

*Heavy Fuel – a Completely Special Liquid?*  
*or*  
*The Myth about “Bad” Heavy Fuel!*

(by Dipl. Ing B. Röder)

This composition is to show that the bunkering of “bad” (off-spec) heavy fuel does not inevitably have to lead to engine damage. The following will further show that operational problems and engine damage are often falsely attributed to “bad” heavy fuel and that these problems / damages are avoidable – because, although “bad” heavy fuel is occasionally delivered, it is more often the case that the on-board, fuel preparation is inadequate, and / or the ship’s diesel engine is working in conditions that are not compatible with heavy fuel.

In reference to a safe and economic operation of a ship, the heavy fuel is by all means a completely special liquid, especially when one thinks that in the course of a ship’s or, respectively, an engine’s lifetime considerable amounts of it are consumed. Within 25 years, e.g. a 10,000 kW engine uses approx. 150,000 tonnes of heavy fuel, which corresponds to the cargo capacity of a middle-sized tanker. The world’s fleet currently uses approx. 200 million tonnes of heavy fuel per year – at an increasing rate.

Contrary to popularly held notions, ship’s diesel engines are no “omnivores”. They are, in fact, rather – like other combustible fuel engines, as well – constructed with defined characteristics for an optimal, design-engineered combustion of fuels. In places where the engine construction is not suitable for the combustion of (in-spec) heavy fuels (as in, e.g. the medium speed running engines of the `70’s / `80’s), such use inevitably results in operation problems and engine damage. Similarly, such problems arise when, inversely, the fuel properties do not allow optimal combustion in a categorically heavy fuel-compatible, modern engine.

VHT observes that operation problems and damage, which are traced back to “bad heavy fuel” from either the on-board or ship operator’s position, are occurring more and more often. The problems range from intermittently raised exhaust temperatures to extreme wear and tear to, finally, a complete breakdown resulting in towage or, even, salvage.

The next question that arises is- what does one understand by the term “bad heavy fuel”? In general, one would like to express that an unsuitable fuel had been delivered on board. At the same time, there is the prevailing opinion that heavy fuel is “the lowest piece of filth, anyway”- which is certainly not true!

Heavy fuels are, in fact, at the end of the crude oil processing chain; however, their characteristics and their permitted constituent parts<sup>1</sup> (e.g. in the ISO specification 8217 (2005)<sup>2</sup>) are extensively stipulated. Presupposing that the heavy fuel is “in spec”- that the ISO specification was observed- it is, assuming suitable preparation, as a matter of principle, generally appropriate for a ship’s diesel engine.

Classification ISO 8217 (2005)													
Category ISO-F- /TOTAL Marine Fuels specifications			ISO RMA30	ISO RMA 30	ISO RMD 80	ISO RME 180	ISO RMF 180	ISO RMG 380	ISO RMH 380	ISO RMK 380	ISO RMH 700	ISO RMK 700	Test method reference
Caractéristique	Dim	Limit											
Density at 15°C	kg/m <sup>3</sup>	max	960,0	975,0	980,0	991,0		991,0		1010,0	991,0	1010,0	ISO 3675 or ISO 12185
Kinematic	mm <sup>2</sup> /s	max	30		80	180		380			700		ISO 3104
Viscosity at 50°C	(a)		30		80	180		380			700		ISO 3104
Flash point	°C	min	60		60	60		60			60		ISO 2718
Pour point (b)		winter	0	24	30	30		30			30		ISO 3016
		summer	6	24	30	30		30			30		ISO 3016
Carbon residue	%(m/m)	max	10		14	15	20	18	22		22		ISO 10370
Ash	%(m/m)	max	0,10		0,10	0,10	0,15	0,15			0,15		ISO 6245
Water	%(V/V)	max	0,5		0,5	0,5		0,5			0,5		ISO 3733
Sulphur <sup>(c)</sup>	%(m/m)	max	3,5		4,0	4,5		4,5			4,5		ISO 8754 ou ISO 14596
Vanadium	mg/kg	max	150		350	200	500	300	600		600		ISO 14597 ou IP 501 ou IP 470
Aluminium plus silicon	mg/kg	max	80		80	80		80			80		ISO 10478 ou IP 501 ou IP 470
Total sediment, potential	%(m/m)	max	0,10		0,10	0,10		0,10			0,10		ISO 10307-2
Used lubricating oil (ULO)			The fuel shall be free of ULO <sup>(d)</sup>										
Calcium	mg/kg	max	30		30	30		30			30		ou IP 501 ou IP 470
Phosphore	mg/kg	max	15		15	15		15			15		ou IP 501 ou IP 470
Zinc	mg/kg	max	15		15	15		15			15		ou IP 501 ou IP 470

