Photo: Southern Cross Maritime

$$VCF = \frac{V_T}{V} = \frac{\rho}{\rho_T} = EXP\left[- \alpha_T \Delta_t (1 + 0.8 \alpha_T \Delta_t) \right]$$

Why the tables are incorrect

Are you sitting comfortably? When the oil loading tables were compiled, the boffins did not check that crude's behaviour was constant.

They treated all oil as a Newtonian fluid, where its expansion and contraction is constant through a range of temperatures.

That is the reason why they used an exponential form of equation in calculating the coefficient of expansion.

To be accurate, they should have used a 3rd order polynomial form of equation. The standard form of a 3rd order polynomial equation has two inflection points. In these circumstances, the inflection points denote a change in gradient of the density/temperature relationship of the crude at the specific temperatures. This would have reflected a change in the physical characteristics of the crude oil.

Many dollars and barrels

	Rough estimate
Amount of seaborne crude carried since 1980	223.2 Bn US bbls
Average price of seaborne crude since 1980	$24 /barrel
Total value of seaborne crude since 1980	$5,356,800,000,000
0.23% of $5.35 trillion	$12,320,640,000

Inaccurate tables cost shipping $1Bn

Different grades of crude behave in unique ways. The oil industry's loading estimates fail to account for that obvious scientific fact, so producing countries are out of pocket

By Andrew Lansdale
Markets Editor

There are many variations of 'trust me'. 'Trust me, I'm a doctor' is a favourite. 'Trust me, I'm a journalist' is a less well established variation. 'Trust me, I'm an oil company' has never been suggested.

The evidence is now available to underline why. It has to do with reduction tables used to measure crude oil cargo quantities: 'The Revision of Petroleum Measurement Tables', *Oil & Gas Journal*, 24 December 1979.

When a ship loads crude, the oil is pumped into the ship at a temperature much higher than the ambient reading. It flows better. To calculate what the theoretical volume would be at 15 degrees Celsius and to ensure that everyone is singing from the same song sheet, a coefficient is applied to the loaded volume. This is pulled out of the aforementioned Tables by referring to the cargo temperature and the cargo's gravity.

The corrected amount is the bill of lading figure. The oil buyer usually pays the supplier for his cargo at so many dollars per barrel, based on this bill of lading figure. The shipowner is usually paid freight on the bill of lading figure.

Various exchequers collect taxes and royalties based on the bill of lading figure. The '80 tables' (see box, right) are therefore central to the way that money changes hands in the oil industry.

An official in the Sullom Voe oil terminal in the Shetland Isles tells *Fairplay* that the current system is computerised, using a flow meter. The laboratories have equipment that measures the average gravity and loaded temperature as well as the volume. The '80 tables' are also loaded onto the computer. The coefficient is automatically applied.

A ship will call for, say, 600,000 barrels, and the computer will place a shore-stop on the supply when the computer signals that this amount has been

Δ_t

=

Industry's reaction?

The oil sector's reaction will probably be rather muted. The new Gunner study is likely to trigger a major industry-wide study into the behaviour of oils throughout their temperature ranges.

Such a report should also include a study into the behaviour of clean and dirty petroleum products, which so far has been lacking.

In shipping terms, if claims fall under a charter party term, there will probably be a 12-month time bar on claims. If they fall under a bill of lading term, there will probably be a statute of limitations guillotine of six years.

From the supplier's angle, OPEC will probably look into the matter and take legal advice. The sector will certainly look forward to announcements from that quarter.

TIMELINE AND PROBLEMS

- Problem: **Oil was measured in US barrels, a unit of volume. It was recognised that cargo volumes varied with cargo temperature.**
- 1910: **A simple formula was introduced to reduce all cargoes to the volume at 15 degrees Celsius (60 degrees F).**
- Problem: **It was recognised that oil had properties that varied with the region of origin.**
- 1950: **A book of tables was produced by the American Petroleum Institute in which one looked up the gravity and the cargo temperature to obtain the coefficient to apply to calculate the volume at 15 degrees Celsius. These are referred to as the "50 tables".**
- 1975: **The API and others contributed half a million dollars to bring together a team to study the tables and to update them if necessary. The team was led by RW**
- 1980: **'Hank' Hankinson of the Phillips Petroleum of Bartlesville, Oklahoma. It took five years before the updated tables were published. These were referred to as the '80 tables'.**
- 1995: **Researchers voiced concerns in a paper published in the *Oil and Gas Journal* in May, 15 years after the first tables were published.**

Where did the API go wrong?

Describing its Petroleum Measurement Tables project, the API stated:
The American Petroleum Institute and the National Bureau of Standards initiated a co-operative venture, funded by the API, to create a data base of density measurements on both crude oils.

On pages IX-8 & IX-9 in footnote 1, the API states: "The alpha (thermal expansion coefficient) and density [are] obtained [by] using nonlinear regression on each individual data sample. The results obtained from fits on individual data samples are not recommended unless there is a minimum of 10 density data points covering at least a 30°C temperature range and encompassing the 15°C base temperature."

But on the very same page, it tabulates all the crude oils sampled. There are 124 samples in all. Of the 124 tested, just seven had more than 10 data points. The average was 5.5 data points for each sample, rather than the recommended 10.

This was the comment made on pIX-7 in the tables about the peculiar behaviour of some crude oil samples:
The working group used all the data supplied in final form by the NBS [National Bureau of Standards]. However, the preliminary data on a number of the samples showed physically impossible behaviour such as density increasing with temperature. These...were reported to the NBS, which either withdrew the sample or reran it and provided acceptable data.

