Quality and Quantity Accounting during Bunkering

When considering systems to monitor quality and quantity during bunkering (and at the engine) it is important to identify the collective requirements and ensure that the chosen solution addresses all of those requirements.

Drivers

The initiatives to address both quality and quantity primarily result from, and must be responsive to:

- ISO 8217 2010 compliance
- Fuel fit for use (i.e. satisfies the specific engine requirements)
- MARPOL 73/78 Annex VI regulation 18 (and its enforcement)
- Value for money

Due to the lack of investment in bunkering over the years, many suppliers will not be able to supply fuels of the requisite quality and consistency nor with the appropriate fuel. Whether or not suppliers will come to address these issues depends on the importance attached to them by vessels and the policies adopted.

The solutions chosen will reflect that intent.

Quantity Accounting

Presuming that flow metering is a more advantageous and secure system than tank dipping, the choice of a meter technology must be governed by a range of factors which are normally evaluated as part of any meter selection process.

1. Fluid Viscosity

The flowmeter chosen must be able to handle a range of viscosities from gas oils to heavy fuel oils.

The range of technologies suitable for gas oils and heavy fuel oils and potentially capable of the required accuracies includes coriolis, positive displacement and ultrasonic[1]. (Ultrasonic meters are today available for viscosities up to 3500 cst with full fiscal accuracy).

2. Accuracy

The industry needs an *equable* standard, fair to both supplier and vessel.

2.1. Existing Quantity accounting methods

Conventionally, mass is determined from the volume (tank dipping), the BDN declared density (15ºC) and the fuel temperature.

[1] PD meters may require some compensation for viscosity effects for optimum accuracy. *(see end notes)*

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Density measurements (on the vessel) are often rounded up to the nearest 0.5kg/m^3.[2]

Tank dipping is wide open to both error and fraud but where well conducted, it has obviously delivered an acceptable accuracy.

Positive displacement meters suitable to manage the highest viscosity fuels will have some degree of calibration shift (increased slip flow) when used for lower viscosity fuels (the error is in the favour of the vessel; the lower viscosity fuels are the most expensive) which, where fitted with mechanical registers, do not permit compensation for SG, temperature variation nor viscosity effects but with online instruments and electronic registers, these problems are resolved.

2.2. Summary

Taken together, the existing volume and density measurements suggest that the industry doesn't *need* a full blown fiscal standard. Bunker fuel is not petrol and it isn't taxed, so what accuracy is required?

Optimum accuracy might lie somewhere between 2% and 0.15%.

Coriolis, ultrasonic and PD are all available capable of delivering 0.15% accuracy and all are used for fiscal metering.

SPRING is suggesting 0.5% accuracy when considering entrained air coriolis meters. It may be that if it is acceptable to accommodate a lower accuracy that a slight extension will allow alternative solutions for entrained air or that where there is no entrained air, lower accuracy will allow less expensive meters or that full fiscal accuracy is feasible.

3. Operational Factors

In bunkering we might isolate two key factors which will potentially differentiate between the technologies:

3.1. Pressure drop

Pressure drop is already an issue for bunkering but consider where the industry is going:

- Bigger vessels with larger stems and higher lifts
- Faster turnarounds
- Higher viscosities

These trends have a common consequence: they each introduce higher pressure drops.

Meters ranked according to pressure drop:

- Ultrasonic are the best (no more pressure drop than the pipe they replace)3;
- PD are next, but already sometimes a problem;
- Coriolis generally have the highest pressure drop of all meter technologies.

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[2] See BP Presentation (extract in end notes)

[3] Some caution is required as it may require *reducing* the meter size from the pipe size in order to meet minimum velocity requirements. The new Cameron Ultrasonic meter is effectively a reduced bore meter.

Thus one way to manage pressure drop is to select the technology with the lowest pressure drop.

Another way (or in combination with selecting the meters for pressure drop) is to find some combination of pump size and meter size, or to elevate the fuel temperatures to bring it within acceptable limits.

Already, some operators are over-sizing coriolis meters, but what happens if both the vessel and the barge have coriolis meters in series?

