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Paper 1.2

API/IP Density Referral Constants – An Investigation into the Impact of Changing from K0 and K1 Values to API/IP Standard Values for the Flotta Pipeline System

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1 INTRODUCTION

The Flotta Pipeline System has used custom density referral constants, K_0 and K_1, for a number of years. This approach was introduced with the intention of making the density referral calculations more accurate by using coefficients that were more representative of the fluids actually being produced in each of the Flotta system fields, rather than those values given in API 11.1.

These custom constants have not been updated for several years now, due to costs and practicalities caused by constantly changing production profiles. Accordingly it has been proposed that the Flotta Pipeline System moves back to using the standard API constants in order to provide increased traceability.

KELTON were requested to undertake a study to assess the impact of this proposed change on the calculated production rates from each field in the Flotta allocation system. This paper summarises the findings of this study.

2 DENSITY REFERRAL CALCULATIONS

2.1 Purpose of Calculations

The density of oil varies with temperature and pressure, with the density increasing with decreasing temperature and increasing pressure. For a typical crude oil with a density of 800 kg/m^3, a 1°C temperature decrease will cause an increase in density of approximately 0.1%. The pressure effect is much smaller, with a 1 barg increase in pressure resulting in a density increase of approximately 0.01%. This is a "rule of thumb" and will vary with different oils and at different conditions. The relative change in density for a 1°C or 1 barg change is larger for lower density oils, and smaller for higher density oils.

In custody transfer oil measurement systems, the actual volume flowrate is commonly measured using a turbine meter, or some other form of volume flowmeter. This volume flowrate can then be converted to either a mass flowrate or a standard volume flowrate.

Mass flowrate is determined from:

$$q_m = q_v \times \rho_m \qquad [1]$$

where

q_m = mass flowrate (kg/s)
q_v = actual volume flowrate (m^3/s)
ρ = density at meter (kg/m^3)

whilst standard volume flowrate is determined from:

$$q_{v,std} = q_v \times C_{TPL} \qquad [2]$$

where

$q_{v,std}$	=	standard volume flowrate (kg/s)
q_v	=	actual volume flowrate (m^3/s)
C_{TPL}	=	volume correction factor for temperature and pressure (-)

For the mass flowrate calculations the oil density at the meter is normally calculated from the measured density at the densitometer, corrected to account for the difference in oil temperature and pressure between the densitometer location and the meter itself. The densitometer is normally located in a bypass loop, although the temperature and pressure would be close to those at the meter.

For the standard volume flowrate calculations, the C_{TPL} term represents the volume correction factor from meter temperature and pressure to standard temperature and pressure.

In both cases it is clear that the change in density from one temperature and pressure to another must be accounted for in the flow calculations. The specific method for doing this can vary, however the vast majority of systems make use of the calculations given in Chapter 11.1 of the API Manual of Petroleum Measurement Standards (MPMS) [1].

2.2 API MPMS Chapter 11.1

The current version of API Chapter 11.1 standard includes the correction factor for the effects of both temperature and pressure on oil density. Previous version of API 11.1 (1952 and 1980) only covered the temperature effect, with Chapter 11.2 (previously API 1101 Standard) being used for pressure corrections.

The overall correction term is given as the product of the temperature correction and the pressure correction:

$$C_{TPL} = C_{TL} \cdot C_{PL} \qquad [3]$$

The temperature correction term is given as:

$$C_{TL} = \exp\left[-\alpha_{60}\Delta t\left(1 + 0.8\alpha_{60}\Delta t\right)\right] \qquad [4]$$

$$\alpha_{60} = \frac{K_0}{\rho_{60}^2} + \frac{K_1}{\rho_{60}} + K_2 \qquad [5]$$

where

α_{60}	=	thermal expansion coefficient at 60°F (/°F)
Δt	=	temperature difference between measured and base (t – 60°F) [°F]
ρ^*_{60}	=	base density at 60°F [kg/m^3]

The constants K_0, K_1 and K_2, are given in the standard for various commodity groups. For crude oils, K_0 = 341.0957, and $K_1 = K_2 = 0$, for a 60°F base temperature.

