QuantityWare

Working Paper

Comparison of ASTM D1250 standard implementations

"Brute force" comparison calculations to examine the differences between ASTM D 1250-52 / ASTM D1250-80 / ASTM D1250-04 implementations

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Notes

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Contents

Introduction

In May 2004 the American Petroleum Institute (API) released a new version of the

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**

Adjunct to: ASTM D1250-04 and IP 200/04

QuantityWare offers software implementations within the BCP (Bulk Calculations – Petroleum) product for all available versions of ASTM D1250.
In this working paper we provide a brief overview on the historical development of ASTM D1250, followed by a detailed analysis of the calculation differences (base density and volume correction factors) between ASTM D1250-80 and ASTM D1250-04, which is motivated by the implementation procedure changes of both standard versions. Business and policy decision makers need to be aware of these differences when deciding which standard version shall be used.

The ASTM D1250 standard not only defines bulk petroleum product density, temperature and pressure corrections, but the mass to weight conversion tables and algorithms that need to be applied too. This paper only considers the density and temperature corrections provided by ASTM D1250. For a detailed comparison of weight conversion tables and algorithms please refer to our working paper QuantityWare Comparison ASTM D1250 2008 1980 .

The results of our comparison calculations between ASTM D1250-80 and ASTM D1250-04 implementations are presented in chapter 5. Business decision makers will find high level summaries and recommendations in chapters 7 and 8.

Editorial Note:

The decimal point and thousand separators for numbers and quantity values for this document are defined as follows: The decimal point is a comma ',', the thousand separator is a dot '.'. Example: 123.456.789,987

1. Motivation

Why do we need to consider the effects of temperature on liquid products?

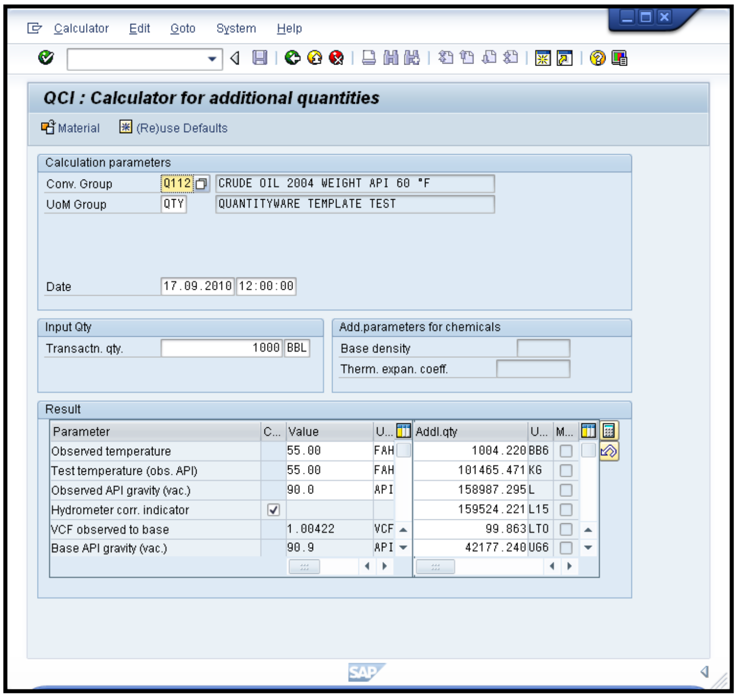
The observed volumes (and thus the densities) of petroleum products depend on the observed temperature at which product is stored, transported and consumed. Your measurement for a delivery of 1000 barrels at observed conditions may be:

Measurement	Observed value
Density	90 °API gravity
Temperature	55 °F
Volume	1000 bbl (barrel)

In order to compare volumes that are measured at different observed temperatures, the global oil industries and national governments have defined three standard reference temperatures against which volumes are to be corrected via defined calculations based on e.g. ASTM D1250. These “standard” or “base” temperatures are: 15 °C, 20 °C and 60 °F; some countries also require standard/base temperatures such as 23 °C or 85 °F. Thus, for every goods movement, one needs to calculate a volume at standard conditions based on the observed (measured) movement density and temperature values; **this approach then provides us with a common and well-defined basis for the determination of prices and taxes -** i.e. everyone agrees on the quantity of petroleum product under discussion. The calculation of a volume at standard conditions is achieved via a volume correction factor (VCF).

Within modern ERP systems such as the SAP Oil & Gas system, standard volumes, masses and weights can be calculated for all goods movements. This data provides the basis for all relevant business documents.

The following screen print shows a calculation example for a goods movement of 1000 barrels of crude oil, using SAP software and the standard ASTM D 1250-04 implementation delivered by QuantityWare:



What is shown on this screen? For those unfamiliar with the SAP application, we can provide a ‘translation’:

Measurement	Observed value
Density: observed API gravity(vac.)	90,0 API Gravity
Temperature (observed and test)	55,00 °F
Volume	1000 barrel
Calculated results at 60 °F	
Volume	1004,220 barrel (BB6)
Volume correction factor	1,00422
Base density at 60 °F	90,9 API Gravity

If all companies involved in energy goods movements used the same highly specialized and well-developed standard, all parties concerned would calculate the same standardized quantities, independent of environmental conditions; this is however, not the case.

Let us consider a single standard - the ASTM D1250 - companies all over the globe currently utilize versions from 1952, 1980 and 2004 (with respect to temperature and pressure corrections) for their logistics transaction calculations. In the following chapter we provide a short historical overview on the development of ASTM D1250, which shows how the current situation developed.

2. History of ASTM D1250

This chapter provides a brief overview of the ASTM D1250's history [2, 4, 5, 6]. For additional information, refer to the web sites and documents of the American Petroleum Institute (API), the American Society for Testing and Materials – ASTM International (ASTM) and the Institute of Petroleum (IP).

1.2.1. Year 1916 – The start

The first development of the thermal expansion of liquid hydrocarbons was published by the National Bureau of Standards (US). Owing to the lack of computer technology at this time, printed tables were published reflecting a matrix of density and temperature - the result being a volume correction factor (VCF). It took generations to replace such printed tables with formulae and procedures that can be implemented in a computer program.
The original tables from 1916 were superseded in 1924, 1936 and 1945 by tables in British units.

1.2.2. Year 1952 – A big step forward

The American Society for Testing and Materials (ASTM) and the Institute of Petroleum (IP) published the "Blue Book Tables". For the first time in history these tables covered US units, British (Imperial) units and metric units.
These tables were available for a base temperature of 60 °F and 15 °C and for density in API Gravity, Relative density and density (kg/m^3), as printed lists in a standard book.
Some of these tables are still used today in various countries (e.g. for LPG and NGL calculations as well as crude oil export calculations, although superseded).

1.2.3. Year 1965 – API adopted the 1952 tables

The American Petroleum Institute (API) adopted the 1952 tables. A major rewrite was started in 1974.

1.2.4. Year 1980 – New temperature correction tables

The API separated the tables and developed sets for different products:

- Crude Oil
- Refined Products
- Special Applications
- Lubricating Oils (1982)

LPGs and NGLs were not yet supported.

For the first time in history, the defined implementation procedures and not the printed tables were “the standard”. However, for reasons of practicality, the printed tables were published as books as well. The printed tables provide VCF with 4 decimals accuracy and need to be entered with density values that are corrected for glass hydrometer readings.

1.2.5. Year 1998 – Support of LPGs and NGLs

The GPA (Gas Processors Association) Technical Publication 25 (TP-25) of tables 23E and 24E provided the so far missing modern LPG and NGL support. In 2007, GPA TP-27 also provided support for 15 °C and 20 °C LPG and NGL calculations.

