Fuel Features Related to Operating Experiences in Motor Ships Using Low Cost Fuels

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During the past few years the shipping industry has requested for Diesel engined vessels an increasing supply of fuels intermediate in character between the conventional Diesel and boiler grades. Samples of the fuels bunkered were retained from three such cargo vessels operating from the United Kingdom, two of which were engaged on the Mediterranean route, and the third to Australia. Information was also obtained from a tanker operating mainly between the Gulf and American N.E. coast ports.

The fuels were analysed in some detail and their effect on engine performance was noted. From the rather limited amount of information available some general conclusions were made.

Certain properties of the fuel, such as specific gravity, viscosity, flash point, and sediment and water contents are important because of the type of fuel system installed prior to the main engine fuel pump. For instance, the amount of steam heating available limits the viscosity of the fuels that can be bunkered.

The fuels originating from the Western Hemisphere usually contain appreciable amounts of asphaltenes and to achieve clean combustion it may be necessary in certain instances to advance the period of injection.

INTRODUCTION

The increased number of applications requiring middle distillates has tended to create a world shortage. As the demand for these fuels is likely to continue, the incentive was created for shipowners to investigate the possibilities of using a lower grade of fuel in certain less critical applications. During the past few years an increasing number of shipowners have requested that their new Diesel engined constructions should be capable of burning a residual type of fuel.

This paper presents information obtained on the use of residual type fuels in four Diesel engined vessels as a result of research programmes carried out in the United Kingdom and the United States of America. It includes a section on the importance of the marine Diesel engine as a consumer of petroleum products and data on the popularity of the various types of Diesel engines currently installed.

MARINE DIESEL ENGINES AND THEIR FUELS

The Position of the Motor Ship in World Commerce

The Diesel powered vessel or "motor ship" has proved its place on the world-wide shipping routes throughout the last twenty-five years by virtue of its economy in fuel costs compared with the steamers. For the relatively few large installations the geared steam turbine type of machinery is still predominant but, broadly speaking, there are no developments in view which would lead to the steam turbine or the marine gas turbine becoming generally competitive with the Diesel engine for power units under 5,000 s.h.p. During the last few years development in the oil engine field has been largely directed to increasing the power output by supercharging. In this way the two-stroke type of oil engine will be competitive with the steam turbine for single-screw cargo liners and tankers of up to 15,000 s.h.p.

Fuel Analysis of World Tonnage

In Fig. 1, data are given showing the tonnage of the various types of ships at sea up to 1953. It will be observed that the total world tonnage amounted to about 93 million tons, of which approximately 12 million tons was represented by the U.S.A. reserve fleet which is not in regular use. In 1953 29 million tons of Diesel powered shipping were in regular use.

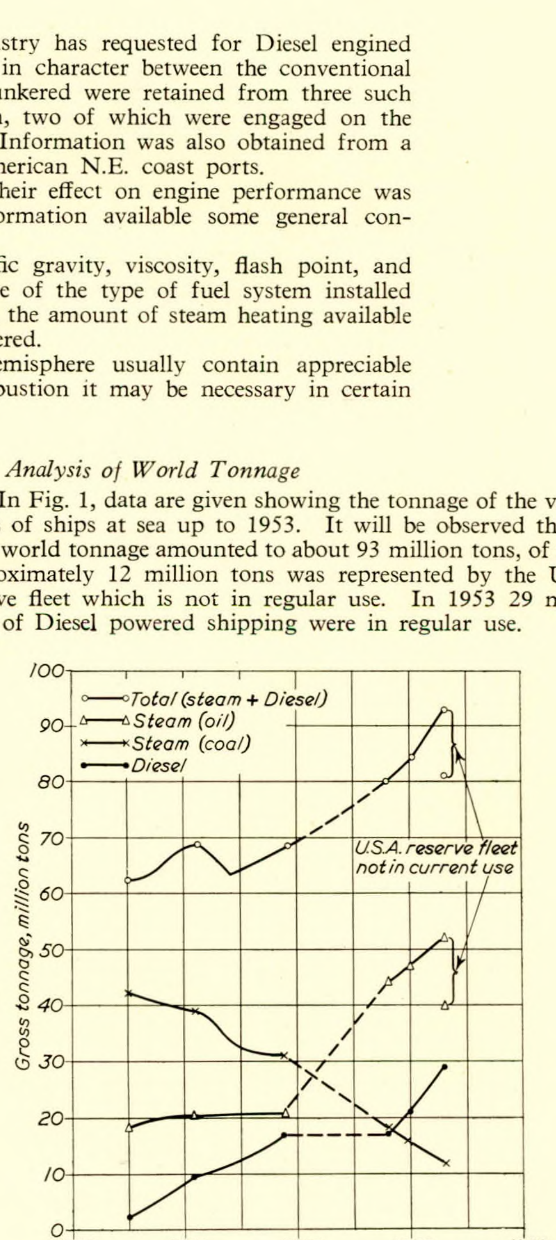

FIG. 1—*Fuel analysis of world tonnage over a period of years*

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It is apparent from the data in Fig. 1 that the trend over the past twenty-five years has been for oil to replace coal as the heating medium for steam raising, and that the Diesel engine up to and since the 1939-45 war has been tending to replace steam for medium powers. It appears probable that, but for the war, when the shipbuilding programmes were concentrated on the production of steam powered vessels, the world tonnage of Diesel ships would at the present time have been equal to the tonnage of steam turbine driven vessels.

Motor ships now represent 31 per cent of the total steam and motor tonnage owned in the world as compared with 25 per cent in 1950, but analysis of the principal maritime countries shows wide variations. In Norway motor ships amount to 79 per cent of tonnage owned, and in Sweden 76 per cent, whereas in Greece and the U.S.A. they represent only 3·9 per cent and 4·4 per cent respectively. The figure for the United Kingdom is 40 per cent.

The figures in Table I, however, do illustrate clearly the post-war trend in shipbuilding, and show that the popularity of the motor ship still continues. In fact, during the past six years motor ships have accounted for 64 per cent of the tonnage completed.

TABLE I—SHIPS COMPLETED 1948-1953.
(Vessels over 100 gross tons)

Year	United Kingdom (1,000 gross tons)		Rest of world (1,000 gross tons)		Total (1,000 gross tons)	
	Steamers	Diesels	Steamers	Diesels	Steamers	Diesels
1948	591·5	621·2	375·1	893·4	967·1	1514·6
1949	533·1	820·3	848·0	912·5	1381·0	1732·8
1950	521·2	867·7	668·5	1196·6	1189·7	2064·3
1951	399·0	941·5	512·0	1705·0	911·0	2646·5
1952	434·2	829·6	938·2	2008·7	1372·4	2838·3
1953	473·7	776·5	1481·3	2206·2	1955·0	2982·7

On a basis of the data already presented an estimate was made of the probable composition of the world's tonnage five years hence, in 1958. By that time, barring any extreme emergencies, at least 40 per cent of the world's tonnage will be powered by Diesels, 51 per cent will be oil fired steamers, and the remaining 9 per cent coal burners.

Popularity of the Various Types of Engines

A comprehensive survey was made of the types of Diesel engines fitted to motor ships completed during the years 1946 to 1953 inclusive. It did not prove possible to get a breakdown covering all the motor vessels afloat at the present time but it is estimated that those analysed constitute at least 30 per cent of the motor ships in service today.

Table II shows that of the 2,229 ships completed during this period, 87 per cent were of the two-stroke type, of which 78 per cent were single acting and 9 per cent double acting. The opposed-piston engine is included under the category of a two-stroke, single acting engine.

TABLE II—TYPE OF ENGINES INSTALLED IN MOTOR VESSELS COMPLETED 1946 TO 1953 INCLUSIVE.

		No. of ships	Percentage
4-stroke		281	12·6
2-stroke:	Single acting	1,736	77·9
	Double acting	212	9·5
Total		2,229	100·0

Fuel Costs

The vast majority of marine Diesels have operated on fuels, the components of which are mainly distillate, or on heavy distillates, but because of their high thermal efficiency (ca 39 per cent) have been able to compete favourably with steam turbines which operate on boiler fuel, although at only about 25 per cent overall thermal efficiency. It is noteworthy that the increase in the popularity of the Diesel occurred during the time when the price differential between marine Diesel fuel and bunker fuel was comparatively small (Figs. 2 and 3). However, since the war the price differential between marine Diesel fuel and bunker fuel has increased considerably, creating a greater incentive for further economy by changing over to intermediate grades for Diesel engines.

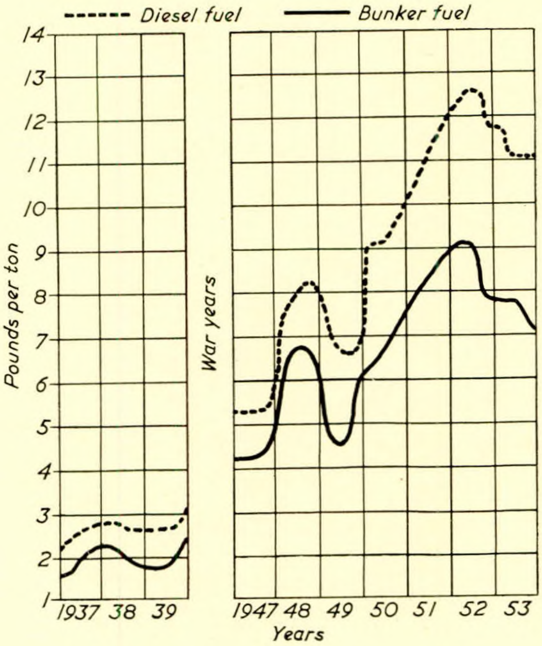

FIG 2—*United Kingdom fuel costs*

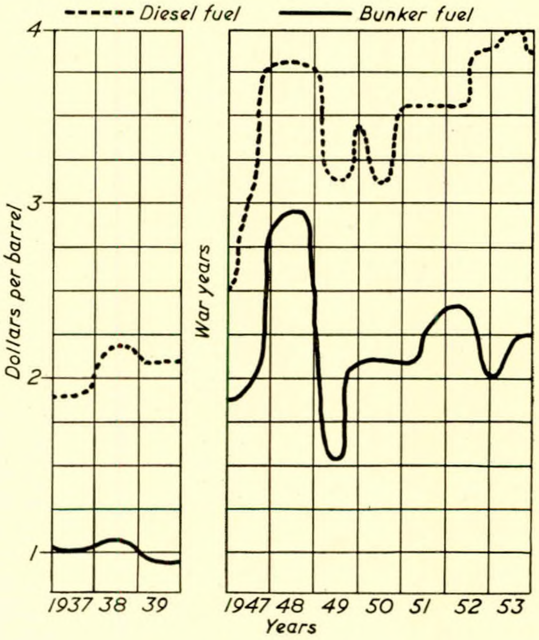

FIG. 3—*New York fuel costs*

The savings in fuel costs available to the shipowner in bunkering marine fuel instead of marine Diesel fuel at most European ports over the past two years was just under £4 per ton. The monetary savings of using fuel oil, therefore, are very attractive to the shipowner, as long as maintenance problems do not increase to the extent of absorbing all the savings.

The annual savings on the fuel bill to the shipowner of using a Bunker C fuel instead of marine Diesel fuel at 1938 and 1953 United Kingdom prices on a normal size of cargo vessel are given below:—

10,000 ton 15-knot motor cargo ship

Fuel consumption	25 tons per day
Days at sea	200 per annum

	1938	1953
Cost of Diesel fuel	£13,250	£55,500
Annual saving in fuel costs if using bunker fuel ...	£3,250	£19,750

These figures are based on the vessel burning full viscosity bunker fuel, but in the majority of cases the owners are requesting fuels having maximum viscosities ranging up to 1,500 seconds Redwood No. 1 at 100 deg. F.

Therefore, if the shipowner in the above example stipulated a fuel of 1,000 seconds Redwood No. 1 at 100 deg. F., a premium of about 15s. per ton might be incurred, thereby reducing his annual fuel savings by £3,750 to £16,000.

DESCRIPTION AND ENGINE DETAILS OF MOTOR SHIPS UNDER REVIEW

Vessels A and B are new constructions, single-screw general cargo vessels operating between the United Kingdom and Middle East ports. Both these ships are powered by four-cylinder Doxford opposed-piston two stroke type engines and were fitted, from new, with the present conventionally accepted type of fuel systems for the burning of residual fuels.

Vessel C is also a general cargo/passenger vessel, but is a twin screw ship powered by two six-cylinder Doxford type engines, and operates between the United Kingdom and Australia. This vessel was also fitted during construction with a fuel system suitable for burning residual type fuels.

Vessel D is a tanker powered by a single five-cylinder Doxford type engine and operates mainly between the Gulf and N.E. American ports. The engine is of an earlier design than those fitted to Vessels A, B and C, and consequently it does not incorporate the more recent improvements made to the Doxford series of engines. The engine was originally built in 1940 for burning marine Diesel type fuels, and was converted for operation on residual fuels after initial engine test results had been obtained, for comparative purposes, whilst operating on the lighter fuels.

The arrangement of the fuel cleaning system is similar on Vessels A, B and C, and of the type commonly employed in vessels burning residual fuels, namely two centrifuges operating in series, the first as a purifier and the second as a clarifier. In Vessel D the two centrifuges are in parallel.

A fuel circulating system is fitted to all the engines so that heated fuel can be circulated through the high pressure part of the system when the main engine is stopped.

Pertinent data referring to these vessels and engines are given in Table III.

TABLE III—DETAILS OF SHIPS AND ENGINES

Details	Vessel			
	A	B	C*	D
Dead weight tonnage	4,600	4,625	14,393	17,950
Number of cylinders	4	4	6	5
Bore, mm.	600	600	725	813
Combined stroke, mm.	2,320	2,320	2,250	2,410
Maximum b.h.p.	3,300	3,300	7,350	7,500
Maximum r.p.m.	108	110	115	94
Number of scavenge air pumps	1	2	3	1

* Twin-screw vessel (total b.h.p. 14,700).

OPERATING DATA AND RESULTS

Vessel A

Test Bed Trials. Initial engine tests of twenty-five hours' duration were made on normal marine Diesel fuel. Full load fuel consumptions of 0·32lb. per i.h.p. hr. and 0·37lb. per s.h.p. hr. were obtained. The fuel supply pressure was 4,400lb. per sq. in. and the exhaust temperature about 650 deg. F. Testing was then continued on a heavy fuel oil.

The heavy fuel oil used had a specific gravity of 0·94, a viscosity of about 1,000 seconds Redwood No. 1 at 100 deg. F., and a sulphur content of 2·8 per cent. The appropriate fuel temperatures at the various stages in the fuel cleaning system are given below.

	Temperature, deg. F.
Heavy fuel oil before purifier ...	170/175
Heavy fuel oil before clarifier ...	165/170
Heavy fuel oil at main engine fuel pump	190

TABLE IV—INSPECTION DATA OF HEAVY FUEL OIL USED DURING SEA TRIALS OF VESSEL A

Tests	Sampling point				
	Shore tank: South Shields	Ships' tanks: untreated fuel	Purifier discharge	Clarifier discharge	Main engine fuel pump
Specific gravity at 60 deg. F./60 deg. F.	0·935	0·934	0·934	0·933	0·936
Viscosity, Redwood No. I					
at 100 deg. F., sec.	525	550	550	510	510
at 200 deg. F., sec.	64	64	65	64	64
Flash point P.M. closed, deg. F.	270	250	260	265	260
Pour point, deg. F.	55	60	55	55	55
Conradson carbon, per cent.	5·5	5·9	5·8	5·9	5·8
Water, per cent.	0·2	0·2	Trace	0·1	0·1
Sediment by extraction, per cent.	0·03	0·06	0·01	0·01	0·01
Ash, per cent.	0·04	0·03	0·01	0·01	0·01
Sulphur, per cent.	2·5	2·5	2·5	2·5	2·5
Asphaltenes, per cent.	—	1·2	1·2	1·2	1·2
Bottoms, sediment and water, per cent.	—	0·2	Trace	Trace	Trace

Some comparative figures are given below while operating at full load on heavy fuel oil and Diesel fuel.

	Fuel oil	Diesel fuel
Temperature at inlet to fuel pump, deg. F.	176	Atmospheric
Average temperature at injectors, deg. F.	178	Atmospheric
Fuel line pressure, lb. per sq. in. ...	6,400	4,400
Average exhaust temperature, deg. F.	571	582
Fuel consumption, lb. per s.h.p. hr.	0·381	0·370
Exhaust	Clear	Clear
Calorific value, B.Th.U. per lb. net	17,870	18,200
Average maximum cylinder pressure, lb. per sq. in. ...	618	577

The 3·0 per cent higher specific fuel consumption on fuel oil is partially accounted for by the calorific value of the fuel which is 1·8 per cent lower than on the Diesel fuel.

Sea Trials. No special blend of heavy fuel oil was supplied for the sea trials, the vessel being bunkered with a currently available marine fuel oil of Middle East origin of about 500 seconds Redwood No. 1 viscosity at 100 deg. F. Inspection data on the samples of fuel oil drawn from the various points in the fuel system are given in Table IV. After purification, significant reductions in sediment by extraction, ash content, and bottoms, sediment and water were obtained, but no apparent change took place in the fuel after the clarifier.

Service Performance. During the first four years of service the vessel completed twenty voyages between the United Kingdom and Eastern Mediterranean ports. The engine has, in general, operated at ratings of about 90 per cent of maximum. The average engine speed has usually been around 100 r.p.m., although for a number of voyages (June 1951 to July 1952) the engine revolutions were increased to about 104 r.p.m. Typical average engine operating conditions are given in Table V.

(*a*) *Fuel Inspections.* During each voyage samples were taken of the fuel as bunkered and at various stages in the fuel cleaning system. The weight of fuel centrifuged and the amount of sludge removed from the purifier and clarifier respectively were recorded on a day-to-day basis. At intervals samples of sludge were retained for analysis. The results have been summarized wherever possible, although a comprehensive tabulation is made of the inspection data from each individual bunker and is presented in Appendix Tables XXVIII, XXIX and XXX.

A summary of the inspection data of the fuels bunkered is given in Table VI and these figures will give some idea of the type of fuels burnt in the engine. With the exception of the initial test bed trials this engine has never used a gas oil or marine Diesel grade of fuel. The fuels used have had specific gravities within the range 0·92 to 0·97, the viscosities at 100 deg. F. have usually been around 1,000 seconds Redwood No. 1, and the closed flash point in excess of 200 deg. F. The sulphur content has tended to rise with averages of 2·4,

TABLE V—TYPICAL ENGINE OPERATING CONDITIONS IN VESSEL A

Voyage/Sheet Number	4/1	4/2	4/3	4/4	14/1	14/2	14/3	18/1	18/2	18/3
Date	8/9/50-12/11/50				2/8/52-11/11/52			8/6/53-12/8/53		
Engine hours										
At sea	17	181	119	287	31	312	364	24	274	280
Manœuvring	9	12	23	18	31	16	24	41	26	14
Number of ports of call	1	1	5	3	3	5	5	4	5	4
Fuel consumption, tons										
At sea	6·9	70·4	39·2	116·7	12·9	84·0	120·2	9·5	124·0	121·0
Manœuvring	2·3	3·0	2·8	3·6	7·7	3·6	5·1	6·9	5·5	3·9
Average engine speed, r.p.m.	102·5	99·2	100·8	99·5	104·2	88·6	90·3	—	102·3	102·1
Average ship speed, knots	12·8	12·1	11·4	12·1	12·9	11·4	10·4	—	13·0	12·6
Temperature, deg. F.										
Fuel at filter block								Coasting	180	180
Exhaust gas maximum	560	618	521	659	524	462	505		588	589
Exhaust gas mean	532	552	467	569	477	411	454		505	501
Air inlet	92	101	104	100	90	103	95		—	—
Pressure, lb. per sq. in.										
Fuel injection	5,600	5,600	5,600	5,600	7,000	5,940	5,980		6,700	6,800
Scavenge air	2·2	2·2	1·7	2·2	2·1	1·6	1·7		2·2	2·2
Lubricating oil consumption, gal.										
per day—All cylinders	6	8·5	8	8	7	6	7		8	8
Crankcase	5	5	4	5	3·5	3	3		4	6

TABLE VI—SUMMARY OF FUELS BUNKERED IN VESSEL A

Tests	May '50-Dec. '51		Dec. '51-Jan. '53		Jan. '53-Jan. '54	
	Min.	Max.	Min.	Max.	Min.	Max.
Specific gravity at 60 deg. F./60 deg. F.	0·926	0·960	0·949	0·964	0·929	0·969
Viscosity, Redwood No. I						
at 100 deg. F., sec.	310	1,650	599	1,462	373	1,755
at 200 deg. F. sec.	53	112	68	107	54	99
Flash point P.M., closed, deg. F.	202	275	206	270	174	260
Pour point, deg. F.	20	70	35	45	—	—
Conradson carbon, per cent.	4·6	10·5	7·1	10·5	—	—
Water, per cent.	Trace	5·0	Nil	0·2	—	—
Sediment by hot filtration, per cent.	0·01	0·11	0·01	0·04	0·02	0·08
Ash, per cent.	0·02	0·10	0·01	0·04	0·01	0·08
Sulphur, per cent.	1·9	3·0	2·2	3·4	2·9	4·2
Asphaltenes, per cent.	1·2	6·0	0·8	1·8	1·1	4·0
Bottoms, sediment and water, per cent.	0·1	6·0	0·1	0·4	—	—

3·2 and 3·6 throughout the three periods into which the fuels are divided. The fuels bunkered during the second half of 1951 were mainly products of Venezuelan origin, as indicated by their lower pour points and higher asphaltene contents, namely 20 deg. F. and 6·0 per cent respectively. The fuels in general were very low in sediment by the hot filtration test; only two fuels of the twenty-six bunkered contained more than 0·07 per cent.

(*b*) *Sludge Weights and Analyses.* The average weights of sludge extracted from the fuel by the purifier and clarifier are given in Table VII. It will be seen that the amount of sludge extracted by both machines varies considerably between the various bunkers lifted, and that the ratio of the material removed by the purifier to that removed by the clarifier is not constant. Considering all the fuels bunkered by this vessel, the only fuel property showing any correlation with the amount of sludge removed is the sediment by hot filtration.

TABLE VII—AVERAGE WEIGHTS OF SLUDGE EXTRACTED FROM EACH TON OF FUEL TREATED IN VESSEL A

Bunker	Quantity treated, tons	Treating rate, tons per hour	Sludge, lb. per ton of fuel	
			Purifier	Clarifier
South Shields 6/2/50	140·4	1·05	0·56	0·27
Alexandria 18/3/50	117·8	1·13	0·25	0·02
London 20/4/50	—	—	Mixed with other fuels before use	
Alexandria 25/5/50	25·2	1·38	0·40	0·29
London 11/7/50	222·5	1·39	0·20	0·05
London 15/9/50	251·5	1·27	0·15	0·06
London 14-15-24/11/50	169·2	1·11	1·52	1·06
Liverpool 3/2/51	101·6	1·25	0·24	0·11
London 10/4/51	140·2	1·18	0·07	0·03
London 2-6/7/51	150·9	0·99	0·17	0·04
London 28/9/51	292·5	0·98	0·39	0·05
Glasgow 30/11/51	248·5	1·04	0·39	0·16
Liverpool 20/1/52	173·8	1·25	0·33	0·19
London 28/3/52	123·5	1·34	0·17	0·04
Liverpool 17-19/5/52	208·6	1·13	0·24	0·09
Hull 7/8/52	—	—	Mixed with other fuels before use	
London 20/8/52	187·6	1·25	0·18	0·04
London 12/11/52	347·9	1·27	0·15	0·05
Manchester –/1/53	143·3	1·21	0·38	0·13
Hamburg 7/4/53	231·7	1·16	0·51	0·29
London 22/4/53	76·0	1·08	0·13	0·04
Hull 10/6/53	151·7	1·19	0·17	0·05
London 12/8/53	84·0	0·98	0·31	0·06
Beirut 21/9/53	118·1	1·05	0·10	Nil
Liverpool 14/11/53	179·3	0·89	0·62	0·66
Ceuta 7/1/54	73·6	0·93	1·30	0·6

The fuels have been centrifuged at a uniform rate of between 1 and 1¼ tons per hr. As the fuel consumption of the vessel is of the order of 10 tons per day there is a considerable surplus of centrifuge capacity available to cater for any emergencies.

Samples of sludges from the centrifuges were examined to determine their approximate composition. It was found that they contained in the majority of cases about 70 per cent of water and oil, the remaining 30 per cent being ash and carbonaceous material.

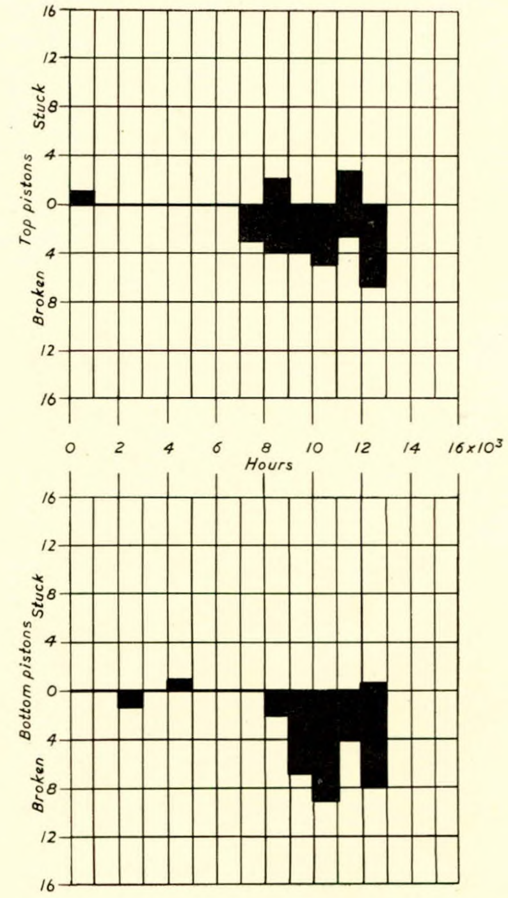

FIG. 4—*Summary of ring condition and breakages in Vessel A*

Several fuels and sludges were examined in more detail in order to identify the metals forming the ash. The results obtained are presented in Table VIII, from which it will be seen that the major metal compounds in the ash of the fuels used were sodium, iron and vanadium, with calcium and mag-

TABLE VIII—QUALITATIVE ANALYSIS OF ASH REMAINING AFTER IGNITION OF VARIOUS FUELS AND SLUDGES FROM VESSEL A*

Voyage Number	Bunker taken	Sampling point	Metallic constituents of ash		per cent V
			Main	Other	
3	July, 1950	Bunker sample	Fe, Na, V	Ca, Mg	0·006
3	,, ,,	Treated fuel	Fe, Na, V	Ca, Mg	0·006
3	,, ,,	Purifier sludge	Ca, Na	Fe, Mg	0·020
3	,, ,,	Clarifier sludge	Fe, Na	Ca, Mg	0·013
5	November, 1950	Bunker sample	Fe, Na, V	Ca, Mg	0·004
5	,, ,,	Treated fuel	Fe, Na, V	Ca, Mg	0·003
5	,, ,,	Purifier sludge	Ca, Mg	Fe, Na	0·040
5	,, ,,	Clarifier sludge	Ca, Na	Mg, Fe	0·021
6	February, 1951	Bunker sample	Fe, Na, V	Mg	0·005
6	,, ,,	Treated fuel	Fe, Na, V	Mg	0·004
6	,, ,,	Purifier sludge	Ca, Fe	Na, Mg	0·042
6	,, ,,	Clarifier sludge	Ca, Fe	Na, Mg	0·032

* Trace constituents not included in table.

