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TRANSACTIONS (TM)

QUALITY OF MARINE FUELS AND SUGGESTIONS FOR THE IMPROVEMENT OF EXISTING STANDARDS

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Quality of Marine Fuels and Suggestions for the Improvement of Existing Standards

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SYNOPSIS

Various organizations have suggested ways of improving the information available on the quality of marine fuels supplied to ships. The 1980s have so far seen the promotion by the International Chamber of Shipping (ICS) of a new and more comprehensive delivery ticket and the publication by the British Standards Institution (BSI) of the first ever standard on 'Petroleum Fuels for Marine Oil Engines and Boilers BS MA 100:1982'. A number of organizations, in particular the classification societies, have introduced fuel quality testing programmes. Participation in a fuel quality testing programme has given an insight into the variety of delivery tickets used by petroleum suppliers and the haphazard way in which the features of a fuel are often either recorded incorrectly or not included. The delivery ticket suggested by ICS does not seem to have been generally accepted and possible reasons for this are discussed and an alternative is put forward. This paper presents information on the percentage of fuels which failed to reach certain levels of quality over a four year period. Marine fuels are measured in volume yet sold by weight, and so it is very important to have the correct density. During the initial deliberations about the contents of the BSI marine fuel standards, it was decided that some quality aspects should be included. However, there was insufficient knowledge on how to define them and it was only possible to include them in an Appendix table. Data from the worldwide fuel quality testing programme will provide information which could be beneficial to all concerned.

INTRODUCTION

A worldwide fuel quality testing programme was introduced to the marine market by Det norske Veritas (DnV) in late 1980 and since then has spread throughout the shipping fleets of many countries. The results obtained in DnV's laboratories for fuel samples taken by ships' staffs at the time of bunkering not only provide useful information for immediate use by the ship operator but also can be tabulated. This gives all the participants in the programme access to additional information when considering future bunkerings.

The data collected over the first 20 months formed the basis of an earlier paper.[1] It is now possible to present data for four years (1981–1984) and extract additional information, which will be useful in the decision making required as additional standards are introduced or those already in existence are updated.

WORLDWIDE FUEL QUALITY TESTING PROGRAMME

Fuel samples received at DnV's laboratories come from a variety of locations, with both steamships and motorships participating in the programme. Many of the samples are taken whilst the vessel is bunkering. These samples are most frequently of residual fuel but a number of operators have considered it advisable to send samples from marine diesel or gas oil deliveries. Samples taken at various locations within the ship's fuel system are also received.

This paper is concerned solely with residual samples taken during the bunkering operations on motorships. Residual fuels have been defined as those fuels which have a kinematic viscosity at 50 °C of 15 cSt and higher. A broad outline of the programme was included in Ref. 1 and a more comprehensive review of the practical aspects of the programme was the subject of Ref. 2.

Mr D. Royle graduated in 1942 with an external engineering degree from London University. He spent six years in the aviation industry, working mainly on fuel test work. In 1947 he joined Esso and remained with them until retiring in 1981. Almost all of his career with Esso was spent working on the quality of marine fuels and lubricants. In 1981 he joined Det norske Veritas, on a part-time basis, to provide expertise on the subject of petroleum for their marine fuel quality testing programme. He has read papers at the Institute of Marine Engineers in 1954 and 1983 on the quality of residual fuels used in motorships and was a member of the British Standards Marine Fuels Working Group.

All vessels taking part in the programme are provided with instructions for taking samples, sample bottles, sealing equipment, labels, report sheets, and a specially prepared sample container that meets the IATA regulations for the transport of fuel oil samples. The samples are despatched quickly by reliable transport to appropriate fuel testing laboratories owned and staffed by DnV personnel. Currently there are three laboratories located in Oslo, New Jersey and Singapore.

Test methods

Considerable attention is paid to the need for all three laboratories to maintain very high standards. The fuels are analysed by the same test methods, and a regular feature of the controls is an internal correlation programme, when fuels of unknown quality are tested by each laboratory. There is also a regular interchange between the laboratory personnel actively involved in the day-to-day analysis work.

In the five years that the programme has been running the high standards set by the laboratories have been accepted by the large petroleum supplying companies. No doubt this confidence will, in time, extend to the smaller companies. However, it seems that there are a number of small commercial laboratories prepared to test residual fuel samples that do not have the necessary expertise. This applies to some of the long established test methods but is probably an even greater problem when it comes to analysing metal contents. This was highlighted in Ref. 3, from which the following is extracted:

Laboratory	*Al* (ppm)	*Si* (ppm)	*Catalyst* (ppm)
Exxon Research	33.0	61.4	194
A	3	13	33
B	12	30	87
C	24	30	110
D	7	18	52

Exxon attributed the failure of Laboratories A, B, C and D to agree with Exxon's results to be caused by deficiencies in their methods of testing.

A similar experience, brought to the attention of DnV by one of the participants in the programme, concerned a residual fuel delivery at a port on the West Coast of the USA. The analysis data are given in Table I. The ship's staff took a fuel sample during the bunkering operation and it was sent to DnV's New Jersey laboratory. On the basis of the analysis results the shipowner complained to the supplier, who then sent his retained sample to Laboratory E. The supplier rejected the shipowner's complaint because the ash, aluminium and silicon contents were low and within accepted limits.

When the vessel reached Singapore the shipowner decided to send the sample given by the supplier to the ship to Laboratory F in Singapore. The samples analysed by Laboratories E and F should have been the same provided that the supplier had taken one large sample and split it into two (one to retain himself and the other to give to the ship). The ash content obtained by Laboratory F was only half of that obtained by Laboratory E but the aluminium content was almost five times higher.

The shipowner then instructed Laboratory F to send what remained of the sample given to the ship by the supplier to DnV's Singapore laboratory. The similarity of the analysis results determined in DnV's laboratories for the samples taken by the ship's staff and the supplier showed that both samples were very similar and that the main reason for the shipowner's complaint against the supplier of the high ash, high aluminium and unfilterable fuel was fully justified. The supplier then agreed to have the fuel offlifted.

GENERAL INFORMATION OBTAINED FROM THE PROGRAMME

General information was given in Ref. 1 but it is appropriate to present similar data for the first four years of the programme. The fuel samples were taken during bunkering operations on 956 ships.

As the quantity of fuel represented by each sample is unknown, the information given is based on the number of samples received. However, vessels taking large deliveries (where two or more barges are used) frequently send a sample taken whilst fuel from each barge is being pumped onboard.

Fuel groups

For convenience the fuels are divided into four viscosity ranges: 15–100, 101–250, 251–400 and above 400 cSt at 50 °C, based on the actual viscosity of the fuel sample tested. The number of samples received and the percentages for 1981–1982 and 1983–1984 are given in Table II.

Comments were made in Ref. 1 that in the whole of the international marine industry the percentage of deliveries to motorships of fuels with viscosities of 251 cSt at 50 °C and above is probably not as high as in Table II. However, over the course of the programme the percentage has risen from 40.4 to 47%. This is due in part to newer ships ordering higher viscosity fuels and in part to the conclusion reached by shipowners participating in the programme that provided their ship can handle the higher viscosity product then there are no operational reasons why they should not make the change. This trend will probably continue in the future.

Table II also shows the growth that has taken place in the

Table I: Variations in analysis results for samples tested at four laboratories

	Sample taken by			
	Ship	*Supplier*		
		Retained by supplier	*Given to ship*	
	DnV, USA	*Lab E, USA*	*Lab F, Singapore*	*DnV, Singapore*
Density at 15 °C (g/ml)	0.973	—	0.973	0.974
Viscosity at 50 °C (cSt)	365	—	362	387
Conradson carbon (% by mass)	9.4	—	12.8	9.0
Ash (% by mass)	0.24	0.06	0.03	0.26
Vanadium (mg/kg)	59	—	64	55
Aluminium (mg/kg)	55	5	24	59
Silicon (mg/kg)	108	11	—	114
Sediment H F (% by mass)	Not filterable	—	—	Not filterable

Table II: Number and percentage of samples of fuels of different viscosities supplied in period 1981–1984

Viscosity (cSt at 50 °C)	*1981–1982*		*1983–1984*		*1981–1984*	
	No. of samples	*%*	*No. of samples*	*%*	*No. of samples*	*%*
15–100	259	6.7	849	8.5	1108	8.0
101–250	2034	52.9	4425	44.5	6459	46.9
251–400	1397	36.3	4220	42.5	5617	40.7
Above 400	158	4.1	445	4.5	603	4.4
Total	3848	100.0	9939	100.0	13787	100.0

Table III: Relative importance of various areas of the world in supplying bunkers in period 1981–1984

Area	1981–1982 No. of samples	1981–1982 %	1983–1984 No. of samples	1983–1984 %	1981–1984 No. of samples	1981–1984 %
USA	1240	32.2	2967	29.9	4207	30.5
Western hemisphere excluding USA	465	12.1	1182	11.9	1647	12.0
Europe	1208	31.4	3202	32.2	4410	32.0
Africa, Middle East, Pakistan, India	446	11.6	1362	13.7	1808	13.1
Far East	489	12.7	1226	12.3	1715	12.4
Total	3848	100.0	9939	100.0	13787	100.0

number of samples received for analysis: 1983–1984 shows a growth rate of 158% over 1981–1982.

Delivery areas

Table III shows the areas of the world where the fuel deliveries took place. There are some small differences in the percentage of samples received from individual areas for 1981–1982 and 1983–1984. The lower percentage of samples from USA ports and corresponding increase from Africa, Middle East, Pakistan and India may be significant.

Major bunkering ports

Table IV lists all the ports from which in any individual year the percentage of samples received was 2.0% or higher. The percentage of samples received from Houston has declined over the years but it is still the second largest source of samples in the programme after Rotterdam. There has been some increase in the percentage of samples received from Jeddah and Hamburg but this was offset by a decline in the percentage of samples originating from bunkerings in New Orleans.

The next port of significance not included in Table IV was Durban, which accounts for 1.6% of the samples.

Bunker suppliers

Table V shows the relative importance of different suppliers based on the number of samples received in the four year period. There were only six suppliers responsible for 700 or more samples and they accounted for just over 50% of all the samples received. Only another four suppliers were included when reducing the number of samples received per supplier to as low as 170 in the four year period. Less than 10 samples were received from bunkerings made by 189 suppliers. This is 60% of the suppliers registered and yet they were responsible for only 4% of the samples received.

The 189 suppliers includes 43 responsible for samples received in 1981–1982 but for no samples in 1983–1984. Taking into account the large growth in the number of samples received in 1983–1984 compared with 1981–1982 (it was 2.6 times greater), it raises the question as to whether many of these 43 suppliers are still involved in supplying fuels to international shipping. If this is the case then purchasers of marine fuels might like to consider whether they are likely to receive any sympathetic concern from such suppliers should they have cause to raise any questions about the delivery.

Following the presentation of Ref. 1 there was some discussion about the importance of the major international oil companies. In the first 20 months of the programme it was reported that 58.9% of the samples came from deliveries made by the major oil companies, but a contributor mentioned that industry figures showed that their market share had fallen to below 40%. Table VI lists the seven international oil companies and Caltex, which is not regarded as a separate supplier as it

Table IV: Percentage of bunker samples received from various ports in period 1981–1984

Port	1981	1982	1983	1984	1981–1984 No. of samples	1981–1984 %
Rotterdam	11.9	13.4	12.9	10.9	1658	12.0
Houston	9.8	8.3	7.4	7.3	1065	7.7
Los Angeles	5.9	5.6	4.8	5.6	744	5.4
Singapore	5.1	4.5	4.5	4.9	652	4.7
New Orleans	5.8	4.8	4.4	4.2	615	4.5
New York	4.4	2.9	3.7	3.0	453	3.3
Jeddah	2.4	2.7	3.5	3.4	443	3.2
Tokyo Bay	3.2	3.6	3.2	2.6	418	3.0
Hamburg	1.4	1.4	2.8	3.7	385	2.8
Antwerp	2.0	1.8	2.5	2.4	316	2.3
Other ports	48.1	51.0	50.3	52.1	7038	51.1

Table V: Relative importance of different suppliers in period 1981–1984

No. of samples per supplier	No. of suppliers	Percentage of total deliveries
700 and above	6	50.5
170–699	4	11.3
100–169	12	10.4
10–99	103	23.8
1–9	189	4.0
Total	314	100.0

Table VI: Relative importance of major international oil companies based on percentage of samples received in period 1981–1984

Supplier	1981	1982	1983	1984	1981–1984 No. of samples	1981–1984 %
BP	12.1	10.9	11.8	11.5	1588	11.5
Shell	7.6	8.6	9.0	11.3	1345	9.8
Exxon	12.7	10.8	8.4	6.3	1148	8.3
Mobil	10.4	9.9	9.4	6.2	1133	8.2
Texaco	8.4	5.0	6.5	7.5	932	6.8
Chevron	6.5	5.6	3.8	4.6	649	4.7
Gulf	4.4	3.2	3.1	3.9	493	3.6
Caltex	1.1	1.3	1.2	1.2	164	1.2
Total	63.2	55.3	53.2	52.5	7452	54.1

supplies on behalf of its parent companies Texaco and Chevron. However, it is shown separately as there is insufficient information to assign the correct percentages to the parent companies.