The three technologies are all still options, but cost, size and weight are now likely to be significantly different for each technology and different solutions might be optimal for different operators, vessels and suppliers. It is also necessary to include the consideration, common to cross boundary metering and implicit in the initiatives in bunkering ports to require metered supply, that both the vessel and the supplier may have flowmeters in series.

3.2. Air

Air in the fuel is a significant issue for quantity accounting but when considering how to address this, it should not be neglected that is also a factor in quality accounting.

Air is an issue in two distinct forms:

- Air pockets
- The “Cappuccino Effect” (the entrainment of lots of bubbles)

The cappuccino effect inflates the volume determined by tank dipping and where using volumetric flowmeters. It also disturbs the measurements made by conventional coriolis meters and ultrasonic meters.

3.2.1. Air Pockets

Air pockets may result from a variety operating procedures.

Common causes may be:

- Starting with empty lines
- Changing from an empty compartment to a new one (and tank stripping)
- Blowing down the lines to purge the hoses of fuel prior to disconnecting.

Air pockets are a problem for all technologies and all generally have the same range of solutions.

All depend on some means to detect the presence of air pockets and inhibit meter registration (which requires flow computers or electronic registers).

Because of a lack of instrumentation air pockets may be more persistent than is necessary and it exposes the meters to frauds resulting from air being metered as fuel.

However, if there is a means to detect air then operators will be able to make rapid and effective changeovers and the meter registration can be inhibited.

There may be some fuel carryover, but where meter registration is inhibited, any errors are then in the client’s favour, an added incentive for suppliers to improve their operation. In the absence of air detection, density limit alarms can be used.

The extent to which entrained air coriolis meters are affected by air pockets needs to be evaluated and also the ability of the sensor to detect air pockets.[4] It is assumed that however much the density measurement might be impaired (or not), density limit alarms will be an effective means to detect excess air either through entrainment or air pockets/air blowing.

3.2.2. Cappuccino Effect

The cappuccino effect is where the fuel has a significant amount of air dispersed in the fuel as bubbles. These bubbles are very difficult to detect where there is no instrumentation and thus air can be accidentally introduced or it can be deliberately introduced as part of fraudulent supply.

How can we deal with the cappuccino effect?

- Remove the air?
- Meter the fluid with entrained air?
- Prevent air entrainment?

Removing the air

Getting air out of a heavy fuel oil is impractical due to the high viscosity, and it may take several days for the bulk of the air to naturally dissipate; as fuels tend toward higher viscosities the residence times will increase, so this is not feasible.

Meter the fluid with entrained air

One proposed solution is entrained air capable coriolis mass meters.

According to Emerson, the problem with air is signal noise and thus accurate mass flow measurement is achieved through signal processing. It is less clear how well density is measured with entrained air. Conventional vibrating tube density meters also suffer from unstable readings with entrained air but they also suffer mean value drift, thought to be due to velocity of sound effects.

An alternative is to use PD meters with EGA (Entrained Gas Amplifier) Density meters[5] to calculate mass.

The PD meter may accurately record the volume of fluid though the fuel volume fraction and actual density are unknown.

An EGA densitometer will report the true density of the fluid. The resultant mass calculated is the mass of the fluid.

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[4] Air pockets may be readily detected by coriolis and ultrasonic meters due to the disturbed readings. Conventional density meters can also detect the air pockets due to the disturbed readings but entrained gas density meters continue to accurately report the density so the solution then is to impose density limits and not to totalise flow where the density is below the limits. Though the mechanism for managing entrained air may differ, it is presumed that coriolis meter signal processing is also able to make a similar determination. That stripping was delayed in the BP trials suggest it may be an issue even for coriolis meters.

[5] EGA Density meters operate at a different harmonic than the conventional liquid density meter. This sacrifices some accuracy but ensure stable drift free measurement of the true density.

This is exactly the same as for coriolis meters, the mass reported is the combined mass of the fuel and air, but though the volume of air may be significant, its mass isn't and thus the mass of the fluid is effectively the mass of fuel.

In either case there is a necessary accuracy penalty.

It would appear to be 0.5% for entrained air coriolis meters (it is not declared how the accuracy varies with varying volumes of entrained airs nor if there is a limit on entrained air. The EGA density meter is accurate from 0% to 100% air)

For PD meters the accuracy is the combined volume accuracy and density meter accuracy, which for the EGA densitometer is <0.5%, i.e. perhaps 0.6-0.7% overall.

