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CONTENTS

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TRENDS IN MARINE FUELS AND LUBRICANTS TODAY AND IN THE 1990s

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SYNOPSIS

The paper summarizes crude oil availability and possible future synthetic fuels. The influence of refining techniques on fuel trends, quality and combustion properties are dealt with in some detail. Other foreseeable problems of storage, incompatibility and purification are also discussed. An example of the economics of onboard blending is given. The influence on lubrication trends by future diesel engine developments, the economics of engine maintenance and the effects of the reduction in ships staff are discussed in some detail for both crosshead and medium speed engines. An example is given of synthetic lubrication economics. Future gas and steam turbine oils and hydraulic fluids are also discussed briefly. The world economy depends on readily available energy. However, the increasing cost of this energy and the indications that known sources of conventional energy are limited underlines the need for continual appraisal of existing supplies. Current forecasts indicate that demand for crude oil will exceed availability from known sources before the end of the century. This paper attempts to set out the marine fuels and lubricants position up to the 1990's as foreseen by the authors' company. It is outside the brief of this paper to discuss more speculative alternate energy sources such as solar, tidal, synthetic fuels, mechanically-operated sails, etc.

MARINE FUELS

The "oil shock" of 1973 resulted the following year in a 13% reduction in the sales of marine bunkers against an estimated 6–7% growth rate. Because of high crude costs, conservation will continue to slow down growth rate to an estimated 3% per annum.

We believe liquid fuels will continue to supply the marine bunker demand into the 1990's and Figure 1 shows the estimated petroleum energy demand for Europe up to 1990. Demand may be above this level in some emergent countries and lower in the USA.

A study of these growth rates gives us a clue as to future refinery crude processing. Broadly speaking, gasoline demand is met by catalytic cracking, distillate demand by vis-breaking. As the future rate of demand is greater for distillates, more refineries are likely to install vis-breakers than catcrackers.

Figure 2 shows that currently only 6.2% of crude is subject to cracking and 2.7% to vis-breaking. The 1983 forecast shows only slight increases on these figures. Furthermore, without cracking, residual fuel can account for up to 38% of the crude processed, whereas with cracking only about 6% is manufactured. These figures show that there is relatively little cracked residual fuel about and the rate of increase is relatively slow. Nevertheless, in certain areas, nearly all the bunker fuel may be cracked and, as the cracking processes have a downgrading effect on the fuel qualities, it is essential that these are recognized so that unnecessary problems can be avoided.

The refining techniques are schematically shown in Figure 3. The maximum gasolene yield is obtained by the use of vacuum distillation of the atmospheric residue and passing the heavy distillate from this distillation through the fluid catalytic cracking unit. (F.C.C.). This process derives its name from the catalyst which is in such a fine powder form that it appears to behave like a fluid.

The cracking process takes more of the light ends, that is to say, more of the hydrogen content from the fuel leaving a higher proportion of carbon which adversely affects the ignition and combustion qualities of the fuel.

Vis-breaking acts on the heavy residual from the vacuum distillation tower. By a low degree of thermo-cracking the vis-breaker reduces the viscosity of the vacuum residue and thus saves the need for adding gasoil to reduce the viscosity. Thus up to 10% more gasoil is made available for automotive and other uses when a vis-breaker is fitted.

Additionally, there is a danger of a small amount of catalyst fines finding their way via the F.C.C. slurry oil into the marine fuel oil. The catalyst consists of aluminium-

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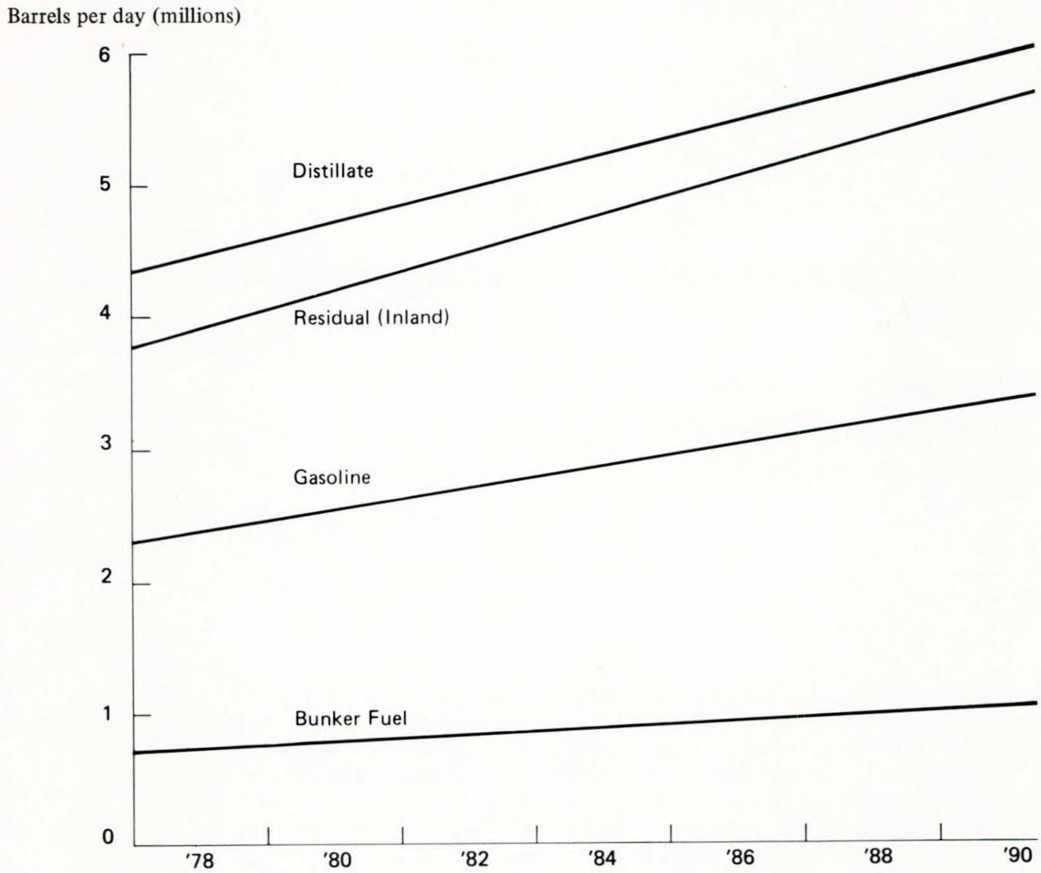

FIG 1 *Fuels demand – Europe*

silicone compounds in fine abrasive particle form which may cause high wear in diesel engine cylinders if not removed by purification.

The following lists some of the effects of the visbreaking and cracking processes:

1) reduction in the amount of residual fuel;
2) increase in specific gravity;
3) increase in conradson carbon value;
4) possible increase in compatibility sediment;
5) possibility of contamination by catalyst fines.

Characteristics of fuels manufactured from the different refinery processes are listed on Table I.

From these facts it will be evident that in order to continue burning the residual fuels of the future it is even more essential that purification processes on board are maintained at a very high level of efficiency to cope with increasing specific gravities and to ensure removal of water and abrasive catalytic fines. Injection timing must be readily adjustable to cope with the slower burning qualities of some fuels. Injector maintenance must be of a very high standard to ensure efficient atomization and combustion. Fuel preheating to the correct temperature becomes even more essential.

FUEL PURIFICATION

Experience on a number of ships has shown that cylinder wear rates are the lowest when centrifuges are used for fuel purification.

Table II shows the results on fourteen vessels using three different methods of fuel purification. Investigation into the high liner wear with filters showed that the filtered fuel contained significant amounts of catalyst fines which were responsible for the high liner wear. Centrifuging the filtered fuel removed the abrasive catalyst fines. Homogonisers do not remove deleterious material and the illustrated case as well as other cases have confirmed this experience.

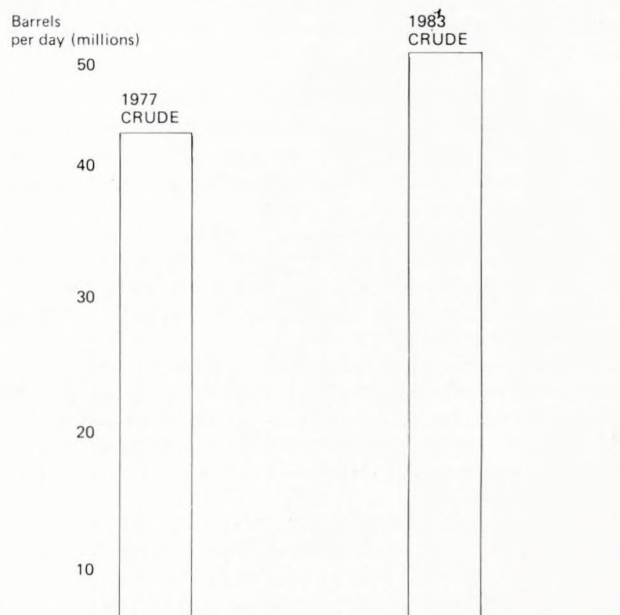

FIG 2 *Catalytic cracking and vis-breaking as a percentage of crude capacity*

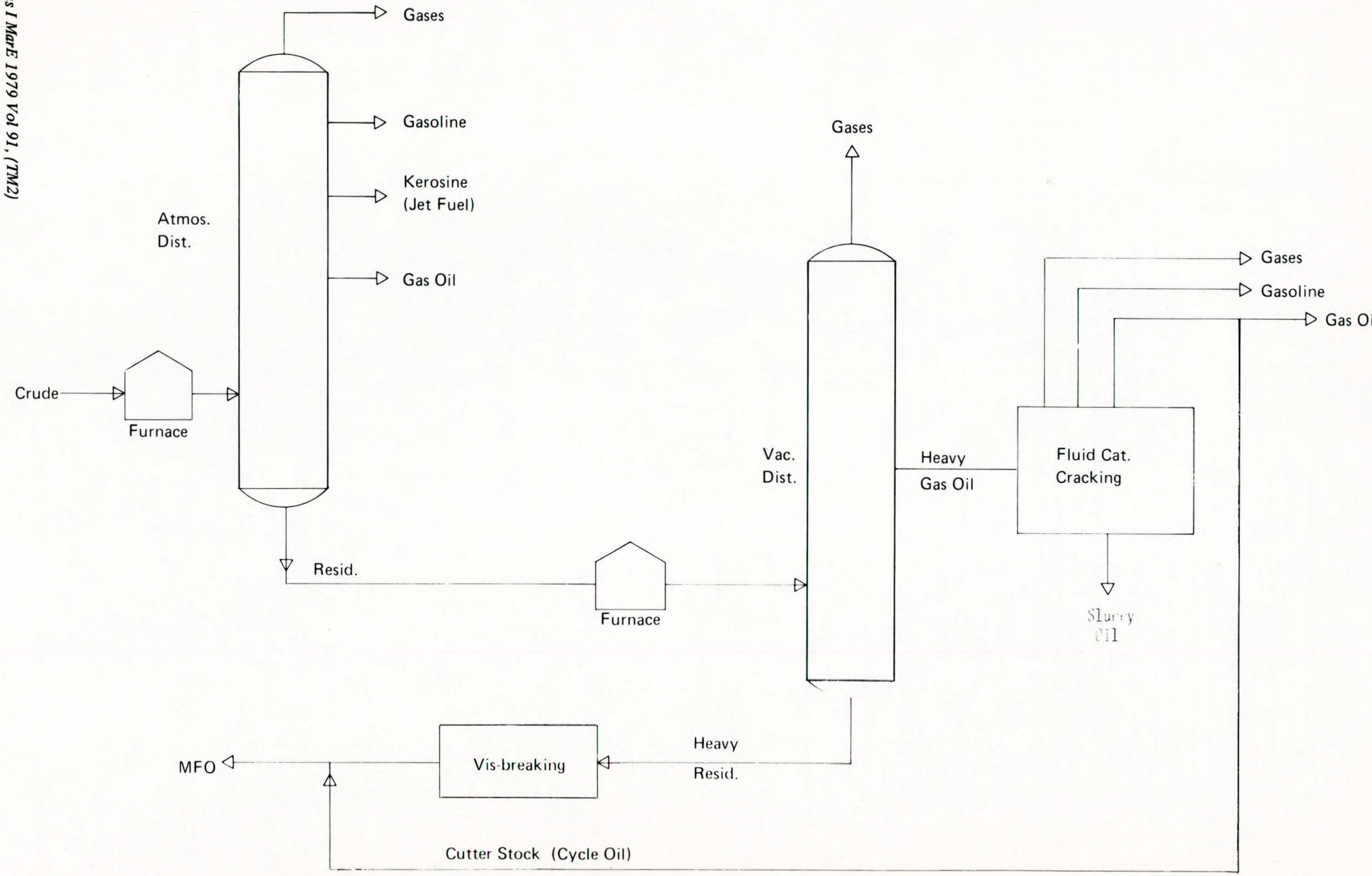

FIG 3 *Oil refining*

COMPATIBILITY

Most fuels can be mixed without precipitating sediment and are said to be compatible. However if when blending residual fuel the heavy hydrocarbons of the heavy component are insoluble in the mixture, a high asphaltene type sediment may be precipitated which can be as much as 6% by volume in exceptional cases.