1.2.6. Year 2004 – New needs and possibilities → new standard ASTM D1250-04

After 1980, many additional needs of the petroleum industry were registered by the API. In the meantime, computer technology made incredible progress. The API reacted to industry needs and developed a 2004 version of the Manual of Petroleum Measurement Standards (MPMS) Chapter 11.1, adjunct to the ASTM D1250 standard, which was released in May 2004. The implementation procedures defined therein represent the standard, which also specifies the technical data format and requirements for floating point calculations. Printed table books are no longer available.

Conclusion

If we now consider that for example, legal requirements for excise duty calculations are based on different versions of ASTM D1250, and that change management processes in various countries around the globe take considerable effort and time, it becomes evident that as a matter of course, various versions of ASTM D1250 for such calculations are still in place. Additionally, changing complex software and hardware landscapes to a new standard version is an extremely costly endeavor.

The next chapter lists all implementation procedure changes that came into effect with ASTM D1250-04.

3. Changes between ASTM D1250-80 and ASTM D1250-04

3.1. ASTM D1250-80 implementation guidelines

At the time when ASTM D1250-80 was released, computer technology was not sufficiently developed to allow the processing of complicated procedures whereby the same results, independent of host, operating system and compiler/language used would be returned. Compromises were necessary which lead to rough rounding and in the worst case, differing results for different implementations (e.g. using FORTRAN, C, or ABAP as a programming language). Furthermore, the procedures (tables) were based on different calculation conditions, such as a temperature base of:

- → 60 °F
- → 15 °C
- → 20 °C (never included into the ASTM D1250-80 standard),

and a density of

- → API gravity
- → relative density or
- → density (in kg/m^3).

The implementation procedure provided a separate set of calculation constants for each standard/base temperature.
This was unacceptable at a time where international trading and movements of petroleum products reached new levels - the development of a new standard was required.
The API reacted and the new standard reflects the oil industries current and future needs.

3.2. Changes between ASTM D1250-04 and ASTM D1250-80 implementation guidelines

After the release of ASTM D 1250-80 in 1980 the needs of the oil industry diversified and computer technology made considerable progress. It was time to improve the standard. This list of changes is taken from reference [2] and [6].

- → The 1980 Petroleum Measurement Tables were based upon data obtained using the International Practical temperature Scale 1968 (IPTS-68) which has been superseded by the International Temperature Scale 1990 (ITS-90). Input temperatures are measured using ITS-90 and must be converted to IPTS-68, before any calculations are performed, which are based on a model derived from experimental data taken with

IPTS-68, standard densities are also adjusted accordingly.

→ The accepted value of the standard density of water at 60 °F has changed slightly from the value of 999,012 kg/m^3 - used in the ASTM D1250-80 standard implementation procedures - to 999,016 kg/m^3. This affects the conversion of density values with relative density and API gravity. The impact of this change can be seen in Tables 5, 6, 23, and 24. The (absolute) density calculations are not affected by this change.

→ In 1988 the IP produced implementation procedures for 20 °C (Tables 59 A, B and D and 60 A, B and D) by extending the procedures used for the 15 °C Tables. This was in response to the needs of countries that use 20 °C as their standard temperature. The calculation based on 20 °C is now included in ASTM D1250-04.

→ Tables for lubricating oils were developed and approved as part the ASTM D1250, but were never fully documented. The implementation procedures are now incorporated in ASTM D1250-04.

→ Rounding of density values in metric tables changed from 0.5 kg/m^3 to 0.1 kg/m^3, to improve discrimination and harmonize with various national standards referring to ASTM D1250, e.g. DIN 51757.

→ The temperature and density ranges have now been extended to lower temperatures and higher densities (i.e., lower API gravities) and the gaps still present in ASTM D1250-80 have been removed.

→ Real-time density measurement using density meters has become more commonly used for input into VCF calculations; the usage of such devices results in higher pressures at the point of measurement. This pressure effect must be taken into account simultaneously with temperature effects. Pressure and temperature corrections have been combined into one procedure.

→ The term VCF has been replaced with the term CTPL (Correction for Temperature and Pressure of a Liquid), the temperature portion now being called CTL.

→ Rounding and truncation of initial and intermediate values have been eliminated. Rounding is only applied to the final CTPL values.

→ The 1980 standard version used a format that resulted in VCF with 5 significant digits and final values were available with 4 or 5 decimal digits, depending upon whether the VCF value was greater than or less than one. VCF less than one were also available rounded to 4 decimals. The final VCF/CTPL values are now rounded consistently to 5 decimal digits only. The standard also provides a mechanism to provide un-rounded factors that, when combined, give the overall rounded CTPL.

→ The 1980 Tables implementation procedure used integer arithmetic in order to allow all existing computer equipment to achieve consistent results. With modern-day 64-bit operating system and hardware architectures, this complexity of the 1980 procedure is no longer needed. Double-precision floating-point math procedures are now used.

→ Flow computers "in the field" have become common for real-time measurement of petroleum fluids. These require improved convergence methods for the correction of observed density to base density. A more robust convergence scheme now accomplishes this calculation.

→ The range of application for the 1980 Chapter 1.1.2.1 method has been extended to be consistent with the ranges now used. The implementation procedure for pressure correction is now the defined standard and no longer the printed table values.

→ As noted above, there were discrepancies between the previous 60 °F, 15 °C and 20 °C tables. Starting from the same input density and temperature, each table may have produced a slightly different VCF value for the same output temperature. These differences could not be concealed in the 1980 tables via rounding and truncation procedures. This revision adopts a new procedure for calculating CTL and CPL factors for metric tables. The procedure ensures that the results are identical with those obtained using the 60 °F calculation. Internally, all calculations are based on 60 °F and density values in kg/m^3; other base temperature data is then calculated via a soft conversion procedure.

→ The calculation of Special Applications has been changed. In ASTM D1250-80 such methods were only provided to calculate the VCF from base to alternate conditions (tables 6C, 24C, 54C and 60C). The calculation was based on the thermal expansion factor in relation to the base temperature (15 °C, 20 °C or 60 °F). In ASTM D 1250-04 all procedures provide the calculation of Special Applications in the same way. The thermal expansion factor must now always be provided based on 60 °F in units of 1/°F or 1/°C.

→ Previous editions of the printed tables assumed that density measurements were made with a glass hydrometer. The odd-numbered printed 1980 Tables all included a hydrometer correction on the observed density. In the new ASTM D1250-04 standard, no glass hydrometer corrections are applied. Methods to correct glass hydrometer readings for use in this standard are given in API MPMS Chapter 9 and can be applied before the calculation.

4. Comparison methodology: ASTM D1250-80 and ASTM D1250-04

4.1. Comparison methodology overview

Based on the list of differences described in the previous chapter, only a rough assessment can be made as to the order of magnitude of differences that may be encountered when comparing calculation results of base densities and volume correction factors.

Differences in the order of magnitude of 10^{-4} for density values are to be expected, as well as differences in the calculated volume correction factors (VCF) in the order of magnitude of 10^{-4} to 10^{-5}. It is however, hard to predict how many calculation points will actually show differences at all, if business relevant rounding is applied to calculation results or input data.

For this reason, we decided to utilize a “Brute-Force” method to obtain an overview on the magnitude and distribution of deviations between ASTM D1250-80 and ASTM D1250-04 calculation results. We calculated, for more than one billion data points (where each point is defined as one temperature and one density value within a calculation grid), the base densities and volume correction factors for each standard implementation and compared the resulting values.

