EXPERIMENTAL INVESTIGATIONS OF THE IMPACT OF HEAVY FUEL OIL ON MARINE DIESEL ENGINES

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ABSTRACT

The remarkable change in the characteristics of marine fuels, as a consequence of the energy crisis of the last years, has not been followed by a quick adjustment of related regulations and standards. The recent publication of ISO standards (1987) and the setting up of several information services supplying the characteristics of fuel bunkered worldwide have partially solved the problem of knowing the quality of fuel oil.
As regards the lubricants, the situation is similar: there are considerable difficulties in establishing universally accepted standards, especially for oils of internal circuit in 2-stroke low-speed engines.
Beyond regulations and standards, the research in the real impact of fuels and lubricants in the engine should be considered essential. The research activity of the Naples Istituto Motori takes place precisely in this field: it investigates the performances of a BOLNES 3DNL engine working with poor-quality fuels and lubricants specially prepared.

PREFACE

It is well-known that the socio-economic events developing during 1973 -79 have deeply influenced the availability and distribution of energy sources.
Particularly, the cost of crude oil has risen so much (in this period the price of one barrel of crude-oil has increased from two to almost forty dollars) that it makes the study and technological application of new refining processes convenient. These new processes can obtain the largest quantity of light fractions which are more expensive and consequently more profitable.
The marine field has been seriously affected by such circumstances: the distribution of operating costs showed (fig. 1) an increase of the fuel supply percentage from 10% to 50% [1,2]. The most patent consequence of such a situation has dealt with the same quality of the fuels burnt in marine diesels: the tendency to promote the production of light fuels (with the concentration of an increasing quantity of impurities in the left-overs) and the bewildering rise of diesel oil prices have forced people not to run marine engines with relatively valuable diesel oils anymore but with residuals of crude oil distillation, whose quality worsened more and more because of the exacerbated crude-oil exploitation.
On the one hand, this helps the concentration of impurities in a smaller quantity of fluid and, on the other hand, introduces new impurities (such as the aluminium cat fines).
Clearly, diesel engines forced to burn low quality oils, started working much worse.
Moreover, because of the new levels of the operating cost, in order to be competitive, an engine (both the slow-speed 2-strokes or the medium-speed 4-strokes) should be able to burn oils of close-to-3500° Red/sec (≈ 380 cSt) viscosity, from a certain point on.

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Due to an increased economic engagement in the supplying of fuels and lubricants, it has been necessary to curb oil consumption in any way possible, that is by improving both the specific engine efficiency (mechanical, of combustion, cycle, supercharging, etc.) and the total propulsion efficiency, which is strictly connected to the exploitation of the power available at the engine.
Therefore, systems capable of improving the use of fuels have been studied, and the same engines have been developed to burn heavy fuels.
The stroke-diameter ratios of slow speed engines have passed from values close to 1.5 to values of 4 , while the components involved in injection and combustion have been strengthened or newly calculated so as to burn the new kinds of fuel.
At the same time, a remarkable interest has arisen about the study of the consequences of the use of heavy fuels on engine performance and the remedial measures to be adopted in order to reduce the possibly negative effects. In this field, a research at the Istituto Motori of Naples (CNR) is taking place at the moment and will be more exhaustively described as follows.