a) Annex C gives a brief viscosity/temperature table, for information purposes only. 1 mPa.s = 1 cSt

b) Purchasers should ensure that this pour point is suitable for the equipment on board, especially if the vessel operates in both the northern and southern hemispheres.

c) A sulfur limit of 1,5 % (m/m) will apply in SOx emission control areas designated by the International Maritime Organization, when its relevant protocol comes into force. There may be local variations.

d) A fuel shall be considered to be free of ULO if one or more of the elements zinc, phosphorus and calcium are below or at the specified limits. All three elements shall exceed the same limits before a fuel shall be deemed to contain ULO.

### Extract from ISO-Specification 8217 (2005)

Nevertheless, as already stated, the above-mentioned “heavy fuel caused” operation problems and damages have been being traced back more and more often to the fuel supplier, who is *occasionally*, however, by far, not always at fault. Upon a closer look / analysis, the following circumstances transpire as the most common reason for alleged fuel-related engine problems:

- a) delivery of “poor” (off spec) – unsuitable- heavy fuel ( **seldom** )
- b) improper preparation from the on-board side of (in spec) heavy fuels ( **often** )
- c) heavy fuel- incompatible operational conditions of the ship’s diesel engine ( **occasionally** )

<sup>1</sup> Annex VI of Marpol 73/78 Regulation 14 +18 requires that the fuel is free from inorganic acid, does not include any added substances or chemical waste which jeopardises the safety of ships, adversely affects the performance of the machinery, is harmful to personnel or contributes overall to additional air pollution.

<sup>2</sup> International Organization for Standardization, ref. e.g.: [www.marinefuels.total.com/mf/content/NT00000D96.pdf](http://www.marinefuels.total.com/mf/content/NT00000D96.pdf)

***In response to a) Delivery of “poor” (off spec) - rather, unsuitable - heavy fuel:***

Owing to various reasons, a problem does occasionally stem from the delivery of unsuitable fuel. In this case, the possible reasons are manifold and vary from the supposed accidental wrong order to real criminal sham. Since the consequences of false bunkering can be grave (and, as a rule are), it is the operator's duty to have the new bunker analysed before use.

A further reason for such an analysis is that the heavy fuel in question is, in fact, “in spec”; however, from certain points of view, can be problematic (e.g. incombustible owing to high CCAI- index<sup>3</sup>; high catfine component parts<sup>4</sup>). The results of the analysis heed significant indices for any further proceedings. At any rate, it makes sense or is necessary to:

- take bunker samples precisely according to regulations (e.g. continuous drip sampling<sup>5</sup>), so that, for the purposes of the analysis, a sample representative of the total bunker amount is available, and so that a correspondingly representative result is delivered (*owing to ignorance or a lack of personnel, often only a “spot sample” is taken, which neither delivers a representative result nor allows for a viable analysis result*). At this juncture may attention be invited to the MARPOL regulation (Annex VI, MARPOL 73 / 78, Regulation 18), which came into effect in May of 2005, which prescribes exactly this method for the “MARPOL retain sample” to be drawn.
- to bunker new fuel in detached tanks separate from the stock (*which often remain undone on grounds of organisation e.g. because of tank capacities and charter requirements*).
- to use the new bunker only after the results of the analysis are at hand, and which are already designated as “in spec” (*which often remain undone on grounds of organisation e.g. because of tank capacities and charter requirements*).
- to have adequate “old” heavy fuel on board when leaving the bunker port so that the engine can be operated with the old heavy fuel until presenting the analysis, and, as the case may be, up to the arrival at an alternative port (*which often remain undone on grounds of organisation e.g. because of tank capacities and charter requirements*).