The current version of the Chapter 11.1 is given exclusively in terms of a 60°F reference temperature, with other reference temperatures (i.e. 15°C) requiring a second calculation to correct from 60°F[1]. However most commercial flow computers in current operation will still be using the 15°C base temperature calculations from the 1980 version of Chapter 11.1, where K_0 = 613.9723. It is this 15°C version that will feature later in this paper for comparison purposes.

[1] Older versions of Chapter 11.1 did contain metric conversions to 15°C, however these have not been included in the current version due to difficulties in maintaining consistent calculations with different base temperatures.

The pressure correction term is given as:

$$C_{PL} = \frac{1}{1 - F_P\left(P - P_e\right)} \quad [6]$$

$$F_P = \exp\left[-1.9947 + 0.00013427t + \frac{793290 + 2326t}{\rho_{60}^2}\right] \quad [7]$$

where

F_p	=	compressibility factor [/psi]
P	=	measured pressure (e.g. at meter) [psi]
P_e	=	equilibrium pressure at temperature t [psi]
T	=	measured temperature (e.g. at meter) [°F]

There are other small corrections used in the current Chapter 11.1 calculation to account for differences between the IPTS-90 and IPTS-68 temperature scales; however these are omitted from the above summary for simplicity.

2.2 Limitations of API Calculations

It has long been considered [2] that the constants given in Chapter 11.1 are not suitable for North Sea crude oils, as apparently only 2 out of the 124 oils used in the original research to develop the coefficients were from the North Sea (Forties and Auk fields).

Furthermore, the samples were allowed to stabilise in open containers prior to testing, thus allowing light ends to vaporise off. Water content was also restricted to very low levels, unlike current North Sea production.

Accordingly there have been calls for more representative volume correction factors for North Sea crudes [3] to avoid calculation errors and potential mis-allocation of field productions. Ref [3] claims that very significant errors will be introduced in North Sea allocation systems through the use of the standard API volume correction factors. However the basis for this claim appears to be mistaken as will be discussed later in this paper.

3 FLOTTA PIPELINE SYSTEM

The Flotta Pipeline System transports oil from a number of North Sea platforms to the Flotta terminal in Orkney. The fields producing through this system are AH001, Claymore, Duart, Galley, Highlander, MacCulloch, Piper, Saltire, Scapa, Tartan and Tweedsmuir.

The Flotta Pipeline System has used custom density referral constants, K_0 and K_1, for a number of years. The custom coefficients were calculated for each separate crude oil and NGL stream every three months. The values were based on coefficient of thermal expansion (CTE) analyses performed on periodic samples taken from each production stream. These custom values were then entered into the flow computers.

This approach was introduced with the intention of making the density referral calculations more accurate by using coefficients that were more representative of the fluids being produced, rather than those values given in API Chapter 11.1. However due to the constantly changing production levels from various fields, it became impractical to maintain representative custom coefficients for each field, and consequently these custom constants have not been updated for several years now.

Accordingly it has been proposed that the Flotta Pipeline System moves back to using the standard API K_0 constant in order to provide increased traceability compared with outdated custom values that are unlikely to represent current production fluids.

KELTON were requested to undertake a study to assess the impact of this proposed change on the calculated production rates from each field in the Flotta allocation system, to determine if any particular field(s) would be significantly affected. This paper summarises the findings of this study.

It is not proposed to modify the pressure correction method, therefore this study only addresses the impact of changing the K_0 value. The change in K_0 value will have a second order effect on C_{pl} calculations as the density at 60°F is an input into these.