Fuels

The level of crude oil fractionating obtained by setting up visbreaking and catalytic cracking processes has thus produced very poor-quality residues.
There has been an increase of the contents of all the noxious substances in crude oil, together with an increase in density and viscosity.
Table 1 shows the main characteristics of heavy oils (structural or simply due to the substances contained in them) together with the most frequently adopted methods for limiting the way they damage the engine.
For a more detailed analysis of the characteristics of heavy fuel and of their effects on the engine see [1,2].
It's worth remembering that the new situation has created other problems like the one due to the compatibility and/or stability of fuels. In fact, because of the residues, the characteristics of fuels have started depending from the place of supply.
By mixing fluids with very different (and therefore incompatible) characteristics, precipitations have taken place, with the chance of blocking and sludges.
A better knowledge of the loaded fuel and a larger experience of its manipulation have become necessary. Due to the growing importance of a deep knowledge of the adopted fuel, some international bodies (Bureau Veritas, American Bureau, Lloyd Register of Shipping) offer an information service regarding all the characteristics of the fuel bunkered by a ship in any harbour worldwide, in no more than 72 hours. Those who use such a service receive precious information so as to be able to take the most appropriate countermeasures and prevent malfunctions and damage to the engine.
Such spreading of news is convenient not only to the user, but also to the service organizing agency which, being also an insurance company, can follow more closely the engine management and thus limit its responsibility in terms of compensation for damages in case of breakdown due to operating with poor-quality fuels without taking the necessary countermeasures.
It would be advisable that any information request about the quality of the adopted fuel be satisfied, even if partially, either on board or at the landing harbour with easily available systems, so as to lower as much as possible the risks deriving from the use of low-quality oils.
Other bodies (like the Norske Veritas) organize ample statistics on availability and characteristics of oils, in every bunkering place and issue information bulletins on the subject [3].

TABLE 1

CHARACTERISTIC	DIMENSION	ACTIONS TO COPE WITH THE HARMS
density	kg/dm^3	oil heating
viscosity	cSt	oil heating
pour Point	°C	
flash Point	°C	
water	% volume	centrifugation
Conradson residue	% weight	additives allowing precipitation
ash	% weight	additives allowing precipitation
sulphur	% weight	use of lubricants of suitable alkalinity
vanadium	ppm	additives to lower hot corrosiveness
sodium	ppm	fresh-water washing, demulsifier addition and centrifugation
asphaltene	% weight	homogenization

Lubricants

The low quality of current fuels and the shipbuilders' tendency to raise their engine performance could not but multiply the characteristics required for lubricants, in their protective action on the moving parts of the engine.
Table 2 shows the main requirements for lubricants.
The problems of lubrication in 4-stroke medium-speed engines are rather different from those arising in 2-stroke low-speed crosshead engines.
Indeed, the last ones, in which a diaphragm separates the "hot" and the "cold" parts of the engine, can be lubricated by formulating two different oils, one for each of the specific needs to be satisfied.
On the other hand, the same 2-stroke engines, being fed with the lowest quality fuels, require, at least in the combustion chamber, more sophisticated oils capable of contrasting the action of the fuel impurities in the cylinder.
In the 2-stroke low-speed engines a particularly relevant problem concerns the corrosive wear due to more or less high sulphur contents in the fuel [4].
Such drawback is usually contrasted by adding substances which raise the TBN values appropriately.
The 4 stroke engine is usually fed with less than 180 cSt viscosity fuels so that it needs comparatively less chemical agents to improve the fuel condition. But, since there is no separation between its cylinder and crankcase, a single oil must face two different needs: the one of resistance to high temperature, arising near the cylinder head, and the mechanical need of lubrication of moving parts at low temperature.

Classifications and regulations

What said before has opened a new age in the use of marine fuels. The bunkering has become a critical phase in ship management since it has become necessary to evaluate a large number of factors regarding fuel composition, compatibility with the one previously bunkered, determination of the treatments to be given before the starting of the engine, etc.
On the other side, the answer of standardizing bodies on this subject has not coincided (and could not coincide) with the changing of bunkering characteristics so that, with the beginning of the described situation, there has been a lack of any precise reference to allow oil supplying with the necessary confidence.
Recently (1987), on the basis of CIMAC proposals, the ISO has issued two series of specifications on marine fuels.
Tables 3 and 4 show respectively the standards recommended for distillates and residuals. The evaluation of characteristics neglected in the given specifications can be deducted with a number of methods (obviously not ISO standardized) proposed by various technical organizations.
As far as the lubricants for marine use are concerned, it is well known [1] that generally, before putting a lubricant on the market, there is a stage of physicochemical testing in the laboratory, one of bench testing on the laboratory engine, and finally one of full-scale shipboard testing.
Even if the full-scale testing (indeed long, expensive and not always easy to keep within the instructions set in the beginning) should have the last word on the efficiency of the product, the two previous stages must establish whether the oil has got the required characteristics.
The bench testing represents, then, the first impact of the lubricant with the engine before the navigation testing.