There are three main complicating facts when attempting to compare ASTM D1250-80 with ASTM D1250-04 calculation results:

- → The input rounding increments defined for ASTM D1250-80 differ from those defined in ASTM D1250-04 (no rounding except VCF to five decimals)
- → The density and temperature ranges differ between ASTM D1250-80 and ASTM D1250-04, ASTM D1250-04 provides extended ranges
- → Different country specific rounding and accuracy rules have to be considered

One example for country specific rounding rules is the so called “German rounding”.
“German rounding (GR)” is a term that is utilized within the SAP Oil &Gas ERP community to describe the fact that metric ASTM D1250 table calculations require rounding of observed temperature values in °C to 0,05 °C, and rounding of observed density values in kg/m³ to 0,1 kg/m³. This is a requirement of many European and Asian countries where, e.g. the legacy API

c-codes (ASTM D1250-80) have been changed to round density values to 0,1 kg/m³ and the temperature rounding has been left unchanged at 0,05 °C.

Note that German Industry Standard DIN 51757-94 on the other side defines the rounding of observed (input) data as follows:

- If you use the odd tables 53A, B, and D, round the observed temperature values in °C to 0,05 °C, and round the observed density values in kg/m³ to 0,1 kg/m³
- If you use the even tables 54A, B, and D, round the observed temperature values in °C to 0,1 °C, and round the observed density values in kg/m³ to 0,1 kg/m³

Within QuantityWare BCP implementations, "German rounding" of temperature values is defined at 0,05 °C; customers requiring the even table rounding according to DIN 51757-94 have to ensure via system configuration that temperature values are passed rounded to 0,1 °C accuracy to the calculation.
In addition, DIN 51757-94 requires that volume correction factors are always applied rounded to four decimal places, while standards in other countries may either adhere to the ASTM D1250-80 distinction between five decimal volume correction factors for values less than 1 and four decimals for values greater than 1, or follow the approach chosen by DIN 51757-94.

4.2. Comparison methodology details

Based on this list of complexities, when attempting to perform comparison calculations between ASTM D1250-80 and ASTM D1250-04, a meaningful comparison grid must be defined with finite incrementing steps for density and temperature values. In order to define this grid, we compiled table 1 to support our choice.

Input and result rounding ASTM D1250-80 / 04							
Input					Output		
1980		2004				1980	2004
Table	Density	Temp.	Density	Temp.		Density	
5A,B,D	0,1	0,1	none	none		0,1	none
23A,B,D	0,0005	0,1	none	none		0,0001	none
53A,B,D	0,5	0,05	none	none		0,1	none
59A,B,D	0,5	0,05	none	none		0,1	none
53A,B,D (GR)	0,1	0,05	not relevant	not relevant		0,1	not relevant
59A,B,D (GR)	0,1	0,05	not relevant	not relevant		0,1	not relevant
						VCF	
6A,B,D	0,1	0,1	none	none		0,0001 or 0,00001	0,00001
24A,B,D	0,0005	0,1	none	none		0,0001 or 0,00001	0,00001
54A,B,D	0,5	0,05	none	none		0,0001 or 0,00001	0,00001
60A,B,D	0,5	0,05	none	none		0,0001 or 0,00001	0,00001
54A,B,D (GR)	0,1	0,05	not relevant	not relevant		0,0001 or 0,00001	0,00001
60A,B,D (GR)	0,1	0,05	not relevant	not relevant		0,0001 or 0,00001	0,00001
6C	0,0000005	0,1	none	none		0,0001 or 0,00001	0,00001
24C	0,0000005	0,1	none	none		0,0001 or 0,00001	0,00001
54C	0,000001	0,05	none	none		0,0001 or 0,00001	0,00001
60C	0,000001	0,05	none	none		0,0001 or 0,00001	0,00001

Table 1: Shown is the rounding increment in respective units of measure (°API for tables 5 & 6, relative density for tables 23 & 24, absolute density in kg/m³ for tables 53, 54, 59 & 60, °F for tables 5,6,23 & 24, °C for tables 53, 54, 59 & 60, 1/ °C for tables 54C and 60C, 1/ °F for tables 6C and 24C) which is defined/applied in the respective implementation guidelines. The "German rounding rule" implementations are listed as well.

We then defined the following grid increments for our comparison calculations: These grid increments were taken from the ASTM D1250-04 implementation guidelines [2]:

ASTM D1250-80/04 comparison grid					
Input			Output		
Table	Density	Temperature		Density	
5A,B,D	0,1	0,1		0,1	
23A,B,D	**0,0001**	0,1		0,0001	
53A,B,D	**0,1**	0,05		0,1	
59A,B,D	**0,1**	0,05		0,1	
				VCF	
6A,B,D	0,1	0,1		0,0001	0,00001
24A,B,D	**0,0001**	0,1		0,0001	0,00001
54A,B,D	**0,1**	0,05		0,0001	0,00001
60A,B,D	**0,1**	0,05		0,0001	0,00001
6C	**0,000001**	0,1		0,0001	0,00001
24C	**0,000001**	0,1		0,0001	0,00001

Table 2: Shown is the rounding increment in respective units of measure (°API for tables 5 & 6, relative density for tables 23 & 24, absolute density in kg/m³ for tables 53,54,59 & 60 , °F for tables 5,6,23 & 24, °C for tables 53,54,59 & 60, 1/ °F for tables 6C and 24C) which we define for our comparison calculation grid. ***Note that the increments marked in red are finer than the original ASTM D1250-80 input rounding increments, thus we expected for these calculations a larger number of differences.***

We also needed to define the density and temperature ranges for which the comparison calculations for the increment grid defined above were run. Here, we chose the ASTM D1250-04 ranges as defined in reference [6], but varied the density and temperature values in units of °API and °F (tables 5 and 6), relative density and °F (tables 23 and 24) and kg/m³ (tables 53, 54, 59 and 60) with the above defined increments, and compared the results with our implementation of ASTM D1250-80 with built-in range extensions, as well as with our ASTM D1250-80 "German rounding" implementation. The limits (adjusted to the accuracy of the grid increments) are displayed in table 3:

ASTM D1250-04 Ranges			
Temperature °C	-50,00 to 150,00		
Temperature °F	-58,0 to 302,0		
	Crude	**Products**	**Lubricants**
Rel. density @ 60 °F	0,6112 to 1,1646	0,6112 to 1,1646	0,8017 to 1,1646
°API @ 60 °F	100,0 to -10,0	100,0 to -10,0	45,0 to -10,0
Density, kg/m³ @ 15 °C	611,2 to 1163,8	611,2 to 1163,9	801,3 to 1163,9
Density, kg/m³ @ 20 °C	606,1 to 1161,2	606,1 to 1160,6	798,1 to 1160,7
Thermal exp. coeff., 1/ °F	0,0002300 to 0,0009300		

Table 3: Shown are the starting and ending density, temperature and thermal expansion coefficient values for our comparison calculation grid.

With the grid defined in table 2 and 3, we calculated base densities (odd tables) and volume correction factors. We then compared:

→ the VCF values of ASTM D1250-04 with the respective ASTM D1250-80 values and ASTM D1250-80 “German rounding” values

→ the VCF values - rounded to four decimals (rounding of exact ASTM D1250-04 CTPL values) with the respective ASTM D1250-80 values and ASTM D1250-80 “German rounding” values

→ the base density values

Note that ASTM D1250-80 VCF values for temperatures below the base temperature are always rounded to four decimals, i.e. to a format of 1.XXXX. Thus we expected to see more and larger VCF differences for temperatures below the base temperature for even numbered tables.

We also defined a second smaller grid, where we reduced the temperature intervals to the 90 % “real life” case, as well as doubling the temperature increment steps. In this way, we obtained a distribution estimate of the differences found. The theoretical model used for calculation definition suggested that more differences will be found if temperature values move further away from the respective base temperature.