Incompatibility is usually first noted by over-loading the centrifuge. If the sediment is allowed to the engine, malfunction of the fuel pumps and injectors will quickly lead to combustion problems and engine damage.

Major petroleum companies carry out special tests to ensure their blended fuels are compatible before delivery. However, incompatibility can also be the result of mixing fuels from different indigenous sources and/or different refinery processes such as vis-breaking. Therefore, as two fuels, in themselves compatible, may become incompatible when mixed, ship operators are advised to keep different bunkerings separately.

Incompatibility is more prevalent in the lighter viscosity blends and, therefore, gasoil or diesel fuel should not be added to an incompatible fuel as instead of alleviating the problem it is more likely to increase the sediment precipitation.

The question has often been asked regarding advisability and economics of onboard blending.

Fuel oil blenders for installation onboard ship are readily available and to these must be added the cost of a gasoil and "Bunker C" tanks plus piping, heating, filtration, etc. Before the blend is made a compatibility test must be carried out with the two components. And, in the case of the Mobil centrifuge test, this will take three hours. Tests on the final blend will also need to be made for specific gravity and viscosity. The saving for a shipowner on say a 1500 sec. fuel blended from Bunker C and gasoil could be less than one dollar per tonne based on London spot prices in May 1978. This does not take operating and investment cost into consideration.

MARINE FUEL TRENDS

We do not foresee any broad changes in crude patterns but some regional variations will result as new crudes become available. However, nearly 50% of marine fuels are currently manufactured from Middle East crudes and this situation is not expected to change significantly.

Table III shows typical characteristics of 180LFO from current crude sources.

Although 380–460LFO is more likely to be in use in the 90's, the key properties such as sulphur, metals, carbon residue etc. will only be very little increased for the heavier fuels.

High pour fuels from North African and Indonesian crudes are clean-burning and their good combustion properties are desirable provided adequate heating facilities are available to both handle and store this type of fuel on board.

Fuels from the newer crudes from the North Sea and Alaska are shown on Table IV.

The North Sea fuel is a light crude being low in sulphur and eminently desirable for inland usage, particularly where

TABLE I CHARACTERISTICS OF RESIDUALS FROM REFINERY PROCESSES

Process:	Straight Run Residual Present	Future	F.C.C.	Vis-Breaker
Characteristics			Slurry Oil	Residual
Density	0.96–0.98	0.96–0.98	0.98–1.1	0.98–1.1
Viscosity cSt at 50°C	230–370	250–400	1000	3000
Pour Point °C	10–24	1-–40	20–30	–
Carbon Residue % wt.	8	10	–	12–17
Asphaltenes % wt.	4	6	–	10–20

TABLE II PERFORMANCE OF FUEL CLEANING EQUIPMENT

Engine	BHP	Syst./Cyl. Lubes	Fuel Visc. R.I.	Fuel Treatment	Average Max. Cyl. Liner Wear mm/1000 hrs
B & W 8K74EF	13600	MG300/MG570	1500	Homogenizer	0.33
				Centrifuge	0.09
B & W 8K74EF	13600	MG300/MG570	1500	Centrifuge	0.08
B & W 8K74EF	13600	MG300/MG570	1500	Centrifuge	0.10
B & W 8K74EF	13600	MG300/MG570	1500	Centrifuge	0.07
B & W 984VT2BF	20800	DTE 3/MG570	1500	Centrifuge	0.10
B & W 984VT2BF	20700	DTE 3/MG570	1500	Centrifuge	0.13
B & W 984VT2BF	20700	DTE 3/MG570	1500	Centrifuge	0.13
2 B & W 650VT2BF	2 x 4000	DTE 3/MG593	1500	Centrifuge	0.09
Sulzer 6RD 76	9600	MG300/MG570	1500	Centrifuge	0.08
Sulzer 6RD 76	9600	MG300/MG570	1500	Centrifuge	0.05
B & W 8K7Y EF	13600	MG300/MG570	1500	Filter	0.22
B & W 8K7Y EF	13600	MG300/MG570	1500	Filter	0.29
2 B & W 750VTBF	2 x 4000	DTE 3/MG593	1500	Filter	0.22

TABLE III CHARACTERISTICS OF LIGHT FUEL OIL 180

	Gach Saran	Mid-East Kuwait	Safaniya	North Africa Amal	Venezuela Bachaquero
Sulphur %	2.3	3.8	3.9	0.25	2.3
Carbon Residue %	8.4	8.5	9.4	5.7	9.6
Vanadium ppm	170	43	100	2	335
Pour Point °C (°F)	16 (61)	7 (45)	–4 (25)	38 (100)	–12 (10)
Spec. Gravity	0.949	0.949	0.952	0.904	0.959

TABLE IV MARINE FUELS CHARACTERISTICS – NEW SOURCES

	North Sea *	Alaska *
Sulphur %	0.5	1.5
Pour Point °C (°F)	35 (95)	18 (65)
Vanadium ppm	5	70
Carbon Residue %	3	8
Viscosity RI 100°F	700	4500
Specific Gravity	0.916	0.966

* Topped Crude – 650°F (343°C) + boiling range

TABLE V HEAVY FUEL SPECIFICATIONS

	Current	Possible Future
Viscosity Redwood 1/100 F. Max.	4000	5000
Specific Gravity	0.988	0.988
Pour Point °C (°F) Max.	24 (75)	27 (80)
Sulphur Max. %	4.3	5
Compatibility Sediment Vol. % Max.	0.3	0.3

pollution legislation limits sulphur content. As it commands a higher price it is unlikely to find its way into marine bunkers, even if it does last till the 1990's. Fuel from Alaskan crudes, however, are already finding their way into ships' bunkers in the U S West Coast. These are somewhat heavier than the North Sea crudes but also relatively low in sulphur and make satisfactory marine fuel oils.

Liquid marine fuels will continue to be available for marine bunkers and the major changes will be increases in viscosity, sulphur S.G. and pour point. Table V lists the probable key characteristics of these residual fuels.

Considerable co-operative research work is already being carried out by the oil industry, engine and equipment builders and learned institutions so that the marine industry will have the expertise and equipment to handle these future fuels.

Summarizing, the needs for satisfactory burning of these fuels are:

1) sufficient air supply;
2) effective atomization;
3) easily adjusted injection timing;
4) engine performance monitoring;
5) effective control of fuel temperature etc;
6) efficient fuel purification.

We have been asked to comment on the production of liquid fuels from coal. Solvent extraction under temperature and pressure will produce a product which can be hydrocracked using conventional catalysts to produce one third gasolene and two thirds distillate fuels. (1).

The Mobil process, which is the most efficient, produces only high grade gasolene and a small amount of burnable gas from methanol. Even by the Mobil process the current cost of "synthetic" gasolene would today be around 50 cents per U S gallon dearer than conventional gasolene. In the future, however, this differential could change in favour of the synthetic product.

The availability of gasolene and distillate fuels from coal could help to conserve natural hydrocarbon crudes and, by reducing the need for catcracking or additional visbreaking, make residual fuels available for a longer time. Because of high processing costs residual fuels are not economically produced directly from coal.

LUBRICANTS

The new marine diesel engines which will appear towards 1990 are expected to work under considerably higher b.m.e.p. Even if temperatures of piston rings and cylinder liners are constrained, thermal loading of cylinder lubricating oils will be greater. Lubricating oil systems are expected to become considerably smaller which will increase the quality requirements for system oils. The ship owner will look to increased overhaul periods to defray the anticipated increasing costs of diesel engine maintenance.

Achieving these goals will depend largely on future engine design, the use of suitable materials, and, in particular, on future lubricating oil formulations. We believe that the majority of these lubricating oils will still be refined from conventional hydrocarbon products, using advanced techniques in the production of improved quality base oils, together with a highly sophisticated additive technology. Synthetic lubricants may also begin to play a significant role in marine lubrication. Despite their sophistication, the lubricants of the future must not only perform satisfactorily under exacting conditions, but must do so for long periods with the minimum of maintenance in order to meet reduced manpower requirements.

Considering automation and the unmanned engine room, one can envisage some marine diesels following the principle of the truck and bus diesel: employing small-capacity systems that are operated by running for a predetermined period and then changing the oil. One factor which may make such a scheme more feasible is the increasing cost of residual fuel when compared with the cost of the lubricating oil. For instance, in 1967 the U K cost of 180 LFO was only 5.3% of a system oil lubricant, but in 1978 this increased 14.5%. If the cost of fuel in relation to lubricating oil cost continues to increase, a substantial part