TABLE 2

cylinder oil	crankcase oil	trunk-piston engine
viscosity	viscosity	viscosity
spread ability	oxidation resistance	corrosive and mechanical wear control
alkalinity and alkalinity retention connected with high S contents	bearing and piston cooling	rust inhibition
piston deposits and ring sticking prevention	rust inhibition	piston deposits and ring sticking prevention
mechanical wear control	low acidity neutralization	bearing and piston cooling
port blocking control	varnish and sludge control	demulsifying capability
	demulsifying capability	oxidation resistance
	alkaliness capability	alkalinity and alkalinity retention
	detergency/dispersancy	

ISO standards DIS 8217: designation		DMX	DMA	DMB	DMC	
Inspection		**Limits**				**Test Method**
Density at 15 °C [g/mL]	max	(a)	0.890	0.900	0.920	3675
Viscosity, kinematic at 40 °C [cSt]	min	1.4 (b)	1.5	...	...	3104
	max	5.5	6.0	11.0	14.0	
Flash point, [°C]	min	43	60	60	60	2719
Pour point (upper) [°C] (c) 1 Dec to 31 Mar		...	-6	0	0	3016
1 Apr to 30 Nov	max	...	0	6	6	
Cloud point, [°C]	max	-16 (d)	...	...	...	3015
Carbon residue, Ramsbottom:						
on 10% residue [% by mass]	max	0.20	...	...	...	4262
whole sample [% by mass]	max	...	0.20	0.25	2.5	
Ash, [% by mass]	max	0.01	0.01	0.01	0.05	6245
Sediment by extraction, [% by mass]	max	...	...	0.07	...	3735
Water content, [% by volume]	max	...	...	0.30	0.30	3733
Cetane index	min	45	40	35	...	5165
Sulphur content, [% by mass]	max	1.0	1.5	2.0	2.0	
Vanadium content, [mg/kg]	max	...	...	...	100	

NOTE: conversion factor: 1 cSt = 1 μm²/s
(a) In some countries, there will be a maximum limit
(b) BSI requires min 1.5 cSt at 40 °C.
(c) Purchasers should ensure that pour point is suitable for their trading pattern.
(d) This fuel is not suitable for use at ambient temperatures below -15 °C without heating.

			Designation											
			RMA 10	RMB 10	RMC 10	RMD 15	RME 25	RMF 25	RMG 35	RMH 35	RMK 35	RMH 45	RMK 45	RMH 55
Characteristic	Lim.	T.M.												
Density (1) kg/m^3	max	3675	975	991		991	991		991		--	991	--	991
Kinematic viscosity at 100°C cSt	max	3104	10			15	25		35			45		55
Flash point °C	min	2719	60			60	60		60			60		60
Pour point °C (2)	max	3016	0 6	24		30	30		30			30		30
Carbon Residue (Conradson) % (m/m)	max	6615	10		14	14	15	20	18	22		22		22
Ash % (m/m)	max	6245	0.10			0.10	0.10	0.15	0.15	0.20		0.20		0.20
Water % (V/V)	max	3733	0.50			0.80	1.0		1.0			1.0		1.0
Sulphur % (m/m)	max		3.5			4.0	5.0		5.0			5.0		5.0
Vanadium mg/kg	max		150		300	350	200	500	300	600		600		600

Note: The values in this table are maximum or minimum for each property; the actual values for any batch of oil may vary within these limits.

(1) Density at 15 °C in kilograms per liter should be multiplied by 1000 before comparison with these values.