So is 0.5% as far as a standard might stretch to include coriolis or should it stretch to include PD meters allowing for a lower pressure drop solution?

In either case the accuracy is less than could be achieved with air free fuel.

Preventing the Cappuccino Effect

It is essential to understand that Entrained air (cappuccino effect) is not an intrinsic property of fuel.

Air is introduced either inadvertently or deliberately prior to or during bunkering. In some few cases suppliers may use air for mixing.

Thus there is a third option: prevent air being entrained.

Once air is detectable through instrumentation, the causes can be identified and action taken to correct the problem. If it is due to poor operating procedures, then changes to procedures will remedy the problem. Likewise, if it is an installation or equipment problem then it is resolved by modifying existing installations and designing better new installations.

It may be thought that the primary cause of entrained air is due to fraudulent practise. This depends on the entrained air being undetected (which is easily achieved where there is no instrumentation) and profitable.

Once instrumentation is used or metering methods such that bunkers with entrained air are refused or the mass metered is accurate despite the entrained air, then fraud will no longer be undetected or profitable and the incidence of fraud attempts will be substantially eliminated.

4. Summary

The two key factors are entrained air and pressure drop.

Pressure drop requires either the choice of low pressure drop meters or it requires over sizing pumps and meters.

The choice of ultrasonic meters requires that the fuel is air free.

Entrained air is not an intrinsic property of the fuel but is preventable once instrumentation is used and where it is a policy not to accept fuel with entrained air.

Note that entrained air can cause an increase in the apparent or effective viscosity which in turn will aggravate pressure drop problems.

Managing the Cappuccino effect requires a compromise in accuracy. Fiscal accuracy can be achieved by adopting policies designed to encourage suppliers to solve the problem of entrainment.

Given the possible errors associated with air pockets, and due to tank stripping and that it is possibly still a problem even for entrained air capable coriolis meters, it would be necessary to adopt a policy of inhibiting integration when there are air pockets. Given that it was considered necessary to modify operating procedures on the barge to delay tank stripping, and that when metering on the vessel the vessel has no direct control over the barge operational procedures, it may be necessary for vessel operators to adopt a firm position regarding any instances of entrained air by rejecting any bunkers with the cappuccino effect is detected and inhibiting integration when there are air pockets. Suppliers will then necessarily modify procedures to minimise the delivery of unregistered fuel, especially as such measurements will be in the favour of the vessel.

A further consideration may be that air is undesirable for other reasons, even if it can be successfully metered. This forms part of the consideration of quality Assurance.

Quality Assurance

In disputes it is the laboratory analysis of samples that defines the quality. Very few of the fuel properties can be easily or accurately measured on board.

Conventionally, drip samples are collected during bunkering for laboratory analysis for commercial purposes and, in theory, the MARPOL sample for legislative purposes. The results are only available after bunkering has been completed and de-bunkering can then prove very expensive. However, there is concern expressed[6] that it is too easy to falsify both samples and records and it is evident that some Port State Authorities are collecting spot samples from day tanks and elsewhere. This suggests that homogeneity is going to become an issue.

Spot samples may be taken at the start of bunkering but sampling is easy to defeat and there are too many calls on the engineer’s time for the necessary diligence to analyse a sequence of spot samples and during bunkering.

During bunkering the vessel is thus dependent on the supplier’s quality statement.

There are three key reasons to make on board quality assessments during bunkering:

- To evaluate key operational parameters
- To assess ISO 8217 and MARPOL compliance
- To determine value for money (and prevent fraud)

Because of the limitations of spot sampling for quality testing during bunkering, online measurement is the obvious solution. But since not all properties can be measured on line the question is thus which of those properties that can be measured can usefully be measured? How can anything be learned about those properties which cannot be measured?

The Chief Engineer wants to know: “Can I clean it?” i.e. will the centrifuges be effective? And “Can I burn it?” which generally means if the heaters manage the viscosity. Some engine manufacturers specify an operating envelope defined by the density, the kinematic viscosity

[6] MARTOB and NERA reports to the EU

and the Ignition Index (CCAI is now included in ISO 8217 2010). Ignition index is calculated from the density and viscosity.[7]

Density and viscosity are thus typical tests. MARPOL introduces a need for sulphur accounting (not feasible offline, only online) and water is another readily measured property.