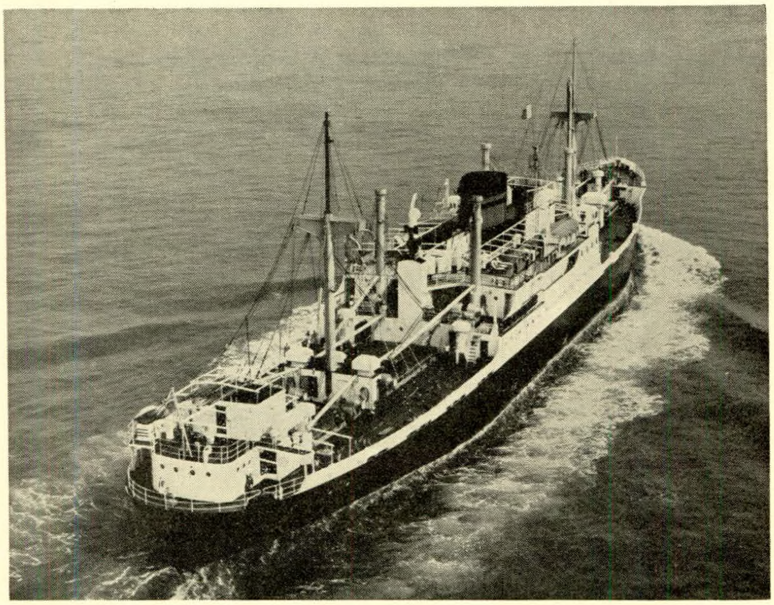

FIG. 5—*Vessel A at full power, burning a residual type fuel*

nesium as the secondary constituents. The metals present in the sludge were not present in the original proportions, indicating that the major constituents of the fuel ash are probably present in a soluble form. Furthermore, it will be observed that the sludge samples were of entirely different compositions, indicating that none of the fuels from which the samples were obtained centrifuged in the same way.

As a matter of interest the vanadium contents of the fuels before and after centrifuging were determined, as shown in the table, but the amounts present were found to be small.

Engine Cleanliness and Wear

The opportunity has been taken to obtain information regarding rates of liner wear and deposit formation during the periodic examinations of the pistons and liners. It should be pointed out that although the pistons have been lifted fairly frequently, the work has always been carried out while the vessel was in port to load or discharge cargo. A summary of the condition of the piston rings is given in Fig. 4. It will be seen that during the first 7,000 hours of operation there were only two stuck and one broken ring. At 8,000 hours new heads were fitted to all the pistons.

When burning the fuel bunkered at London in July 1951, a drop of two to three r.p.m. was noticed with no mechanical alteration and under similar weather conditions, compared with the April 1951 bunker. Smoke of a dark brown colour was always present at the funnel, although it varied slightly from day to day, and there was also a continual discharge of incandescent carbon. At the same time the build-up of sludge was very excessive around No. 2 cylinder. An analysis of a sample of this sludge indicated that it consisted of a 50/50 mixture of oil and carbonaceous material. It was determined

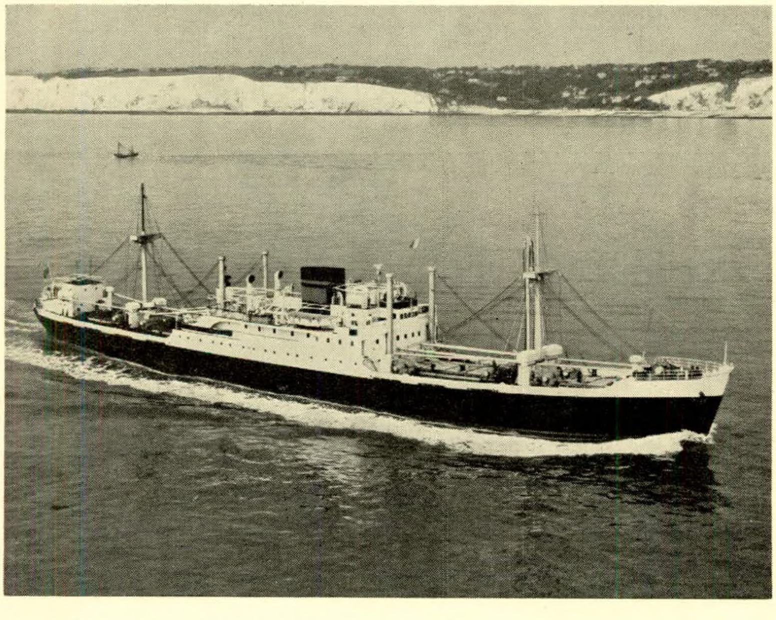

FIG. 6—*Vessel A (4,600-ton d.w.c.): general cargo vessel*

that the oil present had not come from the lubricating oil, but must have been unburnt fuel swept into the scavenge belt at the end of the combustion cycle. The fuel valves were then reset so that the point of maximum valve lift occurred at 4 degrees after piston inner dead centre; this is 3½ degrees advanced on the maker's original setting on the test bed trials of this engine. This adjustment to the fuel valve timing eliminated the sludge and smoke problems.

The two photographs of Vessel A, Figs. 5 and 6, were taken when the engine was developing its maximum horsepower and using the Liverpool May 1952 bunker, a fuel of just under 1,000 seconds Redwood No. 1 viscosity at 100 deg. F., and indicate clearly that there is no exhaust smoking.

The summarized wear data for this vessel are tabulated in Table IX. The wear rates for the individual liners over the three periods of operation are given below:—

Date	Operating hours	Liner wear rates, mm. per 1,000 hr. 1	2	3	4	Average
May '50 to Dec. '51	5,822	0·27	0·23	0·14	0·19	0·21
Dec. '51 to Jan. '53	3,248	0·47	0·48	0·45	0·41	0·45
Jan. '53 to Jan. '54	3,263	0·82	0·61	0·56	0·69	0·67
Overall May '50 to Jan. '54	12,333	0·47	0·41	0·33	0·40	0·40

Curves representing the profile of No. 1 liner after various periods of operating time are presented in Fig. 7. The profiles of the other liners are similar in shape. The relationship between the various positions on the liner where measurements are taken, and the exhaust and scavenge ports is given in Fig. 8; included also are the position of the lubricators and the piston crown and firing ring at inner and outer dead centres.

Vessel B

This vessel went into service in January 1951 and she operates on almost the same route as Vessel A, i.e. to the Eastern Mediterranean. During the period from Jan. 1951 to April 1952 the engine operated fairly continuously at power outputs and speeds approaching the design maximum. The engine speed was then reduced and since that date speeds have generally been around 103 r.p.m. During the initial voyages, although residual type fuels were in use the fuel temperature at the filter block was as low as 120 deg. F. and injection pressures were 6,000lb. per sq. in. They were then gradually increased up to a temperature of 180 deg. F. at the filter block and an injection pressure of 7,000lb. per sq. in.

Typical average engine operating conditions on three voyages are given in Table X.

TABLE IX—MAXIMUM LINER WEAR (TOTAL HOURS)* IN VESSEL A

	Total hours and wear, mm., since new			Hours and wear, mm., since last examination		
	Hours	Wear	Wear rate mm. per 1,000 hr.	Hours	Wear	Wear rate, mm. per 1,000 hr.
No. 1 Liner	616	0·26	0·422	616	0·26	0·422
	2,190	0·81	0·370	1,574	0·55	0·350
	3,963	1·32	0·334	1,773	0·51	0·287
	4,938	1·54	0·312	975	0·22	0·226
	5,863	1·65	0·282	925	0·11	0·119
	7,093	2·06	0·291	1,230	0·41	0·333
	8,338	2·94	0·353	1,245	0·88	0·707
	9,375	3·29	0·351	1,037	0·35	0·337
	10,206	3·81	0·371	831	0·52	0·625
	11,365	4·72	0·415	1,159	0·91	0·786
	12,346	5·72	0·464	981	1·00	1·020
No. 2 Liner	958	0·43	0·449	958	0·43	0·449
	2,661	0·77	0·289	1,703	0·34	0·200
	4,261	1·39	0·326	1,600	0·62	0·387
	5,863	1·57	0·268	1,602	0·18	0·112
	7,654	2·35	0·307	1,791	0·78	0·393
	8,725	2·91	0·332	1,071	0·56	0·522
	9,730	3·41	0·350	1,006	0·50	0·496
	11,000	4·26	0·388	1,270	0·85	0·670
	12,368	4·97	0·403	1,368	0·71	0·520
	12,683	5·20	0·410	315	0·23	0·730
No. 3 Liner	958	0·26	0·271	958	0·26	0·271
	3,266	0·44	0·135	2,308	0·18	0·078
	4,845	0·90	0·186	1,579	0·54	0·342
	6,483	1·01	0·156	1,638	0·11	0·067
	7,944	1·52	0·192	1,461	0·51	0·349
	9,091	2·17	0·239	1,147	0·65	0·567
	10,657	3·22	0·302	1,566	1·05	0·671
	12,001	3·76	0·313	1,344	0·54	0·402
	12,368	3·83	0·315	367	0·07	0·191
	12,596	4·13	0·328	228	0·30	1·315
No. 4 Liner	958	0·40	0·418	958	0·40	0·418
	2,661	0·72	0·270	1,703	0·32	0·188
	3,963	0·97	0·245	1,302	0·25	0·192
	5,841	1·34	0·230	1,878	0·37	0·197
	7,944	1·81	0·228	2,103	0·47	0·223
	9,055	2·66	0·294	1,111	0·85	0·765
	10,206	3·47	0·340	1,151	0·81	0·705
	11,365	4·41	0·389	1,159	0·94	0·811
	12,346	4·93	0·405	981	0·52	0·530

NOTE—The wear figure quoted is the mean of the F and A, and P and S readings at the point of maximum wear.

*Sea plus manœuvring hours

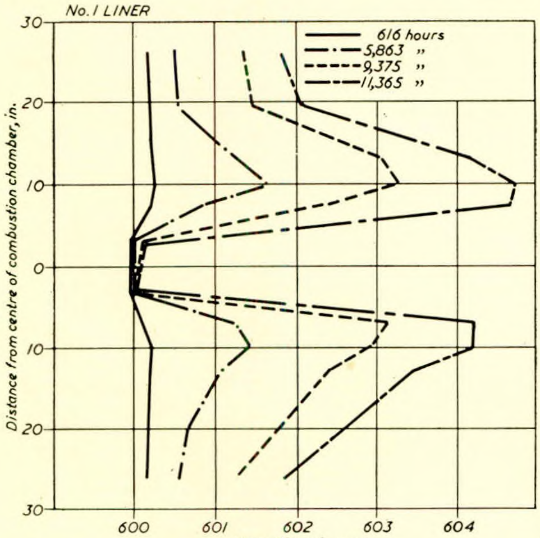

FIG. 7—*Effect of total operating time on liner profile in Vessel A. (Liner diameter shown is mean of F and A, and P and S readings)*

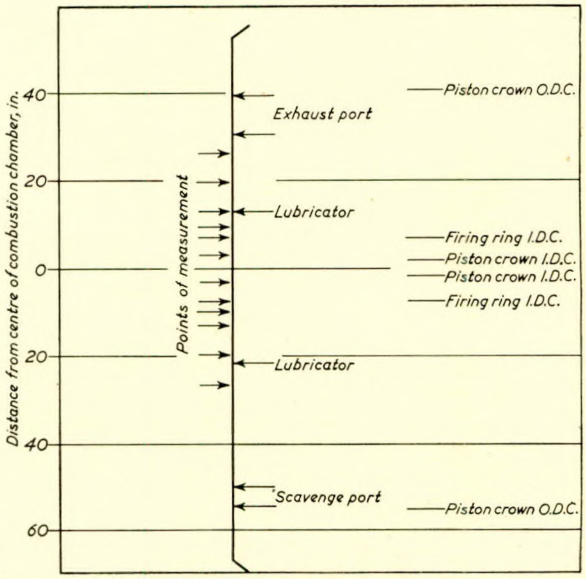

FIG. 8—*Relationship between the gauging points and the positions of ports, lubricators and pistons in Vessel A*

TABLE X—TYPICAL ENGINE OPERATING CONDITIONS IN VESSEL B

Voyage/Sheet number	6/1	6/2	6/3	8/1	8/2	8/3	14/1	14/2	14/3
Date	24/12/51-9/3/52			24/4/52-20/6/52			5/5/53-1/7/53		
Engine hours									
At sea	172	264	6	13	270	229	15	231	225
Manœuvring	164	39	37	81	19	11	18	15	36
Number of ports of call	2	6	2	2	3	1	2	3	2
Fuel consumption, tons									
At sea	86·6	134·3	2·6	4·8	114·7	105·1	6·6	109·9	105·8
Manœuvring	39·7	12·3	12·8	11·2	2·9	4·1	5·2	4·3	9·0
Average engine speed, r.p.m.	108·9	109·5	—	103·3	102·4	105·6	—	105·2	105·4
Average ship speed, knots	14·1	13·2	15·0	14·3	13·1	13·7	—	13·8	13·3
Temperature, deg. F.									
Fuel at filter block	171	170	170	174	175	181	—	180	180
Exhaust gas maximum							Coasting	640	642
Exhaust gas mean	584	620	600	536	567	616		594	604
Pressure, lb. per sq. in.									
Fuel injection	7,000	7,000	7,000	7,000	7,000	7,000		6,800	6,800
Scavenge air	2·9	3·15	3·3	—	2·65	2·95		2·8	2·8
Lubricating oil consumption, gal. per day									
All cylinders	7·3	7·8	7·3	3·5	7·3	7·5		7	7
Crankcase	4·9	4·6	3·4	4·6	6·0	5·2		11	12

TABLE XI—SUMMARY OF FUELS BUNKERED IN VESSEL B

Tests	Jan. '51-Apr. '52		Apr. '52-Dec. '52		Dec. '52-Dec. '53	
	Min.	Max.	Min.	Max.	Min.	Max.
Specific gravity at 60 deg. F./60 deg. F.	0·927	0·956	0·956	0·965	0·950	0·988
Viscosity, Redwood No. I						
at 100 deg. F., sec.	315	1,940	1,200	1,650	947	1,615
at 200 deg. F., sec.	55	124	97	117	86	101
Flash point P.M. closed, deg. F.	178	330	225	335	184	230
Pour point, deg. F.	40	65	10	65	—	—
Conradson carbon, per cent.	6·3	9·9	9·0	12·3	—	—
Water, per cent.	Nil	0·4	Trace	0·5	—	—
Sediment by hot filtration, per cent.	0·01	0·04	Nil	0·05	0·01	0·09
Ash, per cent.	0·01	0·08	0·01	0·08	Trace	0·08
Sulphur, per cent.	2·5	3·7	2·1	3·4	2·9	4·5
Asphaltenes, per cent.	1·0	2·1	1·4	7·5	2·2	8·0
Bottoms, sediment and water, per cent.	0·1	0·8	Trace	0·9	—	—

(*a*) *Fuel Inspections.* Fuel samples were collected on a similar basis to those of Vessel A. A summary of the bunker samples is given in Table XI and more complete data of these samples, together with samples taken at the main engine fuel pump, are given in Appendix Tables XXXI, XXXII and XXXIII. With only one exception the specific gravities ranged between 0·92 and 0·97. A fuel originating from the coal tar industry was bunkered at Flushing in October 1953 which had a gravity of 0·988. The viscosity of the fuels, with the exception of the first year of operation, have been of above 1,000 seconds Redwood No. 1 at 100 deg. F. The sulphur content of the fuels has risen from an average level of 2·8 per cent during 1951 to 3·6 per cent during 1953.

The majority of the fuels were of Middle East origin; however, some originated from the Western Hemisphere as indicated by their higher asphaltene content.

(*b*) *Sludge Weights and Analyses.* The average weights of sludge extracted from the various bunkers by the purifier and clarifier are given in Table XII. It will be seen that generally the amount of sludge extracted by the clarifier is of the same order as that extracted by the purifier. Fuel treating rates averaged about 1 ton per hr. and the sediment by hot filtration of the fuel before the purifier and clarifier showed some correlation with the amount of sludge removed.

(*c*) *Engine Cleanliness and Wear.* As on Vessel A the opportunity was taken to obtain information regarding rates of liner wear and deposit formation during the periodic examination of liners and pistons. A summary of the piston

TABLE XII—AVERAGE WEIGHT OF SLUDGE EXTRACTED FROM EACH TON OF FUEL TREATED in VESSEL B

Bunker	Quantity treated, tons	Treating rate, tons per hour	Sludge, lb. per ton of fuel	
			Purifier	Clarifier
Alexandria 24/4/51	96·0	1·71	0·08	0·07
Alexandria 29/6/51	244·5	1·04	0·10	0·10
Alexandria 29/8/51	113·1	1·03	0·32	0·45
Liverpool 2/10/51	89·1	0·99	0·26	0·28
Thameshaven 29/11/51	141·0	1·04	0·45	0·34
Glasgow 20/2/52	149·3	1·03	0·19	0·08
Liverpool 18/4/52	105·3	1·09	0·33	0·20
Alexandria 15/7/52	184·8	0·98	0·10	0·01
Liverpool 26/8/52	70·5	1·17	0·13	0·02
Newcastle –/10/52	166·0	0·92	0·07	0·01
Ceuta 17/12/52	161·0	1·00	0·23	0·10
Alexandria 29/1/53	183·5	1·00	0·40	0·08
Alexandria 1/4/53	303·0	1·03	0·11	0·06
Liverpool 18/5/53	216·0	1·02	0·16	0·14
London 8/7/53	61·5	1·08	0·01	0·03
Beyrouth 29/7/53	89·5	1·04	Nil	Nil
Manchester 4/9/53	235·5	1·05	0·12	0·10
Flushing 23/10/53	177·0	1·01	0·07	0·04
Ceuta 9/12/53	30·0	1·05	0·28	0·24

TABLE XIII—MAXIMUM LINER WEAR (TOTAL HOURS)* IN VESSEL B

	Total hours and wear, mm., since new			Hours and wear, mm., since last examination		
	Hours	Wear	Wear rate mm. per 1,000 hr.	Hours	Wear	Wear rate mm. per 1,000 hr.
No. 1 Liner	297	0·20	0·674	297	0·20	0·674
	1,136	0·65	0·572	839	0·45	0·537
	2,159	0·92	0·425	1,023	0·27	0·263
	3,703	1·44	0·389	1,544	0·52	0·337
	4,856	2·07	0·426	1,153	0·63	0·546
	6,171	2·46	0·399	1,315	0·39	0·297
	9,303	3·11	0·334	3,132	0·65	0·208
	11,577	4·12	0·357	2,274	1·01	0·445
No. 2 Liner	297	0·23	0·775	297	0·23	0·775
	1,136	0·66	0·683	839	0·43	0·513
	1,882	0·72	0·383	746	0·06	0·081
	3,030	1·26	0·416	1,148	0·54	0·470
	4,352	2·00	0·460	1,322	0·74	0·560
	5,556	2·24	0·403	1,204	0·24	0·199
	6,024	2·26	0·375	468	0·02	0·043
	7,879	3·33	0·423	1,855	1·07	0·577
	9,022	3·66	0·406	1,143	0·33	0·289
No. 3 Liner	565	0·19	0·336	565	0·19	0·336
	1,372	0·59	0·430	807	0·40	0·495
	1,971	0·78	0·395	599	0·19	0·317
	3,453	1·67	0·484	1,482	0·89	0·600
	5,926	2·32	0·392	2,473	0·65	0·263
	7,236	3·11	0·430	1,310	0·79	0·603
	9,901	4·18	0·423	2,665	1·07	0·402
No. 4 Liner	565	0·26	0·460	565	0·26	0·460
	1,136	0·71	0·625	571	0·45	0·787
	1,615	0·77	0·477	479	0·06	0·125
	2,772	1·10	0·397	1,157	0·33	0·285
	3,986	1·60	0·402	1,214	0·50	0·411
	5,257	1·85	0·352	1,271	0·25	0·196
	6,554	2·51	0·383	1,297	0·66	0·509
	8,179	3·38	0·414	1,625	0·87	0·535
	10,627	4·11	0·388	2,448	0·73	0·298

NOTE: The wear figure quoted is the mean of the F and A, and P and S readings at the point of maximum wear.

*Sea plus manœuvring hours.

ring conditions is given in Fig. 9. During the initial period of operation there was a considerable number of stuck rings with hard piston deposits, and blockages in the exhaust ports. The cylinder oil was then changed by the owners from a detergent to a non-detergent type, which was, in fact, accompanied by the elimination of piston ring sticking.

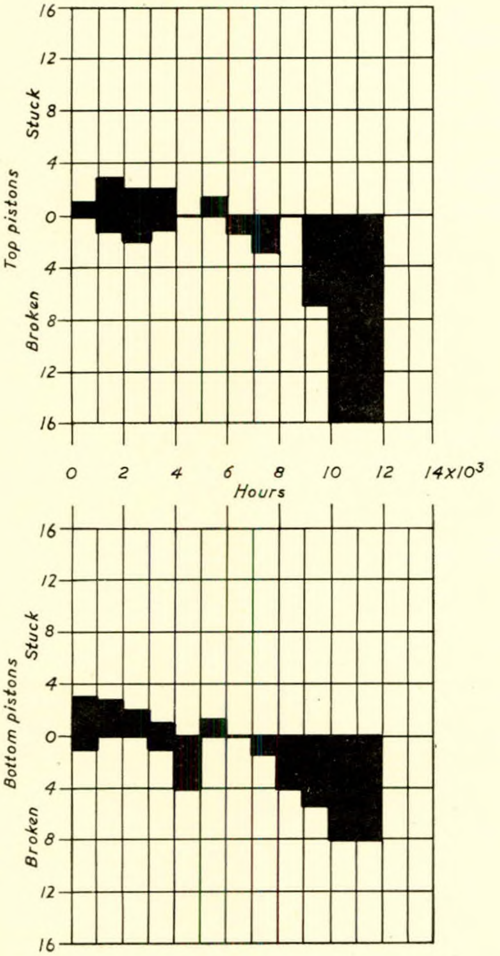

FIG. 9—*Summary of ring condition and breakages in Vessel B*

The summarized wear data for this vessel are tabulated in Table XIII. Individual cylinder wear rates for three periods of operation are given below:—

Date	Operating hours	Liner wear rates, mm. per 1,000 hr. 1	2	3	4	Average
Jan. '51 to Apr. '52	3,448	0·36	0·44	0·51	0·39	0·43
Apr. '52 to Dec. '52	2,529	0·40	0·16	0·26	0·35	0·29
Dec. '52 to Dec. '53	3,760	0·31	0·47	0·47	0·39	0·41
Overall						
Jan. '51 to Dec. '53	9,737	0·35	0·39	0·43	0·38	0·39

The profile of No. 1 liner, which is representative, is shown in Fig. 10; in all cases the areas of maximum wear occur on the top half of the liners. The rather peculiar wear formation will be noticed from the figure, giving two peaks of high wear on each half of the liners, although those on the lower half are not so pronounced. The pistons on this vessel are of the type normally fitted to three-cylinder engines in which the nearness of the first two rings to the crown of the piston is necessary to give positive starting at any crank position.

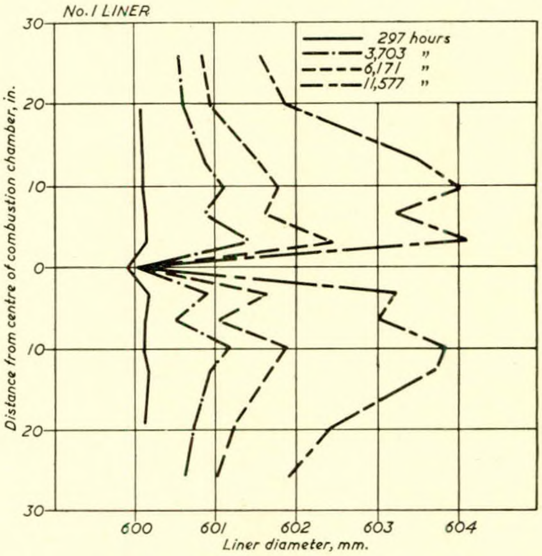

FIG. 10—*The effect of total operating time on liner profile in Vessel B. (Liner profile shown is mean of F and A, and P and S readings)*

Vessel C

Test Bed Trials. The test bed trials refer to the port main engine; the starboard engine was tested only on Diesel fuel.

Prior to the trials on the heavy fuel oil, the engine was run on marine Diesel fuel at various loads to carry out the minor adjustments necessary to balance the engine. The run-

TABLE XIV—INSPECTION DATA ON HEAVY FUEL OIL USED DURING TEST BED TRIALS OF THE PORT MAIN ENGINE IN VESSEL C

Tests	Sampling point: Rail car at Mode Wheel	After purifier	After clarifier	Main engine fuel pump
Specific gravity at 60 deg. F./60 deg. F.	0·963	—	—	—
Viscosity, Redwood No. I				
at 100 deg. F., sec.	1,595	—	—	1,615
at 200 deg. F., sec.	116	—	—	112
Flash point P.M., closed, deg. F.	218	—	—	—
Pour point, deg. F.	15	—	—	—
Conradson carbon, per cent.	11·5	—	—	—
Water, per cent.	0·2	0·15	Trace	Trace
Sediment by extraction, per cent.	0·03	0·04	0·02	0·01
Ash, per cent.	0·05	0·06	0·05	0·05
Sulphur, per cent.	2·3	—	—	—
Asphaltenes, per cent.	7·6	—	—	—
Bottoms, sediment and water, per cent.	0·5	0·4	0·1	0·1

ning on heavy fuel oil consisted of a four-hour run at full load when a specific fuel consumption to 0·365lb. per s.h.p. hr. was obtained.

Inspection data on heavy fuel oil samples taken whilst centrifuging the fuel are given in Table XIV: it will be seen that the fuel was relatively clean.

The quantities of the sludges removed from the purifier and clarifier amounted to only 4·2 and 0·3lb. respectively after treating 15 tons of fuel.

The engine ran with a notable absence of vibration and even at light loads the exhaust was clear. Some comparative figures are given below while operating at full load on heavy fuel and Diesel fuel.

	Fuel oil	Diesel fuel
Temperature at service tank, deg. F.	160	—
Temperature at main engine pump heater, deg. F. ...	180	—
Temperature at main engine filter blocks, deg. F. ...	170	Atmospheric
Fuel line pressure, lb. per sq. in.	5,860	5,600
Average exhaust temperature, deg. F.	690	675
Injectors, number and diameter (inches) of holes	8 × 0·025	7 × 0·025
Control notch	93	94
Fuel control notch	43	43
Fuel consumption, lb. per s.h.p. hr.	0·375	0·365
Calorific value, B.Th.U. per lb. net	17,700	18,200

The higher specific fuel consumption on fuel oil of 2·7 per cent is accounted for by the difference in calorific values of the two fuels.

