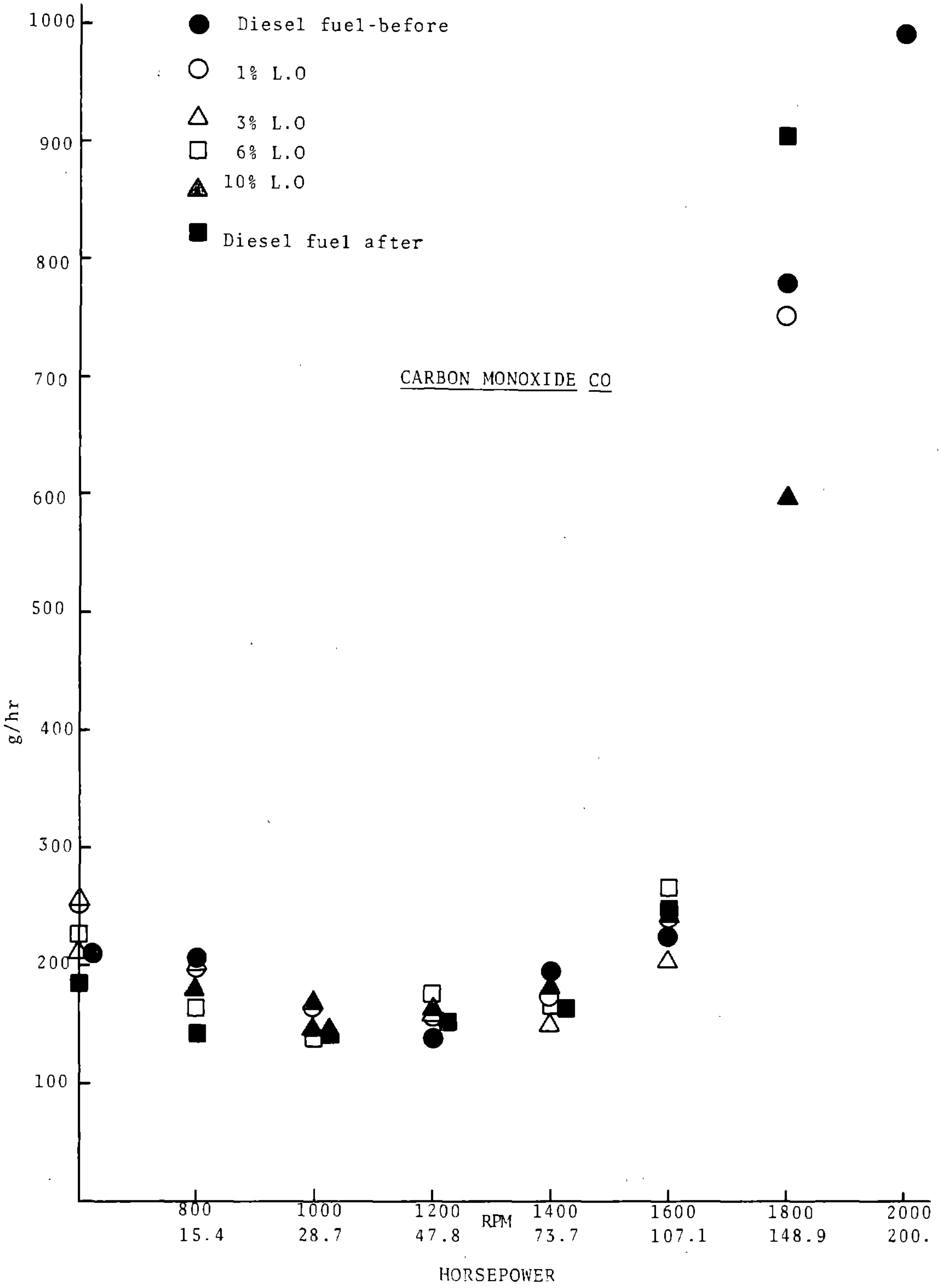


FIGURE 9. MASS EMISSIONS RATES - CO

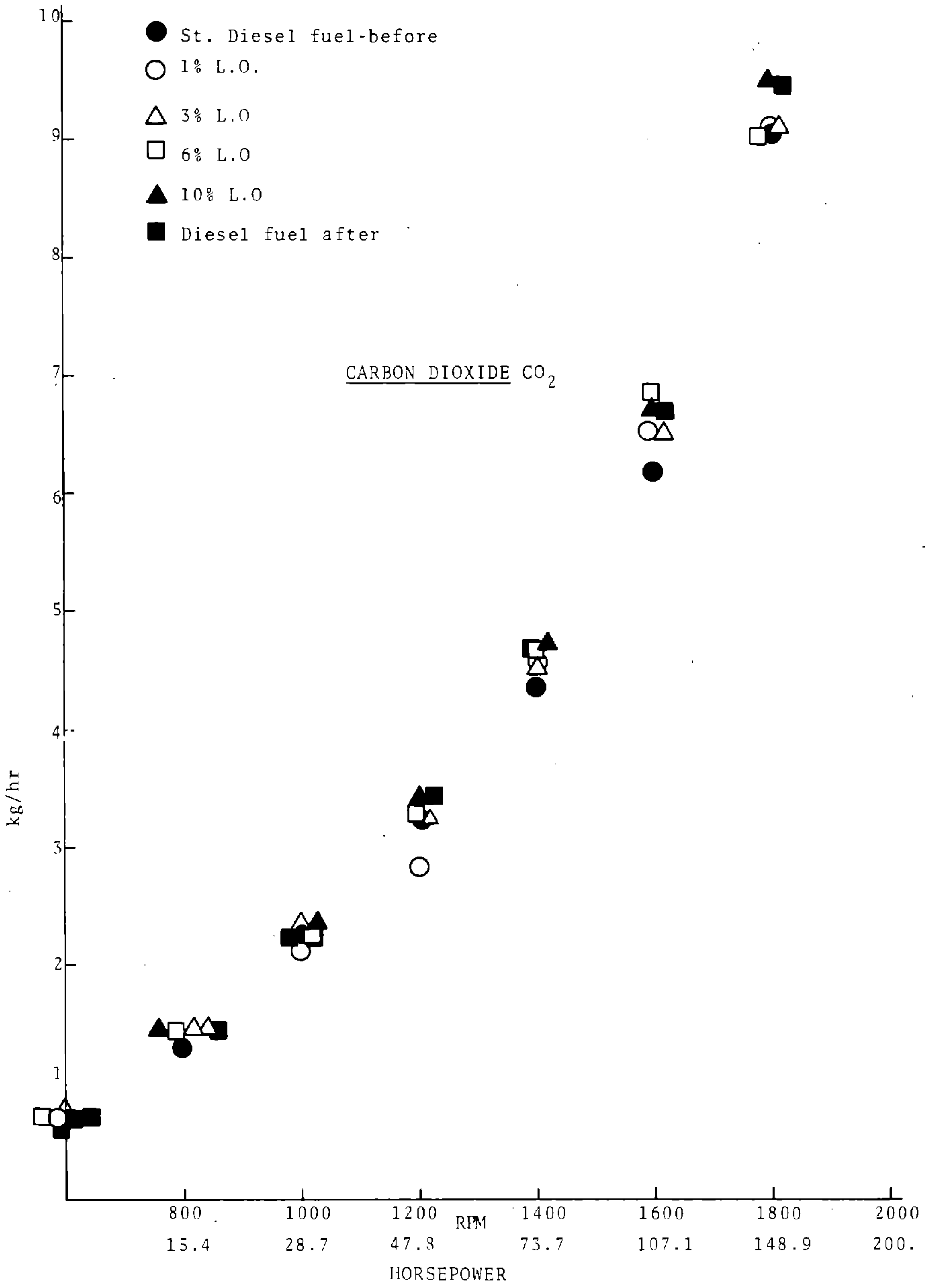


FIGURE 10. MASS EMISSIONS RATES - CO_2

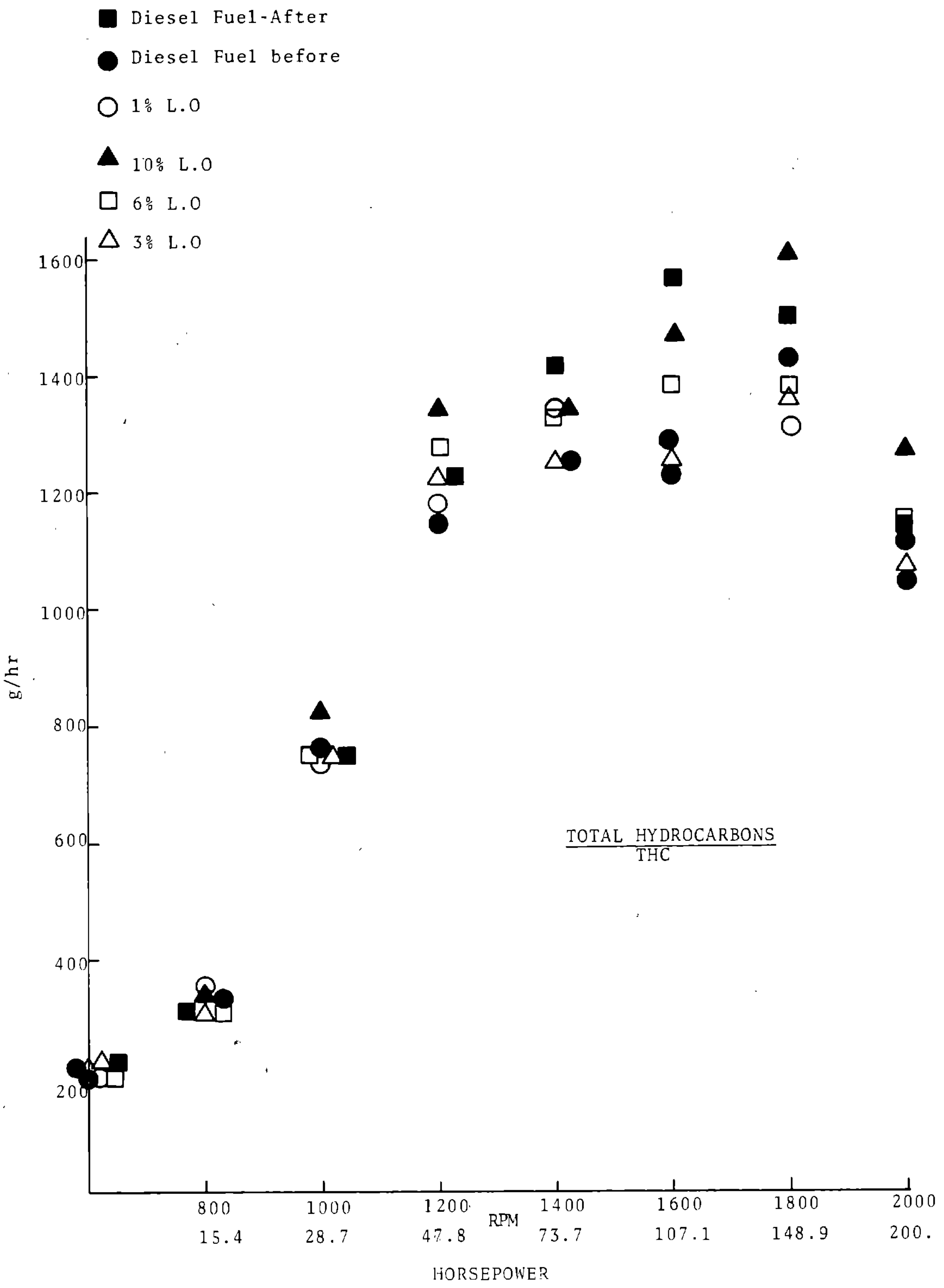