4 STUDY OBJECTIVES

At the outset of the study it was agreed that production data for 12 months from 01/08/06 to 31/07/07 would be used as the basis for the study. Flow weighted average values for density, pressure and temperature were calculated over this period. This data would be used to assess the impact of moving from the custom K_0 values to the standard API values.

The areas identified for investigation were:

- the calculation of standard volume flowrates
- the impact on calculated meter K-factors

It was understood at the time that the effect on standard volume flowrate calculations would be the most significant as this would directly impact the Flotta allocation system and could lead to errors in the quantity of oil allocated to each field in the Flotta system.

During the course of the work, it became clear that the Flotta allocation system was not based on calculated standard volume flowrates, but was actually a mass based allocation system. Accordingly the impact on the mass values reported by each measurement system was assessed also.

5 STANDARD VOLUME CALCULATIONS

Flow weight averaged process variables were calculated for each stream, based on 12 months of PARS data, for the period 01/08/06 to 31/07/07. Tartan process conditions were calculated from 17/02/07 to 31/07/07 as Tartan and Highlander were commingled on this date. These average conditions are shown below in Table 1.

It can be seen that there is a large spread of operating temperatures, pressures and densities across the Flotta system streams.

These average process values were then used to calculate C_{TL} and C_{PL} values for each stream using both the existing custom K_0 values and the standard API coefficient. KELTON's FLOCALC® software was used for these calculations.

Table 1. Average process conditions.

Platform	Stream	FWA Density [kg/m3]	FWA Pressure [barg]	FWA Temperature [ºC]
Claymore	**MOA**	864.54	16.89	57.77
	MOB	865.24	16.36	53.62
	Claymore Average[2]	**864.89**	**16.62**	**55.69**
	MOD	873.59	21.00	40.07
	MOE	892.76	20.83	40.16
	Scapa Average	**883.18**	**20.91**	**40.12**
Piper	**PPOA**	802.59	25.48	70.95
	PPOB	804.07	26.06	70.60
	Piper Average	**803.33**	**25.77**	**70.78**
	PTOA	828.14	32.47	62.50
	PTOB	offline	offline	Offline
	Tweedsmuir A[3]	795.07	30.09	25.85
	Tweedsmuir B[2]	822.39	27.55	24.45
	Tweedsmuir Average	**808.73**	**28.82**	**25.15**
	CML[4]	594.83	78.79	33.24
	NML[3]	520.56	84.09	40.11
MacCulloch	**MOM**	839.40	12.29	46.64
Galley	**MOG**	770.85	10.24	42.53
AH001	**MOA**	826.00	74.90	46.00
	MCA[3]	476.28	59.91	20.41
Tartan	**MOT & MOH**	873.92	12.74	45.11
	MCA	561.83	67.20	34.30

The results of this exercise are shown below in Table 2, which also shows the custom K_0 values currently in use for several systems. It can be seen that most systems would experience an increase in the calculated standard volume flowrate as a result of the change to the API K_0 coefficient.

The Tartan NGL stream (MCA) shows the most significant shift of +0.44%. This is not surprising as being an NGL stream the density is very low, and the custom K_0 value is significantly different from the API value. The density is in fact below the lower end of the current API Chapter 11.1. The correct standard for volume correction for this stream would be GPA TP-27 [4] (also published as API Chapter 11.2.4).

The next most significant shifts are for Claymore (+0.189%), Scapa (+0.180%) and Piper (+0.133%). All the remaining shifts are less than 0.1%, with the Piper test stream (PTOA) being the only stream to show a negative shift, albeit a very small one at -0.005%. The Tweedsmuir and Galley systems already use the API coefficient, therefore there is no impact on these two systems.

Table 3 shows the overall impact in terms of absolute differences as well as relative. From this viewpoint the Tartan NGL stream is not significantly affected as its production level is very low. The largest impact in absolute terms is the Claymore field, which would see standard volume production increase by 8.5 sm^3/day (53.5 bbl/day).