But besides these specific operational measurements, the vessel needs some way to assess the overall fuel properties through the few properties that can be measured. So does the vessel need to monitor all the properties possible or is it sufficient to measure just a few?

Statistical approach

Previously the requirement was simply to determine if the fuel was ISO 8217 compliant.

Density and viscosity were previously sufficient to validate ISO 8217 1998 compliance because, according to data from the test houses (based on commercial sample analysis), if the density and viscosity were both ISO 8217 compliant then the fuel was ISO 8217 compliant in all respects. There was a 99.7% confidence level because in only 0.3% of cases is the fuel not ISO 8217 compliant despite both density and viscosity being compliant.

Today ISO 8217 has been revised and the need to meet the sulphur requirements of MARPOL mean that due to changes in fuel oil production and blending for sulphur compliance, it is no longer safe to assume compliance based on density and viscosity. MARPOL requires exact value reporting. Statistical assessments cannot help with this.

Integrity Fuel Fingerprint Method

In a recent case the YM Fountain had to arrange de-bunkering in Singapore after bunkering a fuel with very high levels of Aluminium and Silicon. This is an expensive operation and the ideal would be to prevent the fuel being bunkered by using online testing. However, there is no online test available for this and it would seem the problem was thus unavoidable.

But: MARPOL requires that the supplier should specify the exact density and the exact sulphur content at the time of bunkering and defines the laboratory tests required to establish these values.

The supplier must therefore have a complete laboratory analysis[8] (or fuel blend calculation based on laboratory analysis of the component fuels) performed sometime prior to bunkering. This analysis will report all the fuel properties specified in ISO 8217. It is presumed that the suppliers BDN declared the Al+Si were within the limits.

If the fuel is then properly managed, these properties will not change except through one of a number of mechanisms such as:

- Adulteration with water (fresh or salt)
- Stratification and separation
- Consolidation of fuels from different batches with different properties.
- Contamination with chemicals

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[7] See chart at the end (source BP).

[8] There is scope in the bunker contract for the vessel to specify the conditions of analysis since MARPOL does not.

In the case of the YM Fountain one might assume that an original analysis would detect the excess Al+Si and that therefore this was only outside the limits due to some subsequent contamination of the fuel. Since this is not likely to be due to the addition of pure aluminium or silicon but as components in a carrier fluid which will affect the density and or viscosity.

Most such mechanisms, if they introduce a significant change in any one property may likely also produce a measurable change in either or both the density or viscosity.

This means that if the vessel (and/or supplier) includes density and viscosity in the online measurements that it will be possible to determine when the fuel being bunkered *is not* the fuel described in the supplier's analysis.

Hence

IF density or viscosity does not match the certified values, the fuel is not of the quality described.

IF the density and viscosity match the certificate values it may be assumed that the fuel is of the quality declared in all respects and was not compromised subsequent to analysis.

It has already been established that density and viscosity have operational value. They can be measured online using a single instrument.

Entrained air (Cappuccino Effect)

Effective quality assurance during bunkering depends on the fuel being air free. The cappuccino effect will cause instability of the online measurements. It will also result in false low density[9] and false high viscosity measurements in the off line tests.

For this reason and because entrained air is not an intrinsic quality of fuel oils, it is suggested that the best response to entrained air is to reject any bunker with entrained air not simply because it may distort quantity accounting except through expensive remedies, but because it defeats some offline quality assurance measures as well as online measurements.

With entrained air the vessel is again dependent on the suppliers original quality declaration but with less reason to be trusting.

Summary

At this time, as is already evident from the density discrepancies, few fuels are exactly as described. This suggests either that the industry must accept quality uncertainty or it must take a strong position which indicates that vessels will no longer accept fuels which are not homogeneous, which are not exactly as described by the original CQ (Certificate of Quality).