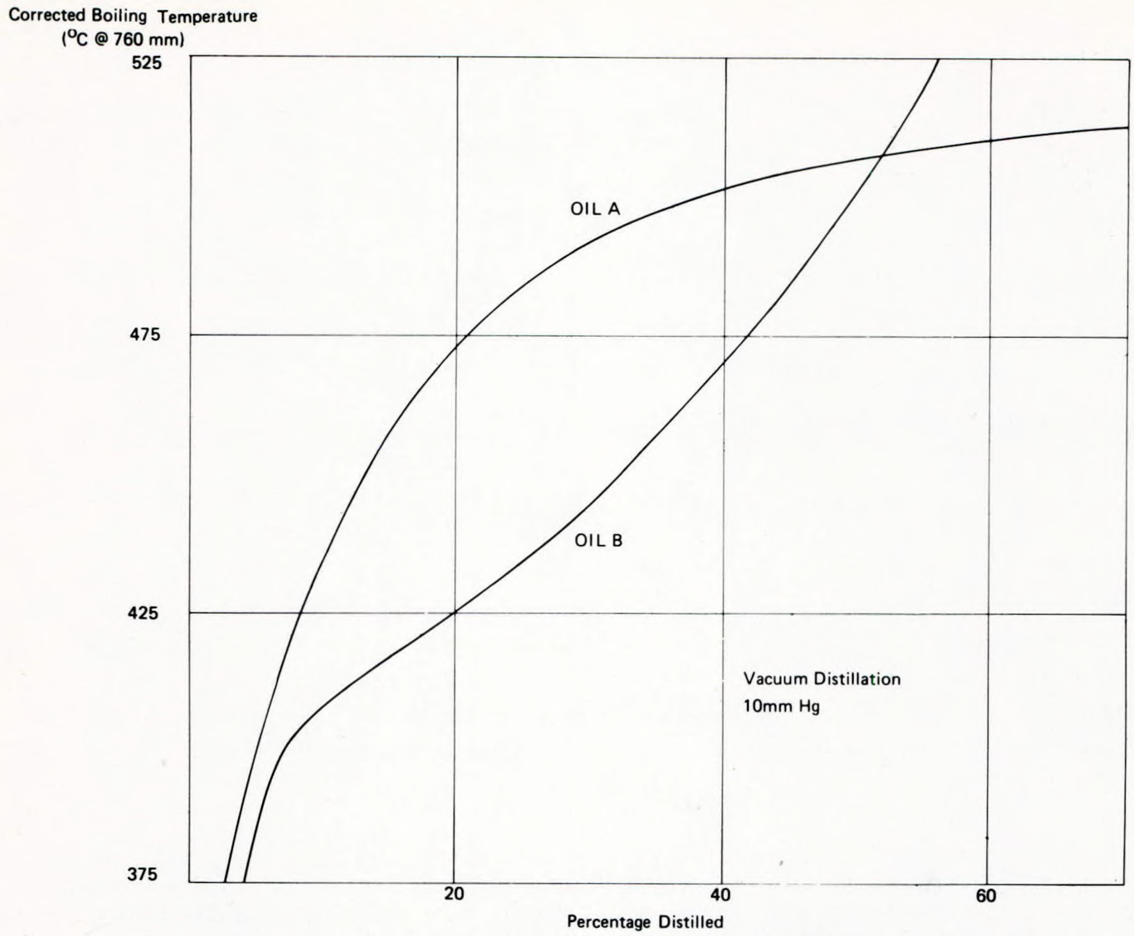

FIG 4 *Cylinder oil volatility SAE 50 viscosity*

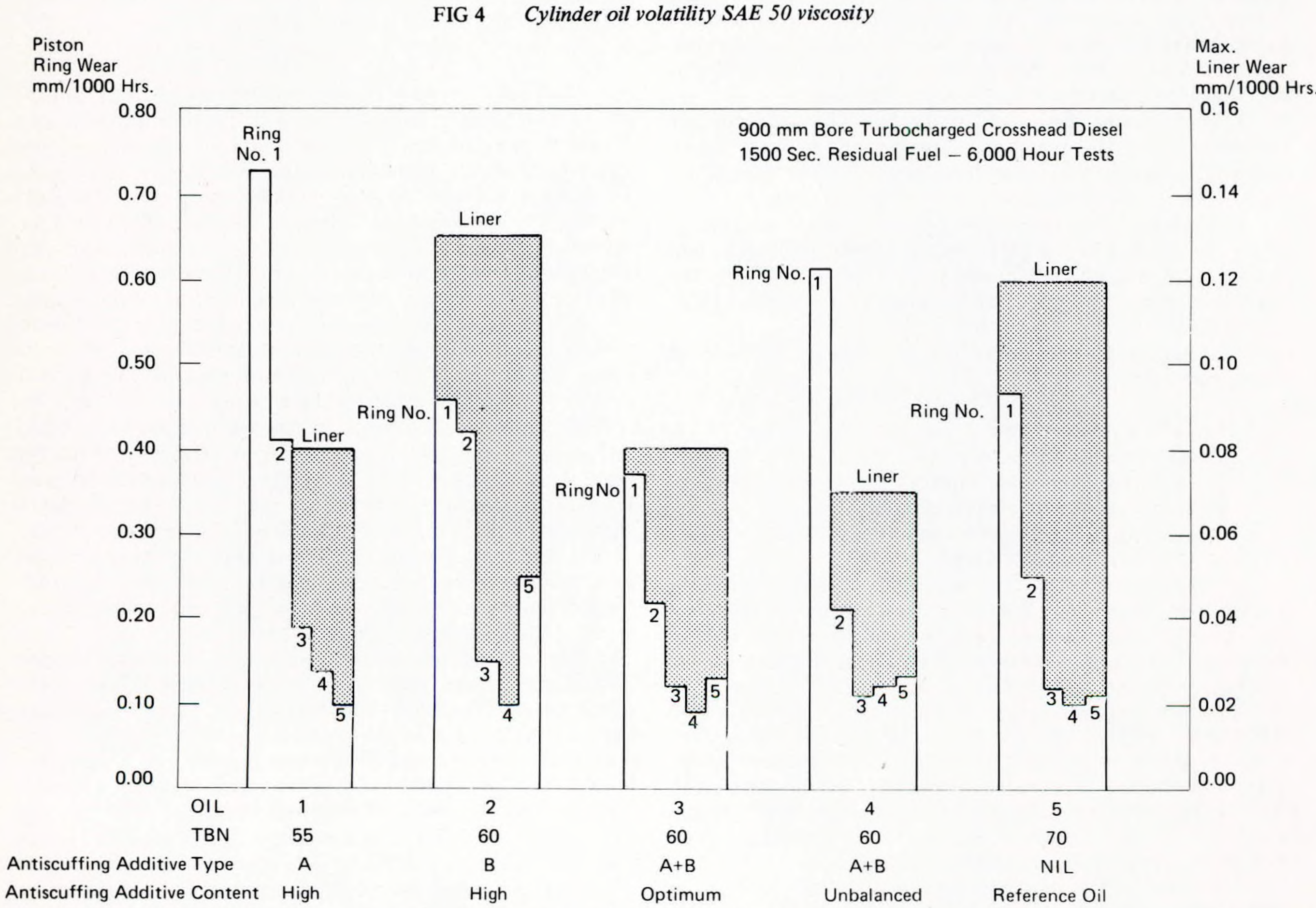

FIG 5 *Effect of antiscuffing additive type and level on piston ring and liner wear*

of the lubricating oil cost would be recovered if the used oil was burnt as a residual fuel when discarded from the engine.

The next part of this paper discusses the requirements for marine lubricants towards the 1990s.

CROSSHEAD ENGINE SYSTEM OILS

The main future changes will be a continuing reduction in system oil size. Already some oil-cooled piston engine vessels are operating with 40% reduction in system oil capacity and a further 25% reduction is envisaged.

Small systems will also lend themselves to operation by the use of two separate charges; each being used and purified alternately, thereby increasing reliability.

Good design, particularly in the arrangement and siting of sump tanks, pumps, piping, ventilation and purifiers etc. will be essential if these small systems are to operate effectively.

Conservation in particular will make it necessary to design "leak-proof" systems, which, together with oil lost when removing water contamination are still the main causes of high "oil consumption".

With reduced engine room staff, future oils should be designed to require minimum maintenance. One of the main reasons for purification of system oils is contamination with water, from causes both inside the engine and externally. Water contamination can best be prevented in the design of the diesel engine itself and also in the design of the lubricating oil system which is often the prerogative of the shipyard. Considerable strides have already been made in providing oils with excellent water separability, even those with fairly high detergent levels. As bearing loads are further increased, the level of water contamination which can be tolerated is reducing.

The other cause of oil deterioration is the result of internal changes caused by engine heat and harmful contamination from combustion processes. The technology already exists to formulate oils to resist these internal changes, and these techniques are expected to improve along known lines, as pressures and temperatures increase with engine development.

Automatic lubricating oil monitoring systems are not yet available as complete units. However, some factors, such as water contamination, can be automatically monitored, such systems being available at high cost. We believe that the use of onboard test kits will continue to play an important role while shipboard personnel are available to use them. Test kits are available for the determination of viscosity, insolubles, acid ingress, and water contamination, and their diligent use has already prevented serious engine problems by determining contamination or deterioration of essential oil characteristics. The use of these kits can also assist oil conservation by extending the oil drainage periods in generators and other auxiliary machinery.

An important function of system oils is to cool pistons in some engines. System oils are available today, which will withstand temperatures of over 300°C in oil-cooling spaces. Refining and additive technology can further improve the resistance to thermal degradation of these hydrocarbon oils. If conventional oils become unable to cope with the thermal degradations to which they may be subject in the future, synthetic oils will be available to take over.

A 12 TBN synthetic system and medium speed diesel oil is already available from the authors' company, but while hydrocarbon oils continue to give satisfactory lubrication, the high cost of the synthetic oil precludes its use in present day engines. However, in a highly-rated medium speed engine with a separate ten gallon lubrication system for the rocker and valve gear, valve and guide seizures were experienced with a hydrocarbon oil and eliminated when the system was changed over to the synthetic oil.

Regarding the other physical characteristics of system oils, we do not foresee any major changes in detergency, dispersancy, water separation and rust and corrosion protection. However, with increased combustion and scavenge pressures, there may be initially an increase in contaminants through stuffing boxes into the system oil, and with higher sulphur fuels, some increases in alkalinity may be required.

Reviewing the future of diesel engine systems, it is interesting to note the comparative progress in hydraulic systems over the last ten years. Pressures have increased from 1500 lbs. per sq. inch up to 6500 lbs. per sq. inch, the circulation time has been reduced from four minutes to 40 seconds in some of the smaller systems, and the increase in bulk oil temperatures has risen from 60°C to 115°C. This progress has been brought about by good, hydraulic design and improved hydraulic fluids.

FUTURE DIESEL CYLINDER OIL REQUIREMENTS

The b.e.m.p. of two stroke, crosshead engines is currently around 12 kg/cm^2, with the exception of one engine operating at 17 kg/cm^2. Future development seems to be in the area of two-stage, turbo-charging and b.e.m.p.'s of 18/20 kg/cm^2 or even higher, will be the order of the day in 1990.

Increasing cylinder pressures will continue to squeeze even thinner the oil film between the piston rings and liner walls, and this, together with higher temperatures, will increase the tendency to vaporisation and thermal degradation and scuffing. The degree of vaporisation is dependent on the volatility characteristics of the oil. The thin oil film on the liner surface is exposed to the high temperature of the expanding combustion gases. This already microscopic film tends to vaporise.

Fig 4 shows the volatility curves of two cylinder oils at atmospheric pressure. It can clearly be seen that at, say, 425°C 20% of oil B has vaporised but only 9% of oil A. Therefore oil A will prove more protection for the cylinder liner surface.

With regard to oil thermal degradation, certain laboratory bench tests, namely the spiral coker (2) and the helix deposit test (3) have been developed by the authors' company and are described elsewhere. These tests conducted at temperatures up to 425°C, have been used to evaluate an oil's resistance to oxidation and thermal cracking. This evaluation temperature can be increased to cater for future generation engines operating at higher temperatures.

As cylinder pressures increase, it may not be possible to allow liner wear to reach 0.6% of the liner diameter, as is customary with most current slow-speed engines. To reduce maintenance costs, liner wear will become increasingly important, and since piston ring wear controls the time between cylinder overhauls, the future cylinder oils must be formulated with very high load-carrying characteristics to reduce both ring and liner wear. Thus the ability to maintain ring wear at a minimum is a significant factor in the overall economics of diesel engine operation.

With cylinder oils high load carrying properties are invariably imparted by specially selected antiwear and antiscuffing additives. The importance of selecting the correct additives is shown on Fig 5. It will be seen that oils 1 and 4 have excellent liner wear but higher ring wear. Conversely oils 2 and 5 have good ring wear at the expense of high liner wear. Oil number 3 has both good ring and liner wear resulting from the correct selection of antiscuffing additives in the optimum proportions. These are the results of shipboard tests on highly rated engines.