Dependent upon the analysis results, the heavy fuel can:

- be used after suitable preparation
- or
- be used after taking into account certain indices
- or
- not be used at all in a ship’s diesel engine

Accordingly, it is up to the on-board crew/the ship operators to react. Furthermore, the density can e.g. be too low or the water content too high so that it would be more reasonable to have recourse to the bunker supplier (considering a bunker amount of 1,000 t might have a false density declaration of 1 %, or, respectively, 1 %; additional water concentration might already be equal to a shortage in the bunker ratio at any one time of 10 t which corresponds to

<sup>3</sup> CCAI = Calculated Carbon Aromaticity Index. Reference value dependent on specific gravity and viscosity of a heavy fuel, which indicates the ignition quality, and thereby its acceptability as a fuel in the combustion engine (e.g.: up to 850 unproblematic, 850-870 conditionally suitable, 870-900 problematic, > 900 unsuitable !!).

<sup>4</sup> Catfines = catalyser residua. Allowed according to ISO 8217 max 80 ppm (sum Si + Al). Highly abrasive effects. Must undergo purification under 15 ppm to not be damaging to the engine components.

<sup>5</sup> Continuous drip sampling means that the sample is drawn continuously during the entire bunker process.

\$3,300<sup>6</sup>). To be able to have recourse to the bunker supplier in any way possible, it is extraordinarily important for the retained samples under seal to represent effectively the bunkered heavy fuel supply.

To this end, it is absolutely imperative that not just any sample surrendered by the bunker supplier should be acknowledged as a retained sample, but rather only the ones, which have consistently been under crew supervision according to the “drip sampling” procedure, should be taken, filled, sealed, labelled, and from both parties (ship-side and delivery side) be accepted as a sample.

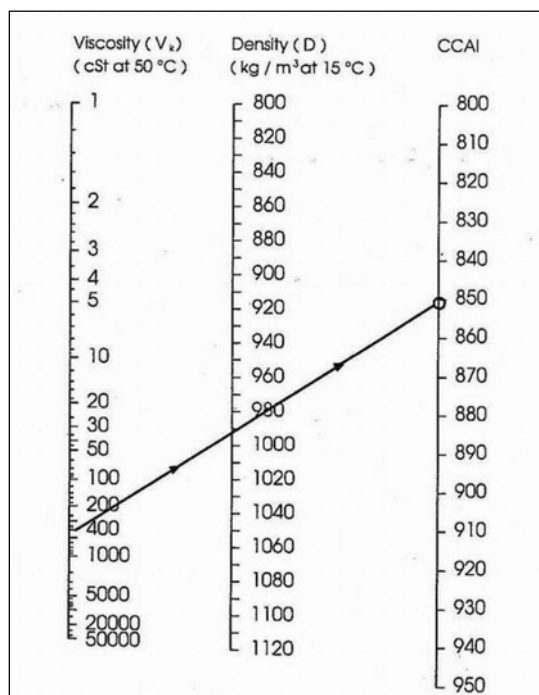


Diagram used to determine the CCAI-value

Since there are not always binding marginal values available (e.g. according to ISO specification 8217) for each relevant criterion (e.g. CCAI index), and in cases in which the heavy fuel preparation system found on-board (e.g. purification-, pre-heating systems) do not correspond to the necessary requirements, it makes sense to agree to additional criteria beyond the ISO standards upon ordering the bunker – as, for example, “CCAI index max. 850<sup>7</sup>; Catfines (Si + Al) max. 15 ppm”. Otherwise, it may happen that the bunkered heavy fuel in question is, indeed, “in spec”, but not suitable for use, whereby there is no possibility to legally hold the supplier responsible.

### ***In response to b) Wrongful preparation by the on-board party of (in spec) heavy fuel:***

Even under the assumption that the heavy fuel delivered is “in spec”, it can not be consumed at any time directly by the diesel engine exactly as it has been delivered – that means it must first of all be correspondingly prepared on the part of the ship’s crew. Furthermore, it is to be expected that the heavy fuel on board (e.g. in the bunker tanks) has had additional contamination by sea- and / or perspiration water, rust, sludge deposition, etc. The board-side heavy fuel preparation is limited, as a rule, to the reduction of water- and solids contents as well as to the adjustment of the required injection viscosity by pre-heating. Although the fuel preparation alternatives available on board are limited, they are quite effective and sufficient with proper use. Certainly, the individual preparation steps must be consistently checked for effectiveness and evaluated.