For this grid we chose a symmetrical temperature interval around the base temperature. The values are listed in table 4.

ASTM D1250-04 90 % Temperature ranges & grid	
Temperature °C (15 ° base)	-10,00 to 40,00 - 0,1 increment
Temperature °C (20 ° base)	-5,00 to 45,00 - 0,1 increment
Temperature °F	14,0 to 104,0 - 0,2 increment

Table 4: Shown are the starting and ending temperature of the 90 % "real life" grid, as well as the increment steps. 90 % "real life" means that within that temperature range, 90 % of crude oil and product movements (in terms of volume) take place globally on a daily basis. This assumption may of course be violated if we consider countries that produce exclusively in very cold or very hot climates.

4.2.1. Tables 5 and 6 comparison run

For these tables, we selected the starting and ending API gravity as well as the temperature range in °F according to table 3. API gravity was increased by 0,1 per calculation, the temperature by 0,1 °F per calculation.

Firstly, the ASTM D1250-04 implementation was called with these values. In order to do so, the API gravity values were converted to kg/m³ values, no additional rounding was performed. The °F values were passed directly to the implementation.
The resulting exact base density values were converted back to °API and these final values were rounded as defined in table 2. We obtained three VCF values, the value rounded to five decimals and the exact value, which we rounded to two VCF with four decimals (one statistically rounded, one commercially rounded).

The ASTM D1250-80 implementation was called with the increment values as defined in table 1, followed by the ASTM D1250-80 defined input value rounding, (occurring within the implementation). After input value rounding, API gravity was converted to an absolute density value in kg/m³ and that value was rounded to 0,01 kg/m³ by the implementation.
The resulting values were also rounded as defined in table 1 within the ASTM D1250-80 implementation. We also noted if the ASTM D1250-80 calculation was outside the ASTM D1250-80 defined ranges; such range extension calculations may fail due to the less robust convergence scheme and differing number format.

4.2.2. Tables 23 and 24 comparison run

For these tables, we chose the starting and ending relative density as well as the temperature range in °F according to table 3. The relative density value was increased by 0,0001 per calculation, the temperature by 0,1 °F per calculation.

Firstly, the ASTM D1250-04 implementation was called with these values. In order to do so, the relative density values were converted to kg/m³ values and no additional rounding was performed. The °F values were passed to directly the implementation.
The resulting exact base density values were converted back to relative density values and these final values were rounded as defined in table 2. We obtained three VCF values, the value rounded to five decimals and the exact value, which we rounded to two VCF with four decimals (one statistically rounded, one commercially rounded).

The ASTM D1250-80 implementation was called with the increment values as defined in table 1, followed by the ASTM D1250-80 defined input value rounding, (occurring within the implementation). After input value rounding, relative density was converted to an absolute density value in kg/m³ and that value was rounded to 0,01 kg/m³ by the implementation.
We also noted if the ASTM D1250-80 calculation was outside the ASTM D1250-80 defined ranges; such range extension calculations may fail due to the less robust convergence scheme and differing number format.

4.2.3. Tables 53, 54, 59 and 60 comparison run

For these tables, we chose the starting and ending absolute density as well as the temperature range in °C according to table 3. The absolute density starting value was increased by 0,1 per calculation, the temperature by 0,05 °C per calculation.

Firstly, the ASTM D1250-04 implementation was called with these values. In order to do so, the absolute density values in kg/m³ values were passed without additional rounding to the calculation procedure. The °C values were converted to ° F values and passed to the implementation directly without further rounding.
The resulting exact base density values in kg/m³ were rounded as defined in table 2. We obtained three VCF values, the value rounded to five decimals and the exact value, which we rounded to two VCF with four decimals (one statistically rounded, one commercially rounded).

The ASTM D1250-80 implementation was called with the increment values without further conversion; internal rounding as defined in table 1 was performed within the implementation.

The resulting values were also rounded as defined in table 1 within the ASTM D1250-80 implementation. We also noted if the ASTM D1250-80 calculation was outside the ASTM D1250-80 defined ranges; such range extension calculations may fail due to the less robust convergence scheme and differing number format.
In addition, we called the ASTM D1250-80 implementation with built in “German rounding” and compared these results with the ASTM D1250-04 calculations.

4.2.4. Special application tables comparison run

Only the special application tables 6C and 24C were compared in this paper. This restriction is caused by the fact that the ASTM D1250-80 allows the entry of a thermal expansion factor at 15 °C (tables 54C and 60C). This is no longer possible with ASTM D1250-04 as a thermal expansion factor at 60 °F is now required as input for all procedures.

> *We repeated the runs described above using the 90 % “real life” temperature grid for all tables to obtain a good estimate on the distribution of differences – increasing relevance for business decision makers.*

5. Comparison results: ASTM D1250-80 and ASTM D1250-04

The comparison calculations as described above were performed in the main development system at QuantityWare GmbH.
In total, more than 1,2 billion calculations were performed. From the total amount, exactly **1.152.342.059** comparison calculations were successful. The remaining calculation comparison ‘failures’ occurred owing to convergence issues with ASTM D1250-80 (described in Chapter 4).

The results of each single comparison calculation can be assigned to one of five meaningful categories:

Category ID	Short description	Explanation
1	All calculations	All calculation points within the comparison grid
2	80 range, 04 increment	Only calculation points within the 1980 density and temperature ranges for all comparison grid points
3	80 range,80 increment	Only calculation points within the 1980 density and temperature ranges, only calculation points that would lie on the coarser 1980 input rounding grid are considered
4	outside 80 range, 04 increment	Only calculation points outside the 1980 density and temperature ranges for all comparison grid points
5	Outside 80 range, 80 increment	Only calculation points outside the 1980 density and temperature ranges, only calculation points that would lie on the coarser 1980 input rounding grid are considered

For each category, we also list whether a calculation is performed for a temperature below, at or above the base temperature, thus each run provides summarized data for 15 categories.
Additionally, for tables 53, 54, 59 and 60 we provide results for all 15 categories for the comparison of “German rounding rule” ASTM D1250-80 implementations with ASTM D1250-04.
For each category, the following comparison data was calculated:

- → Number of grid points (maximum calculations)
- → Number of successful calculations (may be smaller than calculated grid points)
- → Number of deviations found
- → Number of deviations where 2004 result lies above 1980 result
- → Number of deviations where 2004 result lies below 1980 result
- → Number of deviations which differ by one grid result rounding increment
- → Number of deviations which differ by more than one grid result rounding increment
- → Maximum deviation value
- → Temperature value closest to base at which maximum deviation occurs
- → Density value for closest temperature value where maximum deviation occurs

Thus, for **odd** numbered ASTM D1250-80 tables we obtained comparison data for the base density values.
For **even** numbered ASTM D1250-80 tables we obtained comparison data for five decimal volume correction factor values **and** four decimal volume correction factor values.
One result of our analysis was that no difference was detected between statistical rounding and commercial rounding of the ASTM D1250-04 implementations' full accuracy volume correction factor.

As indicated above, we first compared more than one billion (1.021.268.980) calculations for the complete ASTM D1250-04 calculation grid. These calculations took around 150 hour net calculation time in our SAP Oil & Gas ERP system.
We then compared more than 100 million (131.073.079) calculations for the reduced 90 % "real life" calculation grid. These calculations took around 15 hour net calculation time in the same system.