Acceptable to whom? The API's road to Damascus episode was encountered and ignored. As if to underline its blinkered view, it conducted an independent test. Sohio provided a sample of Prudhoe Bay crude. Phillips Petroleum chilled it to 50°F, and the upper portion was siphoned off. This removed any wax and solids in the original sample. It also remove water that had sunk to the bottom. The sample reached its cloud point, and the wax settled out with the water, making a sort of sludge.

The remains were tested, but without the entire inventory of ingredients, so it behaved in a fashion different from how it would when loaded on a ship at Valdez.

Photo: Martin Erhard

Gunner: 'Temperature correction factors ... were supplying a systemic error that was not being identified'

loaded. Well, here's the rub: the tables are wrong – not by a huge amount, but definitely incorrect. The estimate is off by roughly 0.23% – a hard and fast rule is impossible because every cargo can be different in temperature and gravity from every other.

But in essence the crude oil purchasers have taken more than they have paid for.

Not everywhere; Saudi Aramco insists on using '50 tables', which that company holds to be more accurate.

The tables have cost producer countries a fortune over the years.

Saudi Aramco has had a team of researchers studying these concerns, which resulted in a paper published by *Oil and Gas Journal*. It was largely ignored in the rest of the industry.

The total amount of oil carried by tankers since 1980 is difficult to figure. In 1995-2004, the total was about 110Bn barrels, Clarkson's indicates.

Since 1980, when the new tables were published, the total probably exceeded 220Bn barrels, endeavouring to exclude Saudi seaborne trade. Some sources have estimated that total as high as 460Bn barrels. To err on the side of caution, we have assumed the lower figure.

The average price of crude since 1980 is also difficult to calculate. For the past five years it has stood stubbornly above $20 a barrel. Before that, it was very much hostage to the fortune of world economies.

The monthly average posted and spot price for West Texas Intermediate has averaged $26 a barrel since 1980. The WTI price is normally a couple of dollars higher than other crudes. For that reason, one would guess that the average price of seaborne crude oil has been about $24 a barrel.

All the following estimates are based on current values and assume that the average cost of seaborne crude is about two dollars less than West Texas Intermediate (WTI). By applying the US cost of living index published by

BIG OIL'S $30 BILLION LOOPHOLE

Photo: Dietmar Hasenpusch

The crux of the dispute is that different crudes assume different characteristics when they are loaded

the American Institute for Economic Research to each year's average WTI price, an average price since 1980 has been $39.22 a barrel. Now subtract $2 a barrel to price seaborne crude oil.

At $37.22 a barrel, this produces $20Bn in today's money. An accountant would also apply compound interest to what the tables have cost the shipping industry. A figure including interest could mean that producing countries have been shorted by oil companies as much as $30Bn. So on the face of it, the purchasers of crude oil have hoodwinked, inadvertently or not, the oil producers out of many billions of dollars.

But the story doesn't end there. Shipowners have carried nearly 536M barrels more than they have been paid to carry. Depending on the length of the voyage, this could be as much as $750M in unpaid freight. In today's money, this might exceed $1Bn.

For example, the UK has received more than £50Bn ($87Bn) in oil revenues from the North Sea in the past decade. This is probably close to $220Bn since 1980. The tables might have robbed more than $530M in lost taxes.

A similar picture must prevail in all G8 countries that tax oil. F

Behind the API

The American Petroleum Institute, compiler of the '80 tables', was formed in 1919. As the primary oil industry trade association, API represents more than 400 members involved in all aspects of the oil and natural gas trade.
Its motto: 'We keep America going strong'. But its sub-motto is even more interesting in the context of this article: 'Helping you get the job done right'. Membership includes oil exploration groups, refiners, shippers and also oil companies well known in the shipping arena, such as:

- **Ashland**
- **BHP Billiton**
- **BP**
- **Chevron**
- **ConnocoPhillips**
- **Dow**
- **ExxonMobil**
- **Hunt Oil**
- **Kerr McGee**
- **Loop**
- **Marathon**
- **Murphy**
- **Occidental**
- **Petrocanada**
- **Shell**
- **Total**

Who says so?

British researcher and technical consultant Tim Gunner has submitted his second doctoral thesis for examination at the Norwegian University for Science & Technology, Trondheim. His first doctorate, completed in 1992 at the University of Wales, cast doubt over the accurate measurement of crude volumes. Gunner identified where the Petroleum Measurement Table compilation was flawed.

One reason lay in the choice of 124 crude oil samples used for evaluation. "Of the total population of the oils used, 78 are, however, either of not regularly shipped crude oils (internationally) or from unidentifiable sources, eg 'light export blend' and 'heavy export blend'," he wrote.

Thus, just 46 of the original 124 samples remain in the database for recognised and regularly shipped crude oils. He also identified that instead of the recommended 10 data points, the average was nearer five.

In its conclusion, Gunner writes:
As a result of undertaking a series of tests for density over a range of temperatures on a selection of crude oils, primarily to obtain a secondary method for the determination of the Cloud Point temperature, it was identified that the temperature correction factors as quoted in the Petroleum Measurement Tables were potentially supplying a systematic error that was not being identified within the statistical research into tolerances/accuracy of the measurement of liquids/oils.

His findings and concerns were voiced in a paper published in *Oil and Gas Journal* in May 1995 – about 15 years after the measurement tables were published.

The oil sector reacted scornfully.

His second work, which involved about a dozen years of investigation, was an in-depth study of volatile organic compounds and their loss to atmosphere during transit. In studying in-transit losses of VOCs, he again addressed the petroleum tables, examining 340 regularly traded crudes.

It also involved the plotting of 3,410 data points and examined more than 2,000 crude samples. The database was about six times larger than the one used to compile the API tables. Gunner's conclusion: assumptions in the tables were "inappropriate and therefore introduced significant error".