Based on the samples received for analysis there is a noticeable decline in the importance of Exxon and Mobil as fuel suppliers, with the opposite appearing to be the case for Shell. This is probably a reflection of the active part Shell have taken in discussing their quality standards in the press in recent years. Overall there is some decrease in the percentage of samples attributed to the major international oil companies but it seems to be levelling out at just over 50%.

DELIVERY TICKETS

The International Chamber of Shipping (ICS), a body of shipowner associations from many countries, had a Working Group that promoted what was considered to be a more meaningful delivery ticket. This Group, as originally constituted, ceased to function some years ago. The revised delivery ticket was designed to include, in addition to gravity, viscosity and flash point, other characteristics about the quality of the fuel to be supplied.

It is understood that many thousands of the suggested delivery tickets were distributed by shipowner associations. Participants in the fuel quality testing programme are encouraged to send a copy of the delivery ticket with each bunker sample. However, the number of ICS delivery tickets received is extremely small and it would appear not to have had much impact on suppliers.

Gravity and viscosity still have the major influence on the price paid by the purchaser for the fuel bunkered. These two parameters also influence the correct operation of the centrifuges installed on the majority of motorships and the amount of heat required to reduce the viscosity to the required level.

It has to be recognized that the delivery ticket is often completed by inexperienced personnel and other, more experienced persons with petroleum knowledge are sometimes unable to decipher the information. Not surprisingly chief engineers sometimes make a mistake in abstracting information.

Gravity

The gravity may be expressed as specific gravity, API gravity or density, and the temperature is sometimes not mentioned. Densities are sometimes reported at 20 °C but usually at 15 °C, and the current trend is to change from reporting the result in kg/l or g/ml to kg/m^3. All these variations make it difficult for a chief engineer to be sure he has the correct gravity.

The problems facing a chief engineer can be illustrated by Fig. 1, which is taken from a delivery ticket of a major oil company at a port in the Federal Republic of Germany. The text in *italics* formed part of the printed delivery ticket and the numbers and letters in capitals were typed onto it. The layout is the same as on the delivery ticket.

Contained in this section of the delivery ticket was the only reference to the gravity of the product supplied. The Chief Engineer reported this on the DnV form as 0.975. The fuel sample taken by the ship's staff and sent for analysis had a density at 15 °C of 0.955 g/ml.

Close observation of the data on the delivery ticket reveals that what the Chief Engineer thought was the specific gravity was the volume conversion factor (VCF) and the reported specific gravity was actually 959.1. Even this is an unusual way of defining specific gravity and was probably unknown to the Chief Engineer.

Characteristics of Product			*spec. Gravity*
1065866	*Litres*	*at 50 °C*	VCF 0.975
		at 15 °C	959.1
equal	995572	*Kilos*	
	979.85	LONG TONS	

FIG. 1: Part of a delivery ticket

Viscosity

The viscosity of a fuel is still expressed in a variety of terms such as Redwood, Engler, Saybolt Universal, Saybolt Furol and Kinematic, and at various temperatures. Very often the recorded viscosity has no connection with the actual viscosity of the product delivered; in other words the recorded viscosity is the nominal maximum viscosity for the grade ordered. For example, for a delivery of Intermediate Bunker Fuel 380 the viscosity is shown as 380 cSt at 50 °C.

A delivery by a major oil company at a USA Gulf port illustrates the unfounded suspicion of a chief engineer. The charterer's order, according to information provided by the Chief Engineer, was for fuel of 380 cSt at 50 °C with a maximum specific gravity of 0.99. The delivery ticket showed the density as 0.99 at 15 °C and the viscosity as 380 cSt at 50 °C. There must have been some onboard fuel test equipment because the Chief Engineer recorded on the label attached to the fuel sample bottle 'Visc 154 suspect instrument error'. The viscosity of the sample taken by the Chief Engineer when tested in DnV's laboratory was 168 cSt at 50 °C.

The supplier had, in fact, met the maximum density requirement and this had resulted in the viscosity of the fuel being much lower than 380 cSt at 50 °C but the ship's personnel had not been advised of this.

Density variation

Delivery ticket vs DnV analysis

The amount of fuel delivered to a ship is measured in volume but in almost all countries of the world fuel is priced on a weight basis. In order to make the change from volume to weight the density of the fuel must also be known.

On the assumption that the fuel sample received and tested in a DnV laboratory is representative, then a difference in the two densities is to the financial benefit of the supplier when the density recorded on the delivery ticket is higher than that measured in the laboratory.

This is illustrated in a simple example, making the following assumptions:

1. A delivery of 1000 m^3 at 15 °C.
2. A delivery ticket density of 0.980 at 15 °C.
3. DnV analysis data density of 0.970 at 15 °C.

The customer would be charged for 980 t instead of 970 t. With fuel at say $100/t this represents a loss of $1000 on a delivery of 1000 m^3.

It is possible to extract from the DnV programme data concerning the differences in reported density that are financially beneficial to the supplier.

Table VII covers three large bunkering ports in different areas of the world. At only two of the ports (in Europe and America) are major international oil companies engaged in the bunker business. The data cover about 1100 samples from many ships so any possibility of a bias caused by poor sampling in a few ships should have no effect.

The information concerning deliveries by the major oil companies is very consistent over the separate two year periods. For the other suppliers there has been some improvement at the Middle East and American ports in the last two year period but it is evident that there are a number of deliveries financially favourable to the supplier.

Proposal to improve the standard of delivery tickets

It is recommended that an association such as the ICS should

Table VII: Percentage of deliveries with density difference between delivery ticket and DnV result of more than +0.007 g/ml

	Major suppliers		*Other suppliers*	
	1981–1982	*1983–1984*	*1981–1982*	*1983–1984*
European port	0	2	14	26
Middle East port	—	—	72	48
American port	0	4	42	23

Table VIII: Percentage of fuels with viscosities above 100 cSt at 50 °C that failed to meet specified levels of quality

Quality level	*1981*	*1982*	*1983*	*1984*
Density at 15 °C (g/ml) greater than 0.991	3.8	6.2	5.1	5.0
Density at 15 °C (g/ml) greater than 0.993	2.4	2.9	2.1	1.8
Water (% by volume) greater than 1.0%	2.2	2.7	3.4	2.2
Conradson carbon (% by mass) greater than 18.0%	0.7	0.3	2.0	1.3
Conradson carbon (% by mass) greater than 20.0%	0.0	0.0	0.0	0.0
Sulphur (% by mass) greater than 4.0%	0.9	1.6	1.8	1.4
Sulphur (% by mass) less than 1.0%	0.4	0.8	1.3	1.2
Ash (% by mass) greater than 0.20%	0.0	0.3	0.3	0.3
Vanadium (mg/kg) greater than 300 mg/kg	2.4	4.1	7.1	8.1
Vanadium (mg/kg) greater than 400 mg/kg	0.8	0.9	1.5	2.2
Aluminium (mg/kg) greater than 30 mg/kg	3.6	4.1	5.5	4.8
Sediment H F (% by mass) greater than 0.15%	—	—	1.8	1.5

Table IX: Amounts of water in residual fuels as delivered at two ports in the period 1 June 1985 to 30 November 1985

			Percentage of deliveries with water content	
Location of port	*No. of deliveries*	*Average water content (%)*	*above 0.5%*	*above 1.0%*
USA	205	0.2	2	0
Middle East	49	0.6	47	14

concentrate on trying to obtain the co-operation of all fuel suppliers throughout the world to record on the delivery ticket the density and viscosity in uniform terms.

Suppliers, however, will continue to use delivery tickets conforming to their own format in preference to a layout suggested by someone else, although it might be possible to persuade the suppliers to allocate one small portion of their delivery ticket to record the density, viscosity and flash point in the agreed uniform terms. Because of the importance of these data it would be better to try and achieve this modest objective rather than ask for all the features listed on the ICS delivery ticket and finish up with very little response from the suppliers.

MARINE FUEL QUALITY AND BRITISH STANDARDS LIMITS

The data available from the fuel quality testing programme can be used to show the percentage of fuels that have failed to meet specified quality levels during given periods of time. Some of the quality levels chosen are the maximum permitted figures mentioned in British Standard Marine Series BS MA 100:1982. Other quality levels have been included as being more appropriate in some instances in order to show trends.

The information is presented in Table VIII. Fuels with viscosities below 101 cSt at 50 °C are not included and therefore the information is mainly applicable to British Standards classes M6, M7, M8 and M9.

Density

The British Standards limit for density of 0.991 g/ml at 15 °C continues to be very critical for many suppliers but as the percentage of fuels failing this requirement is not on the increase then it can be assumed that conscious efforts are being taken to meet the requirement. Much of the over-run is very small since in the last two years about 60% of the fuels that were above 0.991 only failed by 0.002, ie they were below 0.994.

Water

The British Standards limit for water is 1.0% and most fuel contracts specify a similar maximum. There is no indication from the programme data that overall there is any trend by suppliers to try and reduce the level of excess water found in fuel samples. This statement needs amplification since there is positive evidence that some suppliers aim for lower levels of water. One such supplier reported in their fuel specification[4] a maximum water content of 0.5%.

During 1984, of the fuels analysed with a water content of over 1.0%, 30% were deliveries by the major oil companies and 70% were deliveries by the other suppliers. As reported in Table VI, the major oil companies were the suppliers of 52.5% of the samples coming from deliveries made in 1984, so the indication is that they are not so prone as other suppliers to deliver fuels containing excess amounts of water. The same conclusion is reached when analysing the samples from deliveries made in 1983.

Deliveries at some ports are more likely to contain higher levels of water than deliveries at other ports. A spot check was made at two ports during a five month period in the latter half of 1985 and the results are given in Table IX. At the two ports chosen all the deliveries were by barge. The difference in the levels of water in the fuels supplied at each port is quite dramatic.

Conradson carbon

The British Standards limit for Conradson carbon is 20.0% for class M6, rising to 22.0% for classes M7, M8 and M9. There is no indication from the samples received in the first four years of the programme of a trend to higher levels of Conradson carbon. The percentage of fuels with a Conradson carbon level above 18.0% has not exceeded 2.0%.

In Ref. 1 it was suggested that the British Standards maximum Conradson carbon content of 22.0% was probably on the high side. This would still appear to be the case in that the number of fuels analysed with a Conradson carbon of over 20.0% was too small to register in the table.

Sulphur

A large majority of fuels continue to have a sulphur content of between 1.0 and 4.0% and no significant trend has been noted in the four year period. The percentage of fuels with a sulphur content above 4.0% or below 1.0% in each case has remained throughout at less than 2%.

Ash

The British Standards limit for ash is 0.15% for class M6, rising to 0.20% for classes M7, M8 and M9. The percentage of fuel received that failed to meet a maximum ash content of 0.20% was very small and in the four years never exceeded 0.3%.

Some of these fuels contained excessive amounts of salt water and if these are excluded the percentage of fuels with an ash content of over 0.20% drops to 0.2%. It is noted in Ref. 4 that a major international oil company is specifying a maximum ash content of 0.15%.

Vanadium

The British Standards limit for vanadium is 500 mg/kg for class M6, rising to 600 mg/kg for classes M7, M8 and M9. These are fairly high values but at the time of the initial discussions in the BSI Working Group they were considered to represent the levels that would be obtainable in some future fuels.

Of all the quality features shown in Table VIII, a maximum vanadium level of either 300 or 400 mg/kg reveals that an increasing percentage of fuels are failing these limits. The continuing rise over each of the four years in the percentage of fuels containing more than 300 mg/kg of vanadium is very significant and should be realised by ship operators. The availability of low vanadium content fuels is decreasing, although now, and maybe even in the future, a maximum level of 500 mg/kg for all BS classes might be more appropriate.

The shipowner representatives participating in the BS Working Group were not interested in having fuel specifications included in the Standard that would not have worldwide availability. No such requirement is applicable to the proposed ISO Standards currently available in draft form or to recommendations put forward by CIMAC, the latest issue of which is also available in draft form. Both these bodies have specified grades with a maximum viscosity similar to IF 180 and IF 380 but the maximum vanadium contents are 200 and 300 mg/kg, respectively.

During 1984, of the 5755 samples analysed in DnV's programme 14.6% of the fuels in the viscosity range 101–250 cSt at 50 °C had a vanadium content of above 200 mg/kg and 9.2% of the fuels in the viscosity range 251–400 cSt at 50 °C had a vanadium content of above 300 mg/kg. Every indication is that fuels below these vanadium levels are becoming scarcer.

Aluminium

The current issue of the British Standards includes in Appendix B a maximum level of aluminium of 30 mg/kg to be specified when a test method has been developed. The Institute of Petroleum test method IP 363 is now available so it seems reasonable to assume that the level of 30 mg/kg now applies.

The fuels analysed still continue to show a significant percentage number with an aluminium content of above 30 mg/kg and no indication over the years of any improvement.