Fuel available to the marine trade will consist of heavier components with increased sulphur content. This

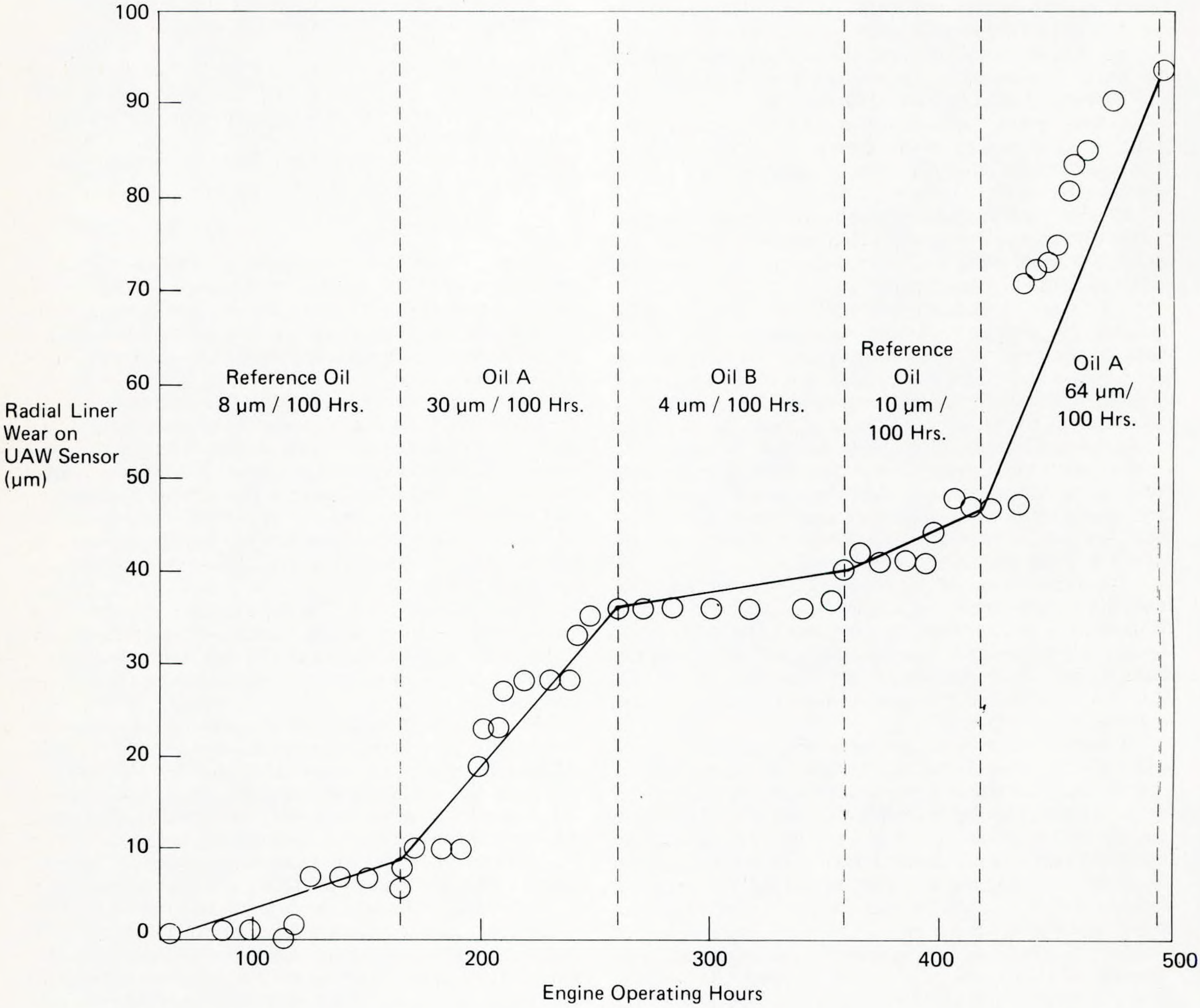

FIG 6 *M/S Mobil engineer liner No.2 wear from upper aft sensor*

could mean less complete combustion, leading to the formation of more carbonaceous deposits and corrosive acids.

As far as alkalinity is concerned, improved additive technology has eliminated the need for very high TBN cylinder oils. We do not foresee a need for TBN above 80.

To maintain satisfactory engine cleanliness and to meet the needs for extended overhaul periods with future fuels, indications are that higher levels of detergency and dispersancy may be needed but this is not expected to pose any problems.

The development of these future diesel cylinder oils will be greatly facilitated by the evaluation of candidate oils in the computerised and fully instrumented liners on board the *Mobil Engineer*. Details of this work are fully reported elsewhere (2) & (4) but a brief description may be of interest.

Certain liners on this vessel are fitted with fifteen specially designed sensors to measure wear and temperatures and indicate when scuffing may occur. Additionally a proximity transducer monitors piston ring conditions and can reveal when they become stuck or broken.

Thus, on any vessel fitted with this type of monitoring equipment, ships' staff can "look into" engines without opening them up and overhaul periods can be extended to such times as they become necessary rather than at arbitrarily determined periods.

Signals from all the monitoring equipment, together with pertinent engine operating details such as load and speed, are recorded at ten minute intervals by a microprocessing data logger on to magnetic tape. The results are later interpreted by computer at our research laboratory.

Fig 6 shows a wear graph from the *Mobil Engineer*. The results show total wear of both rings and liners with a number of different oils. Although evaluation of these test oils only took 100 hours per oil on the *Mobil Engineer*, the results compared accurately with two year shipboard conventional tests with the same oils in similar engines on other ships. It is also interesting to note that wear took place in steps rather than as a gradual slope.

MEDIUM SPEED DIESEL ENGINE LUBRICATION

Current maximum b.m.e.p.'s are around 20 kg/cm^2. With the advent of two stage turbo-charging b.m.e.p.'s are expected to exceed 26 kg/cm^2 by the 1990's. Increases in the power/weight ratio and reductions in oil system sizes will increase the thermal stresses of the lubricant for both the cylinders and the systems. However, as with crosshead engine oils the technology already exists to meet these future needs.

Already 380 LFO is being burned in medium speed engines and the future combustion qualities and sulphur contents of these fuels will engender a need for increased detergency, dispersancy and alkalinity. Increased cylinder pressures will require oils of still higher load carrying/antiscuffing properties.

As with crosshead engines the cylinder lubrication needs are different from the crankcase cooling and lubrication requirements. Therefore the question will be asked, "one oil or two?"

If two oils are to be used the crankcase oil would be of lighter viscosity with nominal alkalinity to allow for better cooling and increased mechanical efficiency. The cylinder oil would be of heavier viscosity for improved volatility and contain all the additives required for crosshead cylinder lubrication. However much of this cylinder oil would scrape down and eventually the crankcase oil would approach the cylinder oil characteristics. Furthermore, most mechanical cylinder lubricators require some attention by engine room staff. Therefore we believe future medium speed engines will have one lighter viscosity oil for crankcase and cylinder lubrication.

An important consideration of future diesel oils is viscosity. A few years ago straight mineral oils of low viscosity index around 30 to 50 were subject to appreciable reduction in viscosity with temperature rise. As load carrying properties of such oils are directly related to viscosity, SAE 30 viscosity oils were standard and SAE 40 oils were and still are popular in hotter engines.

Current good quality diesel oils have viscosity indices of 100 and above and contain special additives to impart load carrying capabilities far and above any viscosity consideration. Thus in the near future a single viscosity oil of, say, "SAE 35" should meet the needs of all medium speed and crosshead system oils. Crosshead cylinders will continue to require heavier oils.

Towards the 1990s however work already done in the automotive diesel field could point the way for future marine oils. The use of synthetic oils of low viscosity, high viscosity index and load carrying properties has resulted in considerable advantages in heavy bus and truck diesel operation. Oil and filter change periods of 100 000 miles with fuel savings of 2.0 to 5.6% and lube oil savings of around 32% are causing price conscious fleet operators in the USA to purchase these synthetic lubricants. This is despite a US gallon cost of S8 compared to only S1.58 for conventional lubricants.

We do not infer that the use of a lighter viscosity synthetic oil is the complete answer to improved efficiency. The engine must be designed to take full advantage of the improved lubricant.

In the field of hydraulic applications synthetic lubricants will also play an important role. While we foresee the next generation of fluids manufactured from conventional hydrocarbon base stocks with improved viscosity index additive treatments, by 1990 we foresee only two synthetic hydraulic oils replacing the current range of six to eight conventional lubricants.

This forecasted reduction in diesel and hydraulic grades will make supply and storage problems at world ports much easier. One estimate puts the figure at half the current number of products. This we feel sure will please everyone in the marine industry.

TURBINE OILS

We can see little change in turbine requirements. Separately lubricated gearing will allow much lighter turbine oils and much higher load carrying gear oils. If required, synthetic gear oils are already available, and in use in certain types of reduction gearboxes.

Synthetic lubricants are already in general use for aviation gas turbines and could be available for marine applications if required.

With a minimum of seagoing staff reliability will be the keynote, efficiency and fuel saving a close second and conservation of natural resources the essential factor for the 1990s. As always this will continue to pose a stimulating challenge to all of us involved in the business of marine engineering.

REFERENCES

(1) "Liquids from Coal" May 1978, Coal Research Establishment, Cheltenham, Glos.
(2) "Crosshead Diesel Cylinder Lubrication" 1978 Mobil Marine Diesel Technology Symposium paper.
(3) "Slow Speed System Oil Lubrication" 1977 Mobil Marine Diesel Technology Symposium paper.
(4) "Unique Shipboard Tests Speed Development of new Mobil Cylinder Oils." Motorship, July 1976.

Discussion

MR D W GOLOTHAN, MIMarE (Shell International Petroleum Company Limited) complimented the authors on a very interesting and timely paper, which gave a wealth of information and much food for thought. He said that changes in the oil supply situation would make a major impact on the shipping industry in the coming years, and it was important that the implications of these changes be considered as soon as possible, so that the appropriate action could be taken by both shipowners and equipment manufacturers.

Certainly the engine manufacturers were aware of the effects that changes in fuel quality were likely to have on their equipment and, from the various articles appearing recently in the technical press, it seemed that they were optimistic about the future and saw no reason to believe that their engines would be unable to burn any of the new types of fuel reviewed in this paper. As the authors have emphasised, these fuels would place increased demands on both the engine and engine operator, but satisfactory operation could continue to be expected if the right steps were taken to handle the fuel and to ensure good combustion within the cylinder. The authors had also rightly drawn attention to the vital importance of adequate fuel treatment, and from the results shown in Table II it would certainly seem that centrifuging is the preferred method of treatment if cylinder wear is to be kept within acceptable limits. In connection with this Table, Mr Golothan asked whether analyses of the various fuels were available, i.e. were all the fuels known to contain abrasive particles from catalyst fines or from any other source?

As a general comment, it was interesting to speculate how far the present trend towards higher power outputs and higher bmep would continue. Potentially very high bmep could be obtained with two-stage turbocharging or improved single-stage turbocharging, but there were signs that engines of the future might have to concentrate more on economy than on even higher bmep. The oil supply situation might well tighten within the period reviewed by the authors, and oil prices and maintenance costs would no doubt continue to rise. Therefore the main future requirements might be summed up as economy, reliability, and conservation, and these might eventually prove to have more influence on engine design than the need to extract ever-increasing power outputs from a given cylinder size.

Commenting on the section dealing with fuels: the vis-breaker fuel in Table I could apparently contain a higher concentration of asphaltenes than the maximum carbon residue. This was unlikely, and suggested that the two sets of figures may have been transposed.

A first impression of Fig 2 was rather misleading, since it showed the concentration of cat-cracked and vis-broken fuel as quite a small proportion of the total crude, both now and in the future. A fairer comparison would be between the cat-cracked and vis-broken fuels and the residual component of the crude, since it was mainly this residual component which would be replaced by the "conversion" fuels. For example, the residual component of the 1977 crude would probably be around 17 million barrels/day, and even less in 1983 - perhaps 15 million barrels/day. The "conversion" fuels obviously became a much more significant proportion of this amount than was apparent from Fig 2.

The authors also had commented that Alaskan crude made satisfactory marine fuel oils. This statement might be true if the crude was refined conventionally but, if catalytic and thermal cracking are applied, the properties of the "conversion" fuels thus produced would probably be very similar to those of the "conversion" fuels produced from crudes from other sources.

With reference to the section on lubricants. Mr Golothan's views on future requirements were very similar to those expressed by the authors, except that he was rather more doubtful about the use of synthetic oils. Although these oils certainly had some technical advantages, their high cost seemed to rule out their use on a commercial basis, especially in the depressed economic conditions of today. Possibly this cost would be more acceptable in more prosperous times, but even then convincing evidence would be necessary to demonstrate to the shipowner that the extra costs were justified by much reduced maintenance costs and/or longer engine life. Mr Golothan also thought that oils of greater than 80 TBN would continue to have a place in the future, especially for severe operating conditions involving fuels of very high sulphur content - as the authors indicated in Table V, this sulphur content might rise to a level as high as 5% on occasions. In the experience of Mr Golothan's company, these severe conditions demanded a cylinder oil having a TBN appreciably higher than 80 to prevent the occurrence of excessive corrosive wear.

Despite the trend to lower capacities for the system oil in crosshead engines, Mr Golothan doubted whether shipowners would copy truck and bus operators and employ a small-capacity system from which the oil would be drained and renewed at fairly frequent intervals. Modern inhibited system oils on the whole gave very little trouble in current large systems in which the life of the oil was indefinite and, if the trend towards even smaller capacities continued, as the authors had suggested, the economics of doing this could be in question, and the disposal of the used oil, even as bunker fuel, would be against the interests of conservation.