Sea Trials. The vessel was bunkered with 880 tons of a currently available Middle East residual fuel and the inspection data of samples drawn from the two shore tanks are given in Table XV. The fuels which had a viscosity of about 400 seconds Redwood No. 1 at 100 deg. F. were relatively clean products and there was no appreciable change in the inspection figures after the fuel had passed through the purifier and clarifier.

TABLE XV—INSPECTION DATA OF HEAVY FUEL OIL USED DURING SEA TRIALS OF VESSEL C

Tests	Sampling point		
	Bowling tank 1	Bowling tank 2	After clarifier
Specific gravity at 60 deg. F./60 deg. F.	0·930	0·929	—
Viscosity, Redwood No. I			
at 100 deg. F. secs.	437	382	—
at 200 deg. F. secs.	57·3	56·3	—
Flash point P.M. closed, deg. F.	235	220	—
Pour point, deg. F.	70	65	—
Conradson carbon, per cent	5·7	5·7	—
Water, per cent.	0·1	0·1	0·1
Sediment by hot filtration, per cent	0·04	0·04	0·04
Ash, per cent.	0·03	0·02	0·02
Sulphur, per cent.	2·1	2·1	—
Bottoms, sediment and water, per cent	0·2	0·4	0·2

Service Performance. The vessel went into service in December 1950, and during the two and a half years under review it completed five round voyages from the United Kingdom to Australia. The average engine powers varied between 75 and 93 per cent of the maker's maximum rating. The average engine speeds were also only 103 r.p.m. compared with a design maximum of 115 r.p.m.

Fuel Inspection. The sampling procedure used was considerably curtailed in this vessel compared with the other two British ships. A sample was retained of each bunker lifted and in the majority of cases a sample of the fuel at the main engine fuel pump was also kept. A summary of the fuels used is given in Table XVI, and the complete inspection data obtained are given in Appendix Tables XXXIV and XXXV. During the first three voyages the fuels bunkered had viscosities of below 600 seconds Redwood No. 1 at 100 deg. F., and in one instance a Diesel fuel grade was bunkered. Latterly fuels were bunkered with viscosities exceeding 1,000 seconds Redwood No. 1 at 100 deg. F. The fuels have all been relatively clean products as indicated by their sediment and ash contents. In the main, flash points have been on the low side and in one or two cases only marginal above the statutory requirement of 150 deg. F. minimum.

TABLE XVI—SUMMARY OF FUELS BUNKERED IN VESSEL C

Tests	Dec. '50-Aug. '52		Sept. '52-June '53	
	Min.	Max.	Min.	Max.
Specific gravity at 60 deg. F./60 deg. F.	0·926	0·941	0·926	0·960
Viscosity, Redwood No. I				
at 100 deg. F., sec.	287	572	226	1,176
at 200 deg. F., sec.	53·8	67·8	—	—
Flash point P.M. closed, deg. F.	160	235	150	184
Pour point, deg. F.	15	70	—	—
Conradson carbon, per cent.	5·7	8·4	—	—
Water, per cent.	Nil	0·2	—	—
Sediment by hot filtration, per cent.	0·01	0·04	0·02	0·06
Ash, per cent.	0·02	0·07	0·02	0·04
Sulphur, per cent.	2·1	2·7	2·6	2·7
Asphaltenes, per cent.	1·2	3·4	3·0	5·1
Bottoms, sediment and water, per cent.	0·1	0·5	—	—

Sludge Weights. A record has been kept of the amount of sludge removed from the centrifuge machines and is given in Table XVII. The fuel requirement of the engines is about 38 tons per day and consequently the centrifuges are running for longer periods than on either of the other two cargo vessels. The average centrifuging rate is approximately 1·6 tons per hr. It is felt that there were insufficient representative fuel oil samples taken directly before the purifier to justify drawing any firm conclusions from the amount of sludge extracted from the various bunkers.

TABLE XVII—AVERAGE WEIGHT OF SLUDGE EXTRACTED FROM EACH TON OF FUEL TREATED IN VESSEL C

Bunker	Quantity treated, tons	Treating rate, tons per hour	Sludge, lb. per ton of fuel	
			Purifier	Clarifier
Glasgow 20/11/50	297·1	1·52	0·08	0·03
Glasgow 4/12/50				
Teneriffe 15/1/51	1105·9	1·73	0·11	0·02
Melbourne 27/2/51	Only used as a mixed bunker			
Fremantle 25/5/51	259·0	1·80	0·12	0·03
Teneriffe 22/6/51	506·3	1·65	0·19	0·02
Teneriffe 30/8/51	1829·4	1·75	0·13	0·02
Teneriffe 31/1/52	522·4	1·58	0·46	0·19
Teneriffe 26/3/52	1072·0	1·58	0·36	0·17
Capetown 14/4/52	200·0	1·67	0·24	0·07
Teneriffe 5/8/52	255·0	1·80	0·41	0·12
Teneriffe 29/9/52	1606·0	1·63	0·21	0·11
Fremantle 30/12/52	285·0	1·58	0·14	0·09
Teneriffe 31/1/53	389·0	1·35	0·62	0·41
Teneriffe 14/3/53	1477·0	1·47	0·34	0·41
Curacao 17/6/53	278·0	1·83	0·13	0·02

Engine Cleanliness and Wear. From visual examination of the cylinder assemblies opened up for inspection in the United Kingdom from time to time, there appeared to be little build-up of carbon in the exhaust ports, and only light carbon deposits behind the rings. The liners and piston skirts were very clean.

TABLE XVIII—MAXIMUM LINER WEAR IN THE PORT ENGINE (TOTAL HOURS*) IN VESSEL C

	Total hours and wear, mm., since new			Hours and wear, mm., since last examination		
	Hours	Wear	Wear rate, mm. per 1,000 hr.	Hours	Wear	Wear rate, mm. per 1,000 hr.
No. 1 Liner	892 1,857 3,630 5,376 7,000 8,688 10,585	0·37 0·71 1·26 1·73 2·26 2·90 4·20	0·413 0·384 0·346 0·322 0·323 0·334 0·397	892 965 1,773 1,746 1,624 1,688 1,897	0·37 0·34 0·55 0·47 0·53 0·64 1·30	0·413 0·356 0·308 0·269 0·326 0·379 0·685
No. 2 Liner	892 4,448 6,201 7,901 9,616	0·19 1·35 2·04 2·84 3·76	0·213 0·306 0·328 0·360 0·391	892 3,556 1,753 1,700 1,715	0·19 1·16 0·69 0·80 0·92	0·213 0·327 0·393 0·470 0·536
No. 3 Liner	892 1,800 3,630 5,376 7,000 8,688 10,585	0·32 0·47 0·75 1·17 1·70 2·14 2·62	0·356 0·261 0·206 0·218 0·243 0·247 0·248	892 908 1,830 1,746 1,624 1,688 1,897	0·32 0·15 0·28 0·42 0·53 0·44 0·48	0·356 0·168 0·153 0·240 0·326 0·261 0·253
No. 4 Liner	892 4,304 6,201 8,019 9,619	0·41 1·61 2·14 2·36 3·38	0·455 0·374 0·345 0·295 0·352	892 3,412 1,897 1,818 1,600	0·41 1·20 0·43 0·22 1·02	0·455 0·352 0·227 0·121 0·638
No. 5 Liner	850 4,303 6,201 8,019 9,580	0·28 1·29 1·92 2·31 3·02	0·328 0·300 0·309 0·288 0·315	850 3,454 1,897 1,818 1,561	0·28 1·01 0·63 0·39 0·71	0·328 0·293 0·332 0·214 0·455
No. 6 Liner	850 2,721 4,304 6,201 8,019 9,580	0·27 0·79 1·26 1·88 2·24 2·77	0·314 0·289 0·292 0·303 0·279 0·290	850 1,871 1,583 1,897 1,818 1,561	0·27 0·52 0·47 0·62 0·36 0·53	0·314 0·277 0·297 0·327 0·198 0·339

NOTE: The wear figure quoted is the mean of the F and A, and P and S readings at the point of maximum wear

*Sea plus manœuvring hours

TABLE XIX—MAXIMUM LINER WEAR IN THE STARBOARD ENGINE (TOTAL HOURS*) IN VESSEL C

	Total hours and wear, mm., since new			Hours and wear, mm., since last examination		
	Hours	Wear	Wear rate, mm. per 1,000 hr.	Hours	Wear	Wear rate, mm. per 1,000 hr.
No. 1 Liner	850 2,721 4,448 6,166 8,055 9,540	0·33 0·60 1·22 1·85 2·18 2·77	0·389 0·219 0·274 0·300 0·270 0·291	850 1,871 1,727 1,718 1,889 1,485	0·33 0·27 0·62 0·63 0·33 0·59	0·389 0·143 0·359 0·367 0·175 0·397
No. 2 Liner	850 2,721 4,448 6,166 8,055 9,616	0·33 0·78 1·32 1·85 2·28 2·62	0·389 0·285 0·297 0·300 0·283 0·272	850 1,871 1,727 1,718 1,889 1,561	0·33 0·45 0·54 0·53 0·43 0·34	0·389 0·237 0·312 0·309 0·228 0·218
No. 3 Liner	850 2,721 4,448 7,000 8,688 10,620	0·24 0·69 1·26 1·98 2·62 3·28	0·284 0·252 0·283 0·283 0·302 0·309	850 1,871 1,727 2,552 1,688 1,932	0·24 0·45 0·57 0·72 0·64 0·66	0·284 0·237 0·330 0·282 0·379 0·342
No. 4 Liner	850 1,800 3,600 5,361 7,000 8,688 10,620	0·28 0·57 0·95 1·55 1·83 2·62 3·35	0·328 0·318 0·264 0·289 0·261 0·302 0·315	850 950 1,800 1,761 1,639 1,688 1,932	0·28 0·29 0·38 0·60 0·28 0·79 0·73	0·328 0·306 0·211 0·340 0·171 0·467 0·378
No. 5 Liner	850 1,850 3,600 5,361 7,901 9,648	0·28 0·66 1·07 1·59 2·49 3·00	0·328 0·357 0·296 0·296 0·315 0·311	850 1,000 1,750 1,761 2,540 1,747	0·28 0·38 0·41 0·52 0·90 0·51	0·328 0·381 0·232 0·295 0·354 0·292
No. 6 Liner	850 2,575 4,304 6,166 7,901 10,620	0·26 0·51 0·99 1·54 2·06 2·90	0·314 0·197 0·230 0·250 0·261 0·273	850 1,725 1,729 1,862 1,735 2,719	0·26 0·25 0·48 0·55 0·52 0·84	0·314 0·139 0·277 0·295 0·300 0·309

NOTE: The wear figure quoted is the mean of the F and A, and P and S readings at the point of maximum wear

*Sea plus manœvuring hours

The maximum liner wear measurements are given in Tables XVIII and XIX for the port and starboard engines respectively, and a summary of these figures is given below for a period of operation of approximately 10,000 hours:—

Liner wear rates, mm. per 1,000 hr.

Engine	1	2	3	4	5	6	Average
Port	0·40	0·39	0·25	0·35	0·32	0·29	0·33
Starboard ...	0·29	0·27	0·31	0·32	0·31	0·27	0·30

These results are very encouraging and do indicate the possibility of achieving similar wear rates from two engines when all other factors, such as operating conditions, fuel and lubricant supplies, are identical.

Curves representing the profile of liners Nos. 2 and 6 of the port and starboard engines respectively after various periods of operation are presented in Fig. 11. The profiles of the other liners are similar in shape. The relationship between the various positions on the liner where wear measurements are taken with relation to the exhaust and scavenge ports is given in Fig. 12. The position of maximum wear nearly always occurs in the top half of the liner at a point approximately 10 inches from the centre of the combustion chamber.

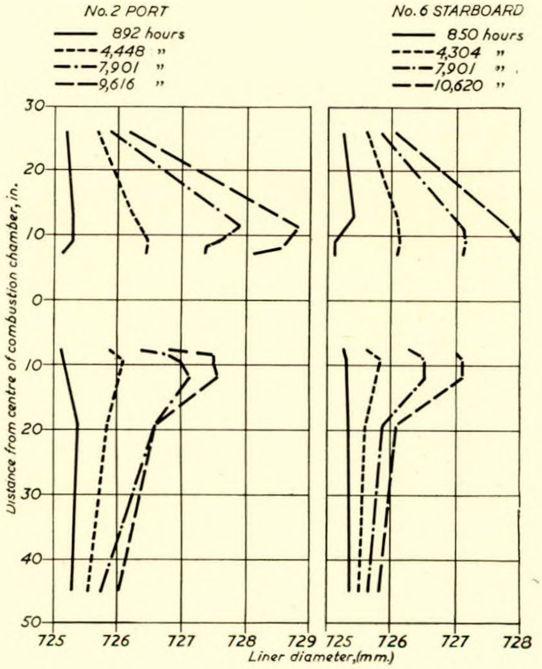

FIG. 11—*Effect of total operating time on liner profile in Vessel C. (Liner diameter shown is mean of F and A, and P and S readings)*

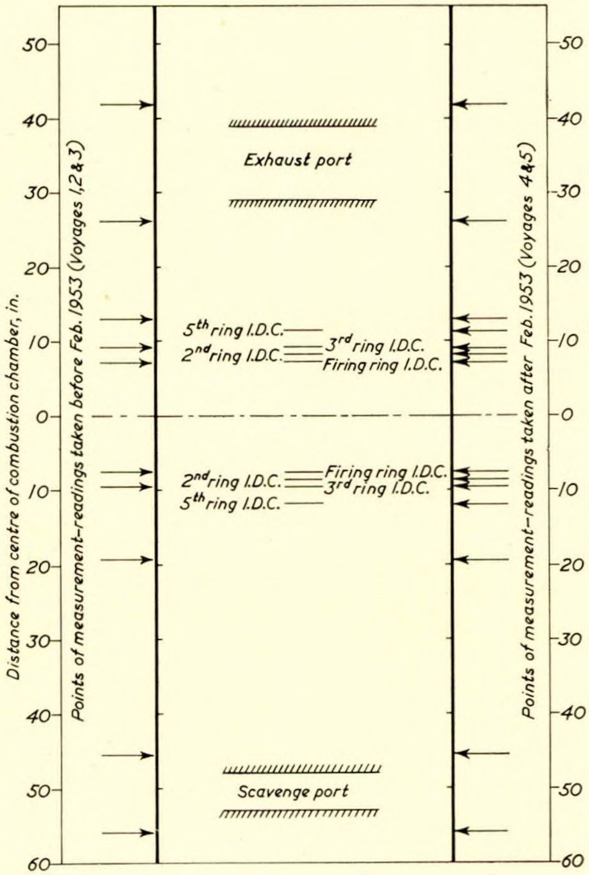

FIG. 12—*Relationship between gauging points and the position of ports and pistons in Vessel C*

Lubricating Oil Inspections. The cylinders and crankcase were lubricated with a dual purpose naphthenic oil. Inspection data of crankcase oil samples drawn from the inlet to the centrifuge are given in Table XX and it will be seen that the condition of the oil is very satisfactory. Samples of the main engine oil taken after the centrifuge show some improvement in its condition.

Vessel D

The field tests with this vessel started in March 1949. Since that time the vessel has operated for four periods of about one year's duration on detergent and non-detergent types of cylinder lubricants and fuels varying from a hundred per cent distillate to a bunker fuel of 3,300 seconds. For convenience a summary of the types of fuels and lubricants used is given below.

TABLE XX—INSPECTION DATA OF NEW AND USED CRANKCASE OIL FROM VESSEL C

Tests	New oil	Period of service, hr.								
		850	1,750	2,650	3,578	4,419	5,563	6,980	8,688	9,236
Specific gravity at 60 deg. F./60 deg. F.	0·899	0·899	0·899	0·898	—	0·901	0·904	0·902	—	0·900
Viscosity Kinematic at 100 deg. F. cs.	122·6	122·3	124·2	125·4	121·8	124·2	127·3	—	—	—
at 210 deg. F. cs.	10·6	10·7	10·4	10·6	10·6	10·6	10·8	—	—	—
Viscosity Redwood No. I at 140 deg. F. sec.	160	160	160	164	160	163	166	163	171	170
Viscosity index	70	71	64	66	69	67	69	—	—	—
Flash point P.M. closed, deg. F.,	425	425	—	400	415	380	Too wet	390	415	440
Naphtha insolubles, per cent	—	0·20	0·13	0·10	0·33	—	0·40	0·30	0·18	—
Benzene insolubles, per cent	—	—	0·13	0·10	0·16	—	0·35	—	—	—
Water (fresh), per cent	Nil	0·1	0·05	0·05	Nil	Trace	2·2	Nil	3·8	Nil
Ash, per cent	—	—	0·02	0·05	0·04	0·03	0·03	0·03	0·03	—

TABLE XXI—INSPECTION DATA OF NEW AND USED CRANKCASE OIL FROM VESSEL D

Tests	New	Distillate fuel			Residual fuel	
		Apr. '49	Apr. '50	May '51	Mar. '52	Mar. '53
Period of service, hr.	0	7,100	13,100	21,700	27,000	33,000
Specific gravity at 60 deg. F./60 deg. F.	0·918	0·917	0·913	0·910	0·918	0·918
Viscosity Kinematic at 100 deg. F. cs.	163·6	145·2	164·7	159	196	189·8
at 210 deg. F. cs.	11·2	10·7	12·1	12·4	13·5	13·3
Viscosity Redwood No. I at 140 deg. F., sec.	185	173	200	196	230	225
Viscosity Index	37	45	57	68	58	59
Flash point P.M. closed, deg. F.	440	395	450	425	430	420
Conradson carbon, per cent.	0·07	0·51	0·47	0·55	0·42	0·99
Isopentane insolubles, per cent.	0·02	0·04	0·15	0·31	0·23	0·68
Benzene insolubles, per cent.	0·02	Trace	0·12	0·25	0·18	0·47
Ash, per cent.	0·01	0·02	0·02	0·05	0·06	0·16
Water, per cent.	Nil	0·4	Trace	Trace	1·8	0·1

Phase of operation	Fuel	Cylinder lubricant 1 2 3	4 5
I	Distillate (shipboard contaminated) ...	High V.I. solvent refined paraffinic oil*	Experimental detergent naphthenic oils†
II	Distillate		
III	1,600 seconds fuel ...		
IV	3,300 seconds fuel ...		

* Redwood No. 1 viscosity at 140 deg. F., 266 seconds
† Redwood No. 1 viscosity at 140 deg. F., 290 seconds

In February 1948 the crankcase of the engine was cleaned out and the system was thoroughly flushed with a clean conventionally refined naphthenic type oil. The system was then filled with 1,400 gallons of new oil. A centrifuge was installed in a bypass position to remove contaminants from the oil during service. Inspection data were obtained on samples of oil taken from the crankcase throughout the whole period of these tests and a few representative figures are given in Table XXI. The oil has remained in good condition throughout the tests; the oxidation products have increased, slowly while the engine was using distillate fuels, and more rapidly since the residual grades were bunkered.

Test Period I—March 1949 to February 1950

Fuel. This test period had as its primary function the establishment of background data regarding the performance of a marine Diesel fuel (100 per cent distillate) in a Doxford engine under typical operating conditions.

In the course of this test it was established that current loading and shipboard handling procedures on this vessel allowed contamination of Diesel fuel by fuel oil, this contamination being estimated at about 2 per cent by volume. Table XXII shows the inspection data of the fuels as taken from the shore tank compared with the fuel actually going to the ship's engines (day fuel tank).

Cylinder Oil. During the test period the cylinder oil consumption rates, of both the high V.I. solvent refined paraffinic type oil being used in cylinders 1, 2 and 3 and the experimental detergent naphthenic oil in use in cylinders 4 and 5, were maintained at a relatively constant level in keeping with previous practice, which was 2·5 to 3·0 gallons per cylinder per twenty-four hours.

The conclusion reached at the end of the test was that the condition of the liners and pistons did not justify initiating any further field tests with the experimental oil.

Cylinder Liner Wear. The cylinder liners were measured at the end of the test period and the wear rates are quoted below. In the case of No. 4 liner this was measured approximately 1,100 hours before the end of the test as numerous jacket and piston cooling water leaks were encountered.

Liner	Operating hours	Wear rate, mm. per 1,000 hr.
1	5,971	0·33*
2	5,971	0·23*
3	5,971	0·20
4	4,883	0·46†
5	5,971	0·36

* Liner new at the start of the test period.
† Liner removed at end of test period.

Test Period II—March 1950 to May 1951

During the annual overhaul prior to starting this test period the opportunity was taken to carry out the mechanical changes to the fuel handling systems to provide for operation on an uncontaminated marine Diesel fuel.

Fuel. The fuel used was the same marine Diesel grade as used during the previous year's work and the inspection data of samples taken from the shore tanks and the ship's day tanks

TABLE XXII—INSPECTION DATA OF FUELS USED IN VESSEL D
Test period I—March 1949 to February 1950.

Tests	Sampling point			
	Shore tank		Engine day tank	
	Min.	Max.	Min.	Max.
Specific gravity at 60deg. F./60 deg. F.	0·873	0·913	0·880	0·912
Viscosity, Redwood No. I at 100 deg. F., sec.	37·4	49·2	37·8	51·8
Flash point P.M. closed, deg. F.	174	222	180	210
Conradson carbon, per cent.	0·03	0·06	0·12	0·68
Cetane number	32	46	34	44
Ash, per cent.	Nil	0·01	Nil	0·02
Sulphur, per cent.	0·67	1·17	0·82	1·31
Bottoms, sediment and water per cent.	Trace	Trace	Trace	0·1

TABLE XXIII—INSPECTION DATA OF FUELS USED IN VESSEL D
Test period II—March 1950 to May 1951.

Tests	Sampling point			
	Shore tank		Engine day tank	
	Min.	Max.	Min.	Max.
Specific gravity at 60 deg. F./60deg. F.	0·872	0·897	0·875	0·893
Viscosity, Redwood No. I at 100 deg. F., sec.	35·5	48	37	39·8
Flash point P.M. closed, deg. F.	168	202	170	206
Conradson carbon, per cent.	0·04	0·19	0·05	0·12
Cetane number	40	45	39	45
Ash, per cent.	Nil	0·01	Nil	0·02
Sulphur, per cent.	0·93	1·19	0·93	1·16
Bottoms, sediment and water, per cent.	Trace	0·04	Trace	0·1

throughout the test period are given in Table XXIII. It will be seen that the contamination originally taking place with boiler fuel grades was eliminated.

Cylinder Oil. The high V.I. solvent refined paraffinic type oil was retained as the cylinder lubricant in cylinders 1, 2 and 3 and a different experimental detergent naphthenic oil was used in cylinders 4 and 5. The cylinder oil consumption rates were maintained at a similar level to previous figures already quoted.

Examination of the pistons and liners after the test again showed that there was no performance advantage resulting from the use of the experimental detergent naphthenic oil compared with the high V.I. paraffinic oil.

Cylinder Liner Wear. The liner wear figures obtained at the end of the test are given below. It was found necessary to remove No. 3 liner because of cracks and water leaks.

Liner	Operating hours	Wear rate, mm. per 1,000 hr.
1	8,637	0·18
2	8,637	0·21
3	8,637	0·14†
4	8,637	0·22*
5	8,637	0·23

* Liner new at the start of the test period.
† Liner removed at the end of the test period.

Test Period III—May 1951 to March 1952

The information collected on engine performance and wear data over the previous two test periods using conventional Diesel fuel grades was considered to be in line with that established by engine manufacturers and operators in the marine field for two-cycle Diesel engines. Additional equipment was then installed and modifications made to the existing fuel handling system so that the vessel could bunker with a medium viscosity residual fuel.

Fuel. Five batches of a blended 1,600 seconds (Redwood No. 1 at 100 deg. F.) fuel, made from 88 per cent bunker fuel and 12 per cent marine Diesel fuel, were prepared and used throughout the test period. Inspection data of the samples taken from the ship's bunker tanks (untreated fuel) and the ship's day tank (treated fuel) are given in Table XXIV. The two components of the fuel were of Western origin which accounts for the sulphur content being lower than that normally available in Europe.

As mentioned previously the two centrifuges were operated in parallel and hence it was possible to reduce the fuel handling capacity of the original centrifuge by 50 per cent. The two machines removed on the average 0·45lb. of sludge per ton of fuel treated.

Cylinder Oils. The same cylinder oils were retained as used in the previous test period. The condition of the pistons and liners at the end of the test was very similar throughout the engine. A noticeable improvement, however, was the reduction in the number of broken rings encountered compared with previous test results. With the distillate fuels, the deposits were hard and flinty as compared with soft sludgy deposits for the residual fuel used. This difference in the characteristics of the deposits was probably effective in eliminating piston ring breakage with the residual fuel.

Engine Performance. A considerable amount of experimental work was done initially to improve the combustion of

TABLE XXIV—INSPECTION DATA OF FUELS USED IN VESSEL D
Test period III—May 1951 to March 1952

Tests	Sampling point			
	Untreated fuel from bunker tanks		Treated fuel from day tank	
	Min.	Max.	Min.	Max.
Specific gravity at 60 deg. F./60 deg. F.	0·955	0·966	0·955	0·966
Viscosity, Redwood No. I				
at 100 deg. F., sec.	920	1,900	1,000	1,800
at 200 deg. F., sec.	88	134	89	127
Flash point P.M. closed, deg. F.	156	186	176	182
Conradson carbon, per cent.	8·1	11·6	6·3	11·8
Water, per cent.	Trace	0·2	Trace	0·2
Sediment by hot filtration, per cent.	Trace	0·06	Trace	0·04
Ash, per cent.	0·05	0·1	0·05	0·1
Sulphur, per cent.	2·2	2·5	—	—
Asphaltenes, per cent.*	7·0	8·2	5·8	8·4
Bottoms, sediment and water, per cent.	0·1	0·2	0·1	0·2

*Determined as insoluble in 86 deg. naphtha.

TABLE XXV—INSPECTION DATA OF FUELS USED IN VESSEL D
Test period IV—May 1952.

Tests	Sampling point	
	Untreated fuel from bunker tanks	Treated fuel from day tank
Specific gravity at 60 deg. F./60 deg. F.	0·982	0·982
Viscosity Redwood No. I at 100 deg. F., sec.	3,000	3,000
at 200 deg. F., sec.	158	158
Flash point P.M. closed, deg. F.	270	—
Pour point, deg. F.	45	—
Conradson carbon, per cent.	13·7	—
Water, per cent.	0·02	—
Sediment by hot filtration, per cent.	0·18	0·15
Ash, per cent.	0·11	0·08
Ash (water soluble), per cent.	0·10	0·07
Sulphur, per cent.	1·6	—
Asphaltenes, per cent.*	8·1	8·1
Bottoms, sediment and water, per cent.	0·2	—

*Determined as insoluble in 86 degrees naphtha.

the residual fuel. Different injector tip designs were tried with various combinations of holes and angles of spray. It would appear that the four-hole tip (i.e. the holes drilled in a vertical plane on a curved tip), as used for distillate fuels in this Doxford engine, with a slight reduction in the diameter of the holes, gave satisfactory atomization. Optimum injector timing was found to be about that specified by the engine builder for distillate fuels.

Liner Wear. None of the liners were gauged at any time during the test period and it is not known whether the wear rate was appreciably higher during the first few months of operation when there were continuous indications of incomplete combustion. The wear rates for each of the liners are given below, covering periods of 4,956 hours in each case.