A more detailed survey covering the two large bunker ports of Rotterdam and Houston is given in Table X and the information has been extended to cover the first eight months of 1985. At Rotterdam, except for one particularly bad time starting in September/December 1981 and getting worse during January/April 1982 reported in Ref. 1, the percentage of fuels failing to meet the maximum aluminium content has been quite low, although some deterioration is evident since August 1984 compared with the previous 20 months. At Houston the failure rate, whilst rarely as low as at Rotterdam, shows some big variations, although there is no evidence to suggest it is a seasonal fluctuation.

One of the big advantages to a fuel purchaser of participating in a fuel quality testing programme is knowing from where and which suppliers better quality fuels are likely to be available. Reference to Table X shows that at Houston during the whole of 1984 about 7% of the samples analysed had an aluminium content above 30 mg/kg. However, by separating the samples into different suppliers A and B, both of which are big suppliers of fuel at Houston, important differences can be seen. For supplier A, out of 96 deliveries, none had an aluminium content above 30 mg/kg, but for supplier B, out of 118 deliveries, 12.7% had an aluminium content above 30 mg/kg.

Table X: Total number of deliveries by all suppliers at Rotterdam and Houston and the percentage with aluminium content over 30 mg/kg

	Rotterdam		*Houston*	
Period	*No. of deliveries*	*Al content above 30 mg/kg (%)*	*No. of deliveries*	*Al content above 30 mg/kg (%)*
1981 Jan.–April	20	5.0	18	33.4
May–Aug.	34	0.0	28	10.8
Sept.–Dec.	68	8.9	55	7.3
1982 Jan.–April	95	22.0	77	6.5
May–Aug.	127	1.6	76	2.6
Sept.–Dec.	156	3.8	83	1.2
1983 Jan.–April	173	1.2	96	11.5
May–Aug.	174	0.0	100	1.0
Sept.–Dec.	186	0.0	111	10.8
1984 Jan.–April	184	1.1	130	5.4
May–Aug.	217	0.0	149	10.1
Sept.–Dec.	224	5.8	142	4.9
1985 Jan.–April	229	3.9	151	2.6
May–Aug.	222	1.8	145	6.9

There is some discussion as to whether it is desirable to continue to specify aluminium as a means of controlling the amount of fluid catalytic cracking material in marine fuels. This topic is covered in a later section of this paper.

Sediment by hot filtration

In the absence of any suitable industry test method for the determination of sediment, the Exxon sediment by hot filtration method was adopted from the start of 1983. In the two years that this test has been part of the normal testing procedure, just under 2% of the fuels have had sediment levels of above 0.15%. This test is at least one method which gives a fairly good indication as to whether there are going to be any fuel centrifuging problems.

ALUMINIUM OR CATALYST

Background

The British Standards Working Group discussed in 1979–1980 a convenient means of restricting the quantity of catalytic fines in the fuel. At that time there was no known method to quantify the catalytic fines, which are mainly a mixture of aluminium and silicon compounds. However, some members of the Working Group had experienced complaints arising from the use of catalyst-containing fuels and in their investigations had determined aluminium as a possible way of identifying the presence of catalytic material.

The decision of the Working Group was to include aluminium in the Standard and the consensus was to accept a maximum limit of 30 mg/kg.[5] Silicon could also have been added to the list of tests in the Standard but the objective was only to include parameters which served some obvious purpose and contributed to a complete specification.

A paper[3] was read in New York in 1984 which introduced a very valid argument as to whether aluminium should be replaced by catalyst, with the catalyst being determined either directly by a new method or by a formula using both aluminium and silicon contents.

The origin of the 30 mg/kg in the British Standard was also explained in Ref. 3. The Working Group, after some investigation, had assessed that typically bunker fuels contained about 150 mg/kg of Al_2O_3 and SiO_2 and, based on the knowledge on hand, assumed that most catalysts had a weight ratio of total catalyst to aluminium of about 5. Thus the 30 mg/kg aluminium specification was born (150 ÷ 5 = 30).

The official minutes of the Working Group do not record any mention that the adoption of the 30 mg/kg maximum for aluminium was reached by assuming that all catalysts have a catalyst/aluminium ratio of 5. It is understood from subsequent talks with individuals who took part in the original decision making that there was no verbal discussion along the lines intimated.

It is important to recognize this fact because Ref. 3 then lists composition data on some 29 commercially available (in 1981) FCC catalysts from six different manufacturers with catalyst/aluminium ratios varying from 3.1 to 14.5. Still supporting the erroneous assumption made by BSI in assuming all catalysts had a catalyst/aluminium ratio of 5, Ref. 3 then translated the 30 mg/kg aluminium specification into anywhere between 93 and 435 mg/kg of catalyst.

In a later paper[6] in 1985 on basically the same subject the

Table XI: Minimum catalyst content and catalyst/aluminium ratio at different levels of aluminium in period 1981–1984

Aluminium (mg/kg)	*Catalyst* (mg/kg)				*Catalyst/aluminium ratio*			
	1981	*1982*	*1983*	*1984*	*1981*	*1982*	*1983*	*1984*
15	73	63	52	56	4.9	4.2	3.5	3.7
16	43	45	58	52	2.7	2.8	3.6	3.2
17	66	49	60	60	3.9	2.9	3.5	3.5
18	55	77	66	60	3.1	4.3	3.7	3.3
19	83	72	59	72	4.4	3.8	3.1	3.8
20	66	76	61	51	3.3	3.8	3.1	2.6
21	125	85	80	85	6.0	4.0	3.8	4.0
22	63	84	76	82	2.9	3.8	3.5	3.7
23	129	99	86	86	5.6	4.3	3.7	3.7
24	77	97	69	90	3.2	4.0	2.9	3.8
25	114	101	109	103	4.6	4.0	4.4	4.1
26	79	109	96	75	3.0	4.2	3.7	2.9
27	154	111	102	96	5.7	4.1	3.8	3.6
28	87	115	113	89	3.1	4.1	4.0	3.2
29	160	138	125	113	5.5	4.8	4.3	3.9
30	87	151	138	112	2.9	5.0	4.6	3.7
31	—	178	123	129	—	5.7	4.0	4.2
32	125	123	123	129	3.9	3.8	3.8	4.0
33	157	135	120	135	4.8	4.1	3.6	4.1
34	146	128	139	107	4.3	3.8	4.1	3.1
35	—	190	139	130	—	5.4	4.0	3.7
36	—	119	139	117	—	3.3	3.9	3.3
37	130	141	151	156	3.5	3.8	4.1	4.2
38	142	151	112	179	3.7	4.0	2.9	4.7
39	—	196	138	138	—	5.0	3.5	3.5
40	157	146	146	131	3.9	3.7	3.7	3.3
41	—	206	165	195	—	5.0	4.0	4.8
42	246	135	199	191	5.9	3.2	4.7	4.5
43	—	218	197	135	—	5.1	4.6	3.1
44	130	—	182	182	3.0	—	4.1	4.1
45	—	263	190	207	—	5.8	4.2	4.6
46	173	271	211	273	3.8	5.9	4.6	5.9
47	—	241	179	230	—	5.1	3.8	4.9
48	—	232	181	181	—	4.8	3.8	3.8
49	341	163	195	185	7.0	3.3	4.0	3.8
50	261	249	212	180	5.2	5.0	4.2	3.6

same author has indicated that over the past three years it is believed that most FCC catalysts in use were in the 5–8 catalyst/aluminium range but catalysts in the 8–15 range were, and still are, being used commercially in a number of areas, including South America and the Far East. Therefore a fuel that met the 30 mg/kg aluminium specification contained between about 150 and 400 mg/kg of catalyst fines. It was also reported in Ref. 6 that an analysis of a large number of fuel samples in the 1979 period indicated that 30 mg/kg of aluminium was equivalent to 240 mg/kg of catalyst.

Information from DnV programme

Almost from the beginning of the fuel quality testing programme it has been the practice to analyse all samples for aluminium and silicon. There is a unique opportunity to calculate the catalyst content and determine the catalyst/aluminium ratio of thousands of samples delivered at ports world wide over a four year period. The catalyst content can be calculated as catalyst (mg/kg) = 1.89 aluminium (mg/kg) + 2.14 silicon (mg/kg).

The information given in this paper is extracted from every individual fuel sample tested that had an aluminium content from 15 to 50 mg/kg, which is 2753 samples. For each level of aluminium the minimum, mean and maximum catalyst content and the corresponding catalyst/aluminium ratio have been determined. The data, divided into four separate years, are presented in Tables XI, XII and XIII. There are a few gaps, particularly in 1981, since there were no fuel samples giving results at certain levels of aluminium. The findings are given in such detail since it is unlikely that any other organization has access to such a vast amount of data.

It will be seen in Table XIII, covering the fuels with the maximum catalyst content and consequently the highest catalyst/aluminium ratio, that a ratio above 9.3 occurs in only two cases, namely 13.9 and 13.3, in 1982 and 1983 at aluminium levels of 35 and 32 mg/kg, respectively. If these two fuels and their results were excluded the maximum catalyst content for a fuel with an aluminium content of 35 mg/kg in 1982 would have been 239 and for an aluminium content of 32 mg/kg in 1983 it would have been 185.

A close analysis of the data in Tables XI, XII and XIII does not show any significant change in catalyst/aluminium ratios over the four years. An average over the three year period 1982–1984 was taken of the minimum, mean and maximum catalyst content at each level of aluminium from 25 to 50 mg/kg and is presented in graphical form in Fig. 2. It was decided not to include the 1981 figures because of the number of gaps in the data. It would seem reasonable to conclude that at an aluminium level of 30 mg/kg the catalyst content would on average be 155 mg/kg with extremes of 120 and 190.

Summary

There is an undeniable argument in favour of improving the means of identifying catalytic fines in a marine fuel and Refs 3 and 6 have made a valuable contribution in introducing the subject. It has even been suggested that a catalyst specification of 250 mg/kg would be appropriate.

Based on the information in Fig. 2, a catalyst specification of 250 mg/kg would mean that probably all fuels with an aluminium content of up to about 40 mg/kg would be acceptable and about 50% of the fuels would be acceptable with aluminium contents above 50 mg/kg.

Table XII: Mean catalyst content and catalyst/aluminium ratio at different levels of aluminium in period 1981–1984

Aluminium (mg/kg)	*Catalyst* (mg/kg)				*Catalyst/aluminium ratio*			
	1981	*1982*	*1983*	*1984*	*1981*	*1982*	*1983*	*1984*
15	97	80	78	78	6.5	5.3	5.2	5.2
16	77	86	82	86	4.8	5.4	5.1	5.4
17	97	94	86	92	5.7	5.5	5.1	5.4
18	90	103	94	94	5.0	5.7	5.2	5.2
19	98	95	94	100	5.2	5.0	4.9	5.3
20	93	108	100	104	4.7	5.4	5.0	5.2
21	125	112	112	112	6.0	5.4	5.4	5.4
22	110	119	114	110	5.0	5.4	5.2	5.0
23	129	131	112	113	5.6	5.7	4.9	4.9
24	114	132	122	122	4.8	5.5	5.1	5.1
25	114	129	126	132	4.6	5.2	5.0	5.3
26	112	146	126	138	4.3	5.6	4.8	5.3
27	164	153	144	142	6.1	5.7	5.3	5.3
28	113	158	143	149	4.0	5.6	5.1	5.3
29	166	155	149	162	5.7	5.3	5.1	5.6
30	142	174	164	157	4.7	5.8	5.5	5.2
31	—	191	172	153	—	6.2	5.5	4.9
32	125	155	158	172	3.9	4.8	4.9	5.4
33	173	175	162	178	5.2	5.3	4.9	5.4
34	147	182	171	166	4.3	5.4	5.0	4.9
35	—	214	195	177	—	6.1	5.6	5.1
36	—	226	197	171	—	6.3	5.5	4.8
37	130	178	164	177	3.5	4.8	4.4	4.8
38	199	204	184	203	5.2	5.4	4.8	5.3
39	—	196	168	202	—	5.0	4.3	5.2
40	202	213	203	204	5.1	5.3	5.1	5.1
41	—	221	201	214	—	5.4	4.9	5.2
42	246	238	218	223	5.9	5.7	5.2	5.3
43	—	229	218	216	—	5.3	5.1	5.0
44	216	—	212	219	4.9	—	4.8	5.0
45	—	263	222	246	—	5.8	4.9	5.5
46	222	289	224	273	4.8	6.3	4.9	5.9
47	—	250	235	248	—	5.3	5.0	5.3
48	—	256	233	251	—	5.3	4.9	5.2
49	341	163	240	247	7.0	3.3	4.9	5.0
50	270	249	212	266	5.4	5.0	4.2	5.3

Other information obtained from 16 fuel samples from various sources analysed in 1978–1980 shows that for fuels with aluminium contents between 20 and 53 mg/kg, and plotted in a similar way to Fig. 2, the catalyst content for a fuel with an aluminium content of 30 mg/kg would be 190 mg/kg.