[2] Claymore C Stream not used in averaging as this is a spare stream and can be from either A or B Separator.
[3] Tweedsmuir & Galley Streams already uses K0=613.9723.
[4] CML, NML & AH001 MCA were not included in study due to their low production quantities.

Table 2. Calculated volume correction factors with custom and API K_0 values.

Platform	Stream	Calculated Values with Custom K0			Calculated Values using API K0			Overall effect on std volume flow
		K0	Ctl	Cpl	K0	Ctl	Cpl	%
Claymore	**MOA**	648.4273	0.96502	1.00128	613.9723	0.96678	1.00129	0.182
	MOB	654.4318	0.96801	1.00122	613.9723	0.96988	1.00123	0.194
	Claymore Avg	651.4295	0.96651	1.00125	613.9723	0.96833	1.00126	0.189
	MOD	672.2635	0.97866	1.00147	613.9723	0.98045	1.00148	0.183
	MOE	672.2635	0.97947	1.00135	613.9723	0.98119	1.00136	0.176
	Scapa Avg	672.2635	0.97906	1.00141	613.9723	0.98082	1.00142	0.180
Piper	**PPOA**	631.1146	0.94964	1.00265	613.9723	0.95089	1.00267	0.133
	PPOB	631.1146	0.95009	1.00269	613.9723	0.95133	1.00271	0.132
	Piper Avg	631.1146	0.94986	1.00267	613.9723	0.95111	1.00269	0.133
	PTOA	613.1146	0.96019	1.00296	613.9723	0.96014	1.00296	-0.005
	PTOB							
	Tweedsmuir A	613.9723	0.98959	1.00282				
	Tweedsmuir B	613.9723	0.99151	1.00229				
	Tweedsmuir Avg	613.9723	0.99058	1.00254				
	CML							
	NML							
MacCulloch	**MOM**	626.8444	0.97309	1.00101	613.9723	0.97362	1.00101	0.054
Galley	**MOG**	613.9723	0.97281	1.00113				
AH001	**MOA**	623.2288	0.97264	1.00669	613.9723	0.97303	1.00670	0.041
	MCA							
Tartan	**MOT & MOH**	637.2569	0.97587	1.00090	613.9723	0.97671	1.00091	0.087
	MCA	684.2582	0.95928	1.02273	613.9723	0.96318	1.02310	0.440

Table 3. Standard volume flowrate impact.

Stream	Old Standard Volume [Sm³]	New Standard Volume [Sm³]	Difference [%]	Difference [Sm³/day]
Claymore Average	4505.3	4513.8	0.19	8.5
Scapa Average	635.3	636.5	0.18	1.1
Piper Average	1979.7	1982.3	0.13	2.6
PTOA/B Average	107.8	107.8	-0.01	0.0
Tweedsmuir Average	2014.6	2014.6	0.00	0.0
MOM	2448.3	2449.6	0.05	1.3
MOG	816.8	816.8	0.00	0.0
AH001 MOA	440.6	440.8	0.04	0.2
Combined MOT & MOH	1687.7	1689.1	0.09	1.5
TARTAN MCA	150.4	151.1	0.44	0.7

6 K-FACTOR CALCULATIONS

When proving turbine meters against a volumetric prover, the meter K-factor is determined from the familiar calculation:

$$K = \frac{n}{V} \cdot \frac{C_{tlm} C_{plm}}{C_{tlp} C_{plp} C_{tsp} C_{psp}} \qquad [8]$$

where

n	=	number of pulses counted during prove [pulses]
V	=	prover volume passed [m3]
C_{tlm}	=	volume correction factor (temperature) from meter to standard conditions
C_{plm}	=	volume correction factor (pressure) from meter to standard conditions
C_{tlp}	=	volume correction factor (temperature) from prover to standard conditions
C_{plp}	=	volume correction factor (pressure) from prover to standard conditions
C_{tsp}	=	volume correction factor (temperature) for prover steel body
C_{psp}	=	volume correction factor (pressure) for prover steel body

The latter two corrections are not relevant to this study as they are not related to the proposed change from custom constants to API values.