If vessel operators are prepared to take a strong position on quantity it makes sense also to indicate a strong position on quality. Unlike quantity problems, which can be resolved during bunkering by mandating the use of the vessel's flow meter, quality issues can be detected but will not be so easily resolved except by adopting a policy designed to encourage suppliers to deliver better fuel management and it will require that suppliers have time to adjust and take steps to remedy defects in fuel management.

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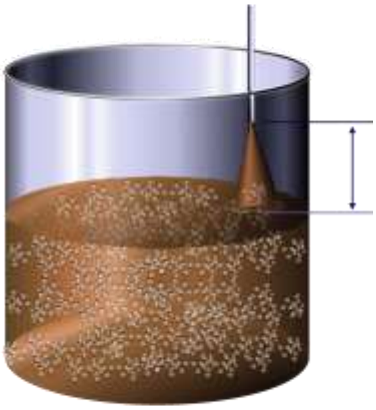
[9] Hydrometers will give false readings if bubbles attach to it. Thus the density may be reported even lower that the actual density of the entrained air fuel.

Appendix

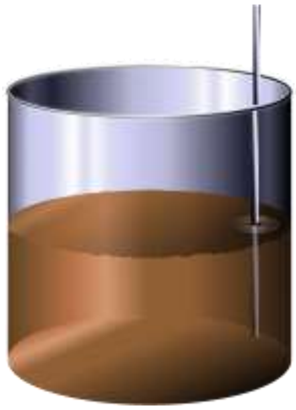
Sources of entrained air

If it is poor equipment, e.g. fuel delivered by sparking, rather than stilling, then the solution is relatively easy and comparatively cheap.



Sparkling introduces air (left) but stilling will avoid the problem (right). This ought to be a relatively inexpensive fix for an installation problem.

In either case, once fixed, always fixed.



Other mechanisms include introducing the air as the fuel is pumped by leaving valves partially open at the pump inlet e.g. to empty compartments, or by pumping air into the fuel via a stilling pipe.

In either case, if it is due to poor operating procedures this is easily remedied.

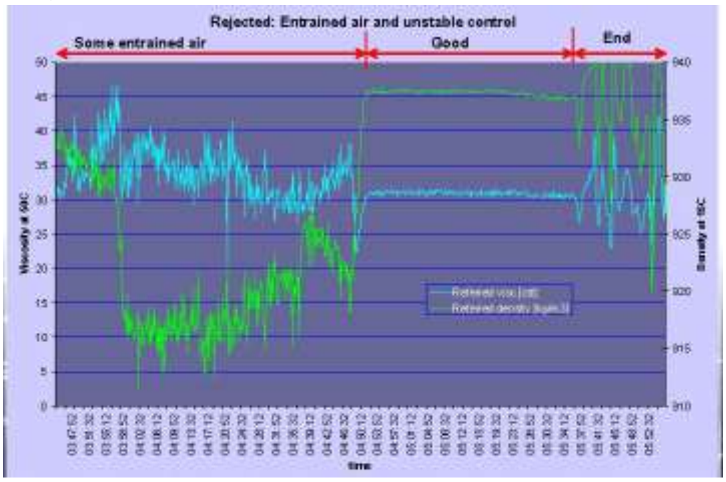
Fraud depends on being undetected and profitable. Once entrained air is “visible” it is neither.

Reject any bunker where entrained air is detected and the problem will be quickly resolved by the suppliers. Of all the problems with bunker fuel, entrained air is probably the most easily and quickly solved, especially if confronted by vessels that will reject any fuel with entrained air.[10]

As quantity accounting is coming under scrutiny, is quality measurement far behind?

Maybe entrained air shouldn’t be tolerated, even if we can measure mass accurately. It would be ironic to adopt a meter standard simply because it can handle entrained air if it is later decided that entrained air should no longer be tolerated for quality assurance reasons.

In an “instrument free” industry the “cappuccino effect” is serious problem because it is very difficult to detect. But, if it is detectable then it can be prevented.



This log clearly shows the difference between airs entrained fuels and air free fuels.

[10] Vessels might even include this as a condition in the bunker contract and even impose a financial penalty to compensate for the costs of arranging alternative bunkers.

Instantly recognisable and easily detected, air can now be dealt with by better fuel management.

Note: With entrained air the density and viscosity measurements are unstable and the mean values tend to drift.