FIGURE 11. MASS EMISSIONS RATES - THC

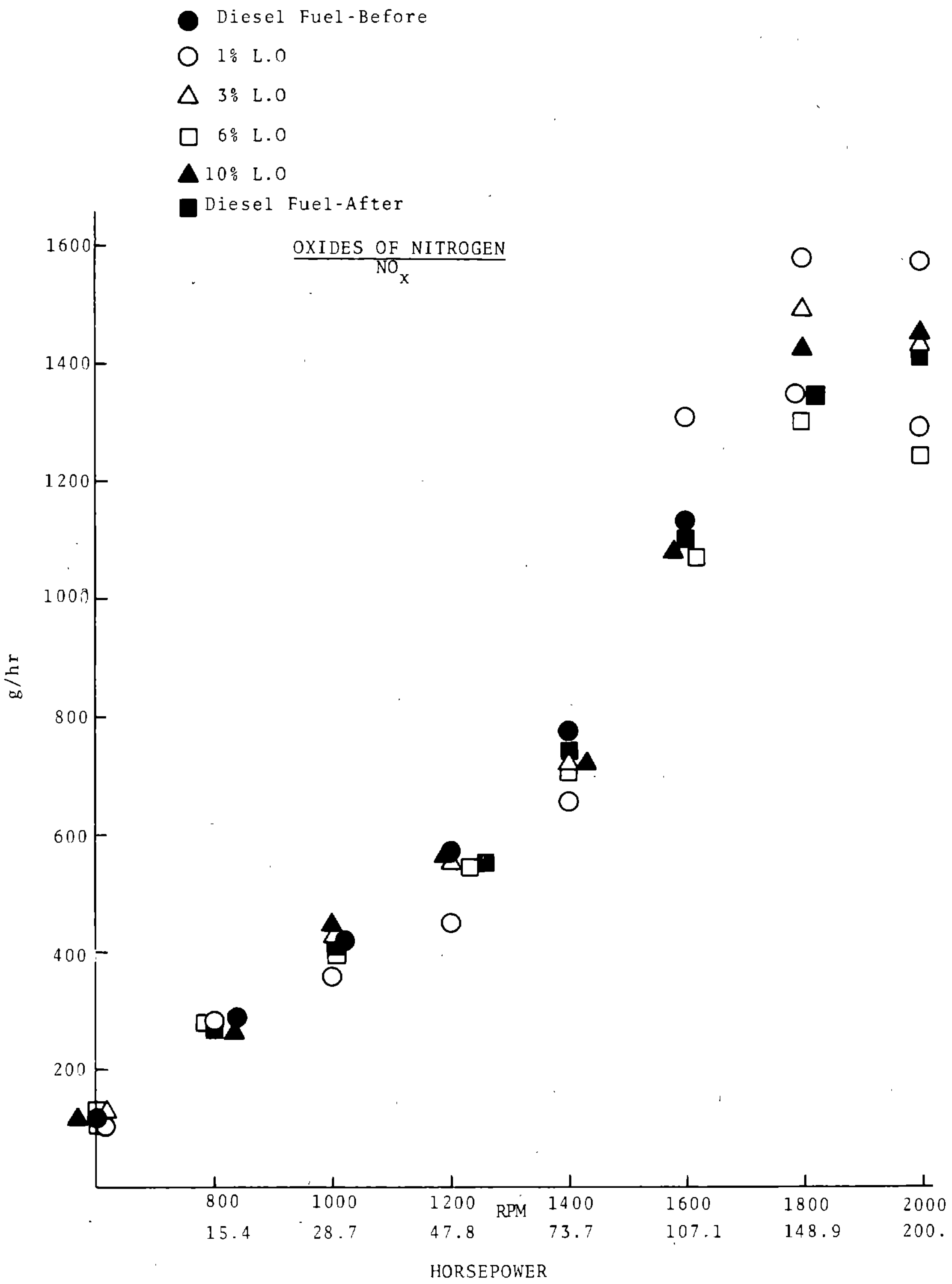


FIGURE 12. MASS EMISSIONS RATES - NO_x

TABLE 11. MASS EMISSIONS FROM A DETROIT DIESEL GM6-71, 200 HP, DIESEL ENGINE, HV-7 INJECTORS, NO LUBRICATING OIL IN THE DIESEL FUEL BEFORE TEST

Mass Emissions (g/hr)					
Horsepower	SFC	CO	NO_X	THC	% Opacity
Idle	---	210	114	230	1.50
15.55	.671	208	281	328	1.50
28.97	.560	190	420	661	1.0
47.62	.511	174	585	1143	1.0
73.33	.465	195	773	1243	1.6
107.68	.430	241	1151	1202	2.2
150.20	.455	780	1587	1431	5.00
189.38		1013	1574	1046	11.5

