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The quality of marine fuels and the safety of navigation: case studies

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Abstract

The quality of marine fuels is standardised by the international standard ISO 8217. As practice shows, even fuels that meet all standard requirements do not completely guarantee avoiding disruptions in smooth and safe operation of the ship. The future is likely to bring more cases of improper operation of vessels, sometimes leading to main propulsion failures. One cause behind main engine breakdowns is the introduction of new products on the fuel market that are intended to meet the ever-increasing requirements of environmental protection (e.g. low sulphur content). As a result, some fuels are chemically different from the previously used residual fuels. Using them in the engine room requires special care on the part of the ship owner and the ship's crew. The article analyses two cases in which the use of conventional residual fuels resulted in main engine stoppage. The authors, bearing in mind the causes of those failures, focus on technical consequences of using marine fuels produced by currently employed technologies.

Introduction

A breakdown of a ship's propulsion system creates a risk to navigation safety by making the ship unmanoeuvrable. The key to the safe operation of the vessel lies in appropriate technical conditions of the power plant, directly supervised and maintained by the crew of the engine department. The condition of the power plant is also affected by the quality of working fluids, including fuels feeding the main propulsion engines and generating sets. Fuel is a structural component of the engine, which means that its physical and chemical parameters should be within the range of values provided by the engine designer. In addition to the essential requirements for the engine, fuel should meet the requirements for storage and transport installations in specific shipboard conditions.

In the past, a number of institutions analysed individual cases of ship failures in which the main cause was attributed to marine fuel properties. On this basis, regulations and principles were gradually worked out to minimise the risk of engine failure due to poor quality of fuel. In short, these principles prescribe four basic steps: 1. take a representative sample of bunkered fuel in the presence of at least one crew member and supplier, 2. deliver fuel samples to a recognised laboratory for analysis, 3. introduce new fuel to the engine fuel supply system only after receipt of the analysis results and implementing laboratory recommendations, 4. do not mix fuels from different deliveries.

The available documents of institutions dealing with marine fuel usage reveal many cases where poor quality fuel was employed (DNV, 2014a; 2014b; 2014c). Laboratories involved in the so-called 'petroleum services' provide information on cases in which limit values of fuel quality indicators where exceeded in different ports. According to data, DNV PS (now Veritas Petroleum Services) alone reported dozens of such cases. The reports analyse the causes and the consequences of disruption of smooth vessel operation, although the analysis is focused on fuel physical and chemical parameters.

This article aims to consider and discuss the effects of non-compliance with both fuel quality standards and procedures of fuel handling in the engine room, leading to dangerous situations such as the loss of manoeuvrability.

Given the variety of crude oils and various production technologies, fuels of the same composition and properties are hardly encountered. In order to standardise marine fuels on the market, the ISO 8216:1 standard: Petroleum products – Fuels (class F) classification – Part 1: Categories of marine fuels) and ISO 8217 standard: Petroleum products – Fuels (class F) – Specifications of marine fuels were published. The set of limits of physical and chemical parameters as per ISO 8217 is a benchmark for the quality of marine fuels on the market.

The paragraphs that follow describe cases of main propulsion failures of ships due to the use of residual fuels; all these cases led to the loss of the ship's manoeuvrability. Those events are well documented and additionally supported by direct and informal observations of crew members involved. In the descriptions the ship names have been omitted. The laboratories that performed the fuel analyses have not been named either, although they are globally recognised.

Ship No. 1

The failure occurred on a methanol carrier, propelled by the main engine Mitsui Man B&W 7S50MC Mark 6, MCR – 10,010 kW at 127 min^{-1}, CSR – 8510 kW at 120.3 min^{-1} running on ISO-F-RMG 380 fuel. The main propulsion failed during a routine operation of the vessel on a route linking the port of Trinidad and Tobago, where methanol was loaded, and one of the discharge ports in the United States. At the time of the incident the ship had been in operation for 11 months after being launched at a shipyard in Japan. Before the failure, the main engine was in excellent technical condition, as confirmed by periodic inspections of the engine, and current assessment of engine and combustion parameters.

Circumstances preceding the failure

The ship routinely bunkered fuel in US ports, and the supplier of fuel was one of the major companies in the industry. On June 27th 2006 the ship bunkered 1,200 MT (Metric Ton, SI unit: MG) of ISO-F-RMG 380 fuel. A sample of the bunkered fuel was sent, in accordance to the ship owner's procedure, to laboratory No. 1 in order to verify the conformity of the fuel characteristics with the ISO 8217. Three days later an e-mail was received with the results of the fuel sample test. The properties of the fuel samples are presented in Table. 1.