The measurements are a false low density (though the density of a fluid with entrained gas will be less than the density of the fuel, the reported density is not consistent with the apparent density) and a false high viscosity.

Note the contrast with the air free measurements.

Fuel Compromises

A common reason for the detected density discrepancies with both gas oils and heavy fuel oils is because the industry has no ullage management procedures.

In this plot it is evident that there are fuels from two different batches which have different density values.

(more examples may be found at http://viscoanalyser.com/page35a.html)

Transaction metering

There are many examples of transaction metering where different standards apply, but which is appropriate as a model?

Domestic water meters deliver *equable* metering. The accuracy requirement of 2% is consistent with a low value product and it is not based on a single transaction but on a sequence of transactions. It factors in the lifetime performance of the meters.

Forecourt metering measurement error (petrol and diesel) must always be in the purchaser's favour and thus a very tight accuracy requirement is essential to minimise the give-away of high value product.

Fiscal metering is intended to deliver performance suitable for high value, duty payable products with optimum single transaction accuracy.

Precision

The following is included to allow an appreciation of the online measurement accuracies.

Density can be measured online with accuracies of from 1kg/m^3 to 0.1kg/m^3 dependent on sensor. Note that with entrained air the density is only 0.5% accurate i.e. 5kg/m^3.

Viscosity can be measured online to an accuracy of +/-1.0% of reading at reference temperature.

Clause 8 refers to ISO 4259

ISO 4259 describes how test data and precision data shall be used in disputes for a product to be considered out of specification based on a single result (upper limit)*Test Result >Specification max + 0.59 *Reproducibility*

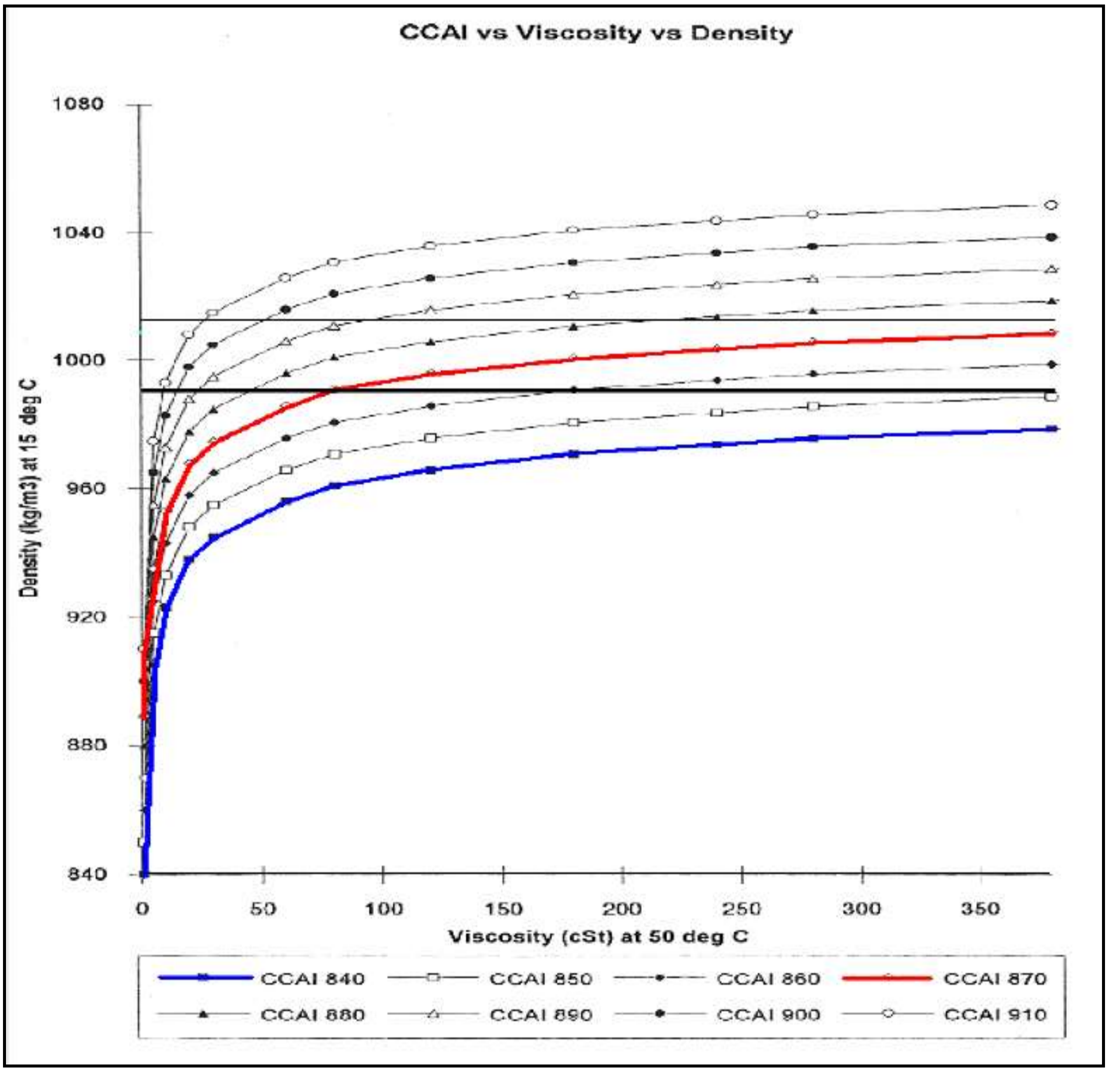
Examples based on a single result are
Density, shall be considered to exceed a spec max of 991.0 kg/m^3 only if measured value is greater than 991.9 kg/m3