5.1. Detailed comparison results – complete grid

The detailed results of our complete grid calculation comparison analysis can be found in the separate Annex A document to this working paper, just click the following link: Annex A

5.2. Detailed comparison results – 90 % "real life" grid

The detailed results of our 90 % "real life" grid comparison analysis can be found in the separate Annex B document to this working paper, just click the following link: Annex B

5.3. Result analysis and business implications - overview

In the following chapters our results are presented as an overview, based on our detailed results. For each table group, first for the odd, then the even numbered tables. We then discuss the business implications per table based on our business impact decision matrix defined in **Annex C**. In this summary analysis, we evaluate the percentage of differences within the ASTM D1250-80 ranges, found for two grid categories:

- → The 1980 grid category where input measurement data is rounded according to ASTM D1250-80.
- → The 2004 grid category, where input measurement data is rounded according to ASTM D1250-04. Note that the percentage values are rounded to 0,1%.

For odd tables, we present the differences' results in base densities, which we observed with our comparison calculations.

For even tables, we present the differences' results in volume correction factors (rounded to five and four decimals), which we observed with our comparison calculations.

- → Based on the known input data rounding differences between ASTM D1250-80 and ASTM D1250-04 implementations for certain tables, we expect a large % value of differences for these tables, typically 80 %.

- → Since ASTM D1250-80 provides a volume correction factor for temperature values below the base temperature (of the format 1.XXXX (four decimals only), we expect for even tables, when considering temperature values below the base temperature, a large % value of differences, typically 90 %, since we assume to the fifth digit is evenly distributed (either 0, 1, 2, 3, 4,…9) throughout the calculation results for such large numbers of calculations.

Thus, differences caused by other changes described in chapter 3 will be "hidden" by these dominating effects.

Finally, the % difference value can be interpreted as a probability to encounter a relevant difference between your legacy ASTM D1250-80 implementation and your new ASTM D1250-04 implementation.

> *Note that the detailed data given in Annex A and B provides much more information which can be analyzed from a more technical point of view. In this analysis, we restrict our interpretation to derive "business relevant guidance statements" per table.*

5.4. Result analysis - tables 5 A, B and D – 1980 and 2004 grid

The following table summarizes our findings for tables 5 A, B and D. The table contains the % numbers of calculations which showed a difference with respect to the total number of successful calculations performed in the respective grid. We also print the maximum differences in °API that we detected. More details can be found in chapter 5.1 and chapter 5.2.

ASTM D1250-80 Table 5 :			
% differences found - 2004 grid, within 1980 ranges			
Quantity compared:	Base API gravity @ 60 °F		
	A - crude oil	**B - products**	**D - lubricants**
all temperatures			
Maximum difference (complete/90%) [°API]	0,1 / 0,1	0,1 / 0,1	0,1 / 0,1
complete grid	1,4%	1,5%	3,0%
90 % grid	0,7%	0,9%	2,3%
temperatures below base			
Maximum difference (complete/90%) [°API]	0,1 / 0,1	0,1 / 0,1	0,1 / 0,1
complete grid	0,8%	1,0%	2,3%
90 % grid	0,7%	0,9%	2,3%
temperatures equal or above base			
Maximum difference (complete/90%) [°API]	0,1 / 0,1	0,1 / 0,1	0,1 / 0,1
complete grid	1,5%	1,7%	3,2%
90 % grid	0,7%	0,9%	2,3%

The 1980 and 2004 results are identical, since both grids are identical. Within the complete 1980 range, an average of 14 (crude), 15 (products) to 30 (lubricants) calculations out of 1.000 calculations show a difference of 0.1 °API; Within the 90 % grid, these values drop down further as expected.

If such a difference of 0.1 °API occurs, the deviations observed in calculated quantities (weights and masses) can be rather large (0,03%) depending on API gravity absolute value) and may be questioned by business users and inspectors. However, due to the low average % deviation value, the overall average risk is smaller.

> ⚠ ***Based on our business impact decision matrix (see Annex C), the financial impact of a change from ASTM D1250-80 to the ASTM D1250-04 version is medium to low for ASTM D1250-80 tables 5. Business users should be informed that differences can occur with the probabilities given in the table above, to avoid business process disruptions.***

5.5. Result analysis - tables 23 A, B and D – 1980 and 2004 grid

The following table summarizes our findings for tables 23 A, B and D. The table contains the % numbers of calculations which showed a difference with respect to the total number of successful calculations performed in the respective grid. We also print the maximum differences in relative density units (dimension one) that we detected. More details can be found in chapter 5.1 and chapter 5.2. The results for the 2004 grid show the expected 80 % deviations, since the input relative density for tables 23 (as well as for tables 24) is rounded to 0,0005 in ASTM D1250-80, whereas ASTM D1250-04 defines no rounding and the grid increment of 0,0001 defines the accuracy as:

ASTM D1250-80 Table 23 :			
% differences found - 2004 grid, within 1980 ranges			
Quantity compared:	Base relative density @ 60 °F		
	A - crude oil	B - products	D - lubricants
all temperatures			
Maximum difference (complete/90%) [1]	0,0003 / 0,0003	0,0003 / 0,0003	0,0003 / 0,0003
complete grid	79,5%	79,7%	80,0%
90 % grid	80,0%	79,9%	80,0%
temperatures below base			
Maximum difference (complete/90%) [1]	0,0003 / 0,0003	0,0003 / 0,0003	0,0003 / 0,0003
complete grid	80,3%	80,2%	80,0%
90 % grid	80,2%	80,1%	80,0%
temperatures equal or above base			
Maximum difference (complete/90%) [1]	0,0003 / 0,0003	0,0003 / 0,0003	0,0003 / 0,0003
complete grid	79,3%	79,6%	80,0%
90 % grid	79,7%	79,8%	80,0%

The results for the 1980 grid are given in the following table:

ASTM D1250-80 Table 23 :			
% differences found - 1980 grid, within 1980 ranges			
Quantity compared:	Base relative density @ 60 °F		
	A - crude oil	**B - products**	**D - lubricants**
all temperatures			
Maximum difference (complete/90%) [1]	0,0001 / 0,0001	0,0001 / 0,0001	0,0001 / 0,0001
complete grid	6,8%	6,9%	9,0%
90 % grid	3,3%	3,3%	2,9%
temperatures below base			
Maximum difference (complete/90%) [1]	0,0001 / 0,0001	0,0001 / 0,0001	0,0001 / 0,0001
complete grid	3,9%	3,8%	3,4%
90 % grid	3,4%	3,4%	3,1%
temperatures equal or above base			
Maximum difference (complete/90%) [1]	0,0001 / 0,0001	0,0001 / 0,0001	0,0001 / 0,0001
complete grid	8,0%	8,2%	10,6%
90 % grid	3,3%	3,2%	2,7%

If your measurements for relative density are reported with an accuracy of 0,0001, you will observe differences in base density values in 80 % of the calculations, with a maximum difference of 0,0003, which converts to a relative difference of approx. 0,03 % (depending on the absolute density value).

If your measurements for relative density are reported with an accuracy of 0,0005, you will observe, within the complete 1980 range, an average of 68 (crude), 69 (products) to 90 (lubricants) calculations out of 1.000 calculations that show a difference of 0,0001 relative density; Within the 90 % grid, these values drop down further as expected.

Based on our business impact decision matrix (see Annex C), the financial impact of a change from ASTM D1250-80 to the ASTM D1250-04 version is medium to low for ASTM D1250-80 tables 23, if your measurement data, the relative density, is reported with an accuracy of 0,0005. Business users should be informed that differences can occur with the probabilities given in the table above, to avoid business process disruptions.

Based on our business impact decision matrix (see Annex C), the financial impact of a change from ASTM D1250-80 to the ASTM D1250-04 version is high to medium for ASTM D1250-80 tables 23, if you already work with measured/observed relative densities with an accuracy of 0,0001. A detailed "Safe Passage" project is recommended.