The reference by the authors to "leak-proof" oil systems brings to mind an article in the Marine Engineers Review for August 1977,* in which some investigators in Israel employed a radioactive isotope technique to detect the sources of oil loss from the system of a crosshead engine with oil-cooled pistons. They found, rather surprisingly, that there was considerable loss of system oil from the pistons, and this oil either leaked into the cylinder and was burnt, or drained into the under-piston space. The figure quoted for oil lost in this way was 220 litres/day in a 10-cylinder engine developing 14914 kW. If this result was typical, it seemed that changes in piston design, or perhaps improved maintenance, would be desirable to

*"A Radioisotope Technique for Determining Oil Losses in Diesel Engines" by L Caras M Pasi and M Zaretzky, Marine Engineers Review, August 1977, P.20

prevent such leakage and so conserve the system oil as much as possible.

The authors indicated the various changes likely to be made in cylinder oil requirements in the future, mainly arising from higher cylinder pressures and temperatures. Undoubtedly, fuel properties would contribute to these more severe conditions, because the fuels from conversion processes might be expected to burn more slowly and to have poorer ignition quality than the majority of current fuels. In addition, the demands for economy and conservation might result in lower cylinder oil feed rates, so that adequate distribution of the oil around the cylinder might become increasingly difficult to achieve. The design of oil grooves would play an important role in this respect, but the distribution might also be improved by changes in the properties of the oil itself.

Fig 5 showed some very interesting relationships connecting oil type with cylinder and piston ring wear, but it was not easy to understand why certain oils should reduce liner wear and not ring wear, while the converse happened with other oils. In theory, it would be expected that wear of piston rings and cylinder liners would be more or less in proportion, although service experience did not always agree with this expectation. Mr Golothan would appreciate some further comments by the authors on the results shown in Fig 5, particularly if they had any explanation to offer for the rather unusual relationships between ring and liner wear.

Finally, the authors company was congratulated on the very interesting and painstaking series of experiments carried out with sensors in the *Mobil Engineer* - this type of equipment was essential to study the effects of fuel and oil variables within a reasonably short space of time, and these sensors were likely to be used increasingly for experimental purposes in the future. It was also to be hoped that they would be used as standard equipment to a growing extent to enable engines to be run at their maximum efficiency and, of prime importance for the future, with maximum economy in all aspects of operation.

MR A J S BAKER, FIMarE (Esso Research Centre) said that the authors were to be complimented on having "grasped the nettle" and discussed the reality of future fuels and lubricants, a subject which is naturally exercising research minds throughout the Oil Industry. However, to claim in their title that their current thoughts might hold into the 1990s, seemed to be adopting much the same attitude as the British Air Ministry did in 1927, the same length of time before the 2nd World War was declared. History had shown repeatedly that although mankind might be slow in its initial reactions, eventually, any foreseeable emergency, whatever it might be, was properly recognized and steps were taken towards remedial action.

To begin with, the possibility of silicate fines from the catalytic cracker reaching the heavy final products was something of which all major refiners were fully aware and ways of minimizing carry-over are continually being implemented, particularly as catalytic cracking becomes a larger percentage of the total crude capacity.

Concerning vis-breaking: Fig 3 showed only one possible system which utilized the residium from the vacuum tower as vis-breaker feed. Although such a system was feasible, producing vis-broken residium with properties similar to those listed in Table I, it was unlikely that vis-breakers in the near future would operate this way. More likely the vis-breaker would use straight run residues as feedstock producing a vis-broken residue little different from the original feed. So there might be a period during which both refiner and user could adjust to the changing processes and products. But this period should last only as long as the funding from the refiner to do things a little differently was unavailable.

On fuel treatment the authors had stated that centrifugation was superior to homogenization, and demonstrated this fact quite clearly in Table II. However, this table did not disclose the relative fines contents of the various fuels. Mr Baker asked how any known form of homogenization could help continuously to reduce the average solid particle size to the sub-micron dimensions needed to pass any current fuel injection system, without causing a degree of damage to the F.I. system, the piston rings or the liners. In dispersing fluid agglomerates such as ashphaltenes an homogenizer could be very effective, at least for a short period before they begin to re-agglomerate. The immediate suggestion was to use homogenization, perhaps in the form of a sonic whistle immediately and continuously before each fuel pump element. If the fuel flow rate proved insufficient at that point, the low pressure fuel circuit might be reworked to circulate the fuel continuously, immediately before each fuel pump gallery.

Current centrifugation methods themselves did not seem to offer the total answer, especially with future fuels having gravities in excess of unity. However, the makers of centrifuges are by no means unaware of this problem, neither are they without the means towards further development. The centrifuge would continue to play a role of increasing importance as fuel qualities continued to decrease.

The authors had virtually dismissed the use of coal as an energy source for marine propulsion, on the grounds of high cost and the energy utilization required for its manufacture into a form of liquid fuel which might be burnt in a current diesel engine. With certain reservations one would agree with this viewpoint. But who was to say that practical ships must continue to be propelled by diesel engines or steam turbines? Not, it seems the authors. (See Fig 7).

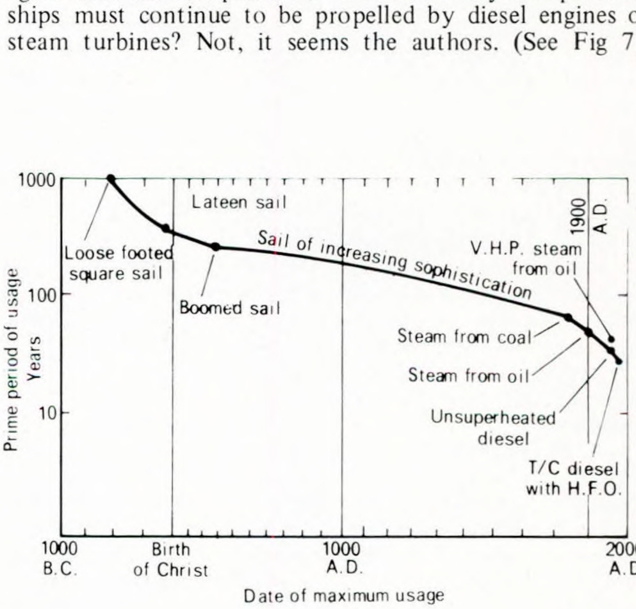

FIG 7 *Marine propulsion development since 1000 B.C.*

It had already been demonstrated in pilot form that coal could be readily converted into a de-sulphurized gas of lowish calorific value in a single operation. This invention was known as the chemically active fluid bed, which was conceived by Dr G Moss of the Esso Research Centre. The first large scale (16 MW_e) gasifier had now been installed on a power station boiler in Texas. The emergence of this technology had opened many exciting possibilities on land or at sea, for instance, the clean-up gas might be used to fire a fluidized bed combuster with which to operate a closed cycle gas turbine. Less bravely, the gas could be used to fire marine steam generators such as those originally designed to burn oil. At a more advanced level, once the particulate clean-up problem had been overcome, open cycle gas turbines became feasible. Discussion with Dr W Ritz of GEC Gas Turbines Ltd., has indicated that a reliable and suitable marine gas turbine, basically similar to their latest industrial machines, could be quickly designed and developed to match either form of gas generator.

Many marine hulls in service today would be heading for the breakers by 1990 and, of course, such a drastic change of propulsion would present many new challenges to the marine industry, which had not always been noted for its lack of conservation. Such matters as automatic bunkering and shipboard coal handling would need vast effort and financial input. But the goal would be to win some remission for oil as the world's most portable fuel. The Doxford paper[1] presented at this Institute had clearly demonstrated that parts of British engineering could still be relied upon to work near miracles if they were given just a fighting chance, to be granted perhaps by Government funding.

The authors were right to point out that system oils needed to be carefully watched, especially with the trend of modern diesels to reduce charge volume. This was predicted in 1974 in a paper to this Institute[2]. But failure to obtain so direct a relationship between volatility and "cylinder surface protection" as might be inferred from the authors comment concerning Fig 4, must be admitted. However, the use of realistic test kits must be commended, provided they are used by people able to understand their results.

Work on piston ring lubrication and dynamics [3,4 & 5] by Leeds University and Mr Baker had proved quite complicated enough without introducing the influence of mysterious anti-scuffing additives defined by the authors as A and B in Fig 5. It was hoped that the authors could give some hint of the rationale or surface function of these mysterious compounds.

Mr Baker noted the authors' prediction of 4-cycle bmep in excess of 26 kg/cm^2 by the 1990's. Esso's Abingdon B2 engine[1] had offered this facility for some time, as had the "Atlas" engine at Ricardo's. Neither test engine had suffered mechanically, but it would be interesting to know whether the authors could quote a potential specific fuel consumption or mechanical efficiency for the engines they had predicted at this load. S.F.C. and mechanical efficiency might suffer to such an extent that engines of this rating might not become very popular.

The synthetic aviation gas turbine lubricants mentioned by the authors, were pioneered by Mr R W Morton, MBE[6] to withstand the high temperatures present in these machines. However, it would seem unlikely that reciprocating engines would actually need them during the period predicted by the paper. Mr. Baker asked if the authors could define specific technical reasons to believe otherwise.

1) HENSHALL S H and ORBECK F, 1978, "The Doxford Three-Cylinder Engine" *Trans IMarE, Vol 91, Part 1* and *Trans NECIES, Vol 85*
2) BAKER A J S and KIMBER J D, 1974, "Research Engines For Low and Medium Speed Engines" *Trans I MarE Vol 86 Part 7 p.p. 125-145*
3) BAKER A J S, DOWSON D and STRACHAN P J, 1973, "Dynamic Factors in Piston Rings" *JSME ISME* Tokyo
4) BAKER A J S, DOWSON D and ECONOMOU P N, 1975, "Dynamic Factors Related to Piston Ring Scuffing" Piston Ring Scuffing *Conf I MechE*
5) BAKER A J S, DOWSON D and ECONOMOU P N, 1977, "Piston Ring Dynamics and Lubrication" *Paper B4 CIMAC*
6) MORTON R W, 1974, "Esso was First" Letter to *Autocar* 14.9.74

COMMANDER E TYRRELL, FIMarE RN, (Consultant) pointed out that over recent months some of the oil companies, and one in particular, had done much to publicize their wishful thinking on the quality of residual fuel oils likely to be saleable towards the end of the next decade or so, particularly for marine bunkers. The actual properties of these future residual fuel oils had not been clearly defined, nor had the possible extent of the intrusion of these fuels into the marine market been quantified. One was indebted to the authors for clearly showing that, by 1983, the amount of these poor quality fuels produced would have increased only slightly and would still be only 6% of the crude manufactured, whereas that produced without cracking was likely to be over 30% of the crude processed.

The current fuel specification B.S. 2869 is entitled "Petroleum fuels for oil engines and burners". The requirements for reasonable combustion under boilers and in diesel engines were somewhat different: residual type fuel oil used by marine diesel engines amounted to about 80m tonnes per annum, whereas the residual type fuel oil produced in the world was about 600m tonnes. The marine diesel fleet therefore used less than 15% of the residual fuel produced. From the figures given by the authors the types of fuel currently being discussed covered only some 18% of the total world production. If marine bunkers receive only their fair share of the poor quality fuels then only some 3% of the total residual fuel oil production was being considered. Surely the more satisfactory solution to the problem must be to produce a specification for "Petroleum fuels for oil engines", rather than to embark on costly research aimed at showing that all marine main propulsion engines could burn the poor quality fuel with which we were now threatened and could be burnt more easily under satisfactory boilers. The cost of this research and the added cost of the additions and changes to the engines must ultimately be passed on to the customer and would be greater than that resulting from the selective use of a mere 3% of the total residual fuel oil produced.

Focus on the possible deterioration of the quality of residual fuels seemed to occur about every 8 to 10 years. The current scare was possibly a little more virulent than those of the past. The slow speed diesel engine manufacturers now claimed that because of the longer burning time available in their engines they would be able to use the poor quality fuels available in the future, whereas medium speed engines would not. In their turn, the turbine and boiler manufacturers were claiming that no diesel engine would be able to burn the types of fuel that would be available. They further claimed that by the use of fluidized bed combustion, other improvements, increased complexity and, hence, cost they would be able to burn these fuels with a fuel economy approaching that of the diesel engine.