viscosity, shall be considered to exceed a spec max of 380 cSt (at 50 °C) only if measured value is greater than 396.7 cSt sulphur, shall be considered to exceed a spec max of 1.00 % m/m only if the measured value is greater than 1.06% m/m

Source: BP - ISO 82172010 by BP Marine Fuels

Density and Viscosity allow a range of calculations to be performed, including CCAI.

CCAI is now included in ISO 8217 and is one of the parameters making up the operating envelope for engines.



This chart is extracted from the BP presentation.

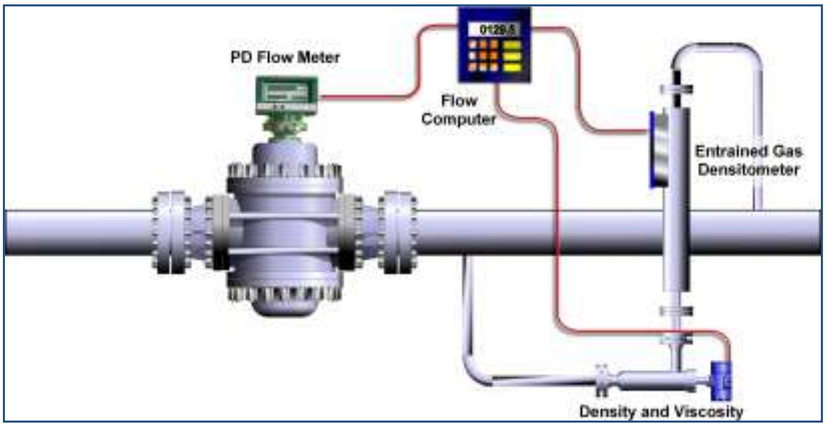
Measurements made by a digital viscometer (either Emerson 7827 or LEMIS DC52):

- **Density**
    - at process temperature
    - at 15ºC
    - at 98ºC
- **Dynamic viscosity at process temperature**
- **Kinematic viscosity**
    - At fuel temperature
    - At 50ºC
- **Ignition Index**
    - CCAI
    - CII

In some cases it may be considered necessary to include online sulphur measurement.