The C_{tl} and C_{pl} factors for both meter and prover would be affected by the change. However as the prover corrections move from prover conditions down to standard conditions and the meter corrections then move from standard conditions back up to meter conditions, the impact of changing the coefficients used in the calculations is likely to be small as the prover and meter will be operating at a similar temperature and pressure.

Calculations were run using KELTON's FLOCALC® software for two systems, Claymore MOA and Piper MOA, to assess the impact of changing K_0 values. The relevant flow weighted average temperature, pressure and density shown in Table 1 were used in the calculations, together with a single pulse and the appropriate prover parameters. An average offset between meter and prover temperature and pressure was calculated and used to allow the prover temperature and pressure to be determined for these current calculations.

The full FLOCALC® outputs are shown in Appendix A for these calculations, however in summary the impact was found to be negligible as shown below in Table 4.

Table 4 below shows the results of the calculations, and it is clear that the impact of changing the K_0 values is negligible. This is due to the fact that the temperature difference between the meter and the prover is very small (approximately 0.3°C on Claymore and 0.6°C on Piper).

Table 4. Impact on K-factor calculations.

Meter Stream	K-Factor (Custom K0)	K-Factor (IP Paper 2 K0)	% Difference
Claymore MOA	0.146648	0.146650	+0.0014
Piper PPOA	0.262134	0.262130	-0.0015

7 MASS FLOWRATE CALCULATIONS

During the course of the study, from discussions with the allocation personnel at Talisman it became apparent that the Flotta allocation system was in fact a mass based system. The mass flowrates from each platform are input into the system and are combined with the analysis of the weekly samples to give component mass values. These are then reconciled with the total mass of each component leaving the Flotta terminal.

Accordingly, the important issue for the allocation system is the impact of changing K_0 values on the calculated mass values from each field. Eq. (1) shows that the mass flowrate is the product of the measured actual volume flowrate and the meter density. The meter density is calculated from the measured density at the densitometer, corrected from the temperature and pressure at the densitometer to those at the meter:

$$\rho_m = \rho_d \frac{C_{tlm} C_{plm}}{C_{tld} C_{pld}} \qquad [9]$$

where

ρ_m	=	meter density [kg/m^3]
ρ_d	=	measured density at densitometer [kg/m^3]
C_{tlm}	=	volume correction factor (temperature) from meter to standard conditions
C_{plm}	=	volume correction factor (pressure) from meter to standard conditions
C_{tld}	=	volume correction factor (temperature) from densitometer to standard conditions
C_{pld}	=	volume correction factor (pressure) from densitometer standard conditions

As for the prover calculations, there will be a large degree of cancelling out, as the meter and densitometer conditions will be very similar. Densitometers are normally installed in the fast loop bypass and are generally well lagged, such that the temperature should not change much between the fast loop and the meter stream.

Attempts were made to obtain data for meter vs. densitometer conditions, however KELTON were advised that many of the systems on the Flotta Pipeline System do not actually measure the temperature and pressure at the densitometer. The meter density is taken as being equal to the measured density.

It is not therefore possible to perform specific calculations on the actual measurement systems, however we can easily make an estimate of the effect based on assumed temperature and pressure differences. Table 5 below shows the results of some example calculations carried out using FLOCALC®.

Table 5. Assessment of impact on meter density calculations.