The responsibility resting on the oil companies was great. If their contentions did not materialize, the research at present being undertaken by many diesel engine manufacturers would have been wasted. Those ship owners who heeded their warnings without due cause would inevitably be lumbered with unnecessarily expensive machinery probably burning, in the case of turbine ships, more fuel than that of their competitors. This could only have an adverse effect on the shipowners financial and competitive positions. One of the largest oil companies in the world maintained that there would be no marked deterioration over the next 10 years in the type of fuels available for marine purposes. One other major company had threatened a very significant deterioration while, most others took up the position somewhere between the two. There was, however, one European company which did not believe it to be economically justifiable to market residual type fuel oil, and its refinery operations gave rise to distillates and refinery coke only. The production of refinery coke was only possible at present when selected low impurity crudes were used. Refinery coke of high impurity content, particularly sodium, vanadium and sulphur, could satisfactorily be burned in fluidized bed combustors which removed the impurities causing super heater clogging and corrosion.

The Advisory Committee on Energy Conservation several years ago suggested that liquid petroleum products might have to be reserved in future for those purposes where the advantages were so great that they could not be displaced economically by some other type of non-liquid fuel. These purposes were petrochemicals and transport, including marine transport. That the marine industry would be prepared to tolerate the type of fuels with which it was threatened, and so accept the use of marine steam turbines and boilers with fluidized bed combustors, was unthinkable when the oil industry could produce distillates and refinery coke for use with fluidized bed combustors in power stations ashore. It seemed that this country would be forced to adopt fluidized bed combustion in power stations. The Swedes and Norwegians were already complaining about the discharge of sulphur dioxide into the air from power stations, which killed off the fish and forests of Scandinavia. Commander Tyrrell felt that the oil companies should not underestimate the profound effects minority groups could have when making emotive demands concerning pollution. Environmentalists had secured a reduction of lead in petrol although there had been no demonstrable health hazard in the use of lead. This reduction had given rise to the use of several million unnecessary tons of petroleum in this country - perhaps this was the reason why the oil companies did not oppose the anti-lead regulations very strenuously. Far more important environmentalists had succeeded in preventing the construction of power stations based on fast breeder reactors, with the result that we were now being overtaken by the French and the Russians. The latter were the largest and most vocal propagandists against fast breeder reactor construction. Perhaps the environmentalists would take up the cudgels and prevent the oil companies from marketing the type of fuel with which we were now being threatened, and, they in their turn might produce what the commercial market required, i.e. distillates and refinery coke for burning under power station boilers with fluidized bed combustion, despite the high capital costs involved.

MR G McCONNELL (BP Research Centre) pointed out that the authors suggestion that in the future it might be economic to burn used oil as a residual fuel. In view of the many references made in the paper to the possible use of synthetic lubricants, he wondered if the authors had any information on the likely combustion characteristics of such lubricants.

Mention was also made of piston undercrown temperatures of 300°C, with a hint that they might rise in the future. To obtain such a temperature on the undercrown, the temperature of the combustion bowl surface could be around 500°C and one thought that any increase in this temperature would mean that piston metallurgy would become the limiting factor of operation and not lubricating oil quality. It was hoped that perhaps the authors could comment on this.

With regard to volatility, the point had been made that an oil which lost 9% of its volume at 420°C would provide better protection of a liner surface than one which lost 20% (Fig 4). It was always dangerous to isolate one quality feature of an oil and use it as an indicator of overall performance. For instance, BP had been investigating the spreadability properties of cylinder oils and had found amongst other things that spreadability was closely related to viscosity. In the case of the two oils quoted by the authors, one suspected that the component of the less volatile oil A remaining at 425°C was more viscous than the similar component of B and that the A component would therefore spread over a smaller area than that covered by the component of B. Thus a choice might have to be made between having a relatively large amount of oil restricted to a relatively small area or a small amount covering a large area; the latter condition might provide the better protection.

In the text, Fig 6 was referred to as showing total wear of both rings and liners whereas the figure itself shows only liner wear and Mr McConnell wondered if there was some information missing from this figure. Also, the authors had pointed out that wear was unusual and he wondered if the authors were convinced that the apparent stepped wear was not in fact a function of the repeatability of the wear measuring technique.

Regarding synthetic trunk piston engine lubricants, there were probably two situations where one might be forced to use them; where exceptionally high operating temperatures were encountered or where good low temperature viscosity was required. For normal operations, synthetic oils would presumably carry additive packages the same as conventional oils and one would have thought that the long drain capabilities of the formulation would still rest heavily on the ability of the additives to retain their properties. The authors were asked to comment on how the properties of the synthetic base oil contribute to the long life claimed for synthetic formulations.

Finally, during the presentation, the authors' had displayed some 4 ball test results which showed how synthetic oils gave better results than those obtained with conventional oils. Had the authors any data correlating 4 ball test data with service performance.

MR D ROYLE, MIMarE (Exxon International) commented on the section of the paper which dealt with fuels.

Fluid catalytic crackers had existed as refinery equipment since diesel ships started to use residual fuels in the first half of the 1950's and vis-breakers had also been in operation since the late 1950's. They were not new and unknown processes within the petroleum industry, and consequently components from them had been used in marine fuels for many years. The use of this type of equipment especially the vis-breaker would increase in the future at additional refineries and using different crudes.

Many articles were currently appearing in the technical Royle believed that members of the petroleum industry must be very careful not to worry the shipowner and diesel engine manufacturer unnecessarily. For example, the uninitiated could read in the paper about the characteristics of fuels manufactured from the different refinery processes listed in Table I and think that these were fuels which the petroleum industry might wish to market. This would not be so. He suggested it might be better to talk about the characteristics of components produced by these processes. These components might then be used in varying percentages with other components by the petroleum industry to make an acceptable marketable residual fuel.

In the section on Marine Fuel Trends it was stated that the key properties such as sulphur, metals, Conradson carbon etc. would only be very little increased for the heavier fuels, and in another paragraph that the major changes would be in viscosity, sulphur, specific gravity and pour point, with Table V listing the probably key characteristics current and possible future. Mr Royle felt these three references to be somewhat contradictory.

The authors were quite right to again highlight some of the essential aspects a shipowner should be aware of when ordering and operating a diesel-engined ship using residual fuel. The comments had applied since residual fuels were first used in a diesel engine and were not something new and only applicable to the fuels of the future.

The use of filters instead of centrifuges to clean the fuel onboard ship had caused a lot of problems. The filter might have cheaper maintenance costs but mesh sizes of 40 microns were just not satisfactory.

Responsible members of the petroleum industry would ensure that the residual fuels supplied to ships were made from compatible components. This had been the policy of Mr Royle's company in the past and it would remain the same in the future. They had never been able to ensure one fuel was compatible with all other fuels that a ship may bunker around the world from a variety of suppliers. For this reason they had always recommended shipowners to design their vessels so that fuels could be kept separate whenever possible. This advice had been forgotten far too often and Mr Royle believed it would be necessary to heed it in the future.

MR G H CLARK, FIMarE, commented that looking into the future decade or two and forecasting liquid marine fuel quality must be rather like peering into a crystal ball, especially when taking into account future demands for other more profitable petroleum products from modern refineries, the various types of crude likely to be refined, marine diesel engine developments and lubricant properties required to meet increasingly difficult operational conditions. In view of the many variables involved (some of them unknown at present), he felt that the authors' opinions were most praiseworthy and interesting.

Refining Processes

The comments on refining, especially those on visbreaking, could well be amplified. The authors had stated that thermo-cracking of vacuum residuum reduced its viscosity, but this was not borne out by the data in Table I which gave the viscosity of the residual from the vis-breaker as 3000 cSt at 50°C, which was about ten times as viscous as current Marine Fuel Heavy or Bunker C. Further, the viscosity was apparently reduced to acceptable viscosity by blending with cycle gas oil. From the refinery flow chart in Fig 3, which was perhaps oversimplified, the residue from the catalytic cracking of heavy gas oil of, presumably, a typical current crude, had a viscosity of 1000 cSt at 50°C (or approx. 12,000 secs Redwood 1 at 100°F). This slurry oil had a viscosity well above the pumpability limit of most pumps currently in service, and must be semi-solid at this temperature. The residuum from the vis-breaker was about three times as viscous and must be solid. Mr Clark asked what would be the approximate proportions of each in the final mixture of viscous slurry oil and residuum from the vis-breaker. He also wondered how much cycle gas oil would be required to produce a final blend equivalent to current Bunker C viscosity 3500 Redwood 1 secs at 100°F (about 380 cSt at 50°C).

One objection to the use of cycle gas oil as a blending component to cut back the viscosity of the final residual fuel, was that this untreated distillate had very poor diesel combustion properties; cetane value figures of 22 to 25 being not uncommon even from a good Middle East paraffinic crude. Many such crudes produced residual fuels with very good combustion properties so that large cycle gas components would adversely affect combustion, especially in medium-speed engines.

If, as suggested, future heavy marine fuel oils would be produced from catalytic cracking and vis-breaking, and straight run residuals currently widely available from vacuum distillation would eventually disappear, then indeed diesel engine operators would encounter many new and severe problems.

Future Fuel Trends

Perhaps, of necessity, characteristics of both current and future heavy fuels (Table I) were limited. One wondered whether these figures were the upper acceptable limits and if so, how did residuals from different crudes compare?

Mr Clark suggested that the term Specifications in Table V should be changed to Typical Inspections. At present there were no internationally recognised specifications for heavy or residual marine fuels, although there was undoubtedly a need for realistic specifications. Additional characteristics should be included: Conradson carbon, soluble and insoluble ash content and vanadium content. From the limited data given in Table V, both the current and possible future heavy fuels listed could well pose many problems if used, as many diesel fuels, particularly in medium-speed, trunk-piston engines. With such a high specific gravity it would be difficult to remove water, foreign matter and ash-forming constituents without resorting to very high temperatures and possibly enclosed, pressurized centrifuges.

It was mentioned that recent investigations had revealed the presence of abrasive catalyst fires in residual fuels. This appeared to be a new problem. It would be of interest to know the amount of increase in insoluble ash content these represented, and the average particle size. Mr. Clark wished to know if this could be regarded as typical of some current residual fuels or if it was the result of malfunction of the catalytic cracker in certain refineries.

Residual Fuel Properties

The fuel pour points listed were typical of residual fuels from some North African paraffinic crudes with a high wax content, but were much higher than widely available residuals from Middle-East crudes and other sources. Unless ships using such waxy residuals were equipped with efficient bunker heating coils and lagged and traced suction pipes, serious pumping problems might well arise. With viscosities as high as 5000 secs Redwood 1 at 100°F, to obtain a suitable viscosity of about 65 to 75 secs at the fuel injectors, the fuel would have to be heated to about 143°C (290°F) minimum. This would be beyond the limit of the fuel pre-heating equipment on many ships. If pre-heat temperatures were too low, combustion would be impaired due to poor spray patterns and insufficient atomization. In addition, the undoubtedly high Conradson carbon residue (probably about 12% plus) and high asphaltene content (possible exceeding 10%) would pose further combustion problems.

Little mention was made of vanadium content, especially from certain crudes, which even with current 1500 sec intermediate fuel oils could cause serious problems with burnt exhaust valves in highly rated, medium-speed, 4-stroke engines. In both medium-speed, and large slow-speed crosshead type 2-stroke engines, vanadium was also objectionable on the grounds that it acted as an active catalyst to promote the formation of highly corrosive sulphuric acid. Mr Clark asked if the authors foresaw any increase in vanadium content of future residual fuels since obviously, the higher the sulphur content of the fuel, the more serious would be the effect of increased vanadium content.

From the practical viewpoint, poorer quality residual fuels would impose increasingly severe demands upon the engine-room staff, and on the fuel handling and cleaning equipment installed. It was probably that in many existing motor-ships the equipment would be unable to clean and preheat these poorer quality fuels efficiently. As a result, trouble might well be experienced with poor combustion, severe liner and ring wear, and excessive ring-zone deposits.