5.6. Result analysis - tables 53 A, B and D – 1980 and 2004 grid

The following table summarizes our findings for tables 53 A, B and D. The table contains the % numbers of calculations which showed a difference with respect to the total number of successful calculations performed in the respective grid. We also print the maximum differences in absolute units (kg/m³) that we detected. More details can be found in chapter 5.1 and chapter 5.2. The results for the 2004 grid show the expected 80 % deviations, since the input density values for tables 53 and 54 are rounded to 0,5 kg/m³ in ASTM D1250-80, whereas ASTM D1250-04 defines no rounding and the grid increment of 0,1 kg/m³ defines the accuracy as:

ASTM D1250-80 Table 53 :			
% differences found - 2004 grid, within 1980 ranges			
Quantity compared:	Base density @ 15 °C		
	A - crude oil	**B - products**	**D - lubricants**
all temperatures			
Maximum difference (complete/90%) [kg/m³]	0,3 / 0,3	0,5 / 0,4	0,3 / 0,3
complete grid	79,5%	79,8%	80,0%
90 % grid	80,0%	80,0%	80,0%
temperatures below base			
Maximum difference (complete/90%) [kg/m³]	0,3 / 0,3	0,5 / 0,4	0,3 / 0,3
complete grid	80,2%	80,2%	80,0%
90 % grid	80,2%	80,2%	80,0%
temperatures equal or above base			
Maximum difference (complete/90%) [kg/m³]	0,3 / 0,3	0,3 / 0,3	0,3 / 0,3
complete grid	79,3%	79,6%	80,0%
90 % grid	79,8%	79,8%	80,0%

The results for the 1980 grid are given in the table below; note that we basically obtained identical results for the “German rounding” implementation for both the 1980 and 2004 grid.

ASTM D1250-80 Table 53 :			
% differences found - 1980 grid, within 1980 ranges			
Quantity compared:	Base density @ 15 °C		
	A - crude oil	**B - products**	**D - lubricants**
all temperatures			
Maximum difference (complete/90%) [kg/m³]	0,1 / 0,1	0,2 / 0,2	0,1 / 0,1
complete grid	12,6%	7,9%	3,3%
90 % grid	3,7%	3,5%	0,5%
temperatures below base			
Maximum difference (complete/90%) [kg/m³]	0,1 / 0,1	0,2 / 0,2	0,1 / 0,1
complete grid	4,6%	4,0%	0,5%
90 % grid	3,6%	3,3%	0,4%
temperatures equal or above base			
Maximum difference (complete/90%) [kg/m³]	0,1 / 0,1	0,2 / 0,1	0,1 / 0,1
complete grid	15,2%	9,3%	4,2%
90 % grid	3,8%	3,8%	0,6%

If your measurements for absolute density are reported with an accuracy of 0,1 kg/m³, you will observe differences in base density values in 80 % of the calculations, with a maximum difference of 0,3 to 0,5 kg/m³, which converts to a relative difference of approx. 0,03 % (depending on the absolute density value).
If your measurements for absolute density are reported with an accuracy of 0,5 kg/m³ OR if you are already running a modified “German rounding” ASTM D1250-80 implementation, you will observe, within the complete 1980 range, an average of 126 (crude), 79 (products) to 33 (lubricants) calculations out of 1.000 calculations that show a difference of 0,1 kg/m³; Within the 90 % grid, these values drop further as expected.

Based on our business impact decision matrix (see Annex C), the financial impact of a change from ASTM D1250-80 to the ASTM D1250-04 version is medium to <u>low</u> for ASTM D1250-80 tables 53, if your measurement data, the observed density, is reported with an accuracy of 0,5 kg/m³ or you are already running an ASTM D1250-80 implementation with “German rounding”. Business users should be informed that differences can occur with the probabilities given in the table above, to avoid business process disruptions.

Based on our business impact decision matrix (see Annex C), the financial impact of a change from a non-modified ASTM D1250-80 to the ASTM D1250-04 version is high to <u>medium</u> for ASTM D1250-80 tables 53, if you already work with measured observed densities with an accuracy of 0,1 kg/m³. A detailed “Safe Passage” project is recommended.

5.7. Result analysis - tables 59 A, B and D – 1980 and 2004 grid

The following table summarizes our findings for tables 59 A, B and D. The table contains the % numbers of calculations which showed a difference with respect to the total number of successful calculations performed in the respective grid. We also print the maximum differences in absolute units (kg/m³) that we detected. More details can be found in chapter 5.1 and chapter 5.2. The results for the 2004 grid show the expected 80 % deviations, since the input density values for tables 59 and 60 are rounded to 0,5 kg/m³ in ASTM D1250-80, whereas ASTM D1250-04 defines no rounding and the grid increment of 0,1 kg/m³ defines the accuracy as:

% differences found - 2004 grid, within 1980 ranges			
Quantity compared:	Base density @ 20 °C		
	A - crude oil	**B - products**	**D - lubricants**
all temperatures			
Maximum difference (complete/90%) [kg/m³]	0,3 / 0,3	0,5 / 0,4	0,3 / 0,3
complete grid	79,6%	79,8%	80,0%
90 % grid	80,0%	80,0%	80.0%
temperatures below base			
Maximum difference (complete/90%) [kg/m³]	0,3 / 0,3	0,5 / 0,4	0,3 / 0,3
complete grid	80,3%	80,3%	80,0%
90 % grid	80,2%	80,2%	80,0%
temperatures equal or above base			
Maximum difference (complete/90%) [kg/m³]	0,3 / 0,3	0,3 / 0,3	0,3 / 0,3
complete grid	79,3%	79,6%	80,0%
90 % grid	79,8%	79,8%	80,0%

The results for the 1980 grid are given in the table below; note that we basically obtained the identical results for the “German rounding” implementation for both the 1980 and 2004 grid.

ASTM D1250-80 Table 59 :			
% differences found - 1980 grid, within 1980 ranges			
Quantity compared:	Base density @ 20 °C		
	A - crude oil	**B - products**	**D - lubricants**
all temperatures			
Maximum difference (complete/90%) [kg/m³]	0,1 / 0,1	0,2 / 0,2	0,1 / 0,1
complete grid	12,1%	7,9%	3,4%
90 % grid	3,6%	3,7%	0,4%
temperatures below base			
Maximum difference (complete/90%) [kg/m³]	0,1 / 0,1	0,2 / 0,2	0,1 / 0,1
complete grid	5,6%	5,0%	0,7%
90 % grid	3,7%	3,7%	0,2%
temperatures equal or above base			
Maximum difference (complete/90%) [kg/m³]	0,1 / 0,1	0,2 / 0,1	0,1 / 0,1
complete grid	14,6%	9,2%	4,3%
90 % grid	3,6%	3,7%	0,6%

If your measurements for absolute density are reported with an accuracy of 0,1 kg/m³, you will observe differences in base density values in 80 % of the calculations, with a maximum difference of 0,3/0,5 kg/m³, which converts to a relative difference of approx. 0,03 % (depending on the absolute density value).

If your measurements for absolute density are reported with an accuracy of 0,5 kg/m³ OR if you are already running a modified “German rounding” ASTM D1250-80 implementation, you will observe, within the complete 1980 range, an average of 121 (crude), 79 (products) to 34 (lubricants) calculations out of 1.000 calculations, that show a maximum difference of 0,2 kg/m³; Within the 90 % grid, these values drop further as expected.