Typical installation layouts

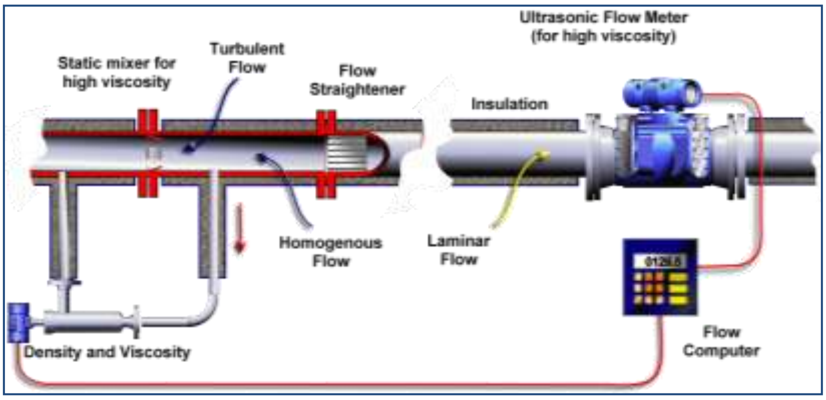
A PD meter



(Illustrated: Petrol Instruments, part of Khrone) with inline digital viscometer (LEMIS) and EGA density meter (Emerson).

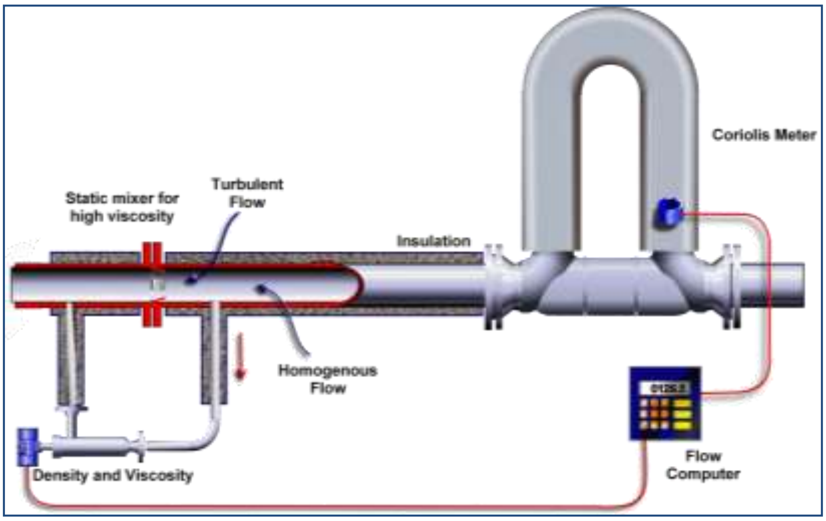
The EGA density meter is only necessary if entrained air is to be tolerated.

An ultrasonic meter



The meter is used only where bunkers with entrained air are to be rejected. The digital viscometer is able to detect entrained air and alarm.

A mass flow meter



This assumes the meter is sized at the nominal pipe size. In reality the meter may need to be oversized to minimise headloss. In this case the digital viscometer is for kinematic viscosity and for quality assurance. This diagram represents a conventional mass meter.

If the coriolis meter is selected for bunker fuels with entrained air then the digital viscometer only has value where the fuel is not entrained with air.

Off line measurements may be similarly compromised.

PD Meter Accuracy

PD, or positive displacement meters, measures the volume flow of fluid through compartmentalising the fluid flow.

In an ideal design (or, as in the case of forecourt meters with elastomeric seals) fluid cannot pass through the meter unregistered. In practise mechanical meters have working clearances which permit some slip flow.

The clearances and calibration are usually optimised for the highest viscosity fluid.

The slip flow depends on viscosity. For a meter toleranced for a high viscosity fluid the calibration is compensated for the amount of slip flow at this viscosity (above certain viscosities the meter is fully positive at the design viscosity) but at lower viscosities the slip flow may increase. This means that flow will pass through the meter unregistered i.e. in favour of the client.

With mechanical registers there is no means to compensate for varying viscosity but with electronic registers viscosity correction is simple as the relationship is linear.

In fiscal metering a range of corrections are possible. The need for all these corrections in bunkering is questionable.

Intermediate Quality Assurance

In place off installing digital viscometers inline, operators may chose to survey the fuel quality on the barge using a dipping viscometer such as the MMC or LEMIS VDM250.2 (diagram).

Portable Viscometer

MMC or LEMIS Portable Tank Gauging

Portable Fuel Oil Test Kits are used to measure actual viscosity and density to calculate blend-ratio either before delivery or in connection with on-board-blending in engine rooms.

CBI / Kittiwake Fuel Oil Test Kit / Viscosity and Density