TABLE 12. MASS EMISSIONS FOR A DETROIT DIESEL GM6-71, 200 HP DIESEL ENGINE HV-7 INJECTORS, ONE PERCENT LUBRICATING OIL ADDED TO THE DIESEL FUEL

		Mass Emissions (g/hr)			
Horsepower	SFC	CO	NO_X	THC	% Opacity
Idle	---	250	115	207	2.3
15.55	0.711	194	283	349	1.8
28.97	0.580	160	360	745	1.5
47.62	0.477	152	453	1176	1.5
73.33	0.486	170	658	1321	1.8
107.68	0.456	238	1312	1285	2.5
150.20	0.454	754	1348	1312	4.5
189.38	0.396	186	1239	1112	17.0

TABLE 13. MASS EMISSIONS FOR A DETROIT DIESEL GM6-71, 200 HP, DIESEL ENGINE HV-7 INJECTORS, THREE PERCENT LUBRICATING OIL ADDED TO THE DIESEL FUEL

Mass Emissions g/hr)					
Horsepower	SFC	CO	NO_x	THC	% Opacity
Idle	---	255	96	147	2.0
15.55	0.711	199	274	313	1.5
28.97	0.631	165	435	749	1.2
47.62	0.543	157	558	1221	0.9
73.33	0.478	155	722	1244	1.2
107.68	0.455	202	1090	1262	1.5
150.20	0.454	590	1494	1375	2.8
189.38	0.396	1008	1435	1067	9.5

TABLE 14. MASS EMISSIONS FOR A DETROIT DIESEL GM6-71, 200 HP, DIESEL ENGINE, HV-7 INJECTORS, SIX PERCENT LUBRICATING OIL ADDED TO THE DIESEL FUEL

Mass Emissions (g/hr)					
Horsepower	SFC	CO	NO_x	THC	% Opacity
Idle	---	212	118	204	3.0
15.55	0.702	174	283	328	2.8
28.97	0.638	144	392	749	2.4
47.62	0.573	162	545	1280	1.8
73.33	0.500	179	704	1335	1.8
107.68	0.475	240	1067	1305	2.0
150.20	0.481	212	1303	1385	3.2
189.38	0.412	194	1244	1162	9.4

TABLE 15. MASS EMISSIONS FOR A DETROIT DIESEL GM6-71, 200 HP, DIESEL ENGINE, HV-7 INJECTORS, TEN PERCENT LUBRICATING OIL ADDED TO THE DIESEL FUEL

Mass Emissions (g/hr)					
Horsepower	SFC	CO	NO_x	THC	% Opacity
Idle	---	229	131	218	2.5
15.55	0.719	164	274	331	2.6
28.97	0.606	138	425	822	2.0
47.62	0.549	173	572	1344	1.8
73.33	0.504	164	722	1330	1.9
107.68	0.481	267	1080	1466	2.1
150.20	0.449	1144	1435	1603	4.5
189.38	0.396	234	1453	1271	13.5

TABLE 16. MASS EMISSIONS FROM A DETROIT DIESEL GM6-71, 200 HP, DIESEL ENGINE, HV-7 INJECTORS, NO LUBRICATING OIL IN DIESEL FUEL - AFTER TESTS

Mass Emissions (g/hr)					
Horsepower	SFC	CO	NO_x	THC	% Opacity
Idle	---	183	138	220	3.0
15.55		141	263	312	2.5
28.97		136	405	755	1.8
47.62		139	534	1226	1.5
73.33		166	725	1421	1.8
107.68		250	1100	1571	2.4
150.20		908	1354	1498	5.00
189.4		---	1405	1164	17.5