- ***Based on our business impact decision matrix (see Annex C), the financial impact of a change from ASTM D1250-80 to the ASTM D1250-04 version is medium to <u>low</u> for ASTM D1250-80 tables 59, if your measurement data, the observed density, is reported with an accuracy of 0,5 kg/m³ or you are already running an ASTM D1250-80 implementation with “German rounding”. Business users should be informed that differences can occur with the probabilities given in the table above, to avoid business process disruptions.***

- ***Based on our business impact decision matrix (see Annex C), the financial impact of a change from a non-modified ASTM D1250-80 to the ASTM D1250-04 version is high to <u>medium</u> for ASTM D1250-80 tables 59, if you already work with measured observed densities with an accuracy of 0,1 kg/m³. A detailed “Safe Passage” project is recommended.***

5.8. Result analysis - tables 6 A, B, C and D – 1980 and 2004 grid

ASTM D1250-80 Table 6 :				
% differences found - 2004 grid, within 1980 ranges				
Quantity compared:	Volume correction factor : observed to base, **5** decimals			
	A - crude oil	**B - products**	**C - special applications**	**D - lubricants**
all temperatures				
Maximum difference (complete/90%)	0,00006 / 0,00006	0,00006 / 0,00006	0,00007 / 0,00007	0,00006 / 0,00006
complete grid	75,0%	77,3%	72,4%	78,5%
90 % grid	57,9%	61,3%	64,0%	56,4%
temperatures below base				
Maximum difference (complete/90%)	0,00006 / 0,00006	0,00006 / 0,00006	0,00007 / 0,00007	0,00006 / 0,00006
complete grid	90,0%	90,0%	90,0%	90,0%
90 % grid	89,9%	90,0%	90,0%	90,0%
temperatures equal or above base				
Maximum difference (complete/90%)	0,00004 / 0,00001	0,00004 / 0,00002	0,00003 / 0,00003	0,00004 / 0,00001
complete grid	69,8%	72,0%	64,1%	75,6%
90 % grid	24,3%	31,2%	36,9%	21,2%

ASTM D1250-80 Table 6 :				
% differences found - 2004 grid, within 1980 ranges				
Quantity compared:	Volume correction factor : observed to base, **4** decimals			
	A - crude oil	**B - products**	**C - special applications**	**D - lubricants**
all temperatures				
Maximum difference (complete/90%)	0,0001 / 0,0001	0,0001 / 0,0001	0,0001 / 0,0001	0,0001 / 0,0001
complete grid	6,6%	7,0%	9,0%	8,6%
90 % grid	1,3%	1,8%	3,1%	1,1%
temperatures below base				
Maximum difference (complete/90%)	0,0001 / 0,0001	0,0001 / 0,0001	0,0001 / 0,0001	0,0001 / 0,0001
complete grid	3,0%	3,8%	5,1%	2,6%
90 % grid	2,3%	3,0%	4,0%	2,1%
temperatures equal or above base				
Maximum difference (complete/90%)	0,0001 / 0,0001	0,0001 / 0,0001	0,0001 / 0,0001	0,0001 / 0,0001
complete grid	7,9%	8,3%	10,8%	10,1%
90 % grid	0,2%	0,6%	2,2%	0,0%

The two tables above summarize our findings for the ASTM D1250-80 tables 6. Although ASTM D1250-04 does not contain the recommendation to round the final volume correction factor to four decimals, we also compared these values with the ASTM D1250-80 four decimal volume correction factors (VCF).

As expected, since ASTM D1250-80 VCF - for temperatures below the base temperature – are available with four decimals only, we observe 90 % differences in that range. Above the base temperature, within the complete 1980 range, we observe an average of 698 (crude), 720 (products), 641 (special applications) to 756 (lubricants) calculations out of 1.000 calculations, that show a maximum difference of 0,00004; Within the 90 % grid, these values drop considerably as expected.

The four decimal results list the differences one has to expect when considering calculating with an ASTM D1250-04 implementation where the VCF is still rounded to four decimals.

ASTM D1250-80 Table 6 :				
% differences found - 1980 grid, within 1980 ranges				
Quantity compared:	Volume correction factor : observed to base, **5** decimals			
	A - crude oil	**B - products**	**C - special applications**	**D - lubricants**
all temperatures				
Maximum difference (complete/90%)	0,00006 / 0,00006	0,00006 / 0,00006	0,00006 / 0,00006	0,00006 / 0,00006
complete grid	75,0%	77,3%	78,4%	78,5%
90 % grid	57,9%	61,3%	63,4%	56,4%
temperatures below base				
Maximum difference (complete/90%)	0,00006 / 0,00006	0,00006 / 0,00006	0,00006 / 0,00006	0,00006 / 0,00006
complete grid	90,0%	90,0%	90,0%	90,0%
90 % grid	89,9%	90,0%	90,0%	90,0%
temperatures equal or above base				
Maximum difference (complete/90%)	0,00004 / 0,00001	0,00004 / 0,00002	0,00003 / 0,00002	0,00004 / 0,00001
complete grid	69,8%	72,0%	73,0%	75,6%
90 % grid	24,3%	31,2%	35,5%	21,2%

ASTM D1250-80 Table 6 :				
% differences found - 1980 grid, within 1980 ranges				
Quantity compared:	Volume correction factor : observed to base, **4** decimals			
	A - crude oil	**B - products**	**C - special applications**	**D - lubricants**
all temperatures				
Maximum difference (complete/90%)	0,0001 / 0,0001	0,0001 / 0,0001	0,0001 / 0,0001	0,0001 / 0,0001
complete grid	6,6%	7,0%	7,1%	8,6%
90 % grid	1,3%	1,8%	2,3%	1,1%
temperatures below base				
Maximum difference (complete/90%)	0,0001 / 0,0001	0,0001 / 0,0001	0,0001 / 0,0001	0,0001 / 0,0001
complete grid	3,0%	3,8%	4,4%	2,6%
90 % grid	2,3%	3,0%	3,4%	2,1%
temperatures equal or above base				
Maximum difference (complete/90%)	0,0001 / 0,0001	0,0001 / 0,0001	0,0001 / 0,0001	0,0001 / 0,0001
complete grid	7,9%	8,3%	8,3%	10,1%
90 % grid	0,2%	0,6%	1,0%	0,0%

As expected, except for table 6C, the results for the 1980 range grid are identical to the 2004 range grid (shown previously).

> ***Based on our business impact decision matrix (see Annex C), the financial impact of a change from ASTM D1250-80 to the ASTM D1250-04 version is <u>medium to low</u> for ASTM D1250-80 tables 6. Business users should be informed that differences can occur with the probabilities given in the table above, to avoid business process disruptions***

5.9. Result analysis - tables 24 A, B, C and D – 1980 and 2004 grid

ASTM D1250-80 Table 24 :				
% differences found - 2004 grid, within 1980 ranges				
Quantity compared:	Volume correction factor : observed to base, **5** decimals			
	A - crude oil	**B - products**	**C - special applications**	**D - lubricants**
all temperatures				
Maximum difference (complete/90%)	0,00008 / 0,00007	0,00021 / 0,00011	0,00007 / 0,00007	0,00007 / 0,00006
complete grid	71,4%	70,8%	72,4%	71,0%
90 % grid	60,6%	62,1%	64,0%	56,2%
temperatures below base				
Maximum difference (complete/90%)	0,00008 / 0,00007	0,00013 / 0,00011	0,00007 / 0,00007	0,00006 / 0,00006
complete grid	90,0%	90,1%	90,0%	90,0%
90 % grid	90,0%	90,0%	90,0%	90,1%
temperatures equal or above base				
Maximum difference (complete/90%)	0,00008 / 0,00003	0,00021 / 0,00007	0,00007 / 0,00003	0,00007 / 0,00002
complete grid	65,1%	63,4%	64,1%	66,3%
90 % grid	29,9%	32,9%	36,9%	20,9%