Liner	Wear rate, mm. per 1,000 hr.
1	0·81†
2	0·68†
3	0·32*
4	0·51†
5	0·77

* Liner new at the start of the test period.
† Liner removed at the end of the test period.

Test Period IV—March 1952 to March 1953

Test work was continued with a high viscosity Bunker C fuel, and the programme was designed to provide information on the limiting qualities of residual fuels for marine Diesel operation. No further modifications were made to the fuel handling and cleaning system at this stage of the work.

Fuel. The test fuel was not available for the first month of operations and, therefore, on two occasions the fuel from the previous test period and an intermediate grade of about 400 seconds Redwood No. 1 viscosity at 100 deg. F. were bunkered. During May the first of the segregated fuels was used, which consisted of a 3,000 seconds Redwood No. 1 viscosity fuel at 100 deg. F., and inspection data of the fuel before and after centrifuging are given in Table XXV. It will be seen that the fuel had a sediment by hot filtration of 0·18 per cent and an ash content of 0·11 per cent. After only one month of operation, test work on this fuel was discontinued because the centrifuges installed on the ship at that time could not cope with the amount of sludge removed from the fuel. The quantity of sludge extracted was 3·2lb. for each ton of fuel treated and with the centrifuges available it was necessary to stop them for cleaning purposes every four hours. This time cycle was considered to be too short for satisfactory operation by the engine room staff.

The test programme was therefore continued for the remaining eight months using a better quality, widely available, Bunker C fuel. Inspection data on this fuel on which the sediment by hot filtration was only 0·04 per cent are given in Table XXVI. With the lower sediment by hot filtration of this fuel compared with the previous test fuel the sludge removal rate was at a more acceptable level. The operation of the engine was satisfactory on all fuels.

Cylinder Oils. The same cylinder oils as for Test Periods II and III were used in the same cylinders.

TABLE XXVI—INSPECTION DATA OF FUELS USED IN VESSEL D
Test period IV—June 1952 TO April 1953

Tests	Sampling point					
	Bunkers			Day tank		
	Min.	Max.	Typical	Min.	Max.	Typical
Specific gravity at 60 deg.F./60 deg. F.	0·969	0·979	0·975	0·970	0·981	0·973
Viscosity Redwood No. I						
at 100 deg. F., sec.	3,200	3,300	3,300	—	—	3,100
at 200 deg. F., sec.	137	180	165	—	—	168
Flash point P.M. closed, deg. F.	184	255	188	—	—	—
Pour point, deg. F.	15	25	20	—	—	—
Conradson carbon, per cent.	12·3	14·1	13·1	12·6	13·5	13·0
Sediment by hot filtration, per cent.	0·02	0·07	0·04	0·01	0·09	0·03
Ash, per cent.	0·07	0·14	0·10	0·08	0·16	0·09
Ash (water soluble), per cent.	0·05	0·13	0·05	—	—	—
Sulphur, per cent.	1·6	2·6	2·5	—	—	—
Asphaltenes, per cent*	3·9	11·4	10·5	—	—	—

*Determined as insoluble in 86 degrees naphtha.

Liner Wear. It was found necessary to open up all the cylinders with the exception of No. 4 at some stage of the programme, due to cracked piston heads or broken studs. No. 5 liner was replaced during the test because it was excessively worn and, therefore, did not develop its full power output. The wear figures are as follows: —

Liner		Hours	Wear rate, mm per 1,000 hr.
1		6,579	0·46*
2		5,856	0·28*
3		6,579	0·36
4		6,579	0·33*
5	old	2,632	0·53
	new	3,947	0·33

* Liner new at the start of the test period.

LINER WEAR IN MARINE DIESEL ENGINES

There are numerous factors which might have an important influence on cylinder liner wear. Some of these are enumerated below.

1. Type of fuel used.
    (*a*) Corrosive properties.
    (*b*) Abrasive properties.
    (*c*) Carbonaceous properties.

2. Type of cylinder lubricant used.
    (*a*) Non-detergent.
    (*b*) Detergent in various forms.

3. Operating conditions.
    (*a*) Piston and liner cooling water temperatures.
    (*b*) Air intake temperature.
    (*c*) Injector spray pattern.
    (*d*) Cylinder mean effective pressures and r.p.m.
    (*e*) Relationship between manœuvring hours and sea hours.
    (*f*) Centrifuging efficiency.

4. General engine design features.

5. Liner material and surface finish.

The results obtained from these vessels have been analysed to confirm if any fuel property or operating condition affects the liner wear rate. It is appreciated that much more data is required before firm conclusions can be reached, but it is thought that the data given will form a useful contribution to be added to existing knowledge. Possibly other investigators will be able to use the information in the light of these experiences.

It would appear that after the liner wear has exceeded approximately 0·6 per cent of the cylinder diameter the wear rate increases rapidly as illustrated by the following figures.

Vessel	Liner diameter, mm.	Number of liners	Wear, mm.	Wear rate, mm. per 1,000 hr.
A	600	4	0·3 to 3·5	0·34
A	600	4	3·5 to 5·0	0·70
D	812	1	Nil to 1·6	0·32
D	812	3	4·0 to 7·5	0·75

This increase in wear rates is thought to be due to mechanical features, such as: —

1. The rapid increase in the number of broken rings which occur at the same time. Figs. 4 and 9 taken from the records of Vessels A and B, illustrate this point.
2. Excessive lateral movement between the piston and liner surfaces accentuated by the movement of the ship.
3. An increase in the quantity of the blowby gases because of the increased clearance between the piston and liner.

In view of these findings it is considered desirable to discard a number of the wear rates reported in the Operating Data and Test Results section in arriving at any conclusions related to fuel properties.

It is reasonable to expect that on similar type engines liner wear rates will be greater in the engine which is operating at the higher brake mean effective pressure, and this fact is illustrated below.

Vessel	I.H.P.	Number of liners	Wear rate, mm. per 1,000 hr.
B	98 per cent of maximum	4	0·43
A	90 per cent of maximum	4	0·34
C	85 per cent of maximum	6 (port engine)	0·32
C	85 per cent of maximum	6 (starboard engine)	0·29

A comparison made between the liner wear rates obtained when using the detergent cylinder lubricating oils compared with the non-detergent ones reveals no significant differences, as shown below.

Vessel	Cylinder oil	Number of liners	Wear rate, mm. per 1,000 hr.
B	Detergent	4	0·43
	Non-detergent	4	0·38
D	Detergent	1	0·36
	Non-detergent	3	0·25
D	Detergent	2	0·33
	Non-detergent	3	0·33

Another factor which should be borne in mind when considering the cylinder liner wear rates, is the adverse effect of abnormal operating conditions which might occur when manœuvring. On vessels A, B and D during the period under review, the ratio of manœuvring to total hours was 1:10, 1:5·5, 1:7·5 respectively. Incidentally, the ratio 1:7·5 for vessel D applies when the vessel was operating on a fuel with a sulphur content of 2·5 per cent. However, previously when on a different trade route, the ratio of manœuvring to total hours was 1:14 and the fuel had a sulphur content of 1 per cent.

In Fig. 13, and also tabulated in Table XXVII, the pertinent liner wear rates are plotted against the average sulphur content of the fuels used and the figures in parenthesis indicate the average fuel ash contents. From these data it is concluded that liner wear rates increase with increasing amounts of sulphur and ash in the fuel. It would appear that the effect of the quantity of sulphur present is more pronounced than the ash within the limits experienced.

From the data available it is difficult to isolate the effect of manœuvring hours on liner wear rates. This factor could

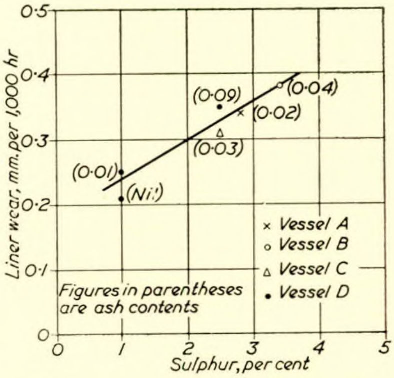

FIG. 13—*Effect of fuel sulphur and ash contents on liner wear rates*

Table XXVII—Summary of Pertinent Liner Wear Data from Vessels A, B, C and D

Vessel	Period of operation, hr.	Number of liners measured	Wear rate, mm. per 1,000 hr.	Fuel inspections Sulphur, per cent.	Ash, per cent.
A	9,500	4	0·34	2·8	0·02
B	7,000	4	0·38	3·4	0·04
C	9,000	12	0·31	2·5	0·03
D	8,500	4	0·21	1·0	Nil
D	6,000	3	0·25	1·0	0·01
D	6,500	5	0·35	2·5	0·09

contribute to the reduction of liner wear attributed above to the sulphur content of the fuel as it is possible that operation under manœuvring conditions could cause more liner wear compared with a similar period under normal operation at sea.

RESIDUAL FUEL PROPERTIES RELATED TO ENGINE PERFORMANCE

From the results already presented it is possible to give some general conclusions on the use of residual type fuels in Doxford engines related to fuel properties. While some of these conclusions are of importance from a technical aspect, it should be pointed out that any restrictions on the quality requirements of residual fuels for Diesel engines above conventional bunker fuel quality levels will tend to increase the cost and possibly decrease the availability of these products to the shipowner. Each shipowner should, therefore, interpret these findings in the light of his own requirements and the state of the fuel oil market at the bunker ports on the routes over which his ships operate.

Specific Gravity

Centrifuges are almost universally used with marine Diesel engines to remove sediment and water from the fuel. In order to separate the water from the fuel by centrifuging, the specific gravity of the fuel should be less than 0·985 at 60 deg. F./60 deg. F. If the fuel has a gravity in excess of 0·985 the purifier may be started by forming the water seal with salt water. Otherwise the purifier will have to be used as a clarifier, which may result in water reaching the fuel injection equipment.

Viscosity

The viscosity of a Diesel fuel affects its atomization by the fuel valves and is limited in most large Diesels to a maximum of 150 Redwood No. 1 seconds at the injectors. Fuels should be chosen, therefore, having viscosities low enough so that with the available shipboard heating capacity the fuels can be pumped from double bottom tanks and their viscosities reduced to at least 150 Redwood No. 1 seconds at the injectors.

Flash Point

There are a number of different tests for flash point determination, of which the most commonly used one is the Pensky Martens closed cup method. Residual and distillate fuels now comply only with the flash specification recognized by the industry of 150 deg. F. minimum and although the large majority of fuels are well above this minimum the position could arise of a 150 deg. F. flash point fuel being supplied. There is a Board of Trade regulation in the United Kingdom which restricts the heating of a fuel in an open tank to a temperature higher than 35 deg. F. below its flash point. At the moment the interpretation of this regulation as far as the fuel centrifuges are concerned is not very well defined. The question arises as to whether the fuel system through the centrifuges can be considered a closed or vented system, and this may vary between vessels. As the usual shipboard centrifuging temperature is around 180 deg. F. it may be advisable to reduce this temperature for any fuels having a flash point below 200 deg. F. It will then be necessary to compensate for the increase in viscosity, resulting from a lowering of the fuel temperature, by decreasing the fuel throughput rate, so as to maintain an equal centrifuge efficiency.

Sediment by Hot Filtration

This property of residual fuels appears to have a bearing on satisfactory centrifuge operation. In general, it can be stated that if two fuels having different sediment by hot filtrations are centrifuged, then the fuel with the higher value will deposit more sludge in the centrifuges. The probable connexion between these two factors is shown in Fig. 14.

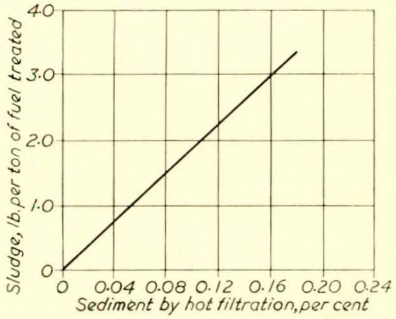

FIG. 14—*Effect of sediment by hot filtration on the amount of sludge removed by the centrifuges*

While engine performance is not adversely affected by fuels containing relatively large quantities of sediment, it does necessitate, however, rather more frequent centrifuge cleaning. Since the sludge handling capacity of centrifuges varies between different manufacturers, it is advisable to install the requisite number of machines required to deal with the anticipated sludge, and this is actually done in practice.

Water

Residual type fuels are more prone to form stable emulsions with water than are distillate fuels. These emulsions are sometimes very difficult to break and can give rise to trouble in the centrifuges. There have been indications that combustion is impaired if the amount of water remaining in the fuel after the centrifuges is above 0·5 per cent.

Conradson Carbon

The Conradson carbon content may be defined as the tendency of a fuel to form carbon deposits under high temperature conditions in the absence of air. Relatively small carbon residues can increase engine maintenance if incomplete combustion is allowed to continue in a Diesel engine. Under conditions of incomplete combustion, fuels high in carbon residue will form more carbonaceous material which will have an adverse effect on engine operation.

Based on the operation of the engines studied, it is felt that the Conradson carbon value is not critical, at least up to values of 14 per cent.

Asphaltenes

Asphaltenes are chemical constituents found in residual fuel which are insoluble in naphtha but soluble in benzene. Since asphaltenes are generally quite refractory and difficult to burn, the connexion between the sludge in the engine scavenge belt and the fuel asphaltene content is apparent. When using fuels having asphaltene contents of above 5 per cent it is advisable to advance the injection timing a few degrees on a two stroke engine to give a slightly longer combustion period. Experience from Vessel D over a period of ten months indicates that fuels containing up to 8 per cent asphaltenes can be successfully burned.

Sulphur

The effect of fuel sulphur content on large slow-speed Diesel engine maintenance is somewhat controversial. Past experience with high-speed Diesel engines has shown that sulphur in Diesel fuel tends to increase engine wear and deposits.

Some of the vessels used in these studies have successfully burnt residual fuels from Middle East crudes with sulphur contents as high as 4 per cent. It is, however, impossible to isolate completely the effect of sulphur on wear and deposits from all the other variables which should be considered.

The majority of the refineries outside the Western Hemisphere are now processing Middle East crudes inherently high in sulphur content and, therefore, the supply of these high sulphur residuals will continue and their distribution will be more widespread in the future.

With high sulphur contents other problems may be encountered, in fact several cases of severe crankshaft corrosion have been reported from the field. The increased maintenance caused by this form of corrosion may in itself be sufficiently great to prohibit the use of certain residual fuels until a satisfactory solution to the corrosion problem is found. But it is known that crankshaft corrosion has occurred in vessels using only marine Diesel fuel and, therefore, the problem may originate from inefficient combustion of the fuel or maladjustment of the engine, the use of residual fuels only aggravating the problem in some instances. The problem may be solved by one or more of the following methods:—

(1) Modifications to the engine to prevent the fuel combustion products and unburnt cylinder lubricating oil entering the crankcase.

(2) The use of more efficient centrifuging and water washing of the crankcase oil.

(3) The possible use of alkaline additives in the cylinder oil, which will help to neutralize the harmful acidic products of combustion and thereby eliminate the build-up of mineral acidity in the crankcase lubricant.

Ash

The effects of ash on engine performance are very difficult to assess, primarily because of the difficulty in separating the ash effect from those of sulphur and carbonaceous deposits. From Fig. 13 it would appear that the ash content may be responsible for some of the increases in liner wear rates, although the information is far from conclusive.

ACKNOWLEDGEMENTS

The authors wish to express their thanks to the directors and superintendent engineers of the shipping companies who made the work possible, and to the directors of the Esso Development Co., Ltd., and the Standard Oil Development Company, for permission to publish this paper.

The aerial photographs of Vessel A are published with the permission of Skyfotos.

The authors also wish to thank all the chief engineers concerned for their co-operation in taking the numerous fuel samples and for their helpful advice on many occasions.

Appendix

TABLE XXVIII—FUELS BUNKERED AND USED BETWEEN MAY 1950 AND DECEMBER 1951 IN VESSEL A

Bunkering port Date	South Shields 6/2/50	Alexandria 18/3/50	London 20/4/50	Alexandria 25/5/50	London 11/7/50	London 15/9/50	London 14/15/24/11/50	Liverpool 3/2/51	London 10/4/51	London 2/6/7/51	London 28/9/51	Glasgow 30/11/51
Fuel bunkered												
Specific gravity at 60 deg. F./60 deg. F.	0·935	0·942	0·929	0·938	0·951	0·936	0·960	0·928	0·926	0·956	0·955	0·950
Viscosity, Redwood No. I at 100 deg. F., sec.	525	786	438	632	1,178	490	850	410	310	1,650	1,049	781
at 200 deg. F., sec.	64	88	58	70	96	60·5	78·5	56·5	53	112	91	82
Flash point, P.M. closed, deg. F.	270	235	240	235	235	226	—	275	216	220	202	240
Pour point, deg. F.	55	65	65	65	70	60	60	65	60	20	25	20
Conradson carbon, per cent.	5·5	8·0	5·9	6·5	8·4	4·6	8·9	5·3	5·9	10·0	10·5	9·8
Water, per cent.	0·2	Trace	0·1	Trace	0·2	5·0	0·5	0·2	0·4	0·1	0·2	0·3
Sediment by extraction, per cent.	0·03	0·01	0·01	0·02	0·02	0·09	0·05	0·02	0·02	0·02	0·04	0·04
Sediment by hot filtration, per cent.	—	—	—	—	—	0·04	0·11	0·03	0·02	0·02	0·07	0·01
Ash, per cent.	0·04	0·03	0·02	0·02	0·02	0·10	0·02	0·03	0·03	0·06	0·06	0·08
Sulphur, per cent.	2·5	2·5	2·1	2·5	3·0	2·0	2·7	1·9	2·1	2·4	2·4	2·5
Asphaltenes, per cent.	1·3	2·5	1·2	1·3	1·9	1·2	2·7	1·5	1·7	6·0	5·7	6·0
Bottoms, sediment and water, per cent.	0·3	0·3	0·1	0·2	0·5	6·0	0·8	0·6	1·4	0·1	0·9	0·3
Fuel at main engine fuel pump												
Water, per cent.	Trace	Trace	Mixed with other fuels before use	Trace	Trace	0·6	0·4	0·2	0·1	0·1	Trace	Trace
Sediment by extraction, per cent.	0·01	0·01		0·01	Trace	0·01	0·03	0·02	0·01	0·02	0·01	0·05
Sediment by hot filtration, per cent.					—	0·01	0·09	0·02	0·01	0·02	0·04	0·02
Ash, per cent.	0·02	0·02		0·02	0·02	0·02	0·02	0·03	0·02	0·06	0·05	0·07
Bottoms, sediment and water, per cent.	0·2	0·2		0·1	0·3	0·9	0·7	0·7	0·2	0·4	0·2	0·3

TABLE XXIX—FUELS BUNKERED AND USED BETWEEN DECEMBER 1951 AND JANUARY 1953 IN VESSEL A

Bunkering port Date	Liverpool 20/1/52	London 28/3/52	Liverpool 17/19/5/52	Hull 7/8/52	London 20/8/52	London 12/11/52
Fuel bunkered						
Specific gravity at 60 deg. F./60 deg. F.	0·949	0·960	0·951	0·964	0·955	0·955
Viscosity, Redwood No. I at 100 deg. F., sec.	599	1,326	944	1,462	764	826
at 200 deg. F., sec.	68	105	88	107	78	—
Flash point P.M. closed, deg. F.	225	206	270	245	235	226
Pour point, deg. F.	35	45	45	35	35	—
Conradson carbon, per cent.	7·1	10·5	8·2	9·3	8·5	—
Water, per cent.	Trace	Trace	Nil	0·2	0·05	—
Sediment by hot filtration, per cent.	0·04	0·03	0·04	0·01	0·02	0·03
Ash, per cent.	0·04	0·02	0·02	0·01	0·01	0·03
Sulphur, per cent.	2·8	3·4	3·1	3·3	3·1	3·7
Asphaltenes, per cent.	0·8	1·1	1·3	1·8	1·3	2·2
Bottoms, sediment and water, per cent.	—	0·1	0·4	0·2	0·1	—
Fuel at main engine fuel pump						
Specific gravity at 60 deg. F./60 deg. F.	—	—	—		—	0·959
Viscosity, Redwood No. I at 100 deg. F., sec.	—	—	—		—	846
at 200 deg. F., sec.	—	—	—	mixed with other fuels before use	—	—
Flash point P.M. closed, deg. F.	—	—	—		—	228
Sediment by hot filtration, per cent.	0·03	0·01	0·01		0·02	0·01
Sulphur, per cent.	—	—	—		—	3·7
Ash, per cent.	0·02	0·01	0·01		0·01	0·02
Asphaltenes, per cent.	—	—	—		—	2·2
Bottoms, sediment and water, per cent.	0·1	0·1	Trace		Trace	—
Water, per cent.	Trace	Nil	Nil		Trace	—

TABLE XXX—FUELS BUNKERED AND USED BETWEEN JANUARY 1953 AND JANUARY 1954 IN VESSEL A

Bunkering port Date	Manchester -/1/53	Hamburg 7/4/53	London 22/4/53	Hull 10/6/53	London 12/8/53	Beirut 21/9/53	Liverpool 14/11/53	Ceuta 7/1/54
Fuel bunkered								
Specific gravity at 60 deg. F./60 deg. F.	0·965	0·929	0·945	0·951	0·948	0·948	0·968	0·969
Viscosity, Redwood No. I at 100 deg. F., sec.	1,159	373	600	602	930	880	1,070	1,755
200 deg. F., sec.	78	55	68	64	84	76	80	110
Flash point P.M. closed, deg. F.	210	260	174	190	235	184	202	187
Sediment by hot filtration, per cent.	0·03	0·04	0·02	0·05	0·02	0·02	0·03	0·08
Sulphur, per cent.	4·2	2·9	3·5	3·9	3·7	3·5	3·7	3·0
Ash, per cent.	0·05	0·03	0·02	0·05	0·02	0·01	0·03	0·08
Asphaltenes, per cent.	3·3	1·3	1·1	3·5	2·0	3·3	2·4	4·0
Fuel at main engine fuel pump								
Specific gravity at 60 deg. F./60 deg. F.	0·965	0·930	0·945	0·950	0·947	0·948	0·968	0·968
Viscosity, Redwood No. I at 100 deg. F., sec.	1,182	380	605	598	951	922	1,034	1,483
200 deg. F., sec.	80	56	64	64	87	78	84	104
Flash point P.M. closed, deg. F.	200	250	172	202	218	198	212	194
Sediment by hot filtration, per cent.	0·03	0·03	0·02	0·02	0·03	0·03	0·01	0·04
Sulphur, per cent.	4·2	2·5	3·7	3·7	3·7	3·5	3·8	3·3
Ash, per cent.	0·03	0·02	0·02	0·02	0·01	0·01	0·02	0·04
Asphaltenes, per cent.	2·8	1·2	1·0	2·9	2·0	3·2	2·4	4·1

TABLE XXXI—FUELS BUNKERED AND USED BETWEEN JANUARY 1951 AND APRIL 1952 IN VESSEL B

Bunkering port Date	Burntisland 15/1/61/51	Alexandria 24/4/51	Alexandria 29/6/51	Alexandria 29/6/51	Alexandria 29/8/51	Liverpool 2/10/51	Thameshaven 29/11/51	London 21/12/51	Glasgow 20/2/52	Manchester 9/3/52
Fuel bunkered										
Specific gravity at 60 deg. F./60 deg. F.	0·927	0·936	0·932	0·932	0·956	0·946	0·946	0·954	0·947	0·948
Viscosity, Redwood No. I at 100 deg. F., sec.	315	494	432	432	1,940	900	1,380	1,380	451	619
at 200 deg. F., sec.	55	62·5	57	57	124	83	98·5	—	64	69
Flash point P.M. closed, deg. F.	178	230	225	225	275	320	320	—	225	330
Pour point, deg. F.	—	65	65	65	55	50	45	40	45	40
Conradson carbon, per cent.	6·6	6·3	6·6	6·6	9·9	8·0	7·5	—	7·6	8·7
Water, per cent.	Nil	0·1	0·3	0·3	0·1	0·4	0·1	0·1	0·2	Trace
Sediment by hot filtration, per cent.	0·01	0·01	0·01	0·01	0·01	0·04	0·02	0·01	0·02	0·02
Ash, per cent.	0·01	0·03	0·03	0·03	0·02	0·04	0·01	0·02	0·08	—
Sulphur, per cent.	3·1	2·7	2·5	2·5	3·7	2·5	2·6	2·9	2·9	3·0
Asphaltenes, per cent.	2·2	1·2	1·3	1·3	1·9	2·1	1·5	—	0·6	1·0
Bottoms, sediment and water, per cent.	0·2	0·2	0·5	0·4	0·5	0·8	0·1	—	—	0·4
Fuel at main engine fuel pump										
Water, per cent.	—	0·1	Nil	0·2	0·1	0·1	0·1	Mixed with other fuels before use	0·2	Mixed with other fuels before use
Sediment by hot filtration, per cent.	—	0·01	Nil	0·01	0·01	0·03	0·01		0·02	
Ash, per cent.	—	0·02	0·02	0·02	0·02	0·02	0·01		0·01	
Bottoms, sediment and water, per cent.	—	0·2	0·2	0·3	0·6	0·5	—		0·2	

TABLE XXXII—FUELS BUNKERED AND USED BETWEEN APRIL 1952 AND DECEMBER 1952 IN VESSEL B

Bunkering port Date	Liverpool 18/4/52	Alexandria 3/6/52	Alexandria 15/7/52	Liverpool 26/8/52	Newcastle -/10/52
Fuel bunkered					
Specific gravity at 60 deg. F./60 deg. F.	0·963	0·956	0·956	0·965	0·96
Viscosity, Redwood No. I at 100 deg. F., sec.	1,313	1,650	1,300	1,200	1,370
at 200 deg. F., sec.	97	117	103	103	—
Flash point P.M. closed, deg. F.	225	335	—	235	215
Pour point, deg. F.	10	65	40	40	45
Conradson carbon, per cent.	12·3	—	9·1	9·0	—
Water, per cent.	0·5	Trace	—	Trace	—
Sediment by hot filtration, per cent.	0·05	0·01	Nil	0·01	0·02
Ash, per cent.	0·08	0·03	0·04	0·01	0·03
Sulphur, per cent.	2·1	2·8	3·2	3·4	—
Asphaltenes, per cent.	7·5	6·2	2·5	1·4	—
Bottoms, sediment and water, per cent.	0·9	0·5	—	Trace	—
Fuel at main engine fuel pump					
Water, per cent.	0·3	Mixed with other fuels before use	0·3	0·35	No sample taken
Sediment by hot filtration, per cent.	0·03		0·04	0·01	
Ash, per cent.	0·07		0·03	0·03	
Bottoms, sediment and water, per cent.	0·7		0·4	0·4	