(2) Purchasers should ensure that this pour point is suitable for the equipment on board especially if the vessel is operating in both the Northern and Southern hemispheres

TABLES 3 AND 4

It is usually carried out on laboratory engines, mostly small ones, and follows given procedures which, by heightening and worsening the operating conditions, would stress the lubricant in a short time but with the same severity as in the full-scale operation.
The laboratory engines used for the screening of lubricants, may be of various types. Regarding the lubricants intended for 4-stroke medium-speed running with heavy fuels there has been an attempt to standardize the testing procedures, as proposed by a number of organization. The laboratory engines are all one-cylinder trunk-piston 4-stroke (Caterpillar, Petter, AVB, MWM, for instance); such a practice derives from the testing of land traction engines.
The engine mainly used in Europe (and elsewhere) for the testing of 2-stroke internal circuit oils is the BOLNES DNL produced by the BOLNES Motoren Fabriek.
The BOLNES DNL is the smallest 2-stroke, crosshead, separate-lubrication engine in existence, its main characteristics will be listed below.
Although this engine has been given building and functioning criteria so as to simulate with large approximation the real operating conditions and make it very adequate to the second stage testing on lubricants, it has not been standardized as yet. Moreover, it has not even been possible to standardize that very crucial part of the testing procedures corresponding to the final evaluation criteria [5].
Even the efforts in this direction by some generally recognized and praised bodies (such as CEC) have not succeeded so far: a marine engine operation depends upon a number of mutually interdependent parameters which can not always be simultaneously and completely reproduced in a laboratory engine, even if it comes very close to the full-scale one.
Besides, the remarkable sensitivity to the fuel quality makes the choice and general acceptance of one (or even of a small group) of "reference" fuels very hard. At the moment, indeed, such a case seems completely unreal: the combination of a lowering in quality with a variability in supplies makes it practically impossible to relate the screening tests to the operation on board.
Anyway, the main oil companies are developing their own testing procedures by using the BOLNES engines to analyze the cylinder lubricant, particularly from the point of view of resistance to corrosion and/or formation of deposits.
Table 5 shows a list of the testing conditions according to the procedures developed by some companies. Each procedure is identified by a number and the type of BOLNES engine used for it (OE = Old Engine ; NE = New Engine).
The conditions indicated in the table are the basis for each procedure. They can be varied according to the particular objective of an investigation: for instance, by reducing coolant temperature one can emphasize the phenomenon of corrosive wear.
As regards the analysis and evaluation of tests results, the CEC has proposed a criterion which applies to both the laboratory and full-scale engines. Such a system has been fully adopted by some users, oil companies and others, with some variations, but always keeping in mind the CEC criterion, particularly as regards the carbon deposits.
Each of the adopted evaluating systems provide for the rating off all (or almost all) the following elements:

- wear ring and ring sticking;
- cylinder liner wear, measured at various levels of the cylinder axis;
- deposits on the ports
- groove and land carbonaceous deposits and lacquers
- TBN, wear metals, water, insolubles in drain oil samples

TABLE 5

		1 (OE)	1 (NE)	2 (NE)	3 (NE)	4 (NE)	5 (NE)
Engine speed r.p.m.		514	600	518	600	600	500
Brake horsepower kW (CV)		198 (270)	362 (485)	286 (389)	375 (510)	381 (518)	273 (371)
Mean eff. press. bar		7.8	12.10	11.2	12.6	12.8	11.0
Coolant temp. °C		70	76 ÷ 80	50 ; 80	74 ÷ 81	--	85
Cyl. oil feed gr/kWh (gr/CVh)		1.0	0.82	0.69	0.95	--	1.41
Fuel	viscosity	1500 (Red/s)	1500 (Red/s)	--	420 (cSt)	180÷900 (cSt)	400÷500 (cSt)
	sulphur % by mass	--	--	3	3	3 ÷ 5	3.5÷4.0
Test during h		100	72	72	84	72	72

It is worth pointing out that any regulation (on the fuel and lubricant characteristics) even if exhaustive, cannot give certain directions about the engines' reactions to operating with heavy fuels and appropriately prepared lubricants because of the complexity of the subject and specially for the variety of the current lubricant quality; only laboratory testing conceived, of course, so as to simulate with the highest possible approximation the real operating conditions) seems capable of giving some reliable information on the matter.