The subject warrants much more discussion but any change in the British Standards from specifying aluminium to catalyst should not be accompanied by a decrease in the lowest quality of fuel that can be supplied to a motorship. The data presented in this paper could suggest that if a change was made then an appropriate maximum for catalyst might be somewhere in the region of 160 mg/kg.

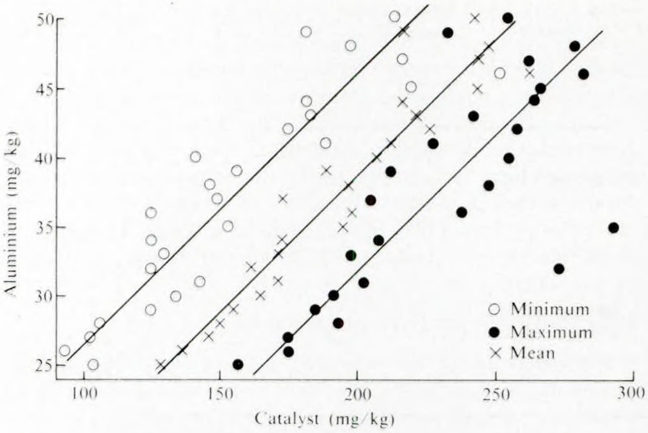

FIG. 2: Total spread of catalyst content at different levels of aluminium averaged over the period 1982–1984

IGNITION QUALITY

Background

The British Standards Working Group considered it was important that recognition should be given to ignition quality in the specifications for residual fuel for use in a diesel engine. At that time no recognized test method was available to define the behaviour of residual fuels. There was discussion at the time as to whether the maximum density of class M4 should be restricted to some level below 0.991 because of possible combustion problems but there was no overall agreement to take such action. The criteria need to be identified, a test method developed and agreement reached between all sections of the marine industry before any finite figures could be shown for ignition quality.[5]

A very recent paper[7] has summarized in some detail the various attempts to quantify analytically ignition and combustion characteristics of residual fuel. References 8–15 also provide useful information.

A report published in 1983[11] covered development work by Shell which gave a formula for a calculated carbon aromaticity index, CCAI, using normally available fuel parameters such as density and viscosity. This has been followed by another formula from BP,[12] using the same two fuel parameters, called a calculated ignition index, CII-1.

No attempt was made in either paper to define acceptable levels of ignition quality using either of the formulae, and furthermore neither of the companies associated with these

Table XIII: Maximum catalyst content and catalyst/aluminium ratio at different levels of aluminium in period 1981–1984

Aluminium (mg/kg)	*Catalyst* (mg/kg)				*Catalyst/aluminium ratio*			
	1981	*1982*	*1983*	*1984*	*1981*	*1982*	*1983*	*1984*
15	99	140	112	105	6.6	9.3	7.5	7.0
16	124	129	124	109	7.8	8.1	7.8	6.8
17	126	118	120	122	7.4	6.9	7.1	7.1
18	154	137	120	120	8.6	7.6	6.7	6.6
19	132	134	128	134	6.9	7.1	6.7	7.1
20	145	149	141	147	7.3	7.5	7.1	7.3
21	125	147	145	151	6.0	7.0	6.9	7.2
22	161	149	153	151	7.3	6.8	7.0	6.9
23	129	155	144	135	5.6	6.7	6.3	5.9
24	169	167	174	178	7.0	7.0	7.3	7.4
25	114	146	169	156	4.6	5.8	6.8	6.3
26	184	195	167	163	7.1	7.5	6.4	6.3
27	179	186	171	169	6.6	6.9	6.3	6.2
28	134	175	198	205	4.8	6.3	7.1	7.3
29	181	179	196	179	6.2	6.2	6.8	6.2
30	266	196	194	183	8.9	6.5	6.5	6.1
31	—	204	193	208	—	6.6	6.2	6.7
32	155	206	424	189	4.8	6.4	13.3	5.9
33	189	212	184	199	5.7	6.4	5.6	6.0
34	148	199	223	203	3.4	5.9	6.6	6.0
35	—	486	201	194	—	13.9	5.7	5.6
36	—	282	214	220	—	7.8	5.9	6.1
37	130	205	185	224	3.5	5.5	5.0	6.1
38	256	224	275	245	6.7	5.9	7.2	6.5
39	—	217	194	226	—	5.6	5.0	5.8
40	247	270	268	228	6.2	6.8	6.7	5.7
41	—	236	225	217	—	5.8	5.5	5.3
42	246	276	255	244	5.9	6.6	6.1	5.8
43	—	263	227	235	—	6.1	5.3	5.5
44	216	—	259	259	4.9	—	5.9	5.9
45	—	263	269	252	—	5.8	6.0	5.6
46	271	307	262	273	5.9	6.7	5.7	5.9
47	—	258	266	258	—	5.5	5.7	5.5
48	—	279	285	270	—	5.8	5.9	5.6
49	341	163	279	255	7.0	3.3	5.7	5.2
50	279	249	212	287	5.6	5.0	4.2	5.7

Table XIV: Percentage of fuels within seven bands of viscosity failing to meet various levels of CCAI and density in period 1981–1984

	Viscosity range (cSt at 50 °C)						
	15–50	*51–100*	*101–150*	*151–200*	*201–300*	*301–400*	*above 400*
CCAI							
841 and higher	34.8	40.9	40.8	55.5	62.7	67.4	67.9
851 and higher	20.8	27.0	26.4	33.0	34.3	21.2	18.4
861 and higher	13.8	14.1	8.5	2.7	1.4	0.5	1.8
871 and higher	7.6	1.7	0.4	0.1	0.2	0.1	0.2
Density at 15°C (g/ml)							
0.980 and above	7.4	15.2	23.4	36.3	50.6	63.8	71.9
0.986 and above	1.9	5.4	12.6	21.0	32.8	39.7	48.2
0.992 and above	0.5	1.3	2.4	2.0	7.0	7.3	15.4
Total number of fuels	419	689	1408	3812	2625	4232	602

formulae have subsequently published anything about acceptable limits. The make of engine will be important in defining acceptable ignition quality limits.

The empirical formula for CCAI gives a low number with fuels that are generally good and a progressively higher number with fuels that might give problems in some engines under certain operating conditions.

Information from DnV programme

Density and viscosity readings are available on all the fuel samples analysed. It was known that the most serious problems with ignition quality were likely to occur with the low viscosity residual fuels. The fuels have been divided into seven viscosity ranges: 15–50, 51–100, 101–150, 151–200, 201–300, 301–400 and above 400 cSt at 50 °C.

The CCAI has been determined and within each viscosity range the percentage of fuels failing to meet a specified CCAI is given. A similar exercise has been done at three levels of density. The data for the four year period 1981–1984 are given in Table XIV.

It will be seen that it is only for the fuels with viscosities in the range 15–50 cSt at 50 °C that there was a substantial percentage (7.6%) failing to meet a CCAI value of 870. Separating the data for the 15–50 cSt viscosity range into individual years reveals that 1984 was considerably worse than any other previous year at all levels of CCAI. For example, the percentage of fuels with a CCAI value above 860 was 6.2, 7.2, 7.3 and 23.5% in 1981, 1982, 1983 and 1984, respectively.

Summary

The viscosity range 15–50 cSt at 50 °C is very similar to BS class M4, on which there was the original discussion about reducing the density below 0.991 so as to ensure diluents with unsuitable ignition quality were not used as blending components. Data from the DnV programme show that a significant number of low-viscosity residual fuels with CCAI of above 870 are supplied to motorships. A maximum CCAI of 870 is only possible with such viscosity fuels when the density does not go above about 0.980 at 15 °C. It is believed a major supplier is contemplating such a density limitation.

CONCLUSIONS

The large amount of data amassed within the DnV fuel quality testing programme continues to add to the knowledge already known about the quality of marine fuels supplied to motorships worldwide. This paper will have served its purpose if the additional information now made available is of assistance to those engaged in committee work discussing the continued refinement of marine standards such as BS MA 100.

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Discussion

A. E. SWINDEN (BP Marine International): I should first like to congratulate Mr Royle for providing a most interesting and informative paper. It effectively gives us a second insight into the vast DnV bunker fuel quality database (the first paper being presented in 1983) and highlights many important features.

My first query concerns the comments made about the variation in analysis results in different laboratories, particularly when determining metal contents. The data previously published by Exxon concerning aluminium, silicon and catalyst levels attributed the lack of correlation to deficiencies in the test methods, notably the fusion or digestion stages. However, in Table I it can be seen that laboratories E and F seem unable to measure even ash content accurately. Was this matter taken up with the laboratories by the shipowner concerned (perhaps with DnV guidance) and was any explanation given for their apparent poor performance? The DnV ash content of about 0.25 wt% indicates very high metal contents, and I should like to ask what other metals were detected in this fuel?

The information contained in Tables VII and IX are interesting and demonstrate that shipowners should assess fuel suppliers' past performance to ensure that an apparently cheaper product will, in reality, prove to be cost effective. Can Mr Royle comment on why the water content of the Middle East fuels (Table IX) was considerably higher than that of the USA fuels, even though all deliveries were by barge?

My final queries concern the relationship between fuel quality and vessel performance and operational problems. This aspect was briefly covered in Mr Royle's 1983 paper but has not been included this time. Based on the feedback provided by Chief Engineers, can Mr Royle please give his views on the applicability of the generally accepted limits of 30 ppm aluminium and 0.15 wt% sediment by hot filtration; when overshoots occur, how often are service problems reported? With regard to ignition quality, the paper implies 860/870 CCAI as a 'limit' value. Is this figure based on feedback from Chief Engineers or from other data?

I would finally like to thank Mr Royle for providing very detailed data relating aluminium, silicon and catalyst fines content. Whilst accepting that, in theory, a true direct measure of catalyst fines would seem to be ideal, BP does not support the complex, and yet still far from precise, centrifuge test procedure promoted by Exxon. The 30 ppm aluminium limit has satisfactorily served the marine and oil industry and at this stage BP sees no compelling reason to change. Mr Royle's data would seem to support this view.

Dr E. K. JOHNSON (FOBAS, Lloyd's Register of Shipping): Thanks are due to Mr Royle for presenting his review of marine fuel quality since 1981 and particularly for bringing forward suggestions on how to improve standards for quality control of fuel deliveries and future specifications.

It would be interesting to know whether Exxon/Mobil's apparent decline is because DnV's samples are proportional to the quantities delivered.

On a more serious note, LRS support Mr Royle's comments on delivery tickets and would like a standard to be adopted using recognized and specified SI units so as to avoid the need for interpretation (and lawyers) in cases of dispute. LRS are in general agreement that the parameters as outlined in the paper have an influence on engine performance. However, LRS consider that the sediment by hot filtration method merits further attention on an industry-wide basis.

I should like to ask a question about the Exxon test as adopted in 1983: are all subsequent results for existent sediment as summarized in the paper? If the answer is positive then the following points should be considered:

1. The fuel to be tested should be subject to similar conditions (temperature etc.) as those likely to be encountered in the ship before reaching the engine.
2. The sediment level then determined must therefore be after ageing equivalent to 24 h at 100 °C to allow for the judgement that there are unlikely to be centrifuging problems.
3. The use of double filters as in the IP 375/86 test is essential to eliminate the uncertainty in the amount of oil absorbed on the filter medium. It is universally accepted that absorbed oil is not detrimental to the performance of centrifuges or engines.

LRS have experience with fuels which gave existent sediment (double filter) of less than 0.10% but which gave an increase in the amount of sediment after ageing of greater than 0.05%. Some examples are given in Table DI.

Such increases can only be caused by flocculation of asphaltenes during the ageing procedure. This flocculation would also occur before or during the centrifuging of the fuel in the ship.

For these reasons FOBAS are incorporating in their analysis scheme the aged sediment as the prime criterion whether a fuel is clean and/or stable. Samples with sediment above 0.10% will be further analysed for existent to define whether the sample is unstable or just dirty.

On the question of aluminium or catalyst, extensive tables, in the view of LRS, tend to support the 30 ppm Al limit since that would seem to indicate not more than 250 mg/kg catalyst. As there is a standard method for determining Al (IP 363/83) it should be used to control supplies which have a reasonable chance of being clean in the centrifuge, if the fuel itself is stable. By keeping the analysis as simple as possible, the supplier is able to analyse and exercise control before delivery takes place.

Lower catalyst/aluminium ratios are the refiners' choice for high Al catalyst to give improved performance and distillate (gasoline) yield. Any benefit should be balanced against the extra housekeeping required when using slurry oil as marine fuel diluent. The disposal of slurry oil should be a problem for the suppliers not for the users.

If it is accepted that high Al catalysts are more abrasive, then it is perhaps appropriate for a more stringent control based on a 30 ppm Al limit. Whatever catalyst is used by the refiner, there should be no problem blending marine fuels below the limit with reasonable housekeeping.

Finally, two points for the future:

1. The need for more control of contaminants which can arise from indiscriminate dumping of waste material into residual marine fuel, such as waste oils containing lead and/or PCBs, which is why FOBAS are including elemental analysis by plasma emission spectrometry in their routine scheme.
2. The need for control of corrosive products, inorganic and organic acids. This requires a strip test, currently being developed by FOBAS, to simulate and signal actual corrosion.