TABLE XXXIII—FUELS BUNKERED AND USED BETWEEN DECEMBER 1952 AND DECEMBER 1953 IN VESSEL B

Bunkering port	Ceuta	Alexandria	Alexandria	Liverpool	London	Beyrouth	Manchester	Flushing	Ceuta
Date	17/12/52	29/1/53	1/4/53	18/5/53	8/7/53	29/7/53	4/9/53	23/10/53	9/12/53
Fuel bunkered									
Specific gravity at 60 deg. F./60 deg. F.	0·962	0·955	0·957	0·969	0·953	0·950	0·971	0·988	0·958
Viscosity Redwood No, I at 100 deg. F., sec.	1,466	1,482	1,503	1,033	1,186	1,313	947	1,615	1,442
at 200 deg. F., sec.	—	—	—	—	70	62	84	102	100
Flash point P.M. closed, deg. F.	188	200	184	230	202	186	230	206	220
Sediment by hot filtration, per cent.	0·05	0·08	0·04	0·04	0·02	0·01	0·03	0·02	0·09
Sulphur, per cent.	3·4	3·4	2·9	4·0	3·5	3·7	4·5	3·5	3·5
Ash, per cent.	0·04	0·08	0·04	0·05	0·03	0·02	0·04	Trace	0·06
Asphaltenes, per cent.	3·3	2·2	8·0	2·7	2·2	3·0	3·8	3·0	2·2
Fuel at main engine fuel pump									
Specific gravity at 60 deg. F./60 deg. F.	0·962	0·953	0·957	0·967	0·955		0·972	0·988	0·958
Viscosity, Redwood No. I at 100 deg. F., sec.	1,436	1,451	1,575	1,086	1,216	No sample taken	933	1,630	1,444
at 200 deg. F., sec.	—	—	—	—	75		88	102	100
Flash point P.M. closed, deg. F.	196	192	188	224	202		230	230	220
Sediment by hot filtration, per cent.	0·03	0·08	0·02	0·02	0·01		0·03	0·01	0·05
Sulphur, per cent.	3·4	3·4	3·3	3·8	3·6		4·0	3·7	3·5
Ash, per cent.	0·04	0·07	0·04	0·04	0·03		0·03	Trace	0·05
Asphaltenes, per cent.	3·3	2·0	7·8	4·1	2·9		3·8	3·6	2·4

TABLE XXXIV—FUELS BUNKERED AND USED BETWEEN DECEMBER 1950 AND AUGUST 1952 IN VESSEL C

Bunkering port Date	Glasgow 20/11/50	Glasgow 4/12/50	Teneriffe 15/1/51	Melbourne 27/2/51	Fremantle 25/5/51	Teneriffe 22/6/51	Teneriffe 30/8/51	Teneriffe 31/1/52	Teneriffe 26/3/52	Capetown 14/4/52	Teneriffe 5/8/52
Fuel bunkered											
Specific gravity at 60 deg. F./60 deg. F.	0·930	0·929	0·933	0·926	0·932	0·930	0·933	0·931	0·940	0·941	0·931
Viscosity, Redwood No. I at 100 deg. F., sec.	437	382	430	329	395	441	520	287	358	572	309
at 200 deg. sec.	57·3	56·3	—	54	61·5	63·5	66·5	55	56	67·8	53·8
Flash point P.M. closed, deg. F.	235	235	204	202	230	172	180	190	160	225	194
Pour point, deg. F.	60	60	70	60	70	70	65	15	55	50	40
Conradson carbon, per cent.	5·7	5·7	6·2	6·1	6·0	6·2	6·3	8·4	6·7	7·8	7·3
Water, per cent.	0·1	0·1	—	—	0·1	0·1	Nil	0·2	0·2	Trace	Trace
Sediment by hot filtration, per cent.	0·04	0·04	0·02	0·01	0·04	0·02	0·01	0·02	0·01	0·01	0·01
Ash, per cent.	0·03	0·02	0·03	0·02	0·03	0·03	0·02	0·05	0·03	0·07	0·02
Sulphur, per cent.	2·1	2·1	2·4	2·4	2·1	2·2	2·2	2·3	2·7	2·3	2·7
Asphaltenes, per cent.	1·6	1·6	1·5	1·5	1·2	1·5	1·9	1·5	2·5	3·4	2·1
Bottoms, sediment and water, per cent.	0·2	0·4	—	—	0·5	0·2	0·1	0·4	0·2	0·2	0·1
Fuel at main engine fuel pump											
Water, per cent.	0·1	0·1	0·1	Mixed with other fuels before use	Nil	Nil	Nil	Nil	0·05	Nil	Nil
Sediment by hot filtration, per cent.	0·04	0·04	0·03		0·01	Nil	0·01	0·01	Nil	0·02	Nil
Ash, per cent.	0·03	0·03	0·02		0·02	0·02	0·03	0·03	0·02	0·04	0·02
Bottoms, sediment and water, per cent.	0·1	0·1	0·5		0·2	0·2	0·1	0·1	0·1	0·1	Trace

TABLE XXXV—FUELS BUNKERED AND USED BETWEEN SEPTEMBER 1952 and JUNE 1953 IN VESSEL C

Bunkering port Date	Teneriffe 29/9/52	Fremantle 30/12/52	Teneriffe 31/1/53	Teneriffe 14/3/53	Curacao 17/6/53
Fuel bunkered					
Specific gravity at 60 deg. F./60 deg. F.	0·959	0·932	0·926	0·964	0·960
Viscosity, Redwood No. I at 100 deg. F., sec.	1,120	226	575	1,170	1,176
Flash point P.M. closed, deg. F.	158	178	174	150	184
Sediment by hot filtration, per cent.	0·03	0·06	0·03	0·05	0·02
Sulphur, per cent.	—	—	—	2·6	2·7
Ash, per cent.	0·02	0·04	0·03	0·04	0·04
Asphaltenes, per cent.	3·0	3·2	3·3	5·1	5·1
Fuel at main engine fuel pump					
Specific gravity at 60 deg. F./60 deg. F.	0·955	0·939	—	0·964	
Viscosity, Redwood No. I at 100 deg. F., sec.	912	350	590	1,094	
Flash point P.M. closed, deg. F.	176	174	178	184	No. sample taken
Sediment by hot filtration, per cent.	0·03	0·01	0·01	0·04	
Sulphur, per cent.	—	—	—	2·5	
Ash, per cent.	0·02	0·02	0·02	0·04	
Asphaltenes, per cent.	3·0	3·5	3·3	4·8	

Discussion

MR. F. G. VAN ASPEREN (Member) said that when the authors asked him to open the discussion on their paper, he hesitated to accept this task for two reasons. Firstly, as a foreigner, he had no wish to take the place of one of their own countrymen who would probably be better qualified; and, secondly, he was no fuel expert and had no special experience with the engines on which their research had been carried out, these being of pure British design and not of Continental make.

On reading the actual paper, however, he had found so many items of general interest and further points relating particularly to the field of his own experience with single-acting pressure-charged two-stroke marine engines, running on heavy fuel, that his original objections had been completely wiped out.

A very important question was stressed in the summary on page 001; namely, the amount of steam heating available apparently limited the viscosity of the fuels that could be bunkered. In fact, very often the improvement in mechanical efficiency of the marine engine and further measures to decrease the specific engine fuel consumption to extremely low values resulted in lower heat content in the exhaust gases after the engine or after the pressure-charging turbo-blowers. For instance, an amount of steam for heating purposes in an installation for heavy fuel of 3,500 seconds Redwood No. 1 at 100 deg. F. was required of 600 to 1,000lb. per 1,000 b.h.p. per hr., which was not an abnormal figure. Very often in two-stroke Diesel installations, these amounts could not be produced in an exhaust gas boiler alone without the help of an auxiliary oil-fired boiler. If the fuel consumption of the latter was added to the engine fuel consumption and included in the fuel bill as specific engine consumption related to the b.h.p. developed—which most owners would probably do when they received the fuel bill—this figure would often rise much above a normal practical value. Some types of engine, especially pressure-charged ones, proved to have a total heat balance where enough steam capacity was obtained by the engine alone without undue increase of the exhaust gas boiler heating surface.

Fig. 15 showed a heat balance. It was important when engines were running on heavy fuel that there should be enough steam capacity to heat the heavy fuels. The authors were right in what they said about the viscosity that could be used. The arrangement in Fig. 15 gave 15 per cent of the induced fuel heat as useful heat in the exhaust gases, which was about enough heat to provide enough steam.

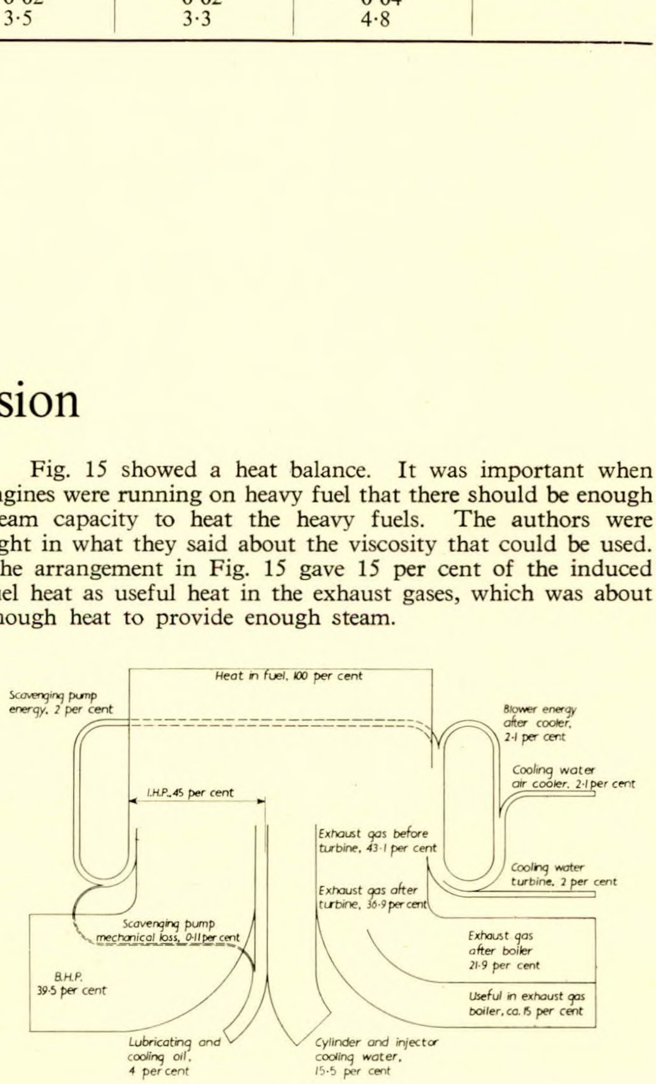

FIG. 15

Fig. 16 showed calories against specific fuel consumption. The amount of heat in the exhaust gases depended on the specific fuel consumption which was shown in the slide in grams (160 gr. per b.h.p.h. = 0·355lb. per b.h.p.h.). With increasing fuel consumption, the calories in the effective power remained the same, while cooling and lubricating oil increased, as well as heat in cylinder and injector cooling water, and turbine and charging air cooler. But the heat supplied in the fuel and what

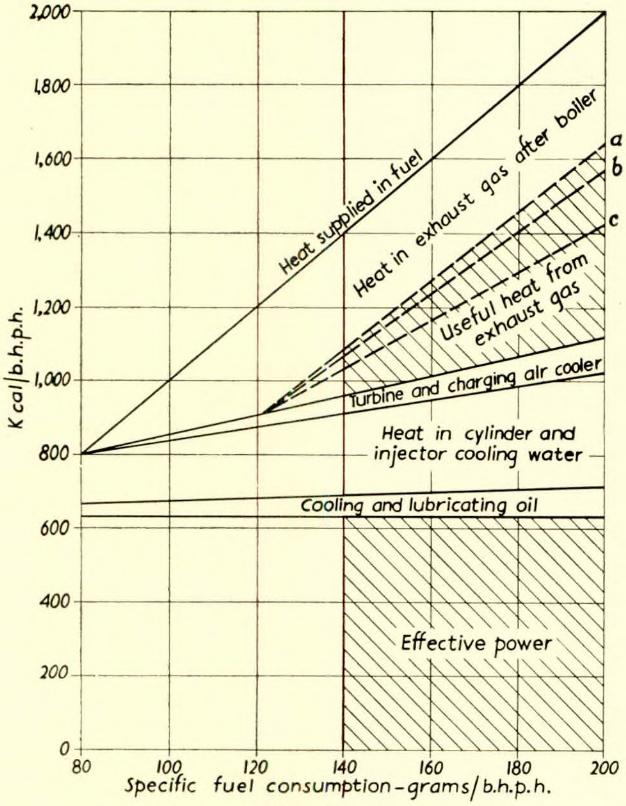

FIG. 16—*Boiler heating surface*

(*a*) 75 m.^{2}/1,000 b.h.p.
(*b*) 50 m.^{2}/1,000 b.h.p.
(*c*) 25 m.^{2}/1,000 b.h.p.

remained in the exhaust gases in the boiler were different. The useful heat from the exhaust gas in the boiler with increased fuel consumption was shown as a function of the specific fuel consumption, dependent on the size of the exhaust gas boiler in *m*^{2}/1,000 b.h.p. The higher fuel consumption brought about more effective heating in the exhaust gas boiler. This was a slight deviation from the actual paper, but the authors had stressed this point at the beginning of their paper, and it was very important.

It was then possible to use fuels with the highest viscosity and lowest costs, as sulphur and ash content did not necessarily show higher values with increasing viscosity, as the authors had shown in the tables given in the Appendix to their paper.

As to liner wear, it had become apparent from recent investigations that the rather high figures, measured on two-stroke engines using heavy fuel, were mainly due to corrosion prior to abrasion, and he would like to stress this.

Experience had shown that figures of 0·4 mm. per 1,000 hours, as given in the paper, at the points of maximum wear in the cast iron liners, could be brought down to one-fifth of that value by using a strongly anti-corrosive type of cylinder lubricating oil. Endeavours to decrease abrasive effects by special cylinder lubricants had also successfully resulted in decreasing wear figures to 60 per cent of the original value.

Furthermore, it seemed that a well-executed system of timed lubricating, arranged to induce the oil between the piston rings during the period of lowest piston position, under the scavenging ports, in a single-acting two-stroke engine, was most effective. The quantity of oil, supplied at a point of low temperature, was then most economically used. It had been proved that the oil was then supplied at the points where one wanted it—the points of maximum wear. This was one of the principal ways of reducing wear. The figures for wear in the paper were not abnormal, but they could be reduced by the anti-corrosive types of oil which were now being developed by different companies. They had, in his opinion, provided the answer to heavy cylinder wear.

As to the quantities of oil mentioned in Tables V and X for vessels A and B, the figures for cylinder oil consumption for a 3,300 b.h.p. engine seemed rather low, while those for crankcase oil consumption could be reduced to nil if they really represented losses in the engine and not a decrease in the total amount of oil in circulation by centrifuging.

He fully agreed with the authors as to their remarks on page 37 about two-stroke oil engines being competitive with steam turbine installations up to 15,000 s.h.p. for single-screw cargo liners, running on low cost fuel. For tankers, however, he did not feel so sure about this power limit.

Most tanker fleet owners would, in fact, be rather concerned about regular maintenance time increasing with higher numbers of cylinders, in relation to time available out of loading and discharging terminals, where engines, owing to regulations, had to remain steadily standing by. Perhaps engines with highly improved accessibility to the moving parts and high cylinder power would only serve that purpose.

It might be of interest to make clear in the data given in Fig. 1 whether the graph referred to total tonnage or only to vessels above a certain specific tonnage as indicated under Table I. This was a minor point. The same question should also be raised where the replacement of steam by Diesel engines was indicated only to refer to medium powers.

In addition to the figures for motorship-percentages of total tonnage, it might be stated that in Holland in September 1954 motorship gross tonnage amounted to 47·7 per cent of the total tonnage of merchant vessels above 100 tons gross under construction. Expressed in numbers of ships, this figure became 83 per cent, the average gross tonnage of steamships being 11,200 tons and of motorships 2,007 tons.

For tankers, motor vessels amounted to 25 per cent in tonnage and 29·2 per cent in numbers of ships. The average specific steam tonnage was 14,100 tons, while the specific motor tonnage was 11,400 tons.

In tankers, therefore, there was not so much difference in size of tonnage, while the tonnage figures for motors and steam

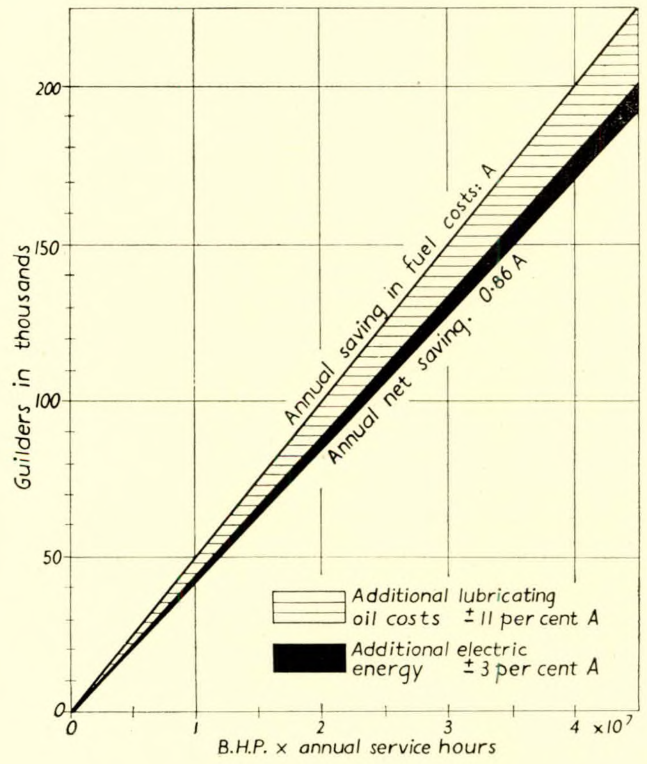

FIG. 17

were 25 per cent and 75 per cent respectively. This proved that there was some difference in judging the value.

As to the saving in fuel costs from the use of bunker fuel, to take up one of the points, it might be honest to point out that, apart from the normal increase in maintenance costs and time already mentioned by the authors, there was a definite reduction in savings as a result of higher cylinder lubricating oil consumption, often at a higher cost per gallon, and increased use of electricity for fuel treatment.

Fig. 17 showed on the horizontal scale the b.h.p. × annual service hours. For instance, on a 6,000 h.p. engine running 5,000 hours a year, the annual saving in fuel costs was the difference between the normal marine Diesel fuel and heavy fuel costs at the values which were normal in Holland. Members would know the local difference from the monthly publications. From the rough savings it was necessary to deduct not only amortization for the fuel installation but also the increased cost of lubricating oil, and the additional cost for electric separator energy, which normally worked out at about 14 per cent of the original savings, should be included in all calculations. Otherwise, the savings would appear to be more than they actually were. Nevertheless, this would not affect seriously the general trend to equip motorships with heavy fuel installations, especially those with high powers and high number of yearly running hours.

With regard to ring conditions as set out in Figs. 4 and 9, which summarized ring conditions and breakages in Vessels A and B, he would like to ask whether the numbers of the rings referred to a special position of the ring on the piston between crown and skirt. It was clear that ring breakage started to occur in a serious way after 7,000 or 8,000 running hours, where deviations from parallelism of the cylinder walls by local wear became evident and even critical.

He would now revert to the question of liner wear as concerned the effect of sulphur, ash, sediments and asphaltenes.

From Table XXVII and Fig. 13 (a very important graph), it would appear that the authors were right in noting the direct influence of sulphur content on the wear rate, although they did not stress this in the paper. The graph giving that relationship was very striking. The question remained, however, as to which factor was mainly responsible for the wear rate of 0·2 mm./1,000 hours at the value of nil sulphur content? If the corrosive effect of sulphuric acids was doubling this wear figure at 3·7 per cent sulphur, the original 0·2 mm. wear per 1,000 hours must have a purely abrasive character.

He quite agreed with the authors' statement on pages 53 and 54 about the influence of manœuvring hours on the wear factor.

It might be understood that ash and solid sediment particles must be looked upon as the most important factors for that part of the wear curve. This brought one back to the purifying and clarifying measures advocated initially by Mr. John Lamb and followed up since 1947 by practically all builders and owners. In fact, these were, up to the present day, the only harmful constituents which in an economical way could be *extracted* from the fuel bunkered.

The remaining and very important part of the wear effect could only be counteracted practically by neutralizing the corrosive influence by the *addition* of special anti-corrosive additives, as applied more or less equally successfully in the case of normal or special cast iron liners or chromium-plated liners.

A very useful indication was the correlation established between percentages of sediment by hot filtration in the fuel and amounts of sludge from the separators, because if the capacity of the separators installed was insufficient for the required grade of centrifuging, this might also affect the amount of ash extracted.

It remained to mention the asphaltene contents. Although these constituents did not directly influence wear conditions, the secondary effect of port fouling and sludge formation in the scavenge belt, by blowing back incomplete combustion products, might adversely affect the combustion air excess. This stressed the latter phenomenon in addition to the factors mentioned by the authors on page 53 under "3. Operating conditions". In his own opinion, the continuous availability of the required combustion air excess in the cylinder, apart from the necessary amount of scavenging air, should be watched in connexion with the factors influencing liner wear rates.

As far as his own experience went, the conclusions on the effect of fuel properties on engine performance were not only true for the type of engine forming the authors' field of research but could also be applied to other single-acting two-cycle engines.

He would, however, welcome more long range data referring to uniflow scavenged engines with exhaust valves in the cylinder head, either with or without pressure-charging, in connexion with the fuel properties mentioned.

He would like finally to give a word of warm thanks to the authors for the most valuable and comprehensive data collected by them and by their co-operators on the different fuels used on different sailing routes and the very interesting conclusions reached as a result of their persevering efforts, as set out in the paper.

MR. A. G. ARNOLD (Member) said he congratulated the authors upon having produced a very comprehensive and useful paper on the burning of boiler oil. He called it boiler oil in spite of the fact that the title of the paper was "Fuel Features Related to Low Cost Fuels" and hoped this would not offend the authors. The paper would be welcomed by shipowners as well as their technical staffs, containing as it did a considerable amount of information which they were seeking. He was particularly interested, due to the fact that he was closely connected with a fleet having thirty-five motor vessels using this fuel, with an additional six vessels to be added by the middle of 1956. The total daily consumption to date of this fuel used by these ships was about 1,100 tons for, say, 200 days per year, and the consumption of individual vessels ranged from 50 to 28 tons per day.

In addition to the main engines using this fuel, they had ninety-five auxiliary engines running on it; the viscosity of the fuel bunkered at the various ports on the trade routes ranged from 250 to 1,500 seconds Redwood No. 1 at 100 deg. F., but the average would probably work out at about 850 seconds. The flash point ranged from 165 to 260, and generally speaking, their results were satisfactory. The comparisons that he would make, however, were the nearest in their fleet to those set out in the paper under Vessel C, but for a longer period. The average rate of wear recorded in Table XVIII worked out at 13/1,000 inch per 1,000 hours. In this case he would be very pleased if the authors would state what they considered to be an acceptable figure; in other words, what was the yardstick by which cylinder liner wear was to be compared. This seemed to him to be a very important point which was seldom mentioned. In his company's case, when they originally went in for two-stroke cycle engines, it was discussed with the experts at that time, and generally agreed that they could expect 8 to 10/1,000 inch per 1,000 hours. That, of course, was based upon using Diesel oil. It was agreed that since then there had been an improvement in methods of lubrication, also combustion, etc., so this figure would probably be reduced to 6 to 8/1,000 inch per 1,000 hours.

He would have liked the authors to give the names of the vessels from which they had taken their records. If this were done and the results were good, the chief engineer and his staff were pleased to know that the results of their efforts were proving to be satisfactory. If, of course, the records were not correctly taken, they might say "This is not the vessel in which I am sailing". There was no doubt that the vessels' engineering staffs played a very big part in the success or otherwise of the burning of boiler fuel.

In the *Bellerophon* class the engines were two-stroke cycle single-acting opposed pistons of the Harland and Wolff/Burmeister and Wain type, 750 mm. diameter, total stroke

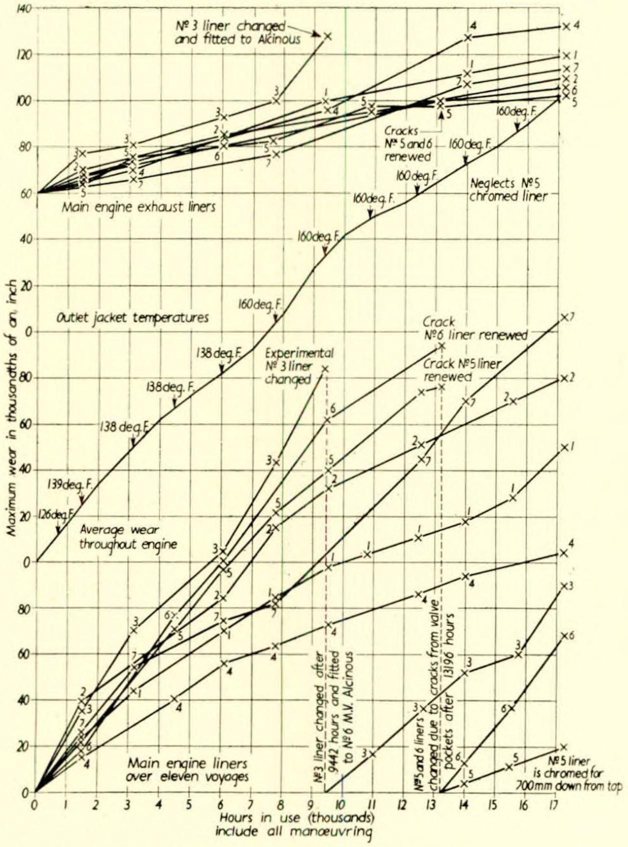

FIG. 18—*Main engine liner wear in m.v.* Bellerophon

Two-cycle opposed piston engine of 750 mm. bore/combined stroke 2,000 mm. Fuel equipment: jerk pumps cam operated.

Note: No. 3 liner changed at Rotterdam after 9,442 hours, maximum wear 0·184.

No. 5 liner changed at Otaru after 13,196 hours, maximum wear 0·189.

No. 6 liner changed at Otaru after 13,196 hours, maximum wear 0·194.

2,000 mm., and for the first 9,000 hours the wear rate was 14/1,000 inch per 1,000 hours, whereas now the average for 17,000 hours was only 11·8/1,000 inch; this reduction in wear was brought about by modification to the builders' fuel oil valves.

In the case of the *Alcinous*—a similar engine running under the same conditions—the wear rate for 11,000 hours was 7·5/1,000 inch per 1,000 hours.

Graphs showing the rate of wear on three vessels of the class were given in Fig. 18 for *Bellerophon,* Fig. 19 for *Alcinous* and Fig. 20 for *Laomedon.* It would be noted that the engines of the latter two vessels were equipped with the Archaouloff system fuel injection equipment.

On page 53 it was stated that when a cylinder liner had reached 0·6 per cent total wear, the wear rate increased rapidly. Did he conclude from this that they would recommend changing the liner when it had only worn this amount? In the case of the *Bellerophon* class they were aiming at 1 per cent of the diameter, i.e. 300/1,000 inch before renewal and after four years' service (twelve voyages); it would appear that this figure was not too optimistic. With the present rate of wear and results obtained, this meant that the liner would give at least an efficient working life of twenty to twenty-two voyages. They knew that fourteen voyages could be completed without renewal. They had not renewed a liner yet for wear; three had cracked with this type of engine, of which there were nine in service, i.e. sixty-three working liners.