The experimental plant for screening tests

The bench testing of lubricants basically requires:

1) A dynamometric bench with BOLNES engine
2) An heavy fuel treating system

1) The BOLNES DNL engine is a 2-stroke diesel engine supercharged with axial-flow scavenging and exhaust valve on the head, crosshead and scavenging pump in series and below the turbocharger.
Lubrication is separated.
The laboratory model has been given a peculiarity: the cylinder oil circuit has been divided into as many independent circuits as there are cylinders in the engine configurations (usually three for laboratory uses). This device makes it possible to analyze at the same time, i.e. during the same test, more than one kind of lubricants, thus profitably reducing time and costs of testing.
In the last decade, the development of testing procedures for the evaluation of of cylinder oils has promoted the production of two successive BOLNES engine models, representing two stages of the building technology of 2-stroke marine diesel engine.
Table 6 shows a comparison between the characteristics of the two models indicated simply by "old" and "new" engine.

The model installed in the CNR Istituto Motori is an "old" 3 cylinder engine.

2) The heavy fuel treatment system reproduces, in laboratory scale, the similar equipment on board ship. In fact, the treatment system recently installed at the Institute include settling tanks, a pre-heating and depuration transfer-to-the-daily-storage group, a storage tank for the light oil to be used in starting and stopping the engine, an on-line regulating station of viscosity, a feeding group equipped with a gravimetric measurement system of the consumption (both total and for each cylinder).
Figure 2 describe the flow pattern and the component of the heavy fuel treatment system.
Figure 3 shows the pattern of the fuel feeding equipment with the unit to measure consumption.

Future activities of the Istituto Motori in the field of marine engines.

The recent installation of the heavy fuel treatment equipment at the BOLNES bench of the Institute has been promoted by the need to carry out a program of experimental activities so as to contribute to the study of compatibility of fuels and lubricants. Such research activity is part of the co-operation program with the state oil company (ENI/EURON).
This program. in its general outline, will be divided in the following stages:

- setting up of the engine with the use of a current heavy fuel and a cylinder oil which has been already tested in full scale, through first a testing procedure and than a comparison with the data available for the users.

- carrying out a testing campaign aimed at the evaluation of the engine's "sensitivity" to the varying combination

TABLE 6

	Old engine	New engine
Model	DNL - 120/500	DNL - 190/600
Bore (mm)	190	
Stroke (mm)	350	
B/S ratio	1.842	
Unit displacement (dm^3)	9.92	
Engine speed (rpm)	500	600
Max unit rating (kW(CV)/Cyl) [4]	88 (120)	140 (190)
b.m.e.p. (bar) [4]	9.7	14.1
Scavenging air pressure (bar)	1.11	2.1

[4] to be obtained only with light fuels

of the lube oil and fuel oil qualities, with the study and development of testing and evaluating procedures.

- development of a testing procedure providing more severe operating conditions (increasing the thermal and mechanical loads), within the safety limits, so as to put the lubricant into environmental conditions as close as possible to those of the big 2-stroke diesel engines of recent building typology.

In parallel, there is a research prospect which, through the study of the damages and the development of diagnostic systems on engines, will allow work on hypothesis on programmed maintenance.

Conclusions

The compatibility of fuels and lubricants for current large marine engines seems to be developing constantly.
If, on the one hand, it is not easy to foresee the characteristics of future fuels, on the other hand it does not seem possible to define the exact consequences of operating with heavy fuels in terms of safety, reliability, the intervals between ordinary servicing, the need for special maintenance, etc.
The experimental research in this field has got, thus two objectives:

- to identify the operating characteristics of diesel engines with low quality fuels and lubricants specifically prepared.
- to stimulate the action from official organization to standardise procedures; that is to promote drafts of regulation which could be the basis on which official bodies would draw up and issue exhaustive standards and regulations which would be generally accepted.

Such an activity will, of course, affect positively the operating efficiency of vessels equipped with diesel engines.