In conclusion, the improvement of existing standards is a desirable goal but the specifications must be kept short and technically based so that all suppliers can carry out the necessary quality control before delivery without jeopardizing the availability and cost of residual fuel for ships.

R. J. CLEMENTS (Shell International Marine Ltd): I found Mr Royle's paper to be both interesting and informative and would like to thank him for a useful update on his previous paper.

For a ship operator, two advantages can be gained from this work but both require careful attention to detail to obtain the full benefit.

The first is an independent check on the quantity and quality of the fuel delivered and an early indication of the need for analysis of retained samples. This may be particularly important when, for operational reasons, the ship does not start to use a fuel and perhaps experience problems within the 30 day

Table DI: Amount of sediment

Aged	0.168	0.141	0.148	0.111
Existent	0.054	0.056	0.076	0.062
Difference	0.094	0.085	0.072	0.049

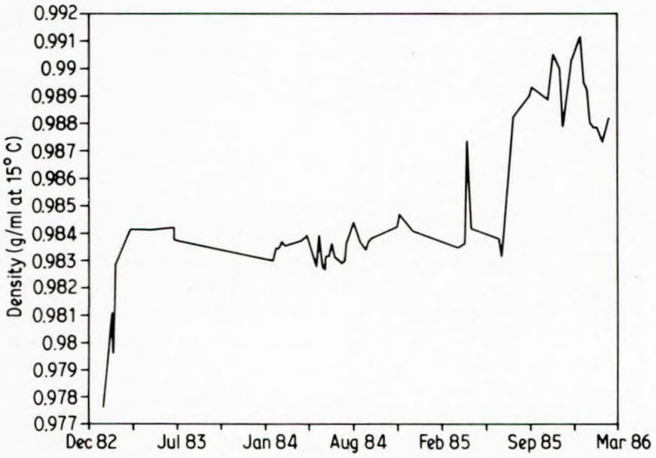

FIG. D1: World-wide average of maximum density (source: *Lloyd's List*)

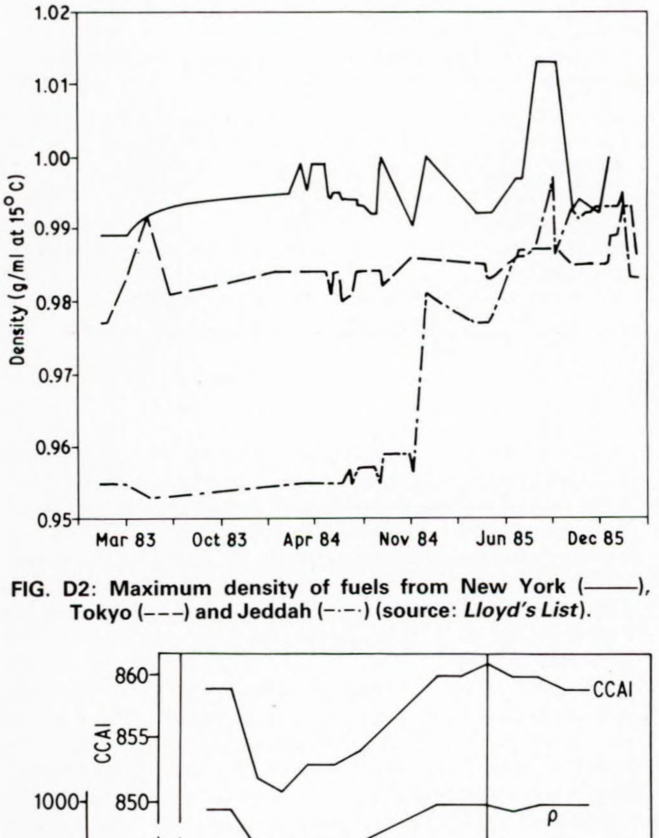

FIG. D2: Maximum density of fuels from New York (——), Tokyo (– – –) and Jeddah (–·–·) (source: *Lloyd's List*).

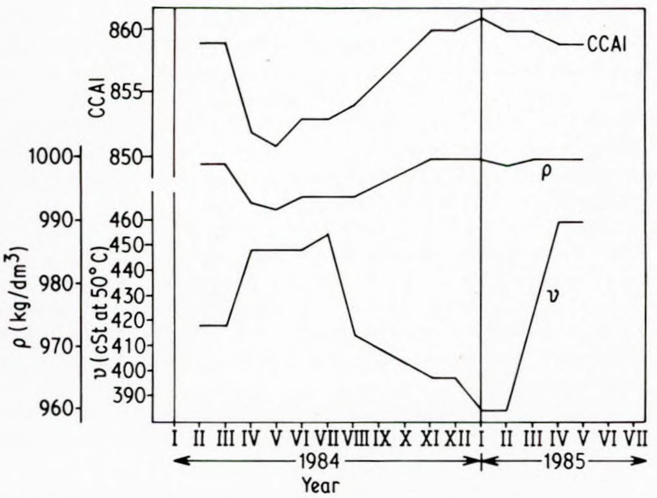

FIG. D3: Bunker quality market reports for Houston (source: *Lloyd's List*)

period common to many Conditions of Sale. However, our experience has been similar to that described on page 3 of the paper where the analysis of the DnV sample is very different from another laboratory's analysis of the retained sample. It would be preferable for one representative sample to be taken from the bunkering line by the supplier and divided into parts for the retained samples and that for routine analysis. We have experience of a supplier taking a sample through the open hatch of one of four tanks on a barge compared with a drip sample from the ship's bunker manifold. It is difficult to accept that the analysis of the former should be contractually binding.

Referring back to the information on page 3, where widely different analyses of the elemental content of a fuel are quoted, this would be more meaningful if the test methods used in the different laboratories were quoted.

The second advantage to be gained from routine fuel analyses is the use of the information on board ship to optimize the fuel treatment system. When the only information given on the bunker receipt may be the maximum density and viscosity and minimum flashpoint of the grade ordered, knowledge of the actual values is useful.

In addition, warnings of potential problems may enable these to be avoided by adjusting engine operating conditions accordingly. However, we have experienced problems with fuels having an analysis which met all the parameter specifications and yet experienced no problems with fuels which exceeded the limits for one or more parameters. Although we accept that the specifications are based on the best knowledge available at this time, I would like to ask what action DnV are taking to relate the analysis with shipboard problems on a wider or routine basis?

Finally, although the desirability of segregating different fuels is accepted, this is not always possible for operational reasons. For ships which send samples of every bunkering to DnV, would it be possible for DnV to introduce a further test or piece of information which informed the operator of the compatibility of the new fuel with whatever fuel or mixture was already on board? This is obviously not an easy thing to introduce but one which would be of great value and comfort to operators in view of the considerable variations in residual fuel oils available today.

H. SJÖBERG (Wärtsilä Diesel): Det norske Veritas and Mr Royle have again provided us (ie the unlucky engine manufacturers who are not allowed to join the fuel quality testing programme) with a mass of useful data on the properties of heavy fuel oil.

It may be argued that the samples from which data are gathered cover only a minute part of the fuels bunkered. It may also be argued that the way most of the data are presented, ie mean values, hides some interesting extremes and trends.

For example, Table VIII suggests that the amount of fuel with density above certain values is not on the increase. My company has plotted maximum density values from the Bunker Quality Market Report published regularly in *Lloyd's List* both as a worldwide average (Fig. D1) and for some important bunker ports (Fig. D2). It appears that maximum density is on the increase. Note the sudden jump in Jeddah at the end of 1984.

Increased density combined with constant or only moderately increasing viscosity indicates reduced ignition quality when determined by the Shell CCAI formula. This can be seen in Fig. D3, which covers fuels bunkered in Houston over a period of time. Note that the CCAI level is probably underestimated because it has been assumed that the maximum density reported is linked to the maximum viscosity reported, which may not always be the case.

Mr Royle points out that neither Shell nor BP have published anything about acceptable limits for the CCAI or CII-1 values, respectively. It has been considered that this is a task for engine manufacturers, and rightly so.

Figures D4 and D5 show how my company have set the limits

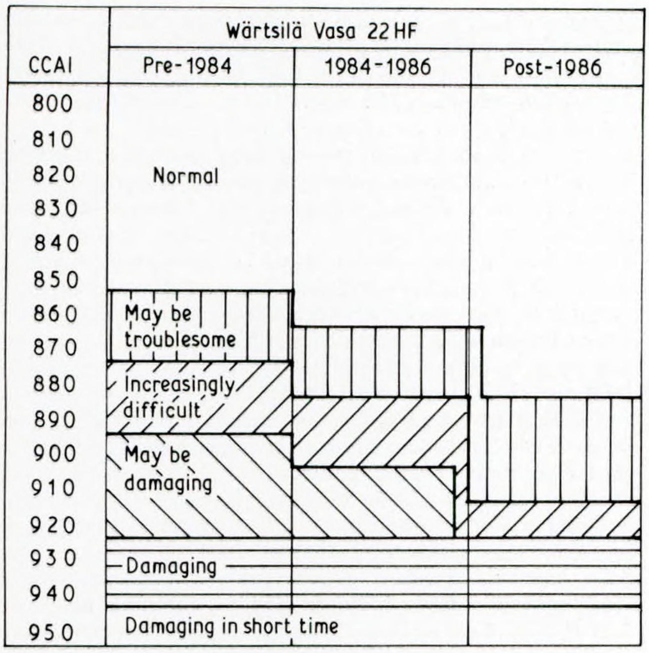

FIG. D4: Response of Wärtsilä Vasa 22 HF engine to fuel with different CCAI values

for two engine types. The limits are based on experience gained by running two test engines on a range of fuels with CCAI values between 840 and 950. Some of the test fuels are listed in Table DII. E-POR IV was chosen as the reference fuel and a series of endurance tests were run using this fuel under different operating conditions.

It is interesting to see on page 11 of the paper that there has been an increase in the percentage of low-viscosity fuels with CCAI values above 860, and in particular a huge increase in 1984. Could Mr Royle please comment on the following:

1. What was the maximum CCAI value found for fuels of 15–50 cSt at 50 °C?
2. What percentages of fuels of 15–50 cSt at 50 °C failed to meet the 870 limit in 1981, 1982, 1983 and 1984?
3. Is the trend for higher-viscosity fuels similar to that for low-viscosity fuels?

It is worth noting that a BS M6 fuel (45 cSt at 80 °C or 180 cSt at 50 °C) will have a CCAI value of 860 when delivered at maximum viscosity and density. Any fuel with a lower viscosity and maximum density of 0.991 g/ml at 15 °C will exceed 860.

In his 1983 paper on the same subject, Mr Royle indicated that adverse remarks concerning engine conditions were made against 10% of the fuels with Al contents from 21 to 30 ppm and against 25% of the fuels containing over 30 ppm. Could Mr Royle give corresponding figures for the fuels covered by this paper?

P. J. NEWBERRY (Shell International Trading Co.) and **Dr J. MILLS** (Shell International Petroleum Co. Ltd): We should like to congratulate Mr Royle for producing such an interesting statistically based insight into marine fuel quality. From the Shell viewpoint we certainly would agree with Mr Royle's statement about the good standards of the DnV service and its laboratories.

The trend to higher viscosities, as predicted in the paper, agrees with our perceptions, indeed it is a trend we have encouraged in the conviction that it represents, in balance, the most economically viable route for our customers. We would add that, despite the present move to low prices, we do not believe this upward viscosity will reverse. Nor do we foresee fuel quality going back to that of former years.

The pictures of delivery areas, major ports and larger suppliers are approximately in line with Shell statistics. In our case three ports account for some 40% of our own delivery profile and ten for 65%. While we would like to think that our preparedness to be more open about quality was significantly at the root of our increasing market share, the main influence is out concentration at a few major ports where refineries are equipped with the appropriate processes for the viable manufacture of economic fuels.