On page 37 the authors stated that to achieve clean combustion it might be necessary to advance the period of ignition; he heartily concurred but would like fuller information as to how best they think it should be done, observing that there was always a limit in any engine to the maximum firing pressure. Was it intended to advance the cams or lift the plunger, or what? All of these, as they knew, would necessitate the engine being stopped, and for some time; when was this alteration to be made, was it on account of the viscosity of the fuel or the flash point of the fuel, etc.? Any enlightenment that the authors could cast upon this subject would be extremely useful, but he did not think the results would be all that they desired. It was also essential for good combustion and reasonable cylinder liner wear to accelerate the rate of burning the fuel; both objects were achieved by fitting pilot injection fuel oil valves, and fuel oil pumps operated on the Archaouloff system.

The authors referred to the number of piston rings, etc., stuck or broken over this period as being satisfactory, but here again his company seemed to have achieved better results. Ten record sheets of the *Bellerophon, Alcinous* and *Laomedon* showed that no piston rings had stuck and only eight had been renewed. The number of exhaust ports found choked were considered to be very few, but his company's results compared very favourably. They did find, however, that the ports immediately below the points of lubricating oil injection choked and to date they had not been able to remedy this; however, a scheme was in hand by which they hoped to deal with this objectionable feature.

On page 55 the authors mentioned that the crankshafts were adversely affected through the burning of this fuel. He

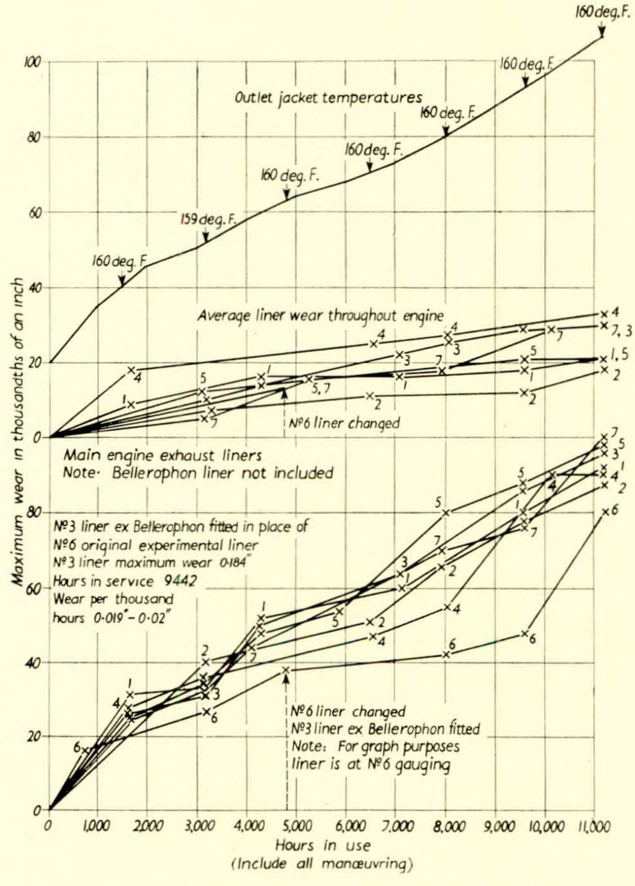

FIG. 19—*Main engine liner wear in m.v.* Alcinous

Two-cycle opposed piston engine of 750 mm. bore/combined stroke 2,000 mm. Fuel equipment: gas operated; fuel: boiler oil.

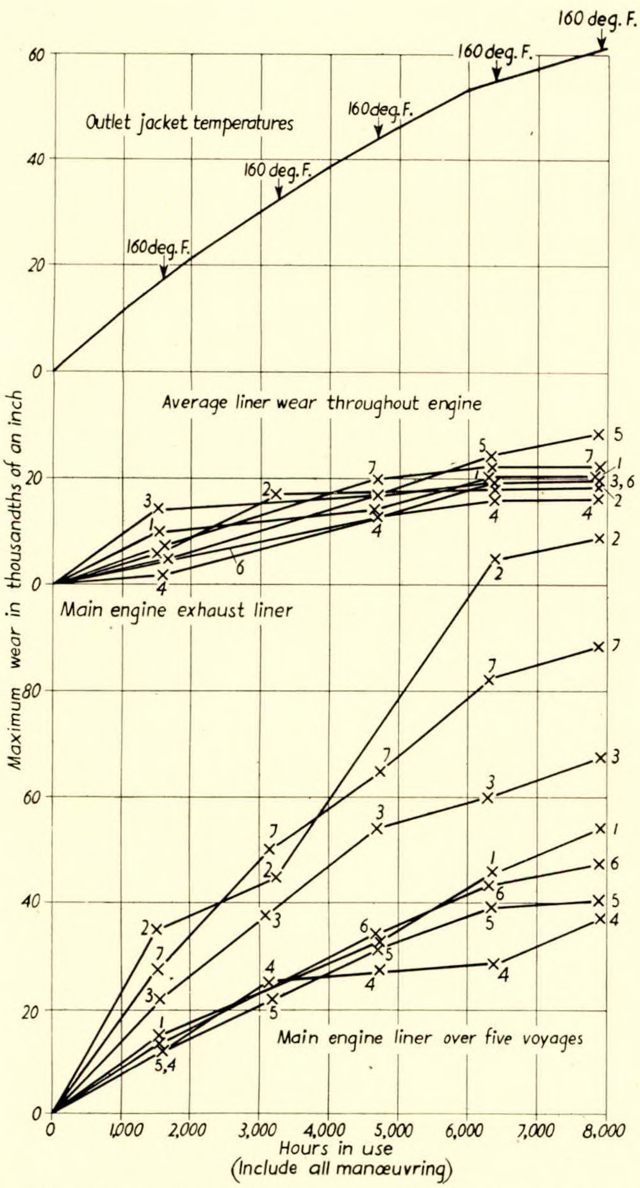

FIG. 20—*Main engine liner wear in m.v.* Laomedon

Two-cycle opposed piston engine of 750 mm. bore/combined stroke 2,000 mm. Fuel equipment: gas operated; fuel: boiler oil.

was afraid that this was another case of blaming boiler oil when perhaps it could only aggravate the situation; his company had not experienced any corrosion on main or auxiliary engine crankshafts and he repeated that the auxiliary engines were of the trunk piston type. He suggested that the reason for the deterioration of the crankshaft was due to water cooled pistons. The more thorough washing of the crankcase lubricating oil referred to would no doubt help the situation, but what would be the maintenance charges on the centrifugal separators?

The authors referred to the working and cleaning of the fuel oil separators and mentioned water being necessary to effect a seal on the machines. With the self-cleaning type, which his company had in all vessels burning this fuel, they did not admit any water for effecting a seal, and it did not seem logical to do so. They used Carnea flushing oil for this purpose, also for creating the hydraulic pressure for cleaning the separators. This oil had a viscosity of only 70 seconds at 70 deg. F. and with this system they had many reports declaring that the separators were only opened up for cleaning and examination, etc., three times per voyage or, say, after 800 tons of fuel had been separated. The authors did not state very much about the filters used on the fuel oil lines. He agreed that these were simple but they played an extremely important part in the efficient working or otherwise of the engine when burning boiler fuel.

Fig. 13 was very interesting, and there was no doubt that they could cope with the sulphur indicated on the graph. He would be very pleased if the authors could let them have a peep into the future as to this important question of sulphur, as there seemed to be a diversity of opinion, and he would like to hear a little more about the additives to the cylinder lubricating oil they would recommend. His own idea was that if they could keep the water away they could deal adequately with oil containing 4-5 per cent sulphur.

Many engineers and shipowners would be pleased to read of the small amount of vanadium impurities found in the samples of sludge that had been analysed. This was also confirmed in an article by Mr. Alfred Brunner of Sulzer Brothers, Ltd., in their Technical Review, No. 2, 1954, when he stated they were only of "marginal significance".

The authors had referred to the economies that could be effected with the burning of boiler oil and his experience was that these could be taken full advantage of, providing the vessels were equipped for the treating of the fuel, and by this he meant the care taken at all stages, i.e. from the double bottom tank at the bunkering port to entering the cylinder ready for burning. They still limited the viscosity of this fuel to 1,500 seconds; heavier oil, if it were absolutely necessary, could no doubt be burned. Economic working of the vessels would be effected, such as the provision of additional steam capacity for heating the fuel, not only for burning it but to have the oil sufficiently warm for transferring the fuel in the double bottom tanks when loading or discharging, possibly up to 4,000 tons of vegetable oil in a number of deep tanks. Any delay or inconvenience to vessels could easily upset these economies. A balance must be struck, therefore, of what could and what could not be done. This was a very important point and one that was often overlooked.

The oil companies interested in bunkering vessels at the different ports might and perhaps should see that fuel up to 1,500 seconds was readily available.

The co-operation of engine builders in connexion with the burning of boiler fuel had been mentioned. To date, they could not claim to have had any great co-operation from the engine builders. It might be that, as owners, they were a little to blame for this and it might also be that having had so little trouble with the engines as delivered they had not had to appeal to them for assistance. He was able so say, however, that one big firm supplying engines to them was now carrying out tests in connexion with the burning of boiler fuel with high sulphur content, and their report was awaited with interest.

COMMANDER(E) H. T. MEADOWS, D.S.C., R.D., R.N.R. (Member) said that, in his opinion, the only figure a shipowner would notice in the paper was that given on page 003, where a case was made in support of burning boiler fuel by making out that the yearly saving to the shipowner on the fuel bill of a 10,000-ton, 15-knot cargo ship was £16,000.

It was not made clear, however, that this figure was computed on the assumption that such a ship spent 200 days a year at sea.

In "Lloyd's List" of the 16th September 1954, he had read as follows:—

> "An article in the September issue of the United Nations Monthly Bulletin of Statistics shows that before the war the average dry cargo vessel spent about 200 days of the 365 at sea, whereas in 1950 dry cargo ships were spending on the average only about 130 days at sea . . .
>
> "The article finally pointed out that though complete statistics for 1953 were not yet available, returns so far received indicated an improvement over 1950

sufficient to bring the average number of days at sea in 1953 to about 150".

The "days at sea" figures given in that article were in fact borne out in the paper. According to his calculations from data given in the paper,

Ship A spent about 85 days a year at sea.
Ship B spent about 136 days a year at sea.
Ship C spent about 176 days a year at sea.

Even the tanker seemed to spend only about 250 days a year at sea.

From the foregoing, it would seem that the saving on the fuel bill would be nearer £12,000 than £16,000.

He thought that the paper would be more valuable if the authors gave the actual saving on the year's fuel bill for each ship described.

MR. P. JACKSON, M.Sc. (Member) said he felt some diffidence in following Mr. Arnold in view of his remarks about engine builders, but would, however, try to make the picture a little less black.

Mr. Arnold and his company had pioneered experimental work on the development of the Archaouloff gear for their various engines and they had recently ordered seven six-cylinder engines of supercharged type and were pioneering the development work which would doubtless be necessary.

His company, however, must have spent at least £80,000 on investigations into the combustion of heavy fuel oil, considering that they had built an experimental engine, constructed foundations and installed all the equipment for these tests and carried out trials over three or four years.

The paper was a valuable record of investigations undertaken at sea, and in this respect was unusual. It was rare for such complete information to be obtained and to be so carefully tabulated from service results. The conclusions arrived at were fair and justifiable. Most of the boiler fuels, however, especially those for vessels A and B, were very good types of boiler fuel of low Conradson carbon value and low sulphur content, and they contained relatively small amounts of solid matter. They would certainly have met the requirements for Doxford engines. When Doxfords first carried out investigations into boiler fuel they obtained samples of two well-known boiler fuels, Ord Oil and Heavy Haifa, and did not find much difficulty in burning these fuels. They therefore decided that ships could operate on them and laid down no restrictions whatsoever, but some of the vessels got into difficulties. Mr. Jones had suggested that engine builders should not restrict the fuels in any way, but if they did not give guidance, vessels would put into San Pedro or San Francisco, take on the cheapest fuel bunkers and then the engines would get into difficulties due to the accumulation of sludge, and the cylinder liner wear would be heavy. In view of the early experiences the recommendation was made that for the present boiler fuels should be restricted to 1,500 seconds viscosity, not more than 0·97 specific gravity, and that the sum of the Conradson carbon value and sulphur should not exceed 14 per cent. If the specific gravity were too high there would be difficulty in centrifuging, but if the centrifuges were 100 per cent efficient and removed all the unburnables from the fuels, there would probably be no need for any restrictions at all. The reason for restricting the Conradson carbon and sulphur was that the sludge deposited seemed to be greater with fuels having a high Conradson carbon value, and this sludge contained high percentages of sulphur, even up to 8 per cent. It was therefore considered that the sum of these two values should be restricted. When this became known, a number of oil companies' representatives protested and Mr. Jones in particular had suggested that it was not the Conradson carbon but the asphaltenes plus the sulphur which were responsible for high rates of wear and other difficulties, and in consequence of this it had been recommended that the sum of the asphaltenes and sulphur should not exceed 9 per cent. So far as was possible, an endeavour had been made to determine which of these factors was responsible for high rates of wear, but so far without success.

It would be seen that every fuel mentioned in the paper for vessels A and B would comply with the above recommendations with the possible exception of the one given in Table IV, where the sum of the sulphur and Conradson carbon was 13·5 per cent and the sum of the sulphur and asphaltenes was 9 per cent.

Mr. Jackson stated that he did not know the names of the vessels, but obviously vessels A and B were British-built cargo vessels, vessel C was either a New Zealand or a Port Line ship and vessel D was definitely an American-built Sun Doxford. The Sun Doxford engine had many features different from the engines built by Doxfords and British licensees, and this might be the reason for the cracked cylinder liners referred to in the paper. In this engine the housings for the fuel valves were screwed into the cylinder jackets with tapered threads, which might be responsible for the liner difficulties.

The wear rates given in the paper were very high. There were many liners on Doxford engines operating on Diesel fuel having a life of over 40,000 hours, with average wear rates of 0·075 mm. per thousand hours, giving a life in cargo ships approaching ten years and in tankers approaching seven years. On boiler fuel the average life of liners was between three and four years, with an average wear rate of 0·2 mm. This was considerably lower than the figures given in the paper, and was possibly due to the method of operation. "A dirty, brown coloured exhaust" on an engine, even operating on boiler fuel, was unjustifiable and, as mentioned in the paper, this had been cured by advancing the fuel valve timing by 3 degrees.

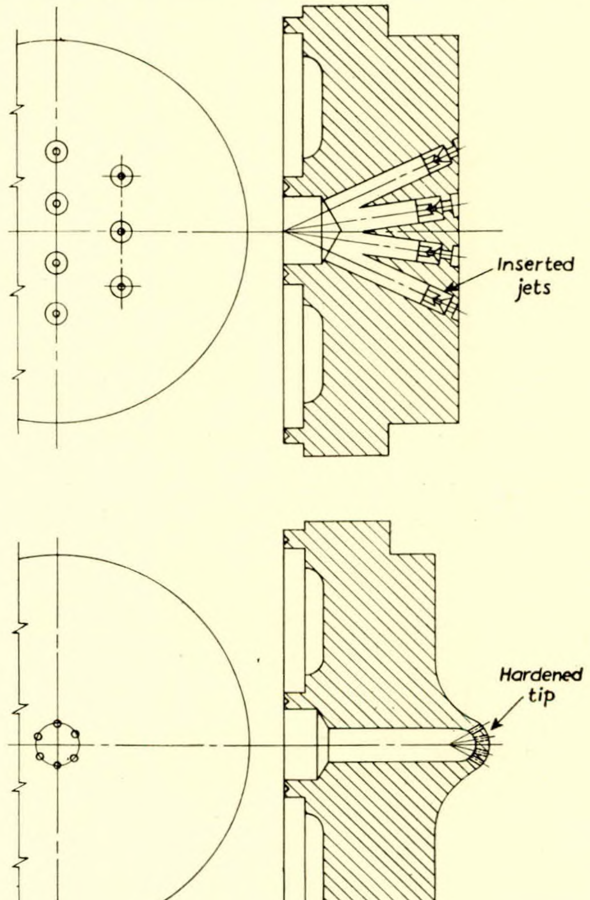

FIG. 21—*Doxford nozzle (above); Doxford nozzle with pip (below)*

This advancing of the timing was necessary with many boiler fuels to maintain the maximum pressure at 600/640lb. per sq. in. It was his experience that good combustion and good results could not be obtained if the maximum pressure did not reach at least 1·6 and probably 1·7 times the compression pressure. Ship A obviously operated for a time with the injection unduly retarded for boiler fuel operation.

He was in full agreement with Mr. Arnold that injection played a great part in operation on boiler fuel. On the standard Doxford fuel valve for the common rail system, the nozzle or flame plate had a number of drilled holes with hardened ferrules pushed in, and the fuel was injected through these ferrules. That type of nozzle sometimes resulted in the ferrules being forced out by the fuel pressure and also the nozzle holes wore at a high rate. In recent years a more normal type of pip-ended nozzle had been developed for the standard fuel valve with a number of small holes arranged symmetrically (so that there was no need to dowel for position), as shown in Fig. 21, and this gave far better results on boiler fuel operation. To his mind, it was well worth the cost for owners to change over to the pip type of nozzle.

In the last two or three years a new injection system had been developed which used normal spring-loaded C.A.V. injectors, and the combustion when using boiler fuels was much better. The fuel consumption was not better by more than 0·003lb. per b.h.p. per hr., but somehow that small improvement in consumption made a considerable difference to the amount of sludge that was deposited in the scavenge belts. This experience was akin to that of Mr. Arnold in his development of the Archaouloff system. Two engines had been changed over from the common rail system to this timing valve system, and other engines were under construction.

Even with the new injection system it was possible to operate under dirty conditions if the temperature of the fuel at the fuel valves was not maintained at 170/175 deg. F., and if it fell below 140 deg. F., sludge could be formed very quickly. Similarly, if the jacket water temperature was allowed to fall, the rate of sludge deposited in the engine could be trebled.

Another way of improving the cleanliness of an engine when operating on boiler fuel was to increase the compression pressure somewhat. It was the heaviest fractions of the fuel which contained the sulphur, and it was these that did not burn under adverse circumstances, and increase in compression pressure and, therefore, the temperature at which the fuel was burnt had a considerable effect in improving the cleanliness of combustion.

He could not understand the low quantities of sludge that were taken from the centrifuges of the engines described in the paper. The fuels must have been very clean. Sludge quantities of ½lb. per ton were obtainable on boiler fuels in this country and on the Continent, having viscosities of 400 to 800 seconds, but with many of the fuels of 1,500 and 2,000 seconds obtained abroad, sludge quantities of 3lb. or 4lb. per ton were not unusual and 7lb. or 8lb. had been obtained. He had known Middle East fuels to yield as much as 40lb. of sludge per ton in the centrifuge, and Mr. Arnold had mentioned in his paper before the Institute two years ago as much as 60lb. of sludge per ton.

With regard to the wear data given in the paper, he agreed with the observation that the maximum wear was about 10 inches from the centre of the combustion space when operating on boiler fuels, whereas with Diesel fuels the maximum wear was at the end of the top ring travel. He suggested that Fig. 10 for Vessel B was unusual, in that wear could not gradually increase from the centre of the combustion space to the top of the first ring. The sludge that was formed from the constituents of boiler fuel was a primary cause of both wear and corrosion. Many samples of sludge had been analysed and they could contain as much as 8 per cent of sulphur. This sludge was also very abrasive, so that it could be responsible for both corrosion and abrasive wear. No adequate answer had yet been found to the question of liner wear, but investigations were proceeding and the wear could be reduced by ensuring good combustion, maintaining the jackets at a high temperature, and ensuring efficient centrifuging of the fuel. Experiments were also proceeding with detergent types of lubricating oils. With regard to detergents, his experience was similar to that given in the paper. With lubricating oils of Supplement 1 type, no consistent benefits had been found, but two types of lubricating oils of Supplement 2 range had been tried and appeared to be definitely beneficial.

In view of Mr. Arnold's remarks on corrosion, he would like to say that in every case of corrosion which he had investigated, water had been present in the crankcase. He was of the opinion that if the water were eliminated from the crankcase, corrosion difficulties would be reduced. There had been a few cases of corrosion on engines operating on Diesel fuel, but in those cases salt water appeared to have got into the lubricating oil and was the responsible agent. He was, therefore, of the opinion that corrosion would be considerably reduced if not eliminated by oil-cooled lower pistons. The number of cases of corrosion on boiler fuels had been greater in proportion than on those engines operating on Diesel fuel. The corrosive action had been due to the sludge containing sulphur which found its way into the crankcase and became mixed with water to form a diluted acid.

The Doxford engine had recently been redesigned with a diaphragm separating the lower end of the cylinder from the crankcase to collect the sludge, and oil-cooled pistons had also been adopted with a view to taking water out of the crankcase. These two steps together would definitely remove the causes of corrosion. It was his opinion that either would probably remove 90 per cent of the causes, but the two together would surely do everything. On the other hand about 180 engines of the previous type were operating on boiler fuels. In no vessel where corrosion had occurred had there been a repetition, and this was due to the operators taking precautions to ensure that their centrifuges were working properly. In one type of centrifuge, there were small nozzles through which the sludge from the lubricating oil was forced by centrifugal action and if this centrifuge were stopped without the nozzles being cleaned they could choke up solid. That type of centrifuge was not really suitable for cleaning the lubricating oil of engines operating on boiler fuel.

Mr. Arnold did not believe in water washing the lubricating oil, but this had been the practice on Doxford engines for many years and many operators carried it out. It was first introduced by Commander Le Mesurier of the Anglo Iranian Oil Company prior to 1930, and properly employed it could remove many of the acids from the lubricating oil. There were, however, two or three precautions necessary: the quantity of water should not exceed 20 per cent of the lubricating oil, and the hot water should be added at least six feet away from the centrifuge so that it had time to act. It was no good adding the hot water at the centrifuge. Having washed the sulphur out of the lubricating oil it was necessary to remove the water and experiments had shown that water could not be removed from lubricating oil at low temperatures. It was necessary to heat up to 180 deg. F. During the past two years improvements in treating the lubricating oil had been adopted by dual centrifuging, and if the oil were water washed and precautions taken to remove the water thoroughly and have the oil treated should routine analysis show that it had a low *p*H value, then corrosion difficulties could be avoided. On occasions the bowls of the centrifuge had been perforated by corrosion and when that occurred, the oil should immediately be suspect and not used in the engine crankcase. It had also been noticed that the bearing lubricating grooves became etched on the surface of the crankpins and this could only occur while the engine was standing, and it was therefore advisable to pump clean, dry oil around the engine whenever there was a prolonged stay in port.

After these general comments, he would like to make one or two remarks on the paper.

On page 39 the authors said: "Full load fuel consumptions of 0·32lb. per i.h.p. per hr. and 0·37lb. per s.h.p. hr. were obtained. The fuel supply pressure was 4,400lb. per sq. in.". These results would not have passed a test at Doxfords, the fuel consumptions being too high for Diesel fuel and the fuel injection pressure too low. This type of engine should give a fuel consumption of 0·34lb. per s.h.p. hr. With regard to the viscosity of the fuel for injection, the paper gave a figure of 150 seconds Redwood No. 1. It had been his general advice to try to obtain 150 seconds and certainly not over 300 seconds. Even at 300 seconds the fuel was not broken up sufficiently by an injection pressure of less than 7,000lb. per sq. in. With regard to the statement that centrifuging should take place at a slower rate if the temperature were reduced, he would like to ask whether it were possible by slowing down the rate of centrifuging to compensate for lack of temperature? That was not his own experience. In his view, temperature was a necessity and to try to compensate by putting the boiler fuel through more slowly at a lower temperature did not remove the sediment.

In conclusion, he would like to say how much he had enjoyed the paper, and for a statistical paper of this type it was really very readable.

MR. C. W. G. MARTIN (Member) thought a very fine standard had been set by both the subject matter of the paper and the very lucid way in which Mr. Jones and Mr. Royle had introduced it.

The paper proved one thing without a shadow of doubt; that the marine Diesel engine had an extraordinarily healthy appetite! Sometimes, in the course of his daily work he almost got the impression that the Diesel engine had become a somewhat unhealthy invalid, that had to be fed on a special diet. The authors and the speakers in the discussion had shown that if ever it had been an invalid it was one no longer, provided the proper rules of hygiene and exercise were complied with.

Once again the ability of the marine Diesel engine to burn furnace fuel oils had been demonstrated over an impressive range of heavy fuels. A study of the analyses of these must have been very enlightening to anyone with preconceived ideas on specific test limits, in view of the apparent ease with which quite wide variations were encountered and accepted.

The paper naturally focused attention on certain points of the specification, such as sulphur and ash, and so on. The authors were frank enough to admit that the evidence regarding their effect was still inconclusive. Undoubtedly there were other factors, many of which—he would suggest—were probably mechanical and had little to do with the fuel.

He would join issue to some extent with the authors about asphaltenes. He knew of the controversy between Mr. Jones and Mr. Jackson and he did not intend to prevent Mr. Jones from exercising his prerogative at the end of the discussion. He hoped, however, that the authors would be able to confirm that the reference to 8 per cent asphaltenes in the paper was merely a rough guide to users, and was not intended in any way to indicate even a rough specification limit; because, if that were so, many people would be able to point to cases where over 8 per cent asphaltenes had been exceeded with complete success (as described in papers by Mr. John Lamb to the Institute).

He had a question about the very clear graph given in Fig. 14, on the determination of sediment by the hot filtration test. There were, of course, several tests of this kind, and another test might well produce a curve of an entirely different shape from that shown in Fig. 14. This one appeared to indicate a direct arithmetical connexion between hot filtration percentage and sludge. He wondered whether this were really so. As a number of people had said during the discussion, centrifuged sludge contained a number of components, one of which was undoubtedly oil. The oil content, far from being a steady 50 per cent, might well vary between 10 and 90 per cent. Moreover, two different types of centrifuge would undoubtedly give different quantities of sludge with the same hot filtration value. Consequently, it was difficult to believe in such a straight line curve, which, when one thought about it, was almost too good to be true.

He was very pleased to hear Mr. Royle's remark about the reproducibility of tests. This was one of the problems that was encountered whenever one tried to add together unlike things such as Conradson carbon, sulphur and asphaltenes. It was quite unrealistic to try to combine the relatively rough accuracy of the empirical Conradson test with the more fundamental and much more reproducible sulphur determination.

He strongly supported the authors' statement on the possible effect on cost and availability of the many but mistaken attempts to graft restrictive tests on to commercial fuel oil specifications. These fuels, whether described as bunker fuel or under some other designation, were meant to be sold as furnace fuels with, as a general rule, only a few points of specification, such as flash point, water, sediment content and viscosity. It was this relative lack of restriction which enabled them to be made available at a price so much more attractive than the conventional Diesel fuels. In his opinion, the authors had done a real service to the shipowners in emphasizing this fact.

MR. F. T. BROWN (Member) said that previous papers read in the Institute by Mr. Lamb, Mr. Arnold and others had provided data on engines other than the type featured by Mr. Jones and his co-authors.

A vast volume of tonnage of many nations was propelled by the British-designed two-stroke opposed piston engine, and the authors were to be congratulated on their fresh approach in concentrating upon the effects of using low cost fuels and special lubricants in this one type of engine.