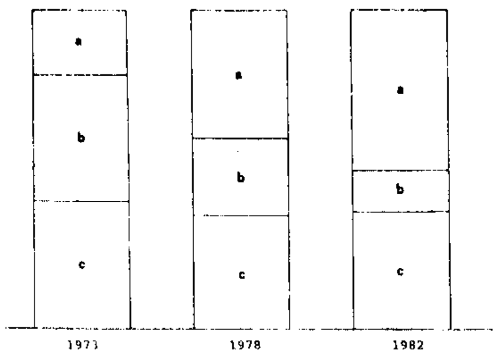

FIG. 1: Ship costs evolution

a Fuel
b Capital
c Others

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FIG.2: HEAVY FUEL TREATMENT PLANT

A HFO STORAGE TANKS
B FEED PUMP
C SEPARATOR PREHEATER
D CENTRIFUGAL SEPARATOR
E SEPARATOR ALARM
F 2-WAY PNEUMATIC VALVE
G FEED PUMP
H PURIFIED FUEL SERVICE TANK
I DRAIN TANK
K DIESEL OIL TANK
L MANUAL CHANGE-OVER VALVE
M MIX PIPE
N BOOSTER PUMP
P BOOSTER HEATER
Q DUPLEX FILTER
R VISCOSITY CONTROL UNIT
S FO SAMPLING UNIT
T FO SYSTEM AND CONSUMPTION DEVICE
U ENGINE
V DRIP RESERVOIR
Z DISCHARGE LINE TO WASTE

The pipes connecting the various components are trace heated

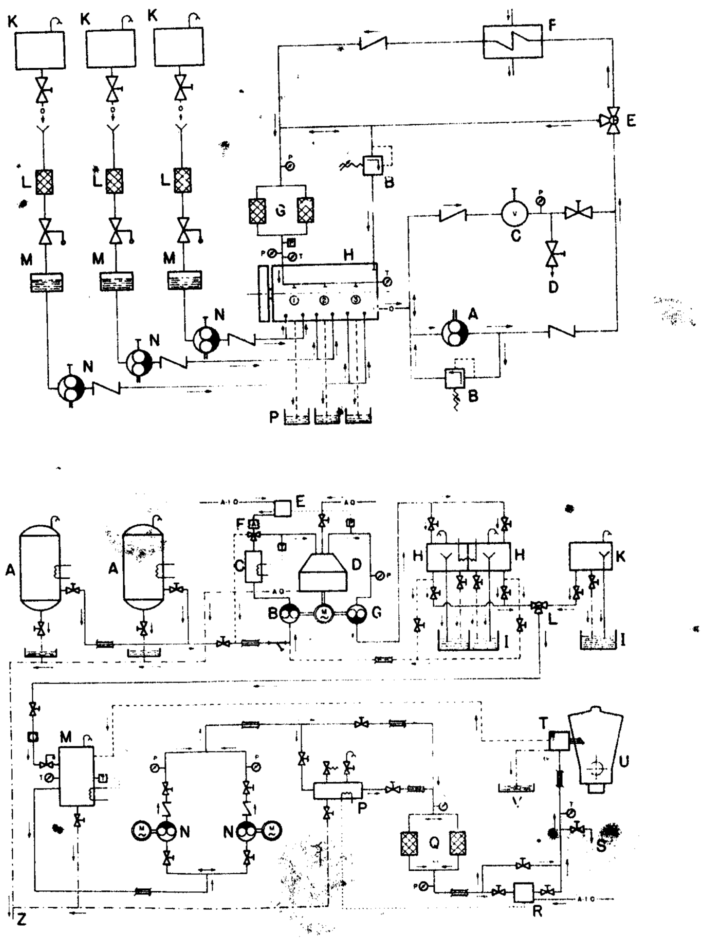

FIG.3: CONSUMPTION MEASUREMENT SYSTEM

A EQUIPMENT (BURET, WEIGH, TIME-METER)
B FUEL ELECTRIC PUMP
C HEATER
D PRESSURE CONTROL VALVE
E ELECTRO-PNEUMATIC VALVE
F INJECTION DEVICE
G 4-WAY VALVE
H MANUAL GATE