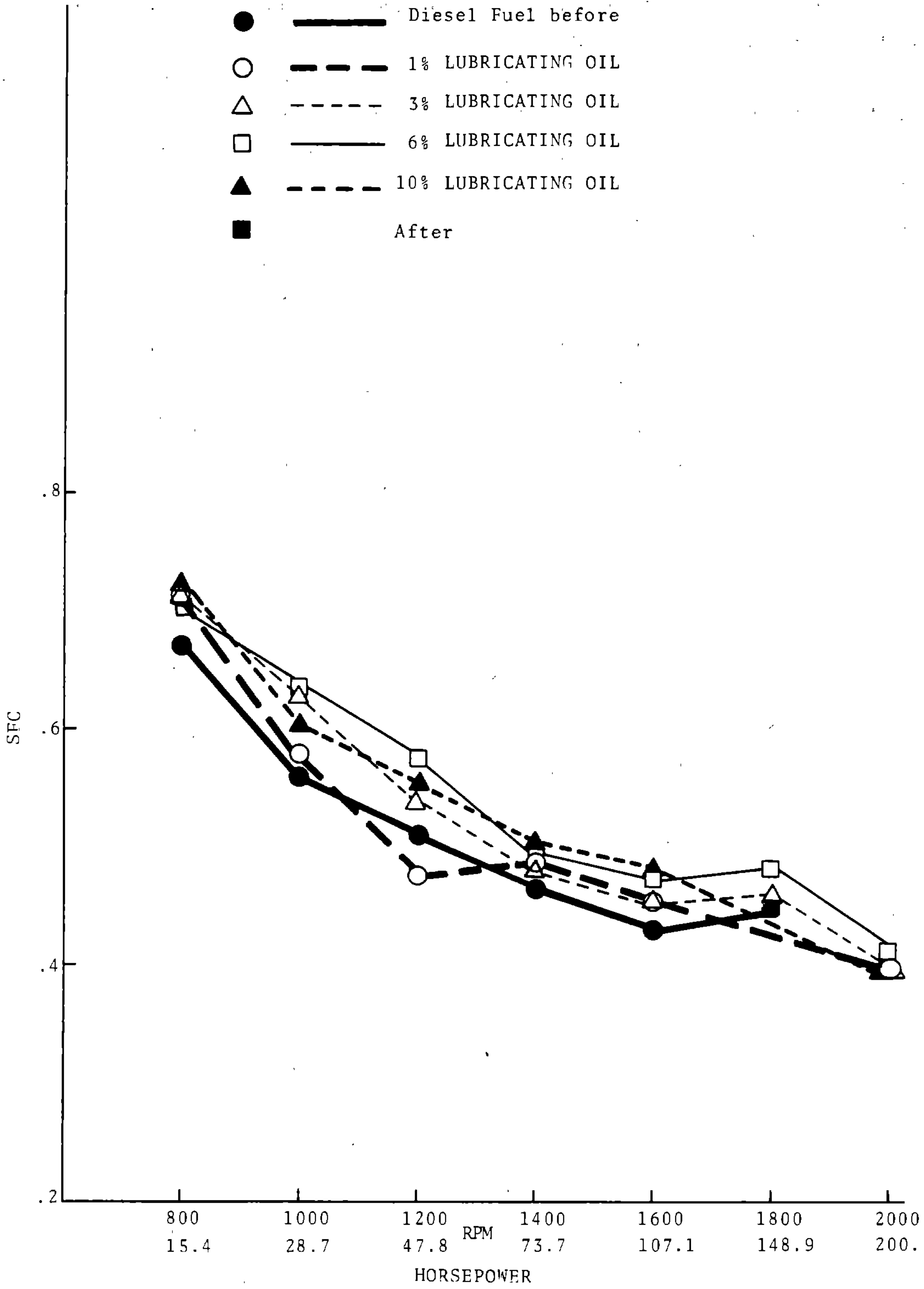


FIGURE 13. SPECIFIC FUEL CONSUMPTION

Federal Emissions Test Cycle (Reference 1). These results should not be construed as an endorsement for burning mixtures of lube oil in fuel oil as high as 10 percent. It should be emphasized that the mix ratio should be kept as low as possible to minimize ash build-up on the pistons, valves, and ports. Although the diesel fuel oil specification (MIL-F-16884F) does not specify trace metal content, the 1 percent mixture used here (Sample L-1, Table 10) has a higher than normal level (66 ppm total) of these metals which subsequently contribute to ash formation.

The tests performed here indicate that no short-term effects are evident when burning mixtures of lube oil in fuel oil; however, the potential for long-term effects should not be overlooked. These long-term effects are presently being investigated by Southwest Research Institute using radioactive tracer techniques.

5. REFERENCES

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