On page 50, in relation to Table XXI on crankcase oil, it was suggested that despite more rapid oxidation when burning residual fuel, the lubricating oil remained in good condition. This, of course, could be more accurately assessed by studying the neutralization value upon each sample. It would be interesting to know why this important test had been excluded from the table. The viscosity increase was relatively high and there was a large quantity of suspended insolubles in the sample drawn at 33,000 hours. Early correction by purification was called for. On this account, the authors' opinion upon the desirability of double centrifuging the lubricating oil would be greatly appreciated. In such an engine dirty circulating oil could constitute a bearing corrosion risk. This was surely to be avoided at any reasonable cost.

In all cylinder lubrication comparisons a high viscosity index solvent-refined paraffinic product appeared to have been used as a pure mineral reference oil. Would the authors agree that some good purpose might have been served by using a low carbon yielding inherently detergent naphthenic cylinder oil in, say, two of the four ships under review?

The paper left the impression that commonly available detergent oils, as well as the experimental grade of naphthenic character referred to on page 50 were to be disregarded as effective cylinder lubricants when burning boiler oil. To a large extent, the wear data supported this contention. Nevertheless, a large number of Doxford engines at sea today were benefiting from detergent cylinder oils. When one of these, using a very low grade fuel, ran into serious difficulties when crossing the Pacific Ocean some two years ago, the only one of the three cylinders that was undamaged was that which employed the additive type lubricant. He mentioned that the ship now used detergent oil in all three cylinders. Such detergent oils were known to fall short of their full requirements, but they should be retained in some places, if only as a comparative stepping-stone towards a more positive solution to heavy cylinder liner wear, frequent piston ring replacement and costly piston ring groove machining. Apart from the development of solvent-refined naphthenic Diesel cylinder lubricants compounded with alkaline additives and possibly ashless detergents, it was common knowledge that lubricants of a more revolutionary design were being field tested in the type of engine in question. It would, therefore, be interesting to know whether any of these less conventional lubricants were proving more beneficial than those mentioned in the paper.

Despite a variety of problems encountered from day to day in the operation of the Doxford engine on heavy fuel, none of them were insoluble. The use of these fuels had come to stay and to defeat the problems there should in future be closer co-operation between the engine builder, superintendent engineer and oil technician. The excellent paper had served a constructive purpose in emphasizing this need.

Correspondence

MR. KAARE HAUG, B.Sc., wished to thank the authors for the valuable information given about low cost fuels in relation to operating experience in motor ships. The amount of data obtained from the four ships was very impressive indeed; but he wished the authors had had reports from ships equipped also with other types of Diesel engines than Doxfords.

He found the references to the various types of lubricating oil, detergent and non-detergent, very interesting. Had the authors any experience in using an additive of colloidal graphite in the cylinder oil? As manager of the technical department of a Norwegian shipping company, he had tried using up to 5 per cent colloidal graphite in the cylinder oil, with very favourable result. The cylinder liners were clean and polished like mirrors, and the piston rings were loose in the grooves, and there were very small deposits in the exhaust ports.

The amount of cylinder liner wear was a main concern for the shipowner, when the question arose whether or not to run Diesel engines on heavy oil fuel. He was not impressed by the results obtained from these four vessels. Most of the results obtained for the various cylinder liners showed a wear rate in mm. per 1,000 hours from 0·26 and up to 0·5 and more. This was almost three times the wear rate expected in normal Diesel oil operation. His company had three ships at present operating on heavy oil fuel, and four more would be operating on heavy oil from next year. He would call the three ships at present operating on heavy oil:—

Ship K (Kincaid B. and W. 5-cylinder single-acting 5,600 b.h.p.).

Ship S (Sulzer 8-cylinder 5,600 b.h.p.).

Ship G (Götaverken 7-cylinder 4,000 b.h.p.).

All ships operated on a boiler oil not exceeding 900 seconds Redwood No. 1 at 100 deg. F.

Ship K. Average cylinder liner wear after 6,627 hours, 0·27 mm. per 1,000 hours. Minimum wear 0·18 mm., maximum wear 0·38 mm. per 1,000 hours.

Ship S. Average cylinder liner wear after 3,496 hours, 0·188 mm. per 1,000 hours. Minimum wear 0·150 mm., maximum wear 0·240 mm. per 1,000 hours.

Ship G. Average cylinder liner wear after 3,794 hours, 0·207 mm. per 1,000 hours. Minimium wear 0·110 mm., maximum wear 0·335 mm. per 1,000 hours.

All these ships used a normal straight mineral oil for cylinder lubrication, and Ship K had just started using a colloidal graphite in the lubricating oil, and so had Ship G. They attributed the good results to the following:—

1. Very careful centrifuging of the fuel oil. The purifier and clarifier were in series, and the oil was treated twice before entering the engine.
2. The cylinder oil was often and carefully checked, and the quantity of cylinder oil used increased by about 10 per cent compared with normal Diesel oil operation.
3. All manœuvring was done on Diesel oil, as the installation was arranged so that the engineers could shift from Diesel oil to fuel oil and back to Diesel oil by turning a handle. During the period of shifting over from fuel to Diesel, the Diesel oil also passed the heater for the fuel oil.
4. The engines were never loaded to more than 80 per cent of normal output and very often not more than to 75 per cent. Personally, he claimed this latter precaution to be very important.

Finally, he would like to know if the authors of the paper had any experience with the new additives to boiler oil and their effect on obtaining clean exhaust ports, free from asphaltenes and carbonaceous matter.

When using the terms maximum and minimum wear, this did not refer to the maximum and minimum wear in one particular cylinder, but to maximum wear in the worst worn liner of the engine. Likewise, minimum wear referred to maximum wear in the least worn liner of the engine. Average cylinder wear represented the mean value of all maxima.

MR. E. H. SMITH (Member) considered that the authors were to be congratulated upon the precise manner in which the result of their investigations in the use of heavy fuels in marine oil engines were presented.

His firm was responsible for supplying the machinery of Vessel A and were kept informed of the general performance during the four years of service covered by this investigation, when there was an almost complete absence of trouble with the main engine, and the only effect of using heavy oil was that the life of the liners was reduced from the customary six or seven years to about four years. It was noteworthy that the majority of fuels bunkered during that time were of Middle East origin.

The experience with Vessels B and C would appear to have been generally the same. It is explained in the paper that Vessel B was generally using Middle East supplies of oil and it would be useful to know the usual bunkering ports for the Vessel C engaged on the United Kingdom-Australia service.

Most oil engine builders must have experiences of vessels using heavy oil of Western origin, where less happy results had been obtained, and an amplification of the data collected on Vessel D would be of great interest in this connexion. The machinery particulars for this ship given in Table III did not conform to the dimensions of cylinder generally employed with Doxford engines built in this country and it would be interesting to know if the design of cylinder was generally in accordance with the British standard.

The rate of liner wear during Test Period I, observing that liners 1 and 2 were new at the start of the test, would appear to be quite normal and this state continued over Test 2 when the total operating time had then amounted to about 14,500 hours and the total wear on these cylinder liners amounted to about 3½ mm. These liners were then renewed at the commencement of Test Period 3 when the wear was at an average rate of about 0·75 mm. per thousand hours. A blended fuel made from 88 per cent bunker fuel and 12 per cent marine Diesel fuel was in use during the Test Period and it would be useful to know the respective properties of the two oils used in the blend and also the authors' opinions about the extent to which the mixture might separate during storage. The probability of this was suggested by the inspection data of the untreated fuel from the bunker tanks quoted in Table XXIV. It would be of considerable value if comprehensive data at different periods of the test, as made available for Vessel A, could be provided for a Test Period while the blended fuel was being used.

The general experience during Test Period 4 with Vessel D would appear to confirm the wisdom of avoiding fuels of viscosities as high as 3,000 seconds whenever possible. Apparently this very heavy fuel was only in use during the month of May 1952 and was then discarded in favour of a better quality, widely available, bunker sea fuel. Does the inspection data of fuels used during Test Period 4 as quoted in Table XXVI refer to the better quality bunker C fuel or the segregated fuel of 3,000 seconds viscosity used during the month of May which had to be discarded?

In the authors' general conclusions on liner wear it was stated that this increased rapidly when the amount of wear has exceeded approximately 0·6 per cent of the cylinder diameter. In plotting the rate of cylinder wear quoted in the paper it would appear that the rate of wear was tending to diminish up to the point where the liner wear amounted to about 0·3/0·35 per cent of the cylinder diameter and then increased progressively at an increasingly higher rate. The factors which were suggested by the authors as influencing the cylinder liner wear were of value and should provide some useful suggestions about the manner in which engine design features could be modified to assist towards an improvement in the conditions. It would be useful if the information provided in the paper could be supplemented by particulars of the types of piston rings in use and also the extent of wear in the piston ring grooves.

DR.ING. GEORG ZIMMERMANN was very pleased about the abundance of material offered in this paper, and fully appreciated the work done on the four test vessels, as well as the trouble that had been taken in evaluating the work. He particularly pointed out the abundance of the heavy oil analyses at the end of the paper (Appendix Tables XXVIII-XXXV). It appeared from these many analyses how the quality of the heavy oil varied in accordance with its origin and the bunker stations all over the world.

At the end of the paper there were many conclusions, which resulted from the tests. He read that the cylinder liner wear depended on five different facts which were specially mentioned. Item 3(a) mentioned the water temperatures for the cooling of the pistons and cylinder liners. He considered this item as particularly important as his company had had many experiences to show that the cooling water temperatures especially were of utmost importance in the formation of residues on the cylinder liners and pistons and in respect of the wear. Through the cooling method generally used today, that is, the use of a separate and special cooling water circuit over a heat exchanger, one was in a position to fix the cooling water temperatures at any desired level. Moreover, one tried to obtain a quick circulation of the cooling water, so as to keep the difference between the inlet and outlet temperatures of the cooling water at the lowest possible level, so that the engine had in itself an equal operating temperature. His company insisted today on a cooling water temperature at the outlet from the cylinders to lie between 140 deg. F. (60 deg. C.) and 149 deg. F. (65 deg. C.), and the inlet temperature not more than 14 to 18 deg. F. (8 to 10 deg. C.) less Nothing would prevent a further increase of the temperatures when operating in the tropics, however, and the engine room temperatures would prevent careful attention to the engine plant. Apart from this, certain questions of material were opposing an increase of temperatures. He would like to hear what experiences had been gained with the four Doxford ships.

They found that the viscosity of the heavy oil should not be greater than 150 seconds Redwood No. 1, which was equivalent to 4·9 deg. Engler, on the injection nozzles. According to their experiences this value was rather high, not to say too high. They insisted on a viscosity between 60 seconds Redwood No. 1, which was equivalent to 2 deg. Engler, and 74 seconds Redwood No. 1, which was equivalent to 2·5 deg. Engler. Especially with heavy oil a perfect atomization was an essential presupposition for a satisfactory combustion in the cylinder, the viscosity of the heavy oil, when injected, being authoritative.

The establishment of a relationship between the hot filtration and the quantity of the dirt removed from the separators, was particularly interesting. They knew of a hot filtration test, developed by Shell, and wondered if the authors had carried through these definitions in a similar manner.

The purification of the heavy oils by separators was limited, as the authors correctly stated, insofar as the heavy oils included incombustible materials, soluble in oil, in a substantially larger quantity. One would, therefore, have to see to it that the heavy oils included from the outset a small amount of incombustible constituents. The many analyses made confirmed this as a matter of fact. His company recommended today that the temperatures should be reduced when using the purifier, in order to be able to get out a part of the asphaltenes, which were also the carriers of matter which combusted with difficulty only. In the clarifier high temperatures were used, which, owing to the reduced viscosity, also assisted the easier separation of impurities.

By using separators, which were self-cleaning, the operation of the purifier and the attention required by it were eased considerably.

Authors' Comments and Reply

Mr. Jones prefaced the actual presentation of the paper on 14th December 1954, with some remarks designed to draw attention to certain broader aspects of the subject, of which the following was a synopsis: —

The paper was essentially a co-operative study by three authors through the help of three shipowners and their engineers, all of whom he thanked. The study started five years ago and there had been further progress on some aspects, the data on which, due to time lag, could not be included in the paper.

The subject, although technical, was tied to economic considerations, as the main reason why the ship operator was interested was because of his desire to economize by using low cost fuel. The fact that bunker fuel was about 40 per cent cheaper than marine Diesel fuel encouraged such economies and this should be studied, bearing in mind the following points: —

(1) The fuels under consideration originated entirely from crude petroleum (but were not crude oil).

(2) Since crude oils varied by origin and in type, the features of the residual fractions, which went into the bunker fuel made from them must, of necessity, also vary.

(3) Different methods of manufacture and processing, even of the same crudes, would also result in noticeable differences between the residua.

(4) Hence, the quality of bunker fuel oils, which consisted mainly of residuum, varied more than other petroleum products, and such variation enabled them to remain the cheapest fuel in the wide range of petroleum products.

(5) The specifications to which bunker fuels were made were comparatively simple and wide, but were determined in order to ensure their suitability for burning satisfactorily in the furnaces of the normal boiler equipment aboard ship.

(6) It was important, therefore, that, firstly, specifications which stipulated permissible limits should be kept to a minimum, as any additional restrictions reduced availability and so ultimately could cause an upward trend in bunker prices, and secondly, freight and handling charges must also be minimized as they were significant features in the valuation of bunker fuel.

(7) The above points were stressed because bunker fuel was the basis and the determining factor both as regards quality and price of any intermediate grades of semi-residual fuel or boiler fuel that might be used in motor ships as a cheap substitute for marine Diesel fuel.

It was emphasized that if additional limiting features were specified by shipowners, this would tend either to restrict supplies of low cost fuel or increase their cost. A user who happened to find a thousand or a two thousand seconds fuel to his liking in one area would be well advised *not* to expect identical features in a thousand or two thousand seconds grade in some other part of the world, where maybe other crude oils, or different methods of manufacture, were used. This was illustrated by the following table: —

Origin	Viscosity, Redwood No. 1 at 100 deg. F., seconds	Sulphur, per cent	Asphaltenes, per cent
Fuel at some European ports ex Middle East crude ...	1,159	4·2	3·3
Fuel at some Caribbean and U.S. ports ex Venezuelan crude...	1,049	2·4	5·7

From these typical tests it would be noted that it would be unwise on the part of a user to insist on a fuel having 2·4 per cent or even 3·0 per cent maximum sulphur, since at some European ports this would involve a premium because the amount of distillate required to meet such sulphur limitations would be greatly increased and might result in a fuel of below 200 seconds viscosity being supplied. A similar position would arise if a maximum of 3·0 per cent for asphaltene content were stipulated for bunkering in some Western Hemisphere ports where high asphaltene content fuels prevailed.

A number of special features such as sulphur, ash, asphaltenes, Conradson carbon and sediment by hot filtration were reported in the paper, with a warning that any tendency to incorporate them into specifications as quality limits would defeat the end everybody was endeavouring to attain—i.e. low cost fuel.

Reference was made to the loose and erroneous interpretation of the term "straight run", which was thought apparently by some to imply fuels which had been drawn "straight" from a tank and not blended to meet an immediate requirement. In the petroleum industry the term "straight run" denoted that none of the components had been subjected to cracking, but it did not in any way eliminate blends. Hence, to insist on "straight run" fuel oils was unsound and such a stipulation would reduce availability and restrict the use of satisfactory blending stock for reducing viscosity.

It should be kept in mind that by far the greater proportion of the world's supply of bunker fuels consisted of blends, and to attempt to avoid blended fuel oils was out of the question. Reliable manufacturers would eliminate unsatisfactory components in the blending of their fuels.

Costs were not quoted in the paper because the authors considered that the shipowner and operator knew more about costs and net savings than the authors.

In regard to wear data, it had been difficult to obtain comparative information between normal Diesel fuels and semi-residual grades. This had prevented the authors from formulating sound conclusions on cylinder wear as related to fuels in general use, and the hope was expressed that such wear figures would be freely mentioned during the discussion.

In conclusion, the authors considered that more research and general study by all concerned was necessary, including both the shipowner and the engine builder, if further progress was to be made.

The authors, in their reply, were pleased about the very useful information given during the discussion by all the contributors. This information would be much appreciated by everybody connected with the burning of low cost fuels in Diesel engines.

The authors did not control the ships and had presented the paper because they wanted to promote co-operation between the shipowners, the oil suppliers and the engine builders. At the outset, the shipowners who let them have the run of their ships (for which they were deeply grateful) did not know they were going to read a paper. They themselves did not know what results they would obtain. After eighteen months or two years, they seemed to be getting something of interest, and later they asked the shipowners if they could publish the results.

The results were in the paper but the shipowners asked to remain anonymous, and as far as the authors were concerned they should remain anonymous because they wanted to be able to get the co-operation of other shipowners and would comply with their wishes if permitted the ready entry to their engines and engineers' logs. Contributors, during the discussion, indicated the desire to see similar long-range data referring to other engine designs and perhaps this would develop when the shipowner, engine builder and oil supplier fully realized how much was to be gained by co-operative effort.

Mr. van Asperen, in his contribution, had touched on some interesting problems which faced a designer of marine Diesel engines and his graphs showing the breakdown of fuel input into its various functions illustrated very clearly how much heat was available in the exhaust gases for possible use in an exhaust gas boiler for raising steam. As pointed out by the authors, the amount of steam heating available limited the viscosity of the fuels that could be bunkered.

The authors hoped that other readers would review carefully the fuel inspection data given in the Appendix to the paper and reach the same conclusions as Mr. van Asperen; namely, that the sulphur and ash content of these fuels did not necessarily increase with the higher viscosity fuels.

The differences in wear rates between adjacent cylinders of one engine was often remarkable and possibly the comments about the advantages of a reliable system of timed lubrication could eliminate these discrepancies. It would appear that no improved methods of cylinder lubrication had been advanced in line with other improvements in the Diesel engine and perhaps this field of development work should be actively pursued to ensure that the cylinder lubricant was used to the best possible advantage. It was possible that the troubles referred to by Mr. Arnold regarding port fouling immediately below the lubricating oil injection points, could possibly be eliminated by the adoption of the above suggestion.

The information used in reporting Fig. 1 was taken from the Annual Report of Lloyd's Register of Shipping and referred to the gross tonnage of all vessels of 100 tons and upwards and consequently the statement that the Diesel engine up to and since the 1939-1945 war had been tending to replace steam for medium powers, did not take into account the large increase of small Diesel powered boats. It was quite true that as large vessels were still predominantly steam powered, the percentage of motor ships to steamers varied considerably depending on whether the percentage was based on tonnage or number of ships, and the discrepancy was even further exaggerated when only the ships under construction in one country during any particular month, were analysed.

The authors now realized that Figs. 4 and 9 were not fully explicit. The number of rings stuck or broken as shown in the figures was in each case the total of such rings on the four top or bottom pistons of each engine. Each piston had five rings and it was usual, if only one ring was stuck or broken, for it to be either the first or second ring.

The authors questioned the accuracy of extrapolating linearly the correlation line of the effect of fuel sulphur content on liner wear rates as shown in Fig. 13 to zero sulphur content, as suggested by Mr. van Asperen. Experimental work on high-speed Diesel engines indicated that variation in sulphur up to at least 1·5 per cent had a pronounced effect on liner wear rates, whereas for fuels of higher sulphur content the liner wear rate did not necessarily increase linearly. A similar state possibly existed in the large slow-speed marine Diesel engine and hence it was considered unwise to extrapolate the correlation line without more information on low sulphur fuels.

Mr. Arnold's assumption that the fuels burnt by Vessels A, B and C were boiler fuels, by which it was presumed he meant normal bunker fuels, was not altogether correct as these vessels had bunkered regularly with fuels premium in quality and price to bunker fuel. The viscosity of the bunker fuel available at many of the ports where these vessels lifted fuel, was of about 3,500 secs. Redwood No. 1 at 100 deg. F. Mr. Arnold was able to bunker his vessels with fuels not exceeding 1,500 secs. viscosity, presumably at bunker fuel price, because of the local conditions existing at the ports where the vessels took bunkers which were tabulated in Table XII of the Twenty-seventh Thomas Lowe Gray Lecture, delivered before the Institution of Mechanical Engineers by Mr. L. Baker*. If his vessels had bunkered regularly in European and Western Hemisphere ports, the viscosity of bunker fuel available would have been normally in excess of 1,500 secs.

As the authors were not shipowners, it was impossible for them to decide what wear figure could be considered acceptable. An acceptable figure could only be arrived at after analysing all the operating costs of an engine, related to a suitable return on investments, and only the operator was in a position to supply all this information. No doubt many operators were eager to obtain wear rates lower than the calculated acceptable figure. It was interesting to hear that when Mr. Arnold's company originally went in for two-stroke cycle engines, which was in 1936, the experts at that time agreed that wear rates of 0·20 to 0·25 mm. per 1,000 hours would be reasonable and that latterly these figures might be reduced to 0·15 to 0·20 mm. per 1,000 hours for operation in all cases on marine Diesel fuel. Mr. Jackson quoted average liner wear rates on Doxford engines running on Diesel fuel of as low as 0·075 mm. per 1,000 hours, giving a liner life in cargo ships approaching ten years, whereas Mr. Smith, in the written correspondence referred to the liner life as six to seven years. The authors had stated during the presentation of the paper that their information on liner wear rates using Diesel fuel was rather limited but what figures they had supported the views of Mr. Arnold and Mr. Smith.

If, when using boiler oil, an average liner wear figure of 0·2 mm. per 1,000 hours and a liner life of three-and-a-half years, as quoted by Mr. Jackson, were used as a basis for calculating the number of days per year a vessel was at sea, assuming that the liner was scrapped when the maximum wear was 1 per cent of the diameter, it meant that vessels with engines similar to Vessels A and B would be at sea for 357 days per year, which was unrealistic. Commander Meadows had read out from "Lloyd's List" that during 1953 the average number of days spent at sea for dry cargo ships was 150. The authors, therefore, did not consider the wear rates reported by them to be very high as suggested by Mr. Jackson, since vessels spending 150 days per year at sea in which the liners last three to four years, would have similar wear rates.

The liner wear rates on the *Bellerophon* were very similar to those on Vessel C, namely 0·35 and 0·32 mm. per 1,000 hours respectively over approximately the first 10,000 hours of operation. The wear rates on the *Bellerophon* then decreased to about 0·30 mm. per 1,000 hours, which Mr. Arnold considered was due to a modification to the builder's fuel oil valves. It could be seen from Fig. 18 that the cylinder cooling water outlet temperature was increased from 138 to 160 deg. F., which in the opinion of the authors, would also contribute to the reduction in liner wear rates. The wear rates for the *Alcinous* and *Laomedon* of 0·21 and 0·20 mm. per 1,000 hours respectively (total operating hours between 8,000 and 11,000 hours) must be encouraging indications to Mr. Arnold of the superi-

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* Baker, L. 21st Jan. 1955. "Some Factors in the Selection of Machinery for Cargo Liners".

ority of the Archaouloff system over other types of fuel injection equipment.

There was no intention on the part of the authors that liners should be replaced when the total wear was equal to 0·6 per cent of the liner's diameter. One of the main reasons for keeping in close contact with these vessels was to investigate what effect different features of the fuel had on day to day operation of the vessels, engine cleanliness and liner wear rates. It was shown in the paper that liner wear rates increased rapidly when the total liner wear exceeded 0·6 per cent of its diameter and this increased rate of wear could not be attributable to any particular feature of the fuel. Hence it was considered advisable to discard these high rates of wear which were attributable, in part at least, to the mechanical condition of the piston and liner assembly in arriving at the conclusions based on fuel features related to wear rates.

Mr. Arnold quoted part of a sentence from the summary of the paper about the desirability of advancing the period of fuel injection in certain instances and had asked for more information on how it should be done and as to whether it was on account of the viscosity or flash point of the fuel. This information was given on pages 42, 43 and 54 of the paper; the ships' engineers took the necessary action and were satisfied with the results.

Mr. Arnold spoke about the vessels in his company having fewer piston rings stuck or broken than in the case of Vessels A and B but it was unfortunate that the figures he quoted had not been more conclusive. Was the reader to assume that in the twenty-one liners in the three ships he mentioned with a combined total operating hours of 36,000 hours, there had been no stuck rings and only eight had been renewed? To the authors it would appear to depend on what period of time was covered by one record sheet.

Mr. Arnold's remarks concerning the causes of crankshaft corrosion were very interesting. As stated in the paper, the authors were of the opinion that this serious condition was caused by a series of factors; the two most important were the presence of water and the ingress of acidic unburnt cylinder lubricant and sludge into the crankcase. The frequency of this trouble had undoubtedly increased with the introduction of residual type fuels; however, it could be recalled that several vessels in the past had suffered from corrosion when operating on marine Diesel type fuels. The complete solution to this problem was very complex but could possibly be solved by modifications to engine design as suggested by Mr. Jackson, coupled with the development of new type cylinder lubricants and improved crankcase lubricant centrifuging technique.

The self-cleaning type of separator was an advantage for everyday use compared with the type that had to be cleaned manually but it was important that its centrifuging efficiency should be as high. The use of the manually cleaned centrifuges on board these vessels had enabled the authors to collect valuable data on the amount of sludge removed from the various fuels on a day to day basis. Filters were often fitted in the fuel lines between the fuel pumps and the injectors in some makes of engines and it was essential to ensure that the porosity and cross sectional area of these filters were large enough to avoid any appreciable pressure drop across them when using residual fuel. If this precaution was not taken, the filter could have an appreciable effect on the pressure and quantity of the fuel available at the injector at the right time in the combustion cycle otherwise the combustion process could be adversely affected.

Steps were being taken to reduce the sulphur content of distillates and research was active on what might be done to reduce the sulphur content in residual fuels. As regards the latter, no economic method was as yet available. It was unlikely, however, that sulphur contents in excess of the figures (4 to 5 per cent) mentioned by Mr. Arnold would be exceeded.

In writing the paper, the authors felt that the general information they had collected from various technical journals would serve as a useful introduction to the main part of the work and they trusted that readers would notice other figures of the paper besides the one highlighted by Commander Meadows. In the example given on page 39 of the annual saving in fuel cost between using Bunker C and marine Diesel fuel, the daily fuel consumption and the number of days the vessel spent at sea were clearly stated. There was no intention that any of the figures quoted referred to the vessels used in the field test described in the paper. An alteration to the number of days at sea could be taken care of by a simple recalculation to assess the fuel saving.

Some approximate calculations were made of how many days the vessels spent at sea and it would appear that there was some error in Commander Meadows's figure of 85 days per year for Vessel A, as the authors' calculations made it very similar to Vessel B, namely 135 days per year. During the period covered by the paper, Vessel D was converted to use residual fuel and this was the reason why the vessel spent an average of only 250 days per year at sea and in any case the vessel was being used for experimental purposes which might in some instances have prolonged its stay in port compared with normal tanker operation.

Mr. Jackson, in his contribution, had given some insight into current development work on Doxford engines and it was interesting to note that in recent years, the standard nozzle or flame plate was now being replaced by a more normal type of pip ended nozzle. In Vessel D, the pip ended nozzle had been in use for many years. It was the prerogative for all research workers to reverse previous decisions and Mr. Jackson described how recently a new injection system using spring loaded CAV injectors had improved the combustion when using boiler fuels, whereas previously he had held the view that the "common rail" system of the Doxford engine with its relatively large holes was more in line with the air injection engine and was better adapted to the use of boiler fuels than systems using the "jerk" type of injection pump. There was no doubt that an efficient injection system was a valuable asset in burning residual fuels and it was encouraging to note that the Archaouloff system, as advocated by Mr. Arnold, was proving very beneficial.