<sup>6</sup> Basis: Price IFO-180 as of March 2006.

<sup>7</sup> Or corresponding specific gravity- and viscosity designation.

### *Drainage*

Heavy fuel often contains a certain amount of water upon delivery, and, furthermore, on a ship there is always the possibility in constitutional measures that this specific water ratio may rise on the way from the supply tank to the main engine (the intrusion of sea water e.g. through defective pipes, welding seams, de-aeration heads, etc., the intrusion of fresh water through defective heating coils, pre-heaters, etc., condensation water build-up). Since the suction heads in the bunker storage tanks are always affixed at the deepest position, it is, as a matter of principle, possible and also advisable to determine even at the early stage of the tank-to-tank fuel transfer to the settling tank whether the heavy fuel contained in the storage tank has eventually already been contaminated with large amounts of water (e.g. upon visual inspection by means of a sampling cock behind the transfer pump). As the case may be, the appropriate measures can be commenced immediately even before the contaminated heavy fuel manages its way into the settling tank.

Moreover, the settling- and service tanks are to be removed regularly and carefully of any water, whereby it is to be observed whether there is a significant increase in the proportion of water, which may be a sign of a sea water- or heating steam intrusion. The purification of heavy fuel in a purifier can certainly not replace the painstaking manual removal of water from the settling tank as purifiers are quickly overstrained by the removal of large quantities of water. Since the service tank is not connected to any purifier downstream, any large quantity of water can quickly lead to a contamination through, for example, condensation water or heating leakages. Therefore, the diligent and manual removal of water from the service tank is especially important.

The necessity of the regular and careful removal of water from the settling- and service tanks can not be regarded greatly enough. Even ship engines do not obviously run on water!! – which is then confirmed no later than when the ship sails into bad weather conditions, and the water accumulated in the service tank is drawn in by the supply pump. On a “one-fuel-ship”, the auxiliary diesel engine would likewise be affected.

### *Purification / Clarification*

During the process of purification, the solids and remaining proportions of water must be removed from the heavy fuel as far as possible because:

- Even small quantities of water in fuels may lead to problems through the adjustment of the injection viscosity (water evaporates during the pre-heating stage).
- Water in fuels damages the fuel-injection parts (leads to extraordinary wear and tear and to seizing).
- Solids in fuels damage the fuel-injection parts and, according to the type, (e.g. - catfines) the pistons / cylinder liners (leads to extraordinary wear and tear).



**Fuel pump plunger with score/seizing marks**

Purifiers are indispensable for an orderly fuel preparation as only through purification can the necessary purity of heavy fuel be achieved. The filters (including automatic filters) in the fuel system mainly serve as a safeguard feature and can certainly not replace the purification process!!

To achieve optimal purification results:

- the proper water disc corresponding to the particular density of the heavy fuel must be mounted (in the modern day, they are often automatically there),
- the viscosity of the heavy fuel must be reduced as far as possible by heating – whereby it is absolutely necessary to remain under the respective evaporation point of water (because steam can not be extracted by a purifier),
- the retention period of the heavy fuel must be as long as possible in the purifier.



**Piston crown with seized rings**

The last point is especially important as the retention period determines the degree of purification (purity). The longer a droplet of heavy fuel remains in the purifier, the more the lighter particles are removed. A repeated purification (circuited purification) does not make any sense, as the retention period is not raised through its performance. Rather, the flow rate must be set as low as possible.

Optimally, two purifiers ought to run in a parallel fashion with an operational capacity of, accordingly, half of the main engine's consumption.

With such a throughput, even the dreaded “catfines”, which have a relatively minute density and are found today in almost every quantity of heavy fuel, can normally be reduced in the purifier to a harmless particle size and amount manageable for the main engine and its fuel-injection parts.