Table 1. Selected data from Fuel Quality Report – ship No. 1

Characteristic	Unit	ISO 8217:1996 RMG 35[1]	Lab 1	
			Supplier's data	Ship's sample 30.06.2006 019701[2]
Density at 15°C	g/cm^3	**Max. 0.991**	0.991	0.9899
Viscosity at 50°C	mm^2/s	**Max. 380**	246	257
Viscosity at 100°C	mm^2/s	**Max. 35**		–
Flash point	°C	**Min. 60**		> 70
Pour point	°C	**+30**		0
Carbon residue	% m/m	**18**		16
Ash	% m/m	**0.15**		0.07
Water	% v/v	**Max. 1.0**		0.2
Sulphur S	% m/m	**Max. 5.0**	3.04	3.7
Al + Si	mg/kg	**Max. 80**		24
Vanadium V	mg/kg	**300**		141
TSP	% m/m	**Max. 0.10**		**0.19**

[1] (ISO-8217:1996); [2] (FQR, 2006)

The results were compared with the ISO 8217:1996 specification for RMG 35 fuel. An exceedingly high value of TSP (Total Sediment Potential, i.e. total quantity of potential deposits after hot filtration) was pointed out, as excess TSP is a signal of possible loss of fuel stability in the conditions prevailing in the engine room. The following operational advice was included in the analysis: "TSP – Fuel stability is suspect and increased sludging is likely to occur. Observe centrifuge operation closely. If sludging is excessive, decrease the time between sludge discharges. If possible operate two centrifuges parallel with minimum throughput. If sludge is unmanageable, recommend you refer to the fuel supplier. **Do not mix with another fuel.**"

The properties of the bunkered fuel raised doubts and discussions between the chief engineer, the ship owner and the charterer concerning safety issues caused by the use of substandard fuel in the main engine. Finally, the ship owner decided to make a tentative use of that fuel, knowing that this may have resulted in operating difficulties. In the port of Trinidad the ship was supplied with an emergency amount of 450 MT of RMG 380 fuel of very high quality, confirmed by Lab No. 1. It was to be used in case of difficulties with the combustion of the US-delivered fuel that did not meet the standards.

Additional information

The installation of residual fuel includes a settling tank with a capacity of 14 m^3 and service tank with a capacity of 16 m^3 fuel. The fuel for the service tank is purified by Mitsubishi SJ 50GH purifiers, equipped with a "multi-monitor" controlling the water content at the purifier outlet and the amount of sludge in the sludge space of the centrifuge drum. The main engine fuel supply installation had a primary filter KS 15 (mesh size 100 µm), automatic back-flash filter (10 µm mesh size) and safety K8FE filter (mesh size 50 µm).

Description of the failure

On July 13th, 2006 at 08.00 local time, during a sea voyage from Trinidad and Tobago to the US ports with a cargo of 43,800 MT of methanol, the ship started using fuel that had been bunkered on June 27th, 2006 in the US. The operation was carried out routinely. Because of the potential problems associated with the use of fuels with high TSP, the purifier capacity was reduced to the minimum and a second purifier was employed. All fuel filters in the ME feeding system were cleaned.

The ship worked in the unmanned engine room regime. On July 15th, at 23.00 LT the duty engineer was watching the engine room and ascertained that all the operating parameters of the main engine were correct. At that time, the ME feed system contained only "new" fuel; its daily consumption by the ME was 32–33 MT. The fuel purifiers were running smoothly, the performance of the filters in the ME fuel supply system also showed no deviation.

On July 16th, 2006 at 03.30 the engine monitoring system registered a large (over 50 degrees) deviation of the temperature of exhaust gases from cylinder No. 1. The chief engineer inspected the engine and found that the injection pump of the ME No. 1 unit did not supply fuel to the cylinder. Observation through the transparent cover of the camshaft revealed that the roller was not resting on the fuel

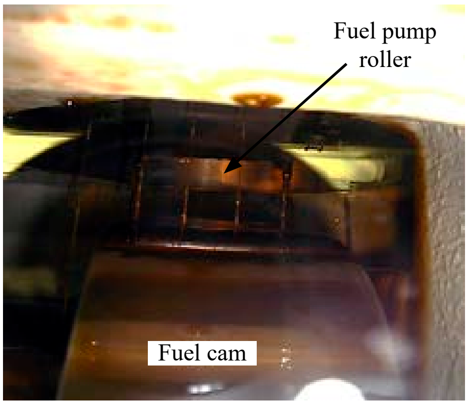

Figure 1. Suspended drive roller of the fuel pump

cam. The injection pump plunger remained in the upper position in the pump cylinder. Figure 1 presents a photo of the suspended drive roller. At 03.40 ME was stopped to replace components of the defective injection pump in ME No. 1 unit and identify the cause of pump failure. The ship was drifting. After dismantling the pump and removing the plunger and barrel from the pump body, the identified defects included plunger seizure, suspension of suction-delivery valve and overflow valve.