System	Calculation method	K0 constant	Measured Density (kg/m3)	Header temp (oC)	Header pressure (barg)	Standard density (kg/m3)	Meter temp (oC)	Meter pressure (barg)	Meter density (kg/m3)	Difference (%)
Claymore ave	IP Paper 2	613.9723	864.89	57.69	16.62	893.404	55.69	16.62	866.279	
	IP Paper 2	651.4295	864.89	57.69	16.62	895.172	55.69	16.62	866.36	-0.010
Scapa MCA	IP Paper 2	613.9723	883.18	42.12	20.91	900.52	40.12	20.91	884.55	
	IP Paper 2	672.2635	883.18	42.12	20.91	902.27	40.12	20.91	884.68	-0.015

Table 5 contains example calculations for two systems, Claymore average and Scapa average. In each case it has been assumed that the densitometer temperature is 2°C higher than the meter temperature. This would be considered a conservatively high temperature difference and in many cases the temperature difference would be lower than this.

It can be seen that the effect on meter density, and hence mass flowrate, of changing from custom constants to the API standard K_0 is very small indeed for the two cases shown above.

8 DISCUSSION OF STUDY FINDINGS

The study assessed the impact of changing from the current custom K_0 values to the standard API values.
It was found that the impact on gross volume flowrates, through K-factor calculations would be insignificant. This is due to the fact that the meter and prover will be operating at very similar temperatures and pressures, therefore the sensitivity to the actual K_0 values used is very low.

The impact on calculated standard volume flowrates was more significant, with shifts of up to 0.19% observed in crude oil streams, and 0.44% on an NGL stream[5]. However, the standard volume flowrates are not used in the Flotta allocation system therefore these shifts have no impact on allocation. It is believed that the pipeline tariffs are calculated on the basis of the standard volume flowrates, therefore there may be a very small financial impact here.

With regards to the impact on calculated mass flowrates, it was not possible to obtain exact data as the systems reviewed did not actually measure temperature and pressure at the densitometer. However assuming a 2°C difference between meter and densitometer, it was shown that the impact would be small, of the order 0.01% to 0.02%.

Overall it can be concluded that the impact of moving from the current custom K_0 values to the standard API value would not have a significant impact on the Flotta allocation system.

9 GENERAL SITUATION FOR UK PIPELINE SYSTEMS

During the course of this study KELTON contacted representatives of several of the other major oil pipelines (Forties, Brent & Ninian) in the North Sea to ascertain if their allocation systems operated in a similar manner to the Flotta system.

From these discussions it would appear that all of the allocation systems also operate on a component mass basis, and the influence of the K_0 values is limited only to the correction of density from densitometer conditions to meter conditions.

Obviously the impact of this would depend on the nature of the fluids involved and on the differences in temperature between the densitometers and meters[6]. As most systems will be fully lagged, it is this author’s opinion that it is very unlikely that there will be temperature differences of more than 1°C or 2°C, and that consequently there would be little impact on calculated mass flowrates and hence product allocations.

It follows from this conclusion that there would seem little justification for any large scale research project to review the density referral coefficients for North Sea crude oils. However in order to further support this viewpoint it would be considered worthwhile to perform a desktop review of the measurement systems involved to ensure that there are no large differences in operating conditions between densitometers and stream meters.

10 REFERENCES

[1] API Manual of Petroleum Measurement Standards. Chapter 11 – Physical Properties Data. Section 1 – Temperature and Pressure Volume Correction Factors for Generalized Crude Oils, Refined Products, and Lubricating Oils. May 2004, Addendum 1, September 2007.

[2] R. THIRD and N. COYLER. Crude Oil Expansion Coefficients. 14th North Sea Flow Measurement Workshop, October 1996, Peebles, UK.

[5] The API Chapter 11.1 calculations should not be used on this NGL stream. Instead GPA TP-27 should be used which gives a very close agreement with the current custom K_0 value.
[6] The pressure differences are considered negligible, due to the lower impact of pressure on density.

[3] J. McNAUGHT et al. The Influence of Fluid Properties on Allocation Accuracy. 7th South East Asia Hydrocarbon Flow Measurement Workshop, March 2008, Kuala Lumpur, Malaysia.

[4] GPA Technical Publication TP-27. Temperature Correction for the Volume of NGL and LPG. Tables 23E, 24E, 53E, 54E, 59E and 60E. September 2007.