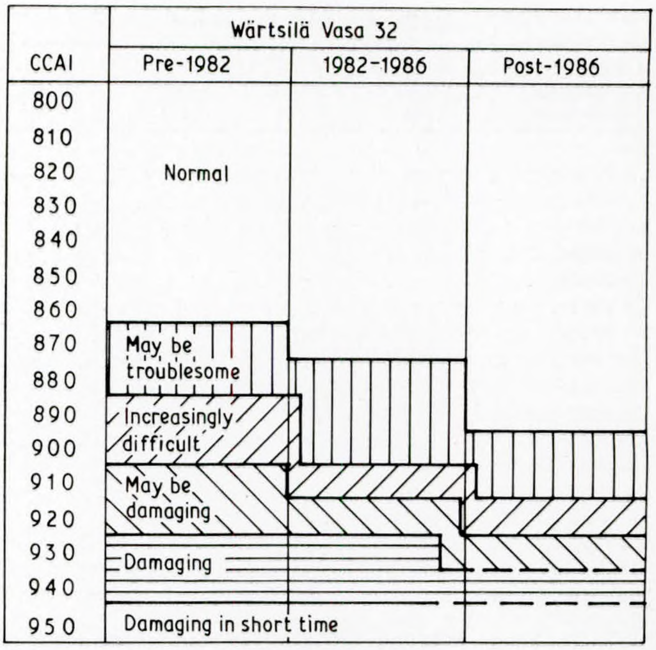

FIG. D5: Response of Wärtsilä Vasa 32 engine to fuel with different CCAI values

Table DII: Fuels used in Wärtsilä testing programme

Fuel	*Viscosity* (cSt at 50 °C)	*Density* (kg/l at 15 °C)	*CCAI*
POR 650	680	0.9850	840
E-POR I	753	0.9828	837
E-POR II	943	1.005	857
E-POR III	608	1.014	870
E-POR IV	155	1.030	900
Shell SFF 7	670	1.007	862
80% slurry + 20% 700 cSt	350	1.060	921
Catalytically cracked slurry	143	1.078	950

Mr Royle's suggestion about a more modest objective for 'delivery tickets' is much more realistic and in line with suppliers' capabilities than the original ICS proposal. In fact the delivery receipt recommended for Shell use has for some time been exactly as suggested in the paper. That it is not universally used perhaps reflects various local difficulties amongst which, for example, can be the need for documentation to meet customs and excise requirements. It should be emphasized that the primary purpose of a delivery receipt is for defining quantity and not quality.

Regarding Mr Royle's reference on page 6 to a Shell 0.5% maximum water specification, this in fact is now 0.3% and applies at certain major ports with 1.0% prevailing elsewhere. Regarding carbon residue levels, we have decided to contain motorship fuels to a maximum of 19% for the higher viscosities until such time as we see an indication of the acceptability of moving upwards.

Could Mr Royle please clarify his statement on page 7 about fuels with certain vanadium levels becoming scarcer. It appears to be a contradiction of Table VIII.

On sediment by hot filtration, the Exxon method is indicated as being used by DnV. IP have now developed and published a method that will be put forward for use in the ISO marine fuel standard. Have DnV evaluated the method and if so what are their views on it?

For Shell refineries, aluminium has been a reasonable means for identifying and controlling levels of catalyst fines. The addition of silicon and/or a change to actual catalyst determinations implies a degree of precision that does not exist, especially given the imperfections of capturing such high-density material representatively when sampling. We are not aware of any failure of aluminium measurement to give the protection required, and indeed the end user could well argue that continued use of aluminium control only errs on the safe side if catalysts are changing to higher aluminium/silicon ratios.

On ignition, Shell's purpose with the CCAI concept was to provide a means of rating the ignition propensity of fuels, with it being for engine builders to identify their actual needs, which indeed we encourage. We recognize the limitations for lower grades which tend to be utilized in more sensitive medium-speed engines and can confirm that we have now reduced the maximum density of our 30 and 40 cSt at 50 °C grades to 0.980 and 60 and 80 cSt at 50 °C grades to 0.985.

Finally, returning to sampling, we are sure Mr Royle would agree that the results given by analysis cannot be any better than the representativeness, and thus the drawing method, of the sample. Perfect sampling, especially to represent very large quantities, is not easy and indeed the sampling imperfections of suppliers often correctly receive critical comment. It seems equally reasonable to assume that there will be a spread in the quality of shipboard sampling. Can Mr Royle give any quantification of this and say whether it is taken into account when selecting the analysis data for statistical assessment?

P. H. VISSER (Texaco Ltd): Mr Royle has produced a paper full of useful statistics from the DnV fuel quality testing programme, which relies on the ship's staff taking a representative sample during bunkering.

In the early stages of the programme the problems of taking a representative sample were recognized and an attempt was made to avoid human errors whilst taking samples. Could Mr Royle please comment on the number of ships in the programme which have been fitted with special automatic sampling devices and whether the fitting of these devices improved the accuracy of sampling?

In Mr Royle's 1983 paper reference was made to the reports submitted by the Chief Engineers of the vessels which showed that about 85–86% of deliveries were reported as trouble free. Could Mr Royle please comment on the number now reported as trouble free.

It should be no surprise to anyone connected with the day to day selling or buying of residual fuels that density heads the list of characteristics that failed to meet specified levels or that non-major suppliers indicate more discrepancies between delivery ticket and actual measured density. Mr Royle's own example indicates that for a 0.01 increase in density the delivered amount as defined in metric tons increases by about 1%. This can be exploited by unscrupulous suppliers to their advantage. Mr Royle may wish to comment on the number of cases where the ship owner or operator successfully obtained a reduction on the invoice because of the reported DnV figures.

The dangers of illegal or accidental use of low flashpoint components as fuel oil on board ship is well known and this hazard has received considerable attention recently. Can Mr Royle please indicate whether any fuels have been found to have flashpoints below 60 °C and also whether any samples indicated contamination with crude oil?

Mr Royle divides the fuels for convenience into four viscosity groups, but in the market place there is a demand for at least 15 different viscosity grades of residual fuel from 30 cSt to above 460 cSt at 50 °C, and to satisfy this demand a supplier has to use a variety of different components. For example, to make two grades of fuel called heavy and medium fuel oil at a modern refinery in the UK, six components are available and the characteristics of each component vary with the types of crude or feedstock being refined. The refinery produces these two grades of residual fuel in accordance with the manufacturing specifications and they are sometimes mixed together in various proportions to meet the requirements of individual shipowners. Alternatively, one of these two residual fuel grades can be further blended with 'cutter' or thinner material to meet the customer's requirements, and it is not uncommon today to calculate a three or four component blend at an installation with more than four storage tanks containing a variety of components. It is pleasing to see that despite the complexity of residual fuel manufacture the major suppliers managed to have fewer discrepancies between delivery tickets and measured characteristics than the other suppliers.

R. H. THORNTON (Exxon International Co.): Many studies plot a handful of data points, fit a curve through them and reach some significant conclusion. In this paper, Mr Royle has assembled thousands of sample data [analysed in a consistent manner by a limited number (three) of well equipped laboratories, specifically established to test marine fuels] and has performed the Herculean task of making sense of it all. As usual he has done it well.

I accept the data presented and concur with many of Mr Royle's interpretations. However, I differ on several key points.

With reference to analysing the metal content of residual fuels, there has been some recent improvement by the small commercial laboratories in that may are now using proven test methods for aluminium and silicon. However, I do not accept the data at face value without first checking on the test method used and investigating the reliability of the laboratory in question. The example given in Table I highlights the confusion that is created when laboratories produce vastly different results. However, as a fuel supplier I must comment that, in my opinion, the key quality characteristic justifying the offlifting of the fuel in question was the high sediment level and not the catalyst level. In the early 1980s, when some of our ports had problems controlling the catalyst fine levels in marine fuel, many ships received, and used, fuels with much higher aluminium/silicon/catalyst levels. Even now, I would think hard before agreeing to debunker a fuel with the catalyst levels shown in Table I. The data in Table XI support this concern.

The percentage of samples of different viscosities shown in Table II is comparable to the distribution found in Exxon's delivery statistics. A continuing shift towards IF380 has been noted but IF180 still predominates at about 45% of the total IF grades delivered. IF380 deliveries amount to about 28% and IF280 about 8%. I attribute this mainly to owners specifying IF180 when outchartering a vessel but ordering IF380 when they operate a ship themselves.

It is difficult to tell if the percentage of samples submitted to DnV shown in Table VI accurately depicts the market place. I'm equally unsure of how Mr Royle can conclude from the data presented that an increase in customer testing of a competitor's fuel is a reflection of their discussion of their standards in the press. Certainly, the decrease in Exxon's samples might be attributed to the closing of several refineries in Europe, Canada and the Caribbean that resulted in reduced availability of residual fuels at some locations.

I would venture to say that most marine fuel sales organizations sympathize with their customers regarding the accuracy and legibility of delivery ticket information. The delivery ticket in Fig. 1 turns out to have been completed correctly and yet, because it was confusing, there were probably many hours of wasted letter writing, testing and investigation before all parties were satisfied.

A well laid out delivery ticket should follow in a logical progression. Taking the case of Fig. 1, the density at 15 °C was determined to be 0.9591 g/ml or 959.1 kg/m^3. Given this density, the volume correction factor (VCF) for converting gross litres (hot oil at 50 °C) to net litres at 15 °C taken from API/ASTM/IP Petroleum Measurement Table 54B is 0.975.

Gross litres (1065866) × VCF (0.975) = net litres (1039219). To get from litres to metric tons (tonnes), you need a conversion factor from Table 56, Vol. XII of the measurement tables. For a density of 959.1 at 15 °C, the factor is 958.0 kg/m^3. Tonnes = net cubic meters (1039219 litres/1000) × 958.0 kg/m^3 × 1/1000 tonnes/kg = 995.572 tonnes.

To get long tons you multiply 995.572 tonnes × 0.98421 long tons/tonnes = 979.85 long tons. It is perhaps not surprising that a bargeman with only a primary school education sometimes gets it wrong.

The difference in density as determined by the supplier could be caused by temperature errors (a major source of error ignored by many) or differences in the samples. To compound problems, some countries require the density to be measured at 20 °C or conversion to tonnes by multiplying the density at ambient temperature by the gross volume. The result is tonnes 'in vacuo' which differs from that measured in air.

The practice of listing the nominal maximum viscosity on a delivery ticket is a longstanding practice. At non-refinery terminals IF grades are usually blended from bunker fuel and a distillate component, such as marine diesel oil, directly into a barge. Alternatively, they can be blended from a barge to the receiving vessel.

The proportions of the components required to make on-spec viscosity grades are calculated from a formula or determined from charts. Good blenders use a safety factor based on experience that ensures the nominal viscosity is not exceeded. They know the viscosity is below 180 cSt but they are not sure what the actual value is, so they list 180 cSt at 50 °C max on the delivery ticket. In other cases, the BFO in tankage is low in viscosity. Rather than advertise the fact that by ordering BFO one could obtain a better quality product, they list the nominal viscosity on the bunker note.

The information in Table VII concerning the differences in actual as against stated density figures is intriguing. It is difficult to tell from the data, which only list delivery percentages with differences of +0.007 g/ml, if the discrepancies are biased or reflect a sloppy operation. It would be of interest to see if there are an equal number of samples with a −0.007 density difference, or if there is a bias does it favour the supplier or the customer.

I would agree with Mr Royle that accurate and uniform reporting of critical characteristics is a more achievable objective for ICS than their recommended bunker delivery note. To further this objective, I would suggest that whenever a ship operator has a valid complaint concerning the inaccuracy or illegibility of a delivery ticket, they include the barging company as a party to their complaint. All too often a port has only one barge operator who is slow to respond to the oil companies' requests. Additional pressure by the customer on the barge operator to improve procedures or train personnel cannot hurt.

Mr Royle mentions an important fact in the section on vanadium that should have been raised earlier in the paper. That is that the high specification levels throughout the BSI standards reflect the notion of the late 1970s that the standards were developed to represent 'the levels that would be obtainable in some future fuels'. As Mr Royle points out, the very high BSI CCR, sulphur, ash and vanadium levels have not yet appeared, and the ISO Draft Standards and CIMAC recommendations for certain grades may be unrealistically low with regard to vanadium content. In such cases, a customer might ask for such a fuel but it may not be available.

I take exception to Mr Royle's second sentence in the section on aluminium. Until any standards, including BSI or ISO, are revised and published with 30 mg/kg aluminium as a specification, including a valid test method, the 30 ppm aluminium limit only applies as a 'market' specification. By that I mean that if most customers ask for a limit on a certain quality characteristic, such as aluminium, then if you want to sell your product you meet the requirement even if you think there is insufficient justification for the specification. For example, blue coloured kerosene sells better in a certain country because customers there think it is a better fuel. Bunker suppliers spend millions of dollars yearly to limit the aluminium level in marine fuels when it is likely that: (a) 30 ppm Al is unnecessarily conservative and (b) aluminium is not the key characteristic that should be measured.

Following the publication of Ref. 3 in 1984, Mr Royle contacted me and advised that my scenario on how the 30 ppm Al specification came about did not in fact occur. I was puzzled because I was sure that it had. In going through my notes of the period, I discovered that indeed BSI had almost settled on a 20 ppm aluminium limit and that CIMAC representatives suggested the 30 ppm limit. At that time, Esso had representatives on both the BSI and the CIMAC working groups and both committees were developing fuel standards/recommendations independently. As Exxon's Fuel Quality Advisor, I had frequent and long telephone conversations with both Mr Royle, our BSI representative in the UK, and Mr Helmut Breyer, our CIMAC representative in Germany. Within Esso, the rationale for the 150 ppm catalyst/30 ppm aluminium relationship was certainly discussed and was the basis for our support of the 30 ppm limit. I naturally assumed that this was also discussed in BSI. In a subsequent paper (Ref. 6), I eliminated reference to the assumed dialogue.

I won't labour the point, but since the catalyst/aluminium relationship was apparently not discussed within BSI, there seems to be even less of a basis for establishing 30 ppm aluminium as the limit.