All internal components of the pump were covered with a layer of sediments that, under high temperature, had sustained carbonization. Figures 2 and 3 show photographs of injection pump elements after failure. Dismantling the injection pump was difficult because of hard deposits that caused seizure

Figure 2. Dismantled barrel of fuel pump, unit No. 1 after failure

Figure 3. Traces of seizure on the fuel pump plunger, No. 1 unit after failure

and jamming of the mating elements. The injection pump of the piston-crank unit was reassembled using new spare parts: a plunger-barrel unit, suction valve, overflow valve, plus a new set of sealings.

During the initial adjustment of the repaired injection pump and preparation of the main engine to resume the voyage, the crew rotated the main engine crankshaft using a turning gear.

After this operation, it was found after this operation that in six the remaining seven fuel pumps, the plungers remained in the upper position. The rollers of fuel pump drive systems were not resting on the surface of the cam surfaces of the camshaft. It was decided to overhaul the remaining six injection pumps. After dismantling, the same condition was observed in each of the pumps as had been found in the injection pump of No. 1 unit. All pumps were repaired with new spare parts: plungers and barrels, suction valves and overflow valves, plus sealings.

The overall repair operation of all injection pumps and the cleaning of fuel feed system took 32.5 hours, and by this time the ship had drifted.

After the failure

The failure of all seven of the ME injection pumps was undoubtedly caused by fuel that did not meet the ISO 8217 standards. It was therefore decided not to use the same fuel to feed the engine and to change to the fuel bunkered as "emergency" in Trinidad. For this purpose, the problematic fuel was removed from the installation, the settling and service tanks. The tanks were cleaned by the engine crew. The power system was flushed with distillate fuel and filled with "good" RMG 380 fuel. The condition of fuel filters was checked and found in good condition.

Representatives of the P&I Club insurer, fuel supplier, ship owner and B&W company arrived onboard in the first US port of methanol discharge. After inspection of the damaged parts of injection pumps, all parties agreed that the poor fuel quality had caused such serious defects. The fuel supplier agreed to cover the losses that the owner incurred in connection with the failure. At the expense of the supplier, the disputed fuel was pumped from the ship to land-based installations in the US.

Causes of the failure

Additional analysis of fuel made after the accident showed chemical contaminations (polymethacrylates) in the fuel, which, among others, were responsible for the TSP value of 0.19%. At the high temperature required to achieve the desired fuel viscosity before the fuel injectors, approximately 135°C, these compounds settled on the injection pump barrel walls, hindering heat exchange between the barrel and the plunger of the injection pump and locally raising the temperature. This process adversely affected lubrication, reducing the plunger-barrel clearance (due to different thermal expansion of the components), and caused seizures due to the coagulating sediments of hard particles.

Ship No. 2

The incident took place on a general cargo ship, driven by a four-stroke main engine 6M32C MAK from Caterpillar Motoren GmbH & Co (in-line cylinders) with a power output of 3000 kW at 600 min^{-1}. It was run on RME 180 fuel. The four-blade controllable pitch propeller Berg BCP 950 with a diameter of 3300 mm was driven by a flexible coupling Vulcan Rato-R and a reduction gear (600/187 min^{-1}).

Circumstances preceding the failure

Fuel was taken on May 22nd, 2010 in one of the ports in West Africa, and the sample was sent to Laboratory No. 2. Analysis of fuel physicochemical parameters showed a significant excess of water content in the fuel (2.05% vol. where the limit was 0.5%). The technical condition of the engine and fuel preparation did not show any defects.

Description of the failure

Disruptions in the functioning of the ME's propulsion appeared on May 22nd, 2010, immediately after introduction of the newly bunkered fuel to the engine installation during departure manoeuvres and consequently made proceeding to sea impossible.

The first symptom observed was difficulty in maintaining the required engine load. After the start of the voyage, increased exhaust gas temperatures on a couple of cylinders were observed, deviating from previously noted temperature differences between the individual cylinders. The level of noise emitted by individual cylinder units was rising. Also, injection valves produced unnatural sounds. The main engine fell into periodic vibrations. The speed governor was setting the fuel pumps in the position of maximum fuel amount, causing an overload alarm. At the same time, the turbocharger did not reach the expected rpm. The sea passage and ship manoeuvring became impossible after the control system reduced the propeller blade angle. As a result, the main engine was stopped.