Information Available on Fuel Properties

Very often the Chief Engineer was given too little information concerning the bunkers he had taken aboard to enable him to treat the fuel properly and burn it efficiently. All too often his bunker chit merely gave the amount taken aboard, its viscosity (usually Redwood 1 at 100°F) and its specific gravity. Several cases had been reported where heavy residual fuels had solidified in the ship's double bottom tanks in cold weather, either due to high asphalt content increasing the viscosity above pumpability limits or, in some cases with highly paraffinic residuals, due to the crystallizing out of paraffin wax. It was hoped that such cases would not increase with the poorer, higher viscosity residuals proposed. A strong plea was made for the fuel supplier to give all essential data concerning the residual fuel bunkered to the Chief Engineer, and where it had unusual properties (e.g. very high asphaltene content and high pour or cloud point) to advise him how to treat and burn the fuel efficiently.

In general terms, it must be accepted that residual fuels used as ships bunkers were the "bottom of the refinery barrel". Even so, it would seem that too much of the desirable properties were being removed in modern refinery processes and the resultant residuum might be difficult to burn satisfactorily in slow-speed engines, and almost impossible to give efficient combustion in very highly rated medium and medium high speed trunk-piston engines.

Lubricants

It is apparent that, apart from the problems posed by poorer quality residual fuels, the more highly rated marine diesel engines of the future would impose much more severe demands upon cylinder lubricants and system oils or upon dual-purpose oils. Together, the future demands would be most difficult to meet.

System Oils

It was not at all clear why the system oil capacity in future engines should be reduced, indeed, there seemed to be a strong case for increasing the capacity. Too small an oil capacity, especially in engines with oil-cooled pistons, could well result in serious problems. The capacity should be large enough to allow at least fifteen oil changes per hour. Obviously, this was governed to a large degree, by the drain tank capacity, which was in turn governed by the space available below, or at the side of, the engine. It was important that the "dwell" time of the oil in the tank after returning from pistons and running gear should be long enough to permit settling out of any water and solids present, before being recirculated through the engine. This reduced oil oxidation and abrasive wear of bearings and other moving parts. It also permitted efficient oil maintenance by centrifuge or static filters.

It was increasingly evident that water was the greatest contaminant problem both in the cylinder and the crankcase of diesel engines, especially when burning heavy residual fuel. Mr Clark asked if the authors favoured the use of detergent/dispersant system oils and if so, what level of detergency and TBN they suggested? He wondered if they were satisfied that future requirements could be met without raising a problem with water separation or the formation or emulsions.

Reference was made to thermal degradation and Mr. Clark asked if this was high temperature oxidation, or thermal cracking, or both? He also wondered if the authors thought it possible to increase the commencement of thermal cracking above about 300°C by improvements in refinery techniques.

Cylinder Lubricants

The comments concerning cylinder oil volatility were interesting. Mr Clark asked whether the authors would agree that the more volatile, predominately naphthenic, base oils burned more cleanly and leaving less ring zone deposits than the less volatile and more oxidation resistant and thermal cracking resistant, paraffinic-base oils. This posed a problem, and their view on the most suitable base oil type would be of interest. He also wished to know if it was their view that the limit of refining to give the maximum oxidation resistance had been reached already, and that further improvement could only be obtained by the use of high temperature anti-oxidants? One must question whether these were really effective at the high temperatures reached on the cylinder walls.

Mr Clark felt the comments on the incorporation of additives to reduce frictional and abrasive wear to be of particular interest, but wondered if these were high temperature boundary lubricants or true EP agents as used in applications such as hypoid rear axles. He asked what, in addition to the use of additives to impart high alkalinity to future cylinder lubricants giving a TBN in the order of 80, were the authors' views on the incorporation of detergent dispersant additives.

In recent years, with the advent of high turbo-charging air pressures, a new problem had arisen due to the cooling of the scavenge air below its dew-point in crosshead type 2-stroke engines. Large volumes of condensed water in droplet form were entrained with the scavenge air and entered the cylinder at high velocity. It was believed that at least some of these droplets passing across the cylinder reacted with combustion products to form corrosive sulphuric acid. As the water droplets struck the opposite cylinder wall they might wash away the protective oil film, resulting in increased abrasive wear. Additionally, if they formed sulphuric, acid they might cause destructive corrosive pitting. The authors' views on this problem and how it would be effected by poorer fuels would be welcomed.

Medium-Speed Engine Oils

It was agreed that it was preferable to use a common lubricant for cylinders and running gear in trunk-piston engines. However, where separate cylinder lubricators were fitted, provided that the cylinder oil was compatible with the crankcase oil, there appeared to be little objection to the use of a relatively high TBN SAE40 cylinder oil with an SAE30 crankcase oil with lower TBN and good detergency/ dispersancy properties, accepting that admixture would occur. The use of synthetic oils appeared to be out on account of cost. Additionally, such oils already available, although having a high viscosity index and good load-carrying properties, might be suspect from the shear-stability point of view. It would be interesting to know if any such oils had been used as dual-purpose lubricants in large medium-speed engines burning residual fuels and whether or not the results were satisfactory.

DR P G CASALE (Exxon International) complimented the authors and said that the paper was characteristically representative of the fascinating work of adding turrets and dungeons to the edifice of the future done by so many researchers and forecasters. Fuels were certainly most topical these days relegating lubricating oils to the Cinderella role, and one should therefore be grateful to the authors for having brought these back into the limelight.

To start with crosshead engine system oils: considerable improvements in reducing system oil consumption had been made over recent years. These had resulted in lesser make-up with fresh oil, hence greater exposure of the same charge to high temperatures. For a given installation, experience had shown that the performance of oils currently used (whether alkaline or non-alkaline) had not suffered from this longer exposure to thermal stresses. One might expect therefore that thermal degradation would be more a function of cooling spaces temperatures than of the total time that the oil would be exposed to such temperatures. This being the case, one must agree with the authors that synthetic oil technology for diesel application (which is not exclusive to the Mobil Oil Company will most probably be confined to exceptional circumstances, where the high cost of such lubricants is no barrier to their application.

With regard to the trend towards reducing system oil size, as the authors pointed out, good system design would be essential for efficient operation and, in this connection, it was to be hoped that the many shipyards so often called upon to design the lubricating oil system, would be ready and able to meet this new challenge.

One very often heard alkalinity associated with the level of performance of a lubricant, particularly cylinder oils for crosshead engines. Of course, alkalinity was very important, but it was not the only contributor to oil quality. However, the possibility of reversing the current TBN trend, i.e. from higher, to lower values, must depend on the rate of utilization of the alkalinity supplied to the cylinder walls and rings - and this rate depended considerably on distribution and regeneration of fresh oil on to the affected surfaces, besides on oil technology. The authors had forecast a rough time for these surfaces and if one correctly interpreted Fig 4 (and its relative commentary), not much help could be expected from improved additive technology. The authors' comments to Fig 4 would suggest, in fact, that more protection to cylinder liner surfaces was dependent on volatility characteristics of finished products regardless of the additive package used. It was assumed, of course, that when the authors spoke of cylinder oil they did not refer to straight mineral oils of the early 1950's.

If volatility characteristics of finished products was so uniquely important, as Fig 4 seemed to imply, then Mr Casale wondered how Fig 5 was to be interpreted? To list a few queries:

1) was each oil tested for 6000 hours or a realistic period with reference to service?
2) were the results obtained in the same engine?
3) were the figures shown for each oil obtained from one single unit or were they the mean of many units?
4) what precautions were taken to ensure uniformity of operation and metallurgy for all the lubricants tested? These two factors could affect the distribution of wear between liners and rings quite considerably.

Such information would certainly add considerable technical perspective to Fig 5. Perhaps it might even explain the liner wear rates shown, which (together with those of Table II) would seem to be generally rather high.

To move away from the particular to the general, one would fully concur with what seemed to be the authors' basic message on lubricants for the future. On the assumption that marine diesel engines of the next decade or so would still be fed conventional hydrocarbon liquid fuels, lubricant technology was ready to cope with the challenge of lower quality fuel and more demanding engine design parameters. In the edifice of the future, this was the turret. We could see clearly a long way ahead.

To keep the metaphor going, there might however be dungeons as well. Perhaps other combustible materials, besides liquid fuels, would begin to play a significant role in supplying the marine bunker demand in the 1990's. Coal-fuelled diesel engines were the obvious case, as it would appear that these were being considered by engine designers. Naturally, it was unlikely that anybody today who could confidently predict if, and when, the switch to coal would take place. Should such change of fuel occur, it was not difficult to foresee that it would have a profound effect on lubrication conditions, and lubricant technology would be faced with a formidable task. As the anticipated problems were not yet defined in detail, obviously it could not be said whether, or how, these could be tackled from a lubrication standpoint. Hence the uncertainty about being able to predict the future.

However, to finish on a brighter note; there was no reason to believe that lubricant technology, which had been so instrumental in the success of the diesel engine, would not be able once again to help that machine when, and if, it decided to change to a diet of coal!

Correspondence

MR J H AUBREY, B Sc C Eng FIMarE, (Vickers Shipbuilding Group Ltd.), in his written contribution, said that the reference to the use of homogenizers in the treatment of fuel oils was disconcerting in its implications and he asked the authors to clarify the types of homogenizers used in their evaluations.

A number of years ago Vickers considered that it did not make economic sense to centrifuge out and dispose of some ½% to 4% of the bunkered fuel in the form of oil sludge, which comprised essentially solid fuel fractions. They considered that a sensible approach would be to grind down these solid fractions to microscopic size and intimately disperse them throughout the body of the fuel in order that the entire fuel potential could be realized, thus eliminating wastage. A review of the available homogenizers at that time showed that they were principally of the ultrasonic or pressure impact ring type and, whilst obviously adequate in the fields for which they were designed, notably milk processing, they had obvious limitations when considering residual fuel oils. Clearly, an homogenizer specifically designed for this duty was required. The Vickers homogenizer was basically a fuel oil grinding machine utilizing a patented "Rolling Disc" principle, designed to grind the asphaltene agglomerates down to particles of maximum size 5 to 10 microns, with the majority much less than this. These were thoroughly dispersed throughout the body of the fuel, allowing the entire fuel bunkered to be utilized in the main diesel engine. Extraneous solids were also ground to microscopic sizes and passed harmlessly through the system. Experience with this machine in several ships operating over a number of years, had not resulted in any reported increase in fuel pump or liner wear directly attributable to residual fuel oils homogenized by this method.

It was noted that the tests carried out to establish the performance of fuel cleaning equipment (Table II) used fuel of viscosity 1500 secs Redwood I. One would doubt that the same relative results as between homogenizing, centrifuging and filtering had been obtained using a heavier fuel oil, say 4000 secs Redwood I specific gravity 0.988.

MR E C HILL, M Sc FInst Pet, MI Biol. (University College, Cardiff) in his written contribution, said that bacterial infection could occasionally occur in crankcase oil of cross-head diesel engines and if unchecked might cause serious additive depletion and corrosion. Current research indicated that any contamination which occurred would be automatically destroyed if purifier temperatures were high and purifier throughput was capable of killing organisms faster than they could grow. He asked if the authors could comment on thermal stability of present and future formulations, on what they would expect to see under conditions of thermal stress and if they could foresee any unavoidable or deliberate changes in future crankcase oil formulations which would affect bacterial infection.

Author's Reply

The authors appreciated the many interesting contributions to their paper. However, as some questions indicated disappointment at the lack of detail in some aspects of the paper, particularly the lubricating oils section, they would point out that it was a "trends" paper, and many of the specific items were mentioned only to emphasize a trend in lube development or research.

Referring to the Chairman Mr Baker's comparison of predictions in the paper with those of a minor ministry of 1927, one of the strengths of any successful oil company was in its future planning. Refineries, cat crackers and vis-breakers were conceived five to six years before they came on stream and five-year plans, and ten-year long range forecasts were normal practice.

As a matter of interest, in 1926 over 70% of the world's motorships were lubricated by the author's company and its marine experience and associations went back much further than that. Of course, other vis-breaking systems were feasible, but like all refinery processes of both today and of the future, they would be selected on the basis of market demand and economics. Irrespective of the particular vis-breaking process adopted, the overall effects on the fuel quality would be similar.