As stated earlier, I accept the test data presented as legitimate. From Table VIII, we find that on average almost 5% of all the samples tested by DnV of intermediate fuels over the last four years had aluminium levels greater than 30 ppm. I believe that the statistics are fairly representative of the industry as a whole. Using some 'back of an envelope' calculations, I have seen estimates that the total marine fuel volume worldwide is about 80 million tons per year. If we accept that figure, it can be concluded that during the last four years 16 million tons had aluminium levels greater than 30 ppm, and if 500 tons represents a typical bunker delivery, then since 1981 about 30 000 bunker deliveries have had aluminium levels above the 30 ppm maximum 'market' specification.

I haven't heard or read of many wear complaints, so empirically it is safe to assume that many ships have burned and continue to burn these higher aluminium and catalyst content fuels without problems.

Mr Royle takes exception to some conclusions I had drawn in Ref. 6 stating that the catalyst equivalent to 30 ppm aluminium was, with new catalyst on the market, currently equivalent to 240 mg/kg. Based on a much greater quantity of data, he determined that 30 ppm aluminium would, on average, be equivalent to 155 mg/kg (with extremes of 120 and 190).

Mr Royle also refers to my recommendation in Ref. 6 that a catalyst specification of 250 mg/kg would be appropriate. I see nothing in this paper that would make me revise my recommendation. Figure 2 shows the wide spread of catalyst content for a given aluminium level. One data point is even off the graph (Table XIII, 1982, 35 Al).

If one accepts the '. . . very valid argument as to whether aluminium should be replaced by catalyst . . .' (as Mr Royle aptly puts it), then the discussion of aluminium/catalyst ratios and averages is academic. A ship does not bunker a mean catalyst content but gets what it is given. Which fuel is worse, one with 50 ppm Al and 180 ppm catalyst (Table XI, 1984) or one with 28 ppm Al and 205 ppm catalyst (Table XIII, 1984). Frankly, I think they are both satisfactory but some shipowners would worry unnecessarily about the former and accept the latter when the opposite might be warranted.

To get a feel for the dispersion of data about the mean, I analysed the catalyst data in Table XII for aluminium levels of 20 to 40 ppm for all four years (Fig. D6). A linear regression on the average of the means is plotted, as is the mean ±2 sigma. (The standard deviation is a measure of the spread in a set of observations.) As items are dispersed more widely from the

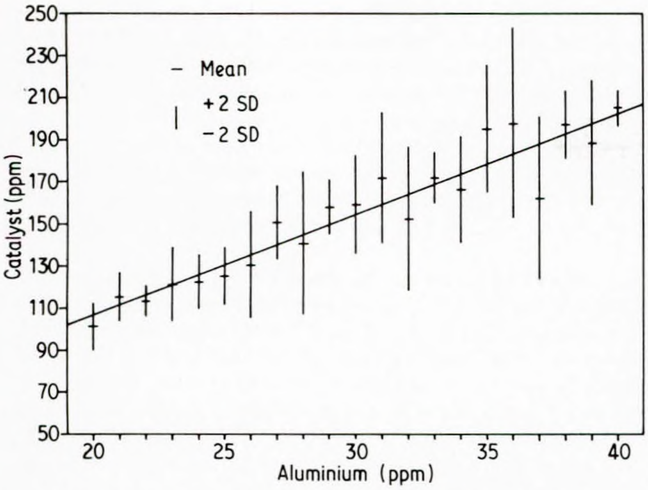

FIG. D6: Linear regression and standard deviation (2 SD) of mean catalyst levels of Table XII

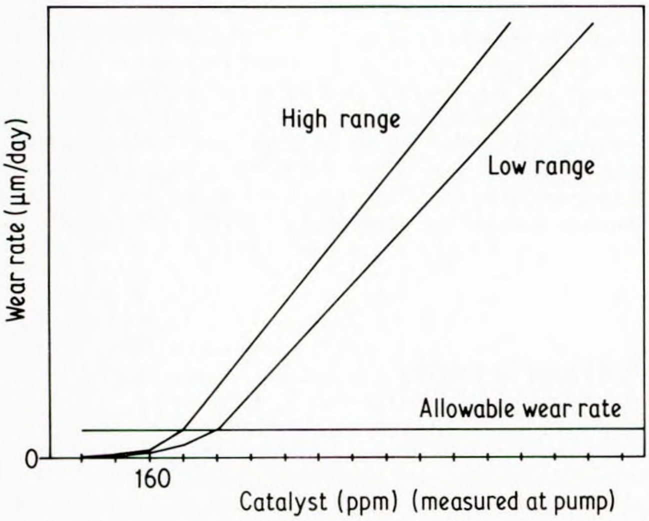

FIG. D7: Plot of wear rate against catalyst content measured at the fuel pump

mean, the standard deviation becomes larger. The mean ±2 sigma will include 95.5% of all items in a normal distribution. However, one does not need to be a statistician to see that in both Fig. D6 and Fig. 2, for a given level of aluminium the catalyst varies significantly. If catalyst content is the important characteristic, and I believe it is, then Fig. 2 and Fig. D6 demonstrate that aluminium alone is not the way to predict catalyst.

Mr Royle states that the data suggest '. . . an appropriate maximum for catalyst might be somewhere in the region of 160 mg/kg . . .'. This conclusion is apparently based on the premise that 30 ppm aluminium is equivalent to a mean of 155 ppm catalyst and since 30 ppm aluminium is the current specification, then 160 ppm catalyst should be the limit of any specification based on catalyst.

The major flaw in logic here is that no one has yet accurately related engine wear to either aluminium levels or, more importantly, catalyst content. Exxon has for some time been studying, in cooperation with a European engine designer, the wear effects of abrasive catalyst fines in residual fuels. This work is still under way and it is unfortunate that I'm not yet at liberty to discuss the findings in detail. In brief, the study involved the irradiation of a fuel pump piston using an advanced thin layer activation technique. Activity losses during the test were measured to estimate material losses caused by wear.

A number of fuels with different levels of catalyst content but all having the same particle-size distribution were continuously circulated on a test bench through a full-scale fuel injection system for two days and the actual wear rate measured against the engine designers 'allowable' wear rate. Figure D7 is a plot of wear against catalyst content. It is most important to note that the catalyst levels were measured at the same fuel pump, or in other words after centrifuging and filtering and not as bunkered. Even if one assumes a conservative degree of catalyst removal by shipboard fuel preparation systems (ie 50–75%) then the 'bunkered' catalyst levels would be 2–4 times those shown on the graph. There was no measurable wear shown at the 50 ppm into engine catalyst level and very high wear at the 1000 ppm level. Questions still to be evaluated in our laboratory work are where exactly does the curve cross the critical 'allowable wear rate' line and what effect catalyst hardness will have on the wear rates.

Until those questions are answered we can only conclude that Mr Royle's suggestion of 160 ppm catalyst as a potential specification limit is a highly conservative and subjective figure based on historical average and not on any relevant research evaluations.

Can Mr Royle please comment on DnV's experience with customer complaints concerning ignition quality? Are they frequent and, if so, do they tend to come more from ships with trunk engines than from those with crosshead engines? Does there seem to be a common CCAI level for these complaints? In other words, should maximum CCAI levels be a function of engine type rather than IFO grade?

Mr Royle and DnV are to be congratulated for contributing a wealth of information to the existing body of knowledge on marine fuel quality. As a member of two marine fuel committees (ASTM and ISO), I know that the data will prove invaluable in our future specification work. Unfortunately, Mr Royle appears to have lost sight of the original goal of the BSI working group. In the 'Aspects of a specification' section of the paper 'Development of marine fuel standards' by R. F. Thomas (Ref. 5), it is stated . . . 'it would not be reasonable to include requirements for which there was no technical importance . . .'.

Mr Royle's suggestion of 160 ppm catalyst as a possible limit for marine residual fuels was based, I fear, not on the technical importance of any catalyst content wear relationships but on average data of what has historically been supplied. This deficiency should be kept in mind by those discussing revisions to standards such as BS MA 100 and ISO.

J. M. PRIESTLEY(Esso Research Centre): In addition to the comments raised by Bob Thornton of Exxon International, I would like to add the following.

The section on 'Test methods' raises the 'age old' issue of sampling as well as laboratory reliability. As a major fuel supplier my company does have a set of standard instructions for taking samples from bunker deliveries, but in situations where third parties are involved it is difficult to ensure that these instructions are implicitly followed.

The data in Table I clearly show the confusion that can arise when a combination of laboratories/samples gives rise to significantly different results. Could Mr Royle please comment on the apparent inconsistency of the ash value and the metal levels shown?

The quoted precision data for density measurement is well below (ie better) than the 'differential figure' used by Mr Royle. Again is this a sample effect or, as I believe, does it relate to inaccuracy in measurement of the sample temperature? Internationally, the practice in several countries of working in density at 20 °C does not help and it would be of benefit if all users focussed on density, not specific gravity.

In developing standards for fuels whch will be tenable for a reasonable period, it is essential to forecast levels which might occur in order to guide designers of engines and fuel systems. The fact that the values in the British Standard have been reached is not, in our view, a reason for adopting lower limits.

If tighter limits are adopted, it could be that supplying companies may not be able to meet these more restrictive requirements, and this could have an effect on availability and/or cost.

It is also worth remembering that the 'compatibility' of a fuel specification and an engine/fuel system takes many years of co-operation between the fuel user, fuel supplier and engine manufacturer. By comparison, the present status of aviation fuel standards represents over 40 years of such dialogue; against this background marine fuel standards are 'quite young' and there is some way to go before these standards become consistent with the requirements of fuel systems, engine design and operation.

The BS MA 100 specification has, as Mr Royle states, a maximum aluminium level of 30 ppm, but no method. The Institute of Petroleum method IP 363 has been proposed for the measurement of aluminium, but it is important to recognize that the procedure is capable of extension to the measurement of silicon (the other component of the catalyst). A request for this method to be formalized and precision evaluated has been made and is being progressed. This will provide an alternative to the ASTM centrifugal separation procedure and hopefully contribute to the acceptance of 'total catalyst' in marine fuel standards rather than aluminium alone.

C. FISHER (T. J. Gunner & Sons Ltd): I understand that the Institute of Petroleum and ASTM have scheduled a sub-committee meeting early this year in order to discuss the centrifuge test method for determination of total abrasive solids. This method is not dependent upon catalyst chemistry.

I should be interested to know if DnV have used this test method and if they consider it to be satisfactory and worthy of adoption by the standard bodies. It would also be interesting to know if Mr Royle has compared the results obtained from the centrifuge test method with catalyst content calculated from aluminium and silicon analysis.

As no standard test method for silicon determination has been adopted by the Institute of Petroleum, individual laboratories will inevitably select different test procedures and it is not therefore surprising that similar results are not obtained. Sample preparation, including ashing and dilution, for either atomic absorption spectroscopy (AAS) or inductively coupled plasma (ICP) can cause results from these two methods to be different. If meaningful conclusions are to be drawn, after comparing results from different laboratories, it is essential that the test method used in each case be specified. With this in mind, would Mr Royle please give details of the test method adopted by DnV for the determination of both aluminium and silicon.

At the end of the day the shipowner will need to rely upon analysis results produced by the appointed laboratory. The laboratory may have been selected after considering the total service offered including the speed of response and costs. However, many laboratories may offer a good service at competitive prices but the data produced may not be reliable.

I suggest that the shipowner should make enquiries in order to establish if the laboratory being used has been accredited by a government body such as NATLAS for the testing of oils. Many countries have their own national accreditation scheme which assesses laboratories and accredits them competent to carry out particular tests. Before acceptance, the laboratories must comply with high standards of competence, and following accreditation the laboratories are closely monitored to ensure that quality control, testing facilities, calibration of equipment and competence criteria are complied with.

As the shipowner and Chief Engineer will be interested in the levels of abrasive material remaining in the fuel after separation and filtration, would Mr Royle agree that knowledge of particle size would provide a better assessment of potential engine damage rather than the amount of fines in the fuel delivered?

Finally, Mr Royle indicated that fuel stability and compatibility problems had been given more publicity than they deserved. However, my company has recently been involved with several such cases indicating that indiscriminate blending of fuel to achieve the desired viscosity and density is still being practised. It is appreciated that after a fuel leaves the refinery it may be bought and sold several times and subsequently blended before it reaches the vessel, but fuel suppliers should not lose control of the resultant fuel stability, and if standards are to be revised this element should surely be introduced.

G. A. WATERS (Gamlen Chemical Co.): I would like to thank Mr Royle for his very interesting paper covering many aspects of fuel analysis and fuel standards. I would like to highlight one aspect that has come increasingly to our notice at the Fuel Technology Centre, and that is the quality of the fuel sample. Everyone will agree that a representative sample is essential for the analysis results to have any meaning at all, but the method of sampling has not been defined and a standard is needed.

Many points of conflict arise over the whole oil sampling/analysis procedure and an agreed system is necessary to eliminate this. Many systems in use today are questionable because of possible operator error, influence of the weather and differences between barge and vessel. A mechanical form of sampling equipment which is accepted and used by both the oil supplier and ship operators would be one way of eliminating this point of conflict and is a natural way of proceeding.