The viscometer indicated high viscosity, initially 14 mm/s^2 at a temperature of 138°C, later both parameters rose to 22 mm/s^2 and 151°C. The automatic fuel filter alarm indicated a high pressure difference before and after the filter. The control system turned off the fuel purifier SA816 (Alcap system) due to high backpressure of fuel.

After stopping the main engine and checking some of its elements and the fuel supply installation, the following was identified:

1. Main engine:
   a) Significant amount of deposits on the nozzle ring of the turbocharger (turbine side), reduced cross-sectional area of flow;
   b) Worn out material on the surfaces of valve spindle and seats;
   c) Hard deposits on atomiser nozzles;
   d) High-viscosity sediments covering the surfaces of pump plungers and cylinders of fuel pumps.
2. Installation of fuel treatment:
   a) Presence of free water in the service and settling tanks;
   b) Surfaces of fuel filters blocked with thick layer of sediment of fibrous structure, presence of water;
   c) Large amounts of high viscosity sediments in the fuel centrifuge bowl;
   d) Faulty viscosity sensor surface (traces of seizure and scratching) in the fuel viscosity control system.

After the failure

In order to continue the voyage the crew decided to use a mixture containing approximately 5 to 10% of troublesome fuel and 95% of the fuel from the previous bunkering. The remaining amount of fuel needed to reach the next bunkering port was prepared in standby tanks in the 5:95% ratio. Fuel transfer pumps were used to homogenise the mixed fuel.

In the following port, fuel samples (shipborne and supplier's) were sent to lab No. 3 and new fuel was bunkered. The engine crew continued to add newly bunkered fuel in the previously defined proportions. The entire amount of fuel from the latest delivery was used after approximately five months, almost 20 MT were discharged ashore.

Table 2. Selected data from Fuel Quality Reports – ship No. 2

Characteristic	Unit	Bunker Delivery Note 22.05.10[1]	Limits 8217:2005 RME 180[2]	Lab 2	Lab 3	
				Ship's sample 03.06.2010 482562[3]	Supplier's sample 14.07.10 482573[3]	Ship's sample 26.07.10 482546[3]
Density at 15°C	g/cm^3	0.9801	**Max. 0.991**	0.9586	0.9625	0.9584
Viscosity at 50°C	mm^2/s	180	**Max. 180**	70.8	159.5	72.63
Flash Point	°C	85	**Min. 60**	> 70	> 76	88
Pour Point	°C	15	**+30**	0	0	< –3
Carbon residue	% m/m	–	**15**	8.6	10.9	8.53
Ash	% m/m	–	**0.10**	0.08	0.062	0,099
Water	% v/v	< 0.05	**Max. 0.5**	**2.05**	0.30	**1.75**
Sulphur S	% m/m	0.92	**Max. 4.5**	1.12	3.31	1.33
Al + Si	mg/kg		**Max. 80**	17	5	20
Vanadium V	mg/kg	–	**200**	48	–	63
Phosphorus P	mg/kg	–	**15**	2	< 1	3
Calcium Ca	mg/kg	–	**30**	43	8	45
Zinc Zn	mg/kg	–	**15**	2	1	3
TSP	% m/m	–	**Max. 0.1**	0.04	0.02	0.06
CCAI	–	–	**Max.**	840	–	839

[1] (BDN, 2010), [2] (ISO-8217:2005), [3] (FQR, 2010)

Over the five-month period, during routine maintenance of the engine components, it was found that all the inspected atomisers, which had operated for 1500 hours, had to be replaced, despite the nominal operating life of 3000 h.

Causes of the failure

In reports of additional tests of samples from the ship and supplier (after the failure), laboratory No. 3 did not indicate any direct cause of the accident, although excessive water content in the fuel was confirmed (Table 2).

The vast majority of failure symptoms described is characteristic of the presence of significant amounts of water in the fuel.

Nevertheless, the analysis previously performed in laboratory No. 2 was followed by these comments and recommendations:

1. The sample indicates the water content is above the specification and this level, if not removed, could cause problems with the fuel injection equipment and give poor combustion leading to deposits in cylinder and turbochargers.
2. If possible, increase the residence time of the fuel in the settling tank.
3. Operate the purifiers in parallel at the lowest possible flow rate (enough to meet daily consumption).
4. Check the settling and service tanks frequently and drain all water.

The recommendations were not known to the crew, because the fuel was used immediately after bunkering, on May 22nd, 2010, and the results of the analyses from lab No. 2 were only known on June 6th, 2010.