The subject of volatility and its effect on both lubricating oil consumption and liner wear was also raised by other contributors. Volatility was mentioned as being one more avenue of investigation in the total research into diesel engine lubrication. Low volatility properties complement other characteristics such as alkalinity, detergency and load-carrying. It was not intended to infer that low volatility would replace these essential properties.

The use of anti-scuffing additives in cylinder oil development was already well known. The example quoted was only one item in a continuous programme indicating yet another avenue of research.

Regarding the prediction of future engines operating at 26 kg/cm^2, this loading was already being used and engine builders had advised of their future development in this power direction. The authors' interest was to be able to lubricate such units satisfactorily and not to evaluate their feasibility.

It was not the aviation synthetic type lubricants the authors were considering for use in marine diesel engines or turbines. Special synthetic oils had been developed which were already used in small and medium speed diesels. This type of synthetic oils had a potential capability for taking over in several fields of applications if and when ambient conditions, engine loads and temperatures exceed those normally accommodated by mineral oils.

The authors appreciated Mr D Royle's comments which also pointed out that cracking and vis-breaking had been carried out for a long time already. This underlined that considerable experience was already available with which to meet future increasing use of these processes.

Mr Royle was, of course, correct in pointing out that Table I showed characteristics of fuel components resulting from the indicated refinery processes and not characteristics of finished fuelds. With regard to Table V, the authors agreed that better words might have been chosen to point out that the changes in fuel characteristics were expected to be of reasonable magnitudes.

Commander Tyrell reiterated the feelings of many shipowners when he proposed a revised fuel specification for oil engines. Such a specification was of particular interest when shipowners were faced with burning fuels provided by the charterers. Shipowners through the GCBS, oil companies, through the Institute of Petroleum and the British Standards Institute were studying such fuel specifications.

Regarding refinery production of only gas oil and coke, a few refineries in the USA had been operating this way. However, the market for this type of coke was specialized and not easily available.

Mr D W Golothan had asked if analysis of the fuels used in the ships in Table II all contained catalyst fines. Catalyst fines were identified only in some of these fuels, but the Table was intended to show that irrespective of the type of sediment, wear rates were lower when fuel cleaning was by centrifuge.

The percentages of asphaltenes and carbon residue shown in Table I were correct.

Mr Golothan's comments on Figure 2 were appreciated, but it was still of interest that straight run residuals equated to as much as 38% of the barrel whereas cracked fuels were only about 6%.

The authors comments on Alaskan crudes were only intended to indicate that fuels from the North Sea crudes were mainly used inland, but fuels from Alaskan crudes were already used for producing ships' bunkers. Cracked fuels were, of course, slower burning than straight run fuels from the same crude source.

Mr Golothan's comments on cylinder oil alkalinity and high sulphur fuel were noted with interest, the authors company did not plan any cylinder oils above 80 TBN as they considered 80 TBN adequate to neutralize the acids, and the special load carrying and anti-scuffing additives described were more effective in controlling liner and ring wear than additional alkalinity additives - and they produced less ash.

The authors did not intend to suggest that a large crosshead system would be operated on a run and dump basis. It would be predominantly small and medium speed systems, where a high degree of contamination was inevitable and system sizes were much smaller, which might be considered for this practice.

Figure 5 was of interest to a number of contributors. It concerned the results obtained over a number of years in half the cylinders of one vessel, the other half being used with a reference branded cylinder oil. Each unit was tested for approximately 6000 hours. Similar tests were made on other vessels with different types of highly rated engines, and similar trends in ring and line wear patterns were experienced. This work was being continued, but an adequate description of the programme would require a paper of its own.

The authors would like to assure Mr G McConnell that synthetic lubricating oils currently being developed for diesel engines would burn satisfactorily as fuels in diesel combustion chambers if, for any reason, it were found desirable to dump them into the fuel tanks.

It was hoped that piston undercrown temperatures currently recorded as high as 300°C would not increase in the future. Much would depend on the design of the cooling system as well as the piston metalurgy.

Regarding volatility, it had already been pointed out that this was only one desirable characteristic of a diesel lubricant. If two oils were of the same initial viscosity, the one with the most vaporization (Oil B) would have the higher viscosity in the oil remaining, which may effect its spreadability. Spreadability was another important aspect of cylinder oil performance but had been referred to in other papers, whereas the authors were not aware that volatility of marine oils had been so discussed.

The authors were grateful to Mr McConnell for pointing out the text error referring to Figure 6. The measurements were, of course, microns of radial liner wear. However, they could not agree that the wear was not stepped. The degree of accuracy of the measurements was about 1 micron. Several measurements were recorded between the steps. Other work done on liner wear showed sub-surface metal fatigue causing the liner surface to break off, resulting in the stepped wear measurements.

Synthetic trunk engine base oils had the following desirable characteristics: very low volatility, excellent resistance to oxidation and high thermal stability, excellent low temperature performance, and good water separability. All these "pluses" lengthened the life of the lubricant. Their properties were further improved by carefully selected additives to ensure optimum performance and drain periods.

The 4 Ball test had no direct relationship with diesel engine performance of an oil. It had, however, been proved as one of several good screening tests for establishing promising formulations for further tests in actual marine engines.

Mr G H Clark's many interesting questions were much appreciated by the authors whose replies are of necessity brief. Vacuum residium entering the vis-breaker had a minimum viscosity around 15,000 cSt amd might be as high as 30,000 cSt. The residium leaving the vis-breaker might be only 3,000 centistokes, and, therefore, considerable viscosity reduction was already achieved before any cycle oil needed to be blended in. Neither the vis-breaker nor the cat-cracker slurry were pumped at 50°C; both were maintained at suitable temperatures to enable ease of handling. Some 15-17% cycle gasoil was required to reduce vis-breaker residium from 3,000 cSt to 380 cSt at 50°C.

The paper clearly stated that all cracked or vis-broken fuels had poorer combustion properties, but set out to explain how such fuels could still be burned successfully in diesel engines. It was not suggested that straight run residuals would eventually disappear within the future time span the paper was considering. Emphasis was also made that the rate of introduction of new cat-crackers or vis-breakers would be relatively slow. The characteristics in Table I were for fuel components from the refinery processes indicated, and not for marketed fuels.

The specific gravity quoted in Table V was 0.988, below the gravity of 0.990 which was claimed by the centrifuge manufacturers to be the limit for satisfactory purification of fuels by current equipment. Articles on this work had been recently published in the technical trade journals.

Despite separation carried out in the FCC process, catalyst fines might carry over into the slurry. Particles were generally below 10 microns, but a few of the larger sizes may also be present.

Difficulties in pumping fuels out of DB tanks in cold weather was due to the waxy nature and not the asphaltene content of a fuel. The high pour point was a characteristic derived from the crude and not the refinery processes. Reputable fuel suppliers had manufacturing specifications for their residual fuels which were far more restricting that ASTM, BS, or similar specifications. Such specifications were under further discussion by interested parties as previously indicated.

Crosshead systems must, of course, have an optimum capacity to enable the oil to circulate a given number of times per day through the engine. However, the longer so called "dwell" time required by straight mineral oils was no longer necessary for modern alkaline detergent oils. One major cause of bearing damage was from "slugs" of settled dirt and water being picked up by the lubricating oil pump suction in heavy weather and passed through the bearings. Modern alkaline detergent oils held water and sediment in suspension in very fine particular form and carried these contaminants to the purifier for removal. Such oils also had good air release properties. They also neutralized combustion acids as they entered the crankcase before they could cause corrosion and offered protection against rusting and corrosion from water ingress. Some oils resisted bacterial infestation. Initial TBN of 6-7 was desirable. The authors contended such oils were essential to offer the maximum protection to micro-finished surfaces in modern engines and when used, considerable reductions in system oil capacity had been effected. Fifteen tons less lube oil could mean fifteen tons more cargo or fuel.

Thermal degradation could be the result of both oxidation and cracking. Resistance to thermal cracking was best obtained by both base oil refining and the selection of suitable additives. Paraffin base oils were more stable to oxidation and had higher viscosity indexes than Naphthenic base oils. When burned in diesel cylinders both oils formed carbon but the paraffinic oils were believed to form a slightly harder carbon. This could, however, be offset by proper additive selection. As all modern cylinder oils contain detergent/dispersant additives, these kept the cylinders and rings clean not only from combustion carbon but also from lubricating oil carbon. Paraffinic base oils were preferred not only as cylinder oils but also for system and medium-speed diesel engine oils, because of their higher viscosity index and greater oxidation stability.

Cylinder oils were exposed to high liner temperatures for relatively short periods before being replaced with fresh oil. They were, therefore, able to withstand higher temperatures than if subjected to continuous heat. Anti-oxidants increased their ability to resist degradation.

The additives used to reduce wear as shown in Figure 5 were combinations of various types of true EP agents of which some were similar, but not the same, as those used in hypoid gears. Without detergent/dispersant additives, piston rings would soon "gum up" and were absolutely necessary in addition to the alkaline additives. It was essential that additive comonents should be extremely carefully balanced against each other.

The type of scavenge air condensation described by Mr Clark was, of course, caused by the increase of the dewpoint at the scavenge pressures involved and excessive cooling of the scavenge air especially with high ambient air humidity. Special baffles and drains with higher intercooler temperatures could overcome the problem. However, such condensation would accentuate acid corrosion problems particularly with high sulphur fuels and incomplete combustion, and acid neutralization by the cylinder lubricant became increasingly important.

Mr Clark stated that synthetic diesel oils might break down under conditions of shear-stability. This was not the case, since these oils had a natural high viscosity index. It was when a high viscosity index was obtained by polymer additives that their effect might be lost by shear-stress. Synthetic oils as mentioned in the paper did not contain polymers. They had completed 100,000 miles without oil or filter changes in arduous long distance lorry and truck operations without appreciable change in viscosity index. The authors had no experience of synthetic oils in large medium speed engines burning residual fuels.

Replying to Mr E C Hill's question on the thermal stability of lubricating oils, each new generation system oil introduced by the authors' company had increased resistance to thermal degradation to resist increasing oil cooled piston undercrown temperatures. Undercrown skin temperatures of over 300°C had been measured in some engines.

Thermal degradation could affect an oil in two ways. Oxidation darkened and thickened an oil and could ultimately result in the formation of organic acidity. Thermal cracking in the absence of air rearranged the molecular structure of the oil-forming light ends and also hard, dense coke. In an enclosed system the light ends redissolved in the oil causing a reduction in both viscosity and flash point. Special base oil refining techniques and addition of carefully selected additives offered the best resistance to either form of thermal degradation.

Oils were screen tested for resistance to oxidation and cracking in several ways. Two important screen tests used by the authors company were the Helix Test and the spiral coker test. In the Helix test the oils were circulated over a steel helix heated to 380°C for a set period in the presence of air emphasizing oil oxidation. In the spiral coker test the oils were circulated over a spiral element heated to 370°F in the absence of air simulating cracking conditions.

No future changes in formulations were foreseen relating to bacterial infection except in efforts to make formulations which having as much resistance as possible to bacterial infection. Mr Hill's investigations into these problems had been of great interest and assistance in this respect.

Homogenizers of Mr J H Aubrey's company were not among those in use in the test ships. Enquiries were made of two shipowners using the Vickers Homogenizer, but no information on liner wear rates on engines using only homogenizers was obtained. The authors would be grateful if Mr Aubrey could supply such information for the ships successfully using the Vickers equipment. All the results with homogenizers the authors had investigated pointed in the same direction as indicated in Table II.

Homogenizing equipment did not remove anything from the treated fuel. If the contaminant was sea water, it would just be dispersed by a homogenizer. Sodium salts could contribute to vanadium ash corrosion by considerably lowering the temperature at which the corrosion occurred. For instance, vanadium salts alone might start to corrode steel at 650°C. When mixed with sodium sulphate in the ratio 13 vanadium to 9 sodium the corrosive attack could start at temperatures of only 350°C.

The authors knew of many ships, including some powered by medium-speed engines, using 3500 Redwood I fuel treated by purifiers and returning good wear rates. These included some twenty diesel tankers of the authors' company.