In summary, my company feels that this problem must be dealt with and agreement should be arrived at covering mechanical samplers. They should be accepted as they can eliminate the problem outlined above and provide the starting point for fuel management onboard vessels.

Author's reply

The discussion following the presentation was most informative and comprehensive and the number of speakers taking part showed that there is still a great deal of interest in the quality of residual fuel supplied to motorships both now and in the future. There were many questions of a similar nature that were raised by more than one contributor and consequently the replies have been grouped together and so do not appear as a direct reply to each contributor.

Mr Swinden, in noting the inability of Laboratories E and F in Table I to measure accurately ash content, wanted to know if this was taken up with the laboratories by the shipowner with perhaps DnV's guidance. The shipowner, using the analysis data obtained by DnV laboratories on two different samples, one taken by the ship's staff and the other by the supplier, was able to convince the supplier that the fuel should be offlifted. The shipowner, having obtained a satisfactory outcome, had no interest in pursuing what to him was an academic exercise as to why other laboratories seemed to be unable to obtain reliable results.

It is standard practice in DnV laboratories to determine additional metals to those given in Table I, but they were omitted from the table since no comparable data were available from the other laboratories. The results obtained on the two samples analysed in the DnV laboratories were similar, although the samples were different (see Table I). The results were

	DnV, USA	DnV, Singapore
Sodium (mg/kg)	73	67
Iron (mg/kg)	124	127
Nickel (mg/kg)	64	64
Calcium (mg/kg)	240	264
Magnesium (mg/kg)	64	75

Mr Fisher suggests that the shipowner could make enquiries to establish if the laboratory chosen to test a sample has been accredited by a government body. This is not considered to be a satisfactory solution since the testing of residual fuels is a specialized business and it is extremely doubtful if a government organization in each country has the required skills to carry out the monitoring mentioned by Mr Fisher.

Would the government body know, for example, what methods could be used and what methods should not be used for the determination of aluminium. A shipowner should approach and use a company with a proven track record in the testing of residual fuels and not leave the decisions to the ship's agent in the port where the ship happens to be.

Mr Clements, in referring to Table I, mentioned that it would be more meaningful if the test methods used in the different laboratories were quoted. The information about the test methods used by DnV was given in the earlier paper in 1983, Ref. 1 in this paper. Mr Fisher also asked about the test method used by DnV for aluminium and silicon. This was also given in Ref. 1.

I agree with Mr Clements that it would be preferable for one representative sample to be taken from the bunkering line by the supplier and used by all parties, but how often is a competent member of the supplying company present during the bunkering operations. Mr Thornton goes to some length to sympathize with the fuel purchaser over the accuracy and legibility of delivery ticket information. However, this is in the hands of a bargeman who is not employed by the supplying company. How much reliability could the fuel purchaser give to samples taken by this same person?

Questions about sampling were raised by a number of contributors. The DnV literature stresses that all ships should record in their log details of when and how the sample sent for analysis was taken so as to strengthen their case when making a complaint against a supplier. It is recognized that ship's staff may take a sample incorrectly and if there is any doubt, because of the results obtained on the sample, judgement is used and such samples are excluded from any statistical assessments that are made public. The use of automatic sampling devices is spreading and there is no doubt they do make their contribution to better sampling.

The DnV form completed by the Chief Engineer and sent with the sample includes a section where the type of sample can be specified. During an eighteen month period starting on 1 January 1985 the samples were reported as follows on a percentage basis:

Continuous drip	59
Composite of a number of spot	21
Spot	10
Automatic	4
No sampling method specified	6

When samples are received that were taken as spot samples or the information is not provided, then a comment is made about it when reporting the results to the customer.

Mr Swinden requested comments as to why the water content of fuels supplied at one Middle East port compared unfavourably with another port in the USA, although all deliveries were by barge. It is felt that readers must draw their own conclusions. However, suffice to say there does not appear to be a technical reason.

A number of contributors requested information about the feedback of information from Chief Engineers concerning the performance of the fuel treatment plant and the condition of the engine. It has to be reported that the feedback from the ships has not fulfilled DnV's expectations as it has often been rather sparse and unreliable. What is available needs very careful vetting before it could be used in a technical paper. It should be possible to do this on a selected basis with a number of ship operators who are as keenly interested as Mr Clements, but it should be recognized that the changing pattern of responsibility for the ship's crew leaves many companies without the facilities to co-ordinate such activities.

I agree with Dr Johnson that whilst the improvement of existing standards is a desirable goal it is important to keep them short and technical based. To this end I believe the standards should state one joint method for the determination of at least ash, vanadium, aluminium and silicon rather than separate methods which make fuel analysis costs prohibitive for the shipowner when each feature of the fuel has to be tested separately.

Mr Clements mentioned the difficulties of always keeping different fuels segregated and would it be possible for ships sending samples to DnV to have an additional test run for compatibility. This has been consideed. The programme expanded and it was desirable to have more than one laboratory. These were strategically located so as to minimize transportation time between the bunker port and the laboratory.

It was considered more important that the analysis results of a bunkering be available as quickly as possible to a customer than that the samples from bunkerings in say New York and Singapore should both be sent to one location in the world so that a compatibility test could be run. As Mr Clements knows, the compatibility result can depend on the percentage of each fuel used and DnV would have to be advised by the ship operator of what percentage to use in each case.

Mr Sjöberg considered it could be argued that the way most of the data are presented, ie mean values, hides some interesting extremes and trends and quoted Table VIII as an example, and density in particular. Table VIII was included and the various levels of quality were chosen to have some fairly close association with limits specified in BS MA 100:1982.

A maximum density of 9.991 g/ml at 15 °C is recognized as the upper limit for satisfactory centrifuge operation and it is a fact that a conscious effort is made by many suppliers to conform to this limit and that much of the overrun is quite small. Table VIII is not meant to imply that the availability of low-density fuels on a percentage basis, say at 0.960, remains the same throughout 1981 to 1984. It would be incorrect if anybody jumped to that conclusion.

As an engine builder Mr Sjöberg is quite rightly very interested in the ignition quality of residual fuels and has used the Shell formula for some of his studies. Since the CCAI value depends on density and viscosity it was decided to present the data in the paper in fairly small viscosity ranges and consequently seven ranges were chosen. The number of fuels included in each range is stated so that the percentage of fuels failing specified parameters can be properly assessed. With the exception of the fuels in the lowest viscosity range, that is 15 to 50 cSt at 50 °C, the percentage of fuels failing to meet a CCAI of 870 is very low for all viscosity ranges and there is no significant trend that can be related to the year of delivery.

I consider that the important message of Table XIV will be lost if too much emphasis is placed on the maximum value of one fuel in a viscosity range covering only 419 fuels over a four year period out of a total of 13 787 fuels tested. As any of the CCAI figures chosen are arbitrary, it was decided to report yearly figures failing to meet a specified level at a level where there were sufficient fuels in each year to give a meaningful result expressed in percentage terms. It may be, when the time comes to present a further paper covering the present and the future, that it will make sense to present more detailed information.

However, as mentioned in this paper and in Ref. 1, the DnV programme is seen by most ship operators as having more interest for vessels burning fuels with much higher viscosity than 50 cSt at 50 °C so the number of fuels analysed in this viscosity range will always be fairly small. It is also known that some suppliers are now imposing their own maximum limit on the density of their lower viscosity grades that is more restrictive than currently allowed in BS MA 100:1982. Mr Newbery in his contribution mentioned some examples.

Mr Newbery spotted an error on page 7 of the preprint concerning the level of vanadium in the fuel. This has now been corrected.

Mr Visser, in commenting on Table VII, requested information about the number of cases where the shipowner or operator had obtained a reduction in the invoice because of the density difference that was in favour of the supplier. There are known cases but the customer is under no obligation to provide us with information and often is reluctant to do so, possibly for commercial reasons.

Mr Thornton wanted to know if the data in the same table reflected a bias or sloppy operation by some suppliers. There were essentially no samples from either group of suppliers where the density difference was more than −0.007. Table VII reflects the concern fuel purchasers should have in buying fuel from some suppliers.

There has been much discussion over the years in all quarters of the world concerning the importance of aluminium or some other criteria to control the amount of catalytic fines allowed in a residual fuel. The DnV laboratories have analysed all the residual fuel delivery samples for both aluminium and silicon. There was a vast amount of information available and it was decided this should be a large part of the paper. It was expected that this subject would be included in many speakers' contributions, the contents of which will no doubt be well read by those involved with fuel standards in the future.

BS MA 100:1982 was issued with a limit for aluminium in an Appendix table awaiting the time when an industry-recognized test method was available. Since its publication there has been continuing discussion in other committees concerned with ISO and CIMAC standards. There is general agreement that the presence of catalytic fines in marine residual fuels must be controlled but the debate continues as to whether it should be defined by the amount of aluminium, or catalyst calculated from a formula involving the amount of aluminium and silicon, or by an entirely new test method. It may be in some suppliers interests to try and get the level of permissible catalyst content at as high a level as possible so as to save the millions of dollars mentioned by Mr Thornton spent limiting the aluminium level in marine fuels.

Other contributors to the paper did not seem to voice the same objections as Mr Thornton and Messrs Swinden and Newbery confirmed that their companies considered aluminium was a reasonable means of identifying and controlling levels of catalyst fines and furthermore did not mention that the present suggested limit of 30 mg/kg was restrictive. Contrary to Mr Thornton's comment, there are no data points off the graph (Fig. 2). The points plotted on Fig. 2 are the average for the years 1982–1984 and the average catalyst content for 35 mg/kg of aluminium is shown.

Mr Thornton may not have heard or read of many instances of complaints concerning wear caused by the use of fuels with a high aluminium content. DnV have customer information related to engine damage attributed to fuels supplied at a port where Mr Thornton's company was delivering high aluminium content fuels. Not long afterwards the fuel quality improved dramatically but it subsequently deteriorated at various times, and during one of these periods another vessel already at sea returned to port for new bunkers and all costs were borne by the supplier. Similar steps were taken at a later date to make the same kind of improvements at another port.

The number of cases of catastrophic wear in ships' engines that hit the headlines has decreased but this is probably due to a reduction in the number of fuels delivered with very high aluminium contents. However, it should not be concluded that these are the only incidents of wear that the fuel standards should protect against. It is hoped Mr Thornton will be able at some future date to discuss publicly the results of a co-operative programme with a European engine designer on this important topic. The second edition of the CIMAC fuel standards has been issued since this paper was presented and it is worth noting it still retains the maximum level for aluminium at 30 mg/kg.

The centrifuge test procedure for the determination of total abrasive solids has been used in one of the DnV laboratories with some success but like Mr Swinden's company DnV would not be happy to have it introduced as a test method in a marine fuel standard. DNV would have no objections to reporting a catalyst figure obtained from the aluminium and silicon contents.

Mr Visser mentioned the dangers of illegal or accidental use of low-flashpoint component as fuel oil onboard ships. There has been no suspicion that fuels as delivered did not meet this statutory requirement for flashpoint. If such admixture with crude oil was taking place onboard it would be extremely unlikely that the ship's staff would be sending DnV samples taken after the admixture had taken place.

I agree with Dr Johnson that the sediment by hot filtration method merits further attention on an industry wide basis.

DnV intended to participate in the IP correlation programme with the new equipment designed by the committee responsible for the existent sediment method. This test was based on similar methods already in regular use by Exxon and Shell. Equipment was purchased. When assembling the equipment and joining the Buchner flask to the drain pipe from the filtration cells it was realized that the steel male and glass female spherical connections were at least 15 mm out of line.

In other words, when the flask was directly under the male connector the flask first was unstable on its support which is a curved spring plate, secondly fouls the framework of the equipment, and thirdly projects outside the back of the equipment. When experimenting with the equipment the Whatman GF/A filters were being cut through; it was as if the operator was using a cork borer.

The problems with the equipment were such that it was never possible to participate in the IP correlation programme.

The cleanliness and stability features of a fuel are important and this is particularly the case with the low-viscosity fuels such as some marine diesel fuels which consist of a mixture of gas oil and residual fuel. Pressure was inserted in some quarters for such a fuel to be included in the British Standard. The specification originally put forward would not have given the user the protection required to be sure the fuel could be safely handled in the fuel system. The committee insisted that if such a fuel was included the sediment by extraction was insufficient and the new sediment test required for higher viscosity fuels must apply to this fuel as well.

ISO in their wisdom decided that because of the maximum viscosity of this grade, 14 cSt at 40 °C, it should be designated as a D grade and not an R grade. It appears in the draft ISO specifications with no sediment control. Fuel users should be aware that this is potentially the fuel grade that will give more shipboard problems than any other fuel sold in the marine market. It is hoped the members of the ISO committee with petroleum background will insist on changes being made in the overall interest of the marine industry.

Customers in the DnV programme, who are aware of the potential hazards, prohibit their engineers from using such fuels until the results of laboratory tests are available. This precaution means the ship will not use an untested fuel in the auxiliary engines that might result in a black out condition when leaving port and in a congested waterway.

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