As already mentioned at the beginning of this section, it is imperative that the individual preparation steps should be checked for their efficiency. In the case of purification, it means that the water content in the heavy fuel should be determined before and after the separation process by the crew (e.g. using a water-in-oil test device). There are often occurrences in which no water reduction takes place in the purifier in which the incorrect water disc had been made use of or a locking disc had been implemented. And, there are also known cases in which the water content had actually been raised through the improper dosage of additive water.

In the case in which the bunker analysis results in an extraordinarily high amount of catfines (e.g. Si + Al above 50 ppm), the efficiency of the purifier should be ascertained ashore by the determination of the Si + Al quantities in the heavy fuel in front of and behind the purifier.

An index for the efficiency, and, respectively, inefficiency of a purifier is the accrual of sludge, and, respectively, in reference to self-cleaning purifiers, the flushing intervals. A purifier, in which little sludge accrues, and, respectively, one which is only rarely flushed, is suspect, per se.

### *Pre-heating / Viscosimeter*

The setting and retention of the specified heavy fuel injection viscosity is of utmost importance as it has the most influence on the operating behaviour of the diesel engine (a too high viscosity leads to a retarded ignition, poor combustion, residue formation in the combustion space, and damage to the piston crown and the cylinder liner). Since the viscosity is set exclusively by temperature (in order to reduce the viscosity, the temperature must be raised), it is necessary to watch that the viscosity does not become too low – the temperature does not become too high, so to say – because the lubrication capacity of the heavy fuel diminishes with decreasing viscosity, which again can lead to the seizing of the fuel-injection pumps and fuel-injection valves.



**Influence of the fuel viscosity on the injection quality**

In practice, however, the heavy fuel is often injected at a viscosity that is too low (see above-mentioned consequences) as the viscosimeter is often located in the immediate vicinity of the last heater (thus far away from the main engine), and the temperature of the heavy fuel significantly decreases on the way from the last heater to the fuel-injection pump.

Once again, this is an indication that the individual preparation steps must be checked for their effectiveness. With the help of the bunker analysis data and a temperature-viscosity diagram or slider, can the pertaining fuel-injection temperature at the desired viscosity be easily ascertained by the crew, and can the thermometer on the fuel supply line adjacent to the fuel-injection pumps be checked just as easily.

### *Filtering*

The filtering of heavy fuels, as mentioned above, essentially amount to a protective feature, which does not make them, however, any less important (purifiers can separate particles below 5  $\mu\text{m}$  while filters normally have a mesh width of 10  $\mu\text{m}$ ). Heavy fuel can be contaminated in a multitude of ways on the way from the purifier (through the service tank, supply pump, last heater, etc.) up to the fuel-injection pumps. The necessary cleaning intervals and the number of flushing cycles with automatic filters, respectively, are, therefore, in a sense, an indication of the quality of the fuel preparation. A sudden increase in the frequency of occurrence in flushing is certainly an alarm signal. By the same token, the absence of flushing cycles is, once again, often an indication of defective filter elements or seals.



**Improper storage of filter candles**

The candle-type filter elements, and, respectively, the strainer elements are often falsely handled by the crew. The sensitive exchange- / spare elements then lie loose for a longer period of time in a cleaning- or storage container in which they end up damaging each other as a result of the swaying of the ship. Also, the cleaning is often done with improper chemicals and tools (brushes, scrapers) in addition to being done in an improper way. The cleaning products and procedures recommended by the filter manufacturer must definitely be observed.



**Improper storage/handling of filter elements**



**Damage to filter candles due to improper storage**

***In response to c) Operating conditions incompatible for heavy fuels in a diesel engine:***

Although heavy fuels, as described above, are essentially appropriate for diesel engines, they must, of course, fulfil certain basic requirements in order to be, and, respectively, remain suitable heavy fuels. While the suitability of the heavy fuel in regard to a new ship and new engine is just assumed, it is to be continuously checked after the ship is put into service by means of the engine's operational data especially because the hull and the engine components are subject to normal wear.

The check is the most successful when one first examines the current operational data for plausibility and then compares them to the test-bed data. Considerable differences between the actual value and the set value are always an indication of a defect – whether it be on the ship, on the propeller, or in the main engine.