The remark was made that the fuels supplied to Vessels A and B would have met the original Doxford requirements, in which case the sum of the Conradson carbon and sulphur should not exceed 14 per cent. This was not altogether true because after determining the Conradson carbon content of the fuels used up to August 1952, this test was omitted from the inspection features as it was thought to bear little or no comparison with engine performance. Mr. Jackson referred to the figures given for Conradson carbon, sulphur and asphaltenes in Table IV, but it was assumed that this was a misprint and he actually meant Table VI. The figures in the minimum and maximum columns of Table VI did not necessarily all belong to one fuel but were the minimum and maximum recorded of each inspection feature during the period stated. For instance, in the period between May 1950 and December 1951, the fuel with the maximum Conradson carbon content of 10·5 per cent had a sulphur content of 2·4 per cent, whereas the fuel with a maximum sulphur content of 3 per cent had a Conradson carbon content of 8·4 per cent. This example and many others that could be taken from the Appendix tables disproved the theory, that because one feature of a fuel was high, all other features were inherently high.

Mr. Jackson had given the impression that what he termed as high wear rates on Vessel A were due to "a dirty brown coloured exhaust" on the engine. This black exhaust only occurred for one voyage until it was cured by advancing the injection timing and, therefore, it could not have affected the wear rates during following voyages, and there was no evidence to show that the wear rates were reduced after altering the fuel valve timing. Operators should watch, however, that the maximum pressure in the cylinder did not fall below 600lb. per sq. in. as suggested by Mr. Jackson, otherwise they could run into troubles through incomplete combustion.

The reasons for the very large amounts of sludge centrifuged from boiler fuels reported by Mr. Arnold in his paper* before the Institute two years ago, and for similar figures given by Mr. Jackson, were not known and it would be interesting to know whether Mr. Arnold had investigated this point with his fuel supplier or expected such sludge realizing that the fuel's primary function was for use under boilers. It was surprising that no fuels of this kind were bunkered by Vessels A, B and C, which used predominantly fuels originating from Middle East crudes; but without inspection data on reliable samples, it was impossible to arrive at any firm conclusions as to whether the sludge was adventitious or inherently in the fuels.

Fig. 10, which represented the effect of total operating time on liner profile in Vessel B, was perhaps not strictly correct in that the liners were gauged at the centre of the combustion space and 3¼in. above and below; the points were then connected by straight lines and it would have been more correct to assume that there was a vertical distance on either side of the centre of the combustion chamber where there would have been no wear. The significant feature between Fig. 7 for Vessel A and Fig. 10 was in the shape of the wear profile attributable to the different piston designs used in each engine.

The authors would strongly endorse Mr. Jackson's remarks concerning the water washing of crankcase lubricants. Their direct experience with two Doxford engined vessels, other than those quoted in the paper, had shown that by the use of water washing, and closely controlled purification in two centrifuges in series, it was possible to remove all traces of mineral acidity from the oil. In the case of one of these vessels, when severe crankshaft corrosion had taken place after only a few months' operation, the adoption of water washing, in conjunction wit' minor modifications to the scraper box assembly, succeeded, j- a short space of time in arresting further corrosion, and in fact several of the smaller etched areas on the shaft disappeared. The methods of centrifuging were similar to those outlined by Mr. Jackson. In one of the vessels a normal continuous centrifuging process was employed. In this system, approximately 10 per cent of fresh water at 180 deg. F. was introduced and dispersed into the dirty oil, also at 180 deg. F. prior to the first centrifuge. The mixture was then passed through two similar centrifuges operated in series, and the final clear oil was passed back into the engine system. It was found that the use of 10 per cent water was sufficiently high to ensure complete washing of the oil, and at the same time low enough to be completely removed by the two centrifuges. By this method the mineral acidity of the oil passing through the centrifuges was completely removed, but only reduced to a given minimum in the overall system. This minimum was determined by the rate of input of acidic sludge into the crankcase resulting from the products of combustion. In the other vessel where corrosion occurred initially, the continuous purification system was augmented by a batch system. This method necessitated carrying two complete changes of oil and increased centrifuging capacity. One charge of oil was batch purified during a voyage while the other in the engine system was centrifuged on a continuous basis. In this way a completely clean change of oil was introduced into the system at the end of each voyage, and circulated whilst the ship was in port to prevent any possible corrosion taking place during the time the engine was stopped.

Mr. Jackson had asked whether it was possible by slowing down the rate of centrifuging fuel to compensate for a lowering in the temperature. At any given temperature of operation the separating efficiency of a centrifuge varied directly with the differential density between the liquid and the media to be separated, and inversely, with the absolute viscosity of the liquid. In view of this, at any given temperature and throughput, an increase in viscosity would bring about a fall in separating efficiency. Thus, as the viscosity of the fuel concerned varied uniformly with temperature, any drop in centrifuging temperature would be associated with a falling off in separating efficiency.

The authors could assure Mr. Martin they had no intention that shipowners should look upon 8 per cent asphaltenes in the fuel as the maximum the Diesel engine could burn and no doubt fuels containing greater amounts could be burnt with complete success. Mr. Lamb, in his valuable contributions* on the general subject of burning boiler oils in marine Diesel engines, had concentrated on the equipment and modifications necessary and had not given much information on the features of the fuels he had used. After the poor combustion on Vessel A had been attributed to the asphaltene content of the fuel, the authors had re-studied Mr. Lamb's papers to see if he had recorded any similar experience but found that in only one instance had he reported an asphaltene content in the fuels actually used at sea.

Mr. Martin and Dr. Zimmermann had asked for details of the test method described as the sediment by hot filtration, and this could be found in an article† in "Industrial and Engineering Chemistry". The method was originally developed as a useful indication for predicting the storage performance of fuel oils and gave promise of value in connexion with tests for determining its tendency towards fouling of preheaters. It had been found that this test predicted field conditions more reliably than the older sediment by extraction test. Whether the correlation between the sludge removed from the fuel and its sediment by hot filtration content was truly arithmetical was perhaps doubtful but the authors felt from all the information they had available from the four vessels, which did not all use the same type of centrifuge, it was possible to show some probable connexion between these two features.

Mr. Martin commented on a remark made by Mr. Royle during his presentation talk on the reproducibility of test methods and for the sake of completeness, the remarks were repeated here: —

> "It should be pointed out that the Conradson carbon tests is not very accurate and the Institute of Petroleum method states that duplicate tests should not differ by more than 20 per cent of the mean. However, the results of tests from one and the same laboratory are usually within 5 per cent of the mean; the user should therefore realize that there are no significant differences between two fuels having Conradson carbon values of 9·5 and 10·5 per cent respectively".
>
> "There are a number of tests which are used in different parts of the world for determining asphaltenes and the results from each test method differ because of the different procedures and solvents used".

Mr. Brown's reference to the importance of determining neutralization value on the used crankcase oil was fully appreciated. The analytical results shown in Table XXI were, however, prepared at several different laboratories, employing different methods for the determination of neutralization value. Thus, to avoid confusion of results, none of the values were reported. The authors would mention that the difference between the iso-pentane and the benzine insolubles represented the complex organic contamination resulting from oxidation of the oil. This value normally increased with an increase in neutralization value, and was also considered to be indicative of general deterioration and oxidation of the oil.

In view of Mr. Brown's comments it should be stressed that the present normally accepted neutralization value method was the total acidity of the oil, namely both organic and inorganic. Thus, whilst the neutralization value mainly indicated the acids formed in the oil due to oxidation, it also included any build-up of mineral acidity that might be taking

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* Arnold, A. G. 1953. "The Burning of Boiler Oil in Two- and Four-stroke Cycle Diesel Engines and the Development of Fuel Injection Equipment". Trans.I.Mar.E., Vol. LXV, p. 57.

* Lamb, J. 1948. "The Burning of Boiler Fuels in Marine Diesel Engines". Trans.I.Mar.E., Vol. LX, p. 1.
1950. "Further Developments in the Burning of Boiler Fuels in Marine Diesel Engines". Trans.I.Mar.E., Vol. LXII, p. 217.

† 1938. Industrial and Engineering Chemistry, Vol. 10, p. 678.

place, as the result of contamination from unburnt cylinder lubricant and sludge, activated with sulphur acids from the products of combustion. It was considered that these mineral acids in the crankcase, in the presence of water and, under certain conditions, were responsible for causing crankshaft corrosion. The mineral acids present represented only a very small proportion of the overall neutralization value, even when corrosion was known to be taking place. In view of this the neutralization value could not be regarded as a control to indicate the possibility of corrosion. Only a specific test for mineral acidity could give such an indication.

The reference made by Mr. Brown that some detergent cylinder oils were known to fall short of their full requirements was interesting and was in line with some of the authors' experiences. They would agree that the limited operational results obtained with the experimental detergent naphthenic oils used in Vessel D could not be considered as conclusive evidence to justify the rejection of all types of detergent lubricants.

In reply to Mr. Kaare Haug's question, the authors had had no experience using colloidal graphite in cylinder oils in marine Diesel engines and while it was to be expected that the liners would have a mirror-like finish and the piston rings would be free in their grooves, the effect of adding colloidal graphite on liner, piston ring and ring groove wear rates would be necessary before reaching a final conclusion. The authors were inclined to agree that the liner wear rates quoted for ships K, S and G were lower than those given in the paper because the engines were never operated at more than 80 per cent of normal output and usually only to 75 per cent. This fact was borne out very well by the way in which the wear figures concerned correlated with the power/wear data given in the paper on page 53 for Vessels A, B and C. But this undoubtedly meant fitting a larger engine at greater capital cost into a ship than was really necessary and, therefore, this step could only be taken after deciding whether it was more economical than running a smaller engine at full power and expecting slightly higher cylinder liner wear rates. The large differences in the maximum liner wear rates between the cylinders of each engine for ships K, S and G indicated the basic errors that might be present when comparing different cylinder lubricant simultaneously in one or two cylinders of a single multi-cylinder engine. As the makes of engines in Vessels K, S and G were all different, the authors reiterated their remarks made when replying to Mr. van Asperen that development work in ensuring the cylinder lubricating oil was used to the best advantage, was necessary and overdue.

Mr. Smith had asked for the names of the bunkering ports used by Vessel C and he would find these and also those for Vessels A and B in the Appendix tables at the end of the paper.

As Vessel D had used fuels which were specially segregated so that a fairly uniform supply was available for each test period, the authors had summarized the fuel inspection data available. It was assumed that a printing error had arisen in that liners Nos. 1 and 2 were not renewed on the comencement of Test Period 3 but at the start of Test Period 4. During Test Period 3, a fuel of about 1,600 seconds viscosity was used and the authors had referred to it in the text of the paper rather loosely as a blended fuel. Mr. Smith would now appreciate after reading the preface to the paper, that all fuels contained many refinery component streams and, therefore, bunker fuels available on the market were in fact blends. There was nothing abnormal about the way the 1,600 seconds fuel was prepared which was in accordance with general procedure throughout the petroleum industry for producing the various viscosity grades of fuel oil sold to all users. From the records the authors had available it was not possible to give the inspection features of the two main components used in making the 1,600 seconds fuel but their viscosities would be about 3,500 and 40 seconds for the bunker and Diesel fuel components respectively.

During the test period five batches of this fuel were made and samples from the storage tank were inspected at frequent intervals and the results were given in Table XXXVI. What differences there were in the viscosities of all these samples could be attributable, firstly, to the difficulties in accurately sampling a large tank of fuel and, secondly, to the practical difficulties in ensuring that the resulting mixture had the desired

TABLE XXXVI.—INSPECTION DATA OF FUEL SAMPLES TAKEN DURING BUNKERING OF VESSEL D. TEST PERIOD III. MAY 1951 TO MARCH 1952

Batch number	1	1	1	2	2	2	3	3	3
Date of sample	26/5/51	10/7/51	24/7/51	6/8/51	21/8/51	2/9/51	16/9/51	30/9/51	14/10/51
Specific gravity at 60 deg. F/60 deg. F.	0·965	0·967	0·967	0·963	0·963	0·963	0·955	0·956	0·955
Viscosity Redwood No. 1									
at 100 deg. F., sec.	1,580	1,700	1,800	1,475	1,450	1,650	1,575	1,600	1,600
at 200 deg. F., sec.	108	115	120	107	108	120	115	109	115
Flash point P.M. closed, deg. F.	196	174	189	194	240	196	245	222	250
Conradson carbon, per cent	11·2	10·7	10·9	10·4	11·2	11·5	10·4	10·4	10·2
Water, per cent	0·1	Trace	Trace	0·1	0·1	0·1	0·1	Trace	Trace
Sediment by hot filtration, per cent	0·03	0·03	0·02	0·03	0·02	0·03	Trace	0·01	0·01
Ash, per cent	0·07	0·09	0·07	0·06	0·07	0·06	0·06	0·06	0·06
Sulphur, per cent	—	—	—	2·3	2·3	2·3	2·2	2·2	2·2
Asphaltenes, per cent*	8·4	8·7	8·5	8·5	8·3	7·8	7·5	7·3	7·5
Bottoms, sediment and water, per cent	0·2	0·1	0·1	0·3	0·3	0·2	0·1	0·1	0·1

TABLE XXXVI (*continued*).

Batch number	4	4	4	5	5	5	5
Date of sample	28/10/51	11/11/51	25/11/51	27/12/51	13/1/52	26/1/52	23/2/52
Specific gravity at 60 deg. F./60 deg. F.	0·959	0·959	0·959	0·961	0·959	0·963	0·965
Viscosity Redwood No. 1							
at 100 deg. F., sec.	1,500	1,510	1,700	2,000	1,950	2,100	2,000
at 200 deg. F., sec.	108	107	120	133	132	142	125
Flash point P.M. closed, deg. F.	228	230	228	180	224	212	204
Conradson carbon, per cent	11·4	11·2	10·7	10·9	10·6	10·8	10·8
Water per cent	Trace	Trace	Trace	Trace	Trace	Trace	Trace
Sediment by hot filtration, per cent	0·10	0·04	0·03	0·01	0·02	0·04	0·05
Ash, per cent	0·07	0·07	0·08	0·09	0·09	0·09	0·08
Sulphur, per cent	2·2	2·2	2·5	2·4	2·4	2·4	2·4
Asphaltenes, per cent*	8·8	8·1	8·1	8·2	8·1	8·1	9·8
Bottoms, sediment and water, per cent	0·1	0·1	0·1	Trace	Trace	Trace	0·2

* Determined as insolubles in 86 degrees naphtha.

viscosity. For instance, there was a variation of 220 seconds in the Redwood No. 1 viscosity scale at 100 deg. F. between the various samples inspected from any one batch of fuel, and a difference of 490 seconds between the mean viscosity figure for each batch. In Table XXIV the viscosities of 920 and 1,000 seconds Redwood No. 1 at 100 deg. F. given as the minimum values for the untreated fuel from the bunker tanks and the treated fuel from the day tank respectively were exceptional figures. During the period of the test twenty-eight samples were drawn from each of these two sampling points and only one pair of samples had viscosities of below 1,360 seconds. The minimum figures quoted in the table were therefore exceptional and most likely the result of some contamination with a lighter product. From all the other features of the fuel, it would be seen that there was no tendency for this fuel to separate out into its original components during storage.

Mr. Smith had gained the impression after reading in the paper of the experiences related during Test Period 4 on Vessel D, that it was wise to avoid fuels of 3,000 seconds viscosity wherever possible. The inspection features of the fuel, which was used during the month of May 1952, were given in Table XXV and similar data on the better quality Bunker C fuel used from June 1952 to April 1953 were given in Table XXVI. The authors realized now that the use of the term "better quality" was not really correct as it could be seen from the data given in these two tables that the only differences between these two fuels were in their sediment by hot filtration and asphaltene contents. The reason for withdrawing the fuel used during the month of May was because the number and size of the centrifuges installed on board the ship at that time could not cope with the amount of sludge removed from the fuel. The amount of sludge was, in fact, only 3·2lb. per ton of fuel treated, and from what Mr. Arnold and Mr. Jackson said, far greater amounts had been encountered in Middle East fuels considerably lighter in viscosity. The authors were, therefore, not in agreement with the suggestion that it was wise to avoid using fuels of 3,000 seconds on the evidence given in the paper.

Dr. Zimmermann had stressed the importance of the cooling water temperatures on the formation of residues on the liner surfaces and piston ring zone with their ultimate effect on wear rates. Mr. Jackson had commented similarly and also referred to the fuel temperature at the fuel valves. The figures quoted by Dr. Zimmermann were lower than those used in the vessels described in the paper, where cooling water outlet temperatures were usually between 155 and 160 deg. F. Troubles encountered in service where excessive deposit formations occurred, could often be attributed to the lower temperatures used for the cooling media but it usually proved impossible to obtain reliable figures. The use of thermostats in the cooling water lines to ensure that the engine did not operate, especially when manœuvring, under cold conditions would be of great assistance to the engineers and relieve them of the need continually to manipulate valves.

Nearly all the contributors had added some extremely useful data to that already given in the paper on the numerous factors that might have an important influence on cylinder liner wear. By carefully observing all these points and using them to the best possible advantage, the troubles experienced in using these residual fuels by some operators, should disappear. The authors agreed wholeheartedly with Mr. Arnold when he said that there was no doubt that the vessels' engineering staffs played a very big part in the success or otherwise of the burning of residual fuels.

INSTITUTE ACTIVITIES

Minutes of Proceedings of the Ordinary Meeting Held at the Institute on Tuesday, 14th December 1954

An Ordinary Meeting was held at the Institute on Tuesday, 14th December 1954, at 5.30 p.m., when a paper entitled "Fuel Features Related to Operating Experiences in Motorships Using Low Cost Fuel", by H. F. Jones, M.C., F.Inst.Pet., D. Royle, B.Sc.(Eng.) (Associate Member), and R. G. Sayer, B.Sc.(Eng.) (Associate Member), was presented and discussed. Mr. J. P. Campbell (Chairman of Council) was in the Chair. Members and visitors present numbered 120 and six speakers took part in the discussion.

A vote of thanks to the authors, proposed by the Chairman, was accorded by acclamation. The meeting ended at 8.10 p.m.

Section Meetings

Calcutta

Mr. J. Connell (Local Vice-President) took the Chair at a meeting of the Calcutta Section on 15th December 1954, at the Directorate of Marine Engineering College in Calcutta. He welcomed the eighty members, guests and cadets of the College who were present and introduced Mr. J. H. S. Stevenson (Member) who, in co-operation with the staff of the Directorate of Marine Engineering Training, had prepared a paper on "Fundamentals of Boiler Water Testing and Analysis". The paper was presented by Mr. K. S. Subramanian (Member), after which the audience were invited into the laboratory to see the various tests referred to in the paper being carried out by students of the college.

The Chairman complimented Mr. Stevenson, Mr. Subramanian and the students on the excellent way the tests were conducted and a good discussion followed, to which Captain T. B. Bose (Member), Mr. S. Kasthuri (Member), and Mr. S. Basak contributed.

The meeting ended after the Chairman had proposed a vote of thanks to Mr. Stevenson and his colleagues.

Merseyside and North Western

At a meeting of the Merseyside and North Western Section held on 3rd January 1955, at 6.30 p.m., at the Royal Institution, Colquitt Street, Liverpool, the Chairman, Mr. T. McLaren, called upon Mr. L. Baker, D.S.C. (Vice-President) and Mr. W. H. Falconer, a local member, to present their paper entitled "Operational Experience with s.s. *Nestor* and s.s. *Neleus*". Mr. Baker introduced the paper and Mr. Falconer presented it, illustrating many points with lantern slides and a short film.

Mr. K. P. Campion opened the long and detailed discussion by complimenting Mr. Baker on his initiative in pioneering this class of vessel.

Mr. T. Kameen proposed a vote of thanks to the authors for the very interesting way in which they had presented their paper and for the excellent manner in which Mr. Baker had answered questions.

Eighty-seven members, visitors and students attended.

Scottish

A Students' meeing was held in Glasgow by the Scottish Section on 14th January 1955, and Mr. D. W. Low, O.B.E., Chairman of the Section, presided.

A very interesting lecture on "Ship and Machinery Trials" was delivered by Mr. J. Rogerson on behalf of the author, Mr. G. E. Barr, who had been called overseas on business. The lecture was illustrated by lantern slides and indicated how ship trials should be run to obtain reliable and useful information. Twelve members and students took part in the discussion which followed.

In his proposal of thanks, which was heartily acclaimed, Mr. A. Robson (Committee Member) expressed warm appreciation to Mr. Rogerson for deputizing for the author on very short notice and asked him to convey the Section's thanks and congratulations to Mr. Barr for an excellent paper.

Junior Section

Wandsworth

On 28th January 1955, a Junior Lecture was given at Wandsworth Technical College. Dr. S. C. Robinson, M.Eng., the Principal of the College, passed the Chair to Mr. W. T. Body, Head of the Mechanical Engineering Department, who called upon Mr. R. B. Cooper, M.B.E., B.Sc., to present his lecture on "Oil Fuel Burning". The discussion that followed was brief but to the point. The lecture was excellent and deserved a larger audience than the eighteen students who attended.

Mr. A. H. Wilson (Member), on behalf of the Council of the Institute, expressed thanks to the lecturer, to Mr. Body and to Dr. Robinson.

Student Lecture

A meeting was held at the Institute on 17th January 1955, at 6.30 p.m., when Mr. W. H. Booth (Member) gave a lecture entitled "Deck Machinery". Mr. H. C. Gibson (Associate Member) was in the Chair.

Mr. Booth said that the purpose of the lecture was to deal with developments in recent years. The lecture was in three sections: the first dealt with steam machinery, the second with electrical machinery, and the third with maintenance, a knowledge of the latter being a vital requirement for the engineer in order that his machines might be always ready for immediate use.

Mr. Booth illustrated his lecture with numerous slides showing windlasses, winches, capstans, the electric deck crane, and the Suez Canal searchlight. Afterwards he answered various questions put by the audience.

At the close of the meeting the Chairman proposed a vote of thanks to Mr. Booth, which was carried unanimously.

Election of Members

Elected on 2nd February 1955

MEMBERS

Clifford Breckon
Ralph Stanley Chambers
Peter Hugh Vernon Evers
Stewart Samuel David Graham
William Martin Grieve
Oswald Helsby
William John, M.B.E.
George Kinchin
John Rhys Murray
William Leonard Spear, Cdr.(E), R.N.(ret.)

ASSOCIATE MEMBERS

Geoffrey Hardy Antieul
Peri Norman Cosmetto
Arthur Duke
Herbert George Evans
Cyril Bertram Rodrigo Goonewardene
Frank Green
William Evan Henson
Colin George Jackson
Charles Riddell Ligertwood
Peter Spencer McMillan
Kenneth Alfred Smith
Robert Colquhoun Stewart

ASSOCIATES

Clifford Catterall
Dorian Davies

Brian Desmond Hamilton
John Julius Wells, M.A.

GRADUATES
Donald Henry Andrew
Michael J. Fonseca
Mazhar Husain, Sub. Lieut.(E), R.P.N.
Brian Hilary Francis Jacotine
Seshachalam Kasturirangan
John Gordon Kellett
Charles Edouard France Lanier
Arthur Nightingale
Philip Edward Sporle
Raymond Frank Surplus
Ian Howard Taylor
Ronald Whittaker

STUDENTS
Bibekananda Bonnerjee
Geoffrey William Goodbody
John Dilnot Watson

PROBATIONER STUDENTS
Thomas Ashton
Alfred William Bryce
Michael Ralfs Casey
Derek George Darley
David Warwick Dean
John Vincent Dodshon
Bryan Geoffrey Gleed
Keith Heald
Rodney Allen Hill
Thomas Herbert Howcroft
Edward Glyn Hughes
John Michael Mitchell
Stewart Affleck Reid
Brian Smith
Peter Waite
Gordon Whalley
David Williams
Ian Atterton Wilson

TRANSFER FROM ASSOCIATE MEMBER TO MEMBER
Stanley George Chapman, B.Sc.(Eng.)

TRANSFER FROM ASSOCIATE TO MEMBER
William Eades

TRANSFER FROM ASSOCIATE TO ASSOCIATE MEMBER
Peter John Atkinson
Norman Edward Brown
Victor Edward Bull, Lieut.(E), D.S.C., R.N.(ret.)
Edward Cherry
John Hampson Dean
John Stanley Dixon
Alexander Forbes Gordon
Charles George Edward Gudge
George Hawkins
Leslie Horton
Eric Coleman Knowles
Hughie Austin Lohrmann
John James McKeon
Eric Hewitt Oakes
Christopher Michael O'Grady
John Leigh Porter
Alan Edward Radcliff
Alfred Emslie Riach
Leonard Sweeney
Kailash Behari Lal Varma
William Peter Walby
Dennis Hinton White
James Whitehead
Cuthbert Thomas Williams
Arthur William James Yeandle

TRANSFER FROM GRADUATE TO ASSOCIATE MEMBER
Albert Ernest Curle, Flight Lieutenant

TRANSFER FROM STUDENT TO GRADUATE
Ronald Atthey Dick, B.Sc.
Geoffrey Christopher Levett

TRANSFER FROM PROBATIONER STUDENT TO STUDENT
Stuart Wilson Blythe
John Duncan Gibb
Alan Stewart Whitaker

OBITUARY

ARTHUR REGINALD KEYMER (Associate Member 7741) died on the 25th January 1955, at Buxted in Sussex, after a long illness which he bore courageously.

After studying at Pangbourne Nautical College, he served his apprenticeship with John Brown and Co., Ltd., at Clydebank, from 1925-30 and attended the Royal Technical College, Glasgow, for three winter sessions, obtaining the Diploma of the College and the Higher National Diploma of the Institution of Mechanical Engineers. He then served at sea with the Avenue Shipping Co., Ltd., the Australind Shipping Co., Ltd., and the China Navigation Co., Ltd., and was elected an Associate Member of the Institute in 1934. He obtained his First Class Motor and Steam Certificates and in 1937 passed the Institute of Marine Engineers' Associate Membership Examination. In 1938 he passed the Extra First Class Engineers' Examination.

After gaining this certificate, Mr. Keymer spent some time teaching and then went out to Burma as an engineer and ship surveyor to the Government Marine Department, holding this position until the country was invaded in 1942. He then made the long trek to India and joined the Royal Indian Engineers, rising to the rank of Lieutenant Colonel. For a time he served as Assistant Director of Transportation and was attached to the 14th Army. He was mentioned in despatches for his services. At the end of the war he returned to Burma and was appointed Principal Ship and Engineer Surveyor to the Government Marine Department.

On his return to this country after serving in Burma, Mr. Keymer took up an appointment as superintendent engineer with the Anglo Danubian Transport Co., Ltd., and its associated companies. Later he served as a superintendent engineer with the Navigation and Coal Trade Co., Ltd. His last appointment was as superintendent engineer with Silvertown Services, Ltd., and throughout his long illness contact was kept with the ships that he loved.

Aviation was another of his great interests; he was a member of the Redhill Flying Club and had completed several hours' solo flying.

Mr. Keymer was well known in shipping circles, both at home and on the Continent; he was loved and respected by all who came in contact with him and this love and respect was undoubtedly due to his kind and understanding manner and his ability as a marine engineer. His passing was mourned by all who knew him. S.G.C., 22/2/55