Ship No. 3

In 2010, on another ship belonging to the company from example I, fuel pump plungers were once again subject to seizures. This time, the fuel came from one of the major ports in Asia. Below is a set of physico-chemical characteristics of fuel, the use of which immobilised the vessel. The study of the fuel was made after the occurrence of the failure (Table 3).

The fuel was found to meet the requirements of the ISO 8217 standard. After the accident, additional analyses were carried out on the chemical composition of the fuel, going beyond the routine analysis and the ISO 8217 recommendations. The following results were found:

1. High levels of asphaltenes (method IP 143/04);
2. High value of xylene equivalent (method: BP);
3. Presence of C16 FAME.

Table 3. Selected data from Fuel Quality Report – ship No. 3

Characteristic	Unit	Limits 8217:2005 RMG 380[1]	Lab 4	
			Supplier's data	Ship's sample 03.01.2011 No. S66191/3393003[2]
Density at 15°C	g/cm^3	**Max.0.991**	0.9895	0.9882
Viscosity at 50°C	mm^2/s	**Max. 380**	372.7	**396.6***
Flash Point	°C	**Min. 60**		>70
Pour Point	°C	**+30**		0
Carbon residue	% m/m	**18**		11.53
Ash	% m/m	**0.15**		0.04
Water	% v/v	**Max. 0.5**	0.1	0.2
Sulphur S	% m/m	**Max. 4.5**	2.4	2.48
Al + Si	mg/kg	**Max. 80**		44
Vanadium V	mg/kg	**300**		98
TSP	% m/m	**Max. 0.10**		0.02

[1] (BDN, 2010), [2] (FQR, 2011)

* Viscosity at 50°C is out of specification, but within the acceptability criteria for ISO 4259 for a single result. Acceptability Criteria for IFO 380 at 50°C ranges from 380 to 396.6 mm^2/s.

Causes of the failure

Based on experience of, among others, the engine manufacturer and on information on the materials used, the failure was attributed to a problem in the unit injector fuel due to the presence of high value-xylene equivalents. The fuel used had a tendency to form hard coke deposits, potentially causing plunger seizure.

Summary

In the above cases, it has been possible to identify the main causes of failure of the main propulsion system. In case of ship I, the technical services of the owner decided to use the fuel, despite the result of the analysis indicating excessive TSP, a parameter essential for the operation of the engine and the engine room. In ship II, the crew decided to use the newly received fuel, before knowing the results of fuel analysis. The report from the fuel examination provided guidelines for minimizing or even avoiding the technical consequences of poor quality fuel. In case of ship III, the crew complied with all procedures for the use of fuel, and still did not prevent a major failure due to fuel properties.

Using fuel that meets all the requirements of the standard for residual fuels does not guarantee trouble-free operation of the engine and engine room.

The results of the analysis of fuel in ship III indicate compliance with the ISO 8217, but the same problem was experienced as in the case of ship I, where TSP values where clearly above the limits.

Even extended and highly specialised tests will not give complete certainty on fuel quality. The cases of ships I and III show that the same effect (plunger seizures) was due to different causes, as noted in the reports of the laboratories 1 and 4.

Cases I and II contribute to the assessment of the role of the human factor in the safety of the ship. The decisions taken, deliberately bypassing the rules and criteria for handling the fuel on board caused the loss of vessel manoeuvrability.

Although information is abundantly available on the characteristics of the single compounds present in fuels, residual fuel is a mixture of many compounds in different proportion. The ability to predict the behaviour of the mixture based on the characteristics of the individual compounds can be highly biased.

Fuel quality is a function of crude oil composition and production technology. In the opinion of "petroleum services" organizations, most uncertainties regarding the quality derive from the so-called "tank farms", where refinery by-products from dozens of tanks are blended to make fuel according to the current demand (Nair, 2014). Concerns relating to the quality of tank contents as well as proportions used in the mixtures (Nair, 2014) suggest the importance of product quality supervision in bunker stations.

Conclusions

1. The complete elimination of the main propulsion failures caused by residual fuel quality is not possible due to:
   a) current technologies of making residual fuels from crude oil;
   b) limited set of selected properties and methods for determining their value within the standards;
   c) specificity of deep-sea ship operation and fuel use cycle.
2. We can significantly reduce the risks related to navigation safety by using the existing procedures for fuel use and accepting the principle that during manoeuvres the newly bunkered fuel should not be used.
3. Monitoring the compliance with marine fuel procedures by the management staff of the ship owner should be complemented by improving and updating the competence of technical service personnel, both on shore and on board, as part of professional training.

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