- **ship / propeller**  
(in general: condition of the shell plating – e.g. marine growth, roughness / waviness, coating, a rise in weather-induced resistance / condition of the propeller – e.g. damage, pitch too large)
- **main engine**
  - contamination (e.g.: scavenge air cooler, inlet ports / inlet valves, exhaust (gas) boiler)
  - wear (e.g.: turbo-charger, cylinder liners, piston rings, fuel injection parts)
  - damage (e.g.: turbo-charger)

Should a ship be further operated in spite of contamination / wear / damage, a vicious circle will ensue as a rule. Contamination, wear, and damage proceed even faster because the structural conditions for proper “heavy fuel operation” are no longer met; this is how consequential damage occurs, and can ultimately cause a complete breakdown of the engine. It is rather often observed that the current operational data are not given any attention, and, respectively, that their plausibility is not put into question. And, it is even more astonishing as the engines and auxiliary machinery are studded with thermometers, manometers, differential indicators, gauges, etc., and, furthermore, the gauging of certain measurements (ignition pressure, compression pressure) can also even be performed by the crew. To this extent it is certainly necessary for the gauges installed and employed to be in a fully functional condition.

We have been noticing more and more often that engine problems are being ascribed to “poor heavy fuel” both by the crew and the ship managers. With the benefit of hindsight, the bunker analyses substantiate that the heavy fuel had actually been “in spec”. And, upon taking a look at the engine log book, one sees that the current operational data had no longer corresponded to the test-bed data for a long time. Then, it is no wonder that the engine poses problems even with good heavy fuel. If the analyses also show that a bunkered fuel is “on the threshold” (e.g. low ignition quality owing to a high CCAI index), this can lead very quickly – despite using fundamentally appropriate heavy fuel – to serious engine problems as the then recommended operational parameters (high scavenge air pressure, high compression-pressure/ temperature, high engine output, high cylinder cooling water temperature) can not be adjusted / reached.

### *Summary*

Heavy fuels are fundamentally suitable for the combustion in diesel engines. Since there are no binding limit values for each relevant criterion in heavy fuel specifications, it makes sense to agree on additional criteria if required when ordering a bunker. For a multitude of reasons, it is one's duty to have the delivered bunker analysed for its ability of use- however, before it succeeds to the settling- and service tanks – and in every case, before it succeeds to the main engine. The necessary sampling methods for this purpose are to be observed without fail. The corresponding measures by means of the analysis results can vary starting with the standard preparation on board and continuing up to the pumping down of the entire delivery. Heavy fuel can never be used directly in the ship's diesel engine in the condition in which it is delivered, but rather must be prepared (reduction of water and solids particles as well as the setting of the required viscosity). The means that the crew have available are limited, however, by all means sufficient if they are properly applied and continuously checked for efficiency.

The diesel engines fundamentally suitable for heavy fuel must also be kept suitable for heavy fuel in practice; otherwise, severe operational problems ensue also with good and most definitely with threshold heavy fuels.

### *A Final Consideration*

#### *The Myth of Poor Fuel Comes to an End as Follows:*

**Once upon a time**, it was not reasonable or possible to have a heavy fuel analysed at short notice. Today, the world-wide infrastructure allows us to have the analysis values back on board within 72 hours after bunkering – which certainly only makes sense if the new bunker was not intermixed with the old bunker, and, respectively, there are sufficient old bunkers on board so that, if necessary, a port of refuge can be reached.

**Once upon a time**, heavy fuel could not be prepared sufficiently on board. When, nowadays, the installed machinery and aids are properly used, and, above all, when continuous checks of the results are performed, the heavy fuel can be prepared in such a way that the engines run properly and without any extra wear and tear. In the case that the machinery installed on board does not allow for the necessary preparation, this should have been taken into consideration upon ordering the bunker.

**Once upon a time**, ships' engines were not capable of consuming heavy fuel. Today, they can! And, thus, today, it is important to keep the diesel engine capable of consuming heavy fuel, in which the operational data are continuously compared with those of the test-bed data so that one is able to take action in time. If an engine is only temporarily or permanently suitable for heavy fuel, this should have been taken into consideration upon ordering the bunker.

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