ASTM D1250-80 Table 24 :				
% differences found - 2004 grid, within 1980 ranges				
Quantity compared:	Volume correction factor : observed to base, **4** decimals			
	A - crude oil	**B - products**	**C - special applications**	**D - lubricants**
all temperatures				
Maximum difference (complete/90%)	0,0001 / 0,0001	0,0003 / 0,0001	0,0001 / 0,0001	0,0001 / 0,0001
complete grid	9,3%	9,2%	9,0%	8,6%
90 % grid	2,3%	3,1%	3,1%	1,2%
temperatures below base				
Maximum difference (complete/90%)	0,0001 / 0,0001	0,0001 / 0,0001	0,0001 / 0,0001	0,0001 / 0,0001
complete grid	4,1%	5,2%	5,1%	2,6%
90 % grid	3,2%	4,0%	4,0%	2,0%
temperatures equal or above base				
Maximum difference (complete/90%)	0,0001 / 0,0001	0,0003 / 0,0001	0,0001 / 0,0001	0,0001 / 0,0001
complete grid	11,1%	10,7%	10,8%	10,1%
90 % grid	1,3%	2,2%	2,2%	0,3%

The two tables above summarize our findings for the ASTM D1250-80 tables 24. Although ASTM D1250-04 does not contain the recommendation to round the final volume correction factor to four decimals, we also compared these values with the ASTM D1250-80 four decimal volume correction factors (VCF).

As expected, since ASTM D1250-80 VCFs - for temperatures below the base temperature – are calculated with four decimals only, we observe 90 % differences in that range. Above the base temperature, within the complete 1980 range, we observe an average of 651 (crude), 634 (products), 641 (special applications) to 663 (lubricants) calculations out of 1.000 calculations that show a maximum difference of 0,00021; Within the 90 % grid, these values drop considerably as expected.

The four decimal results list the differences one has to expect when considering running an ASTM D1250-04 implementation where the VCF is still rounded to four decimals.

ASTM D1250-80 Table 24 :				
% differences found - 1980 grid, within 1980 ranges				
Quantity compared:	Volume correction factor : observed to base, **5** decimals			
	A - crude oil	**B - products**	**C - special applications**	**D - lubricants**
all temperatures				
Maximum difference (complete/90%)	0,00006 / 0,00006	0,00006 / 0,00006	0,00006 / 0,00006	0,00006 / 0,00006
complete grid	75,0%	76,7%	78,4%	77,8%
90 % grid	57,4%	59,8%	63,4%	56,0%
temperatures below base				
Maximum difference (complete/90%)	0,00006 / 0,00006	0,00006 / 0,00006	0,00006 / 0,00006	0,00006 / 0,00006
complete grid	90,0%	90,0%	90,0%	90,0%
90 % grid	90,0%	90,0%	90,0%	90,1%
temperatures equal or above base				
Maximum difference (complete/90%)	0,00004 / 0,00001	0,00004 / 0,00002	0,00003 / 0,00002	0,00004 / 0,00001
complete grid	69,9%	71,4%	73,0%	74,7%
90 % grid	23,3%	28,3%	35,5%	20,5%

ASTM D1250-80 Table 24 :				
% differences found - 1980 grid, within 1980 ranges				
Quantity compared:	Volume correction factor : observed to base, **4** decimals			
	A - crude oil	**B - products**	**C - special applications**	**D - lubricants**
all temperatures				
Maximum difference (complete/90%)	0,0001 / 0,0001	0,0001 / 0,0001	0,0001 / 0,0001	0,0001 / 0,0001
complete grid	6,6%	6,9%	7,1%	8,4%
90 % grid	1,2%	1,6%	2,3%	1,0%
temperatures below base				
Maximum difference (complete/90%)	0,0001 / 0,0001	0,0001 / 0,0001	0,0001 / 0,0001	0,0001 / 0,0001
complete grid	3,9%	3,5%	4,4%	2,5%
90 % grid	2,3%	2,7%	3,4%	1,9%
temperatures equal or above base				
Maximum difference (complete/90%)	0,0001 / 0,0001	0,0001 / 0,0001	0,0001 / 0,0001	0,0001 / 0,0001
complete grid	7,0%	8,2%	8,3%	9,8%
90 % grid	0,2%	0,5%	1,0%	0,0%

The results for the complete 1980 grid show a slightly higher % value of differences, which reverses within the 90% “real life” grid. This is apparently a combined effect of the different input rounding and increasing number of differences when calculating far away from the base temperature.

Based on our business impact decision matrix (see Annex C), the financial impact of a change from ASTM D1250-80 to the ASTM D1250-04 version is <u>medium to low</u> for ASTM D1250-80 tables 24. Business users should be informed that differences can occur with the probabilities given in the table above, to avoid business process disruptions.

5.10. Result analysis - tables 54 A, B and D – 1980 and 2004 grid

ASTM D1250-80 Table 54 :			
% differences found - 2004 grid, within 1980 ranges			
Quantity compared:	Volume correction factor : observed to base, **5** decimals		
	A - crude oil	**B - products**	**D - lubricants**
all temperatures			
Maximum difference (complete/90%)	0,00011 / 0,00007	0,00053 / 0,00022	0,00006 / 0,00006
complete grid	74,9%	67,5%	59,0%
90 % grid	64,0%	61,0%	50,7%
temperatures below base			
Maximum difference (complete/90%)	0,00008 / 0,00007	0,00027 / 0,00022	0,00006 / 0,00005
complete grid	90,0%	90,3%	90,0%
90 % grid	90,0%	90,3%	90,1%
temperatures equal or above base			
Maximum difference (complete/90%)	0,00011 / 0,00003	0,00053 / 0,00019	0,00005 / 0,00001
complete grid	69,8%	58,6%	50,9%
90 % grid	38,1%	31,7%	11,4%

ASTM D1250-80 Table 54 :			
% differences found - 2004 grid, within 1980 ranges			
Quantity compared:	Volume correction factor : observed to base, **4** decimals		
	A - crude oil	**B - products**	**D - lubricants**
all temperatures			
Maximum difference (complete/90%)	0,0002 / 0,0001	0,0006 / 0,0002	0,0001 / 0,0001
complete grid	13,6%	9,3%	4,3%
90 % grid	3,3%	4,4%	0,5%
temperatures below base			
Maximum difference (complete/90%)	0,0001 / 0,0001	0,0003/ 0,0002	0,0001 / 0,0001
complete grid	5,1%	6,2%	1,5%
90 % grid	4,0%	4,9%	1,1%
temperatures equal or above base			
Maximum difference (complete/90%)	0,0002 / 0,0001	0,0006 / 0,0002	0,0001 / 0,0001
complete grid	16,5%	10,5%	5,1%
90 % grid	2,6%	3,8%	0,0%

The two tables above summarize our findings for the ASTM D1250-80 tables 54. Although ASTM D1250-04 does not contain the recommendation to round the final volume correction factor to four decimals, we also compared these values with the ASTM D1250-80 four decimal volume correction factors (VCF).

As expected, since ASTM D1250-80 VCFs - for temperatures below the base temperature – are calculated with four decimals only, we observe 90 % differences in that range. Above the base temperature, within the complete 1980 range, we observe an average of 698 (crude), 586 (products) to 509 (lubricants) calculations out of 1.000 calculations that show a maximum difference of 0,00053; Within the 90 % grid, these values drop considerably as expected.

The four decimal results list the differences one has to expect when considering running an ASTM D1250-04 implementation where the VCF is still rounded to four decimals.

ASTM D1250-80 Table 54 :			
% differences found - 1980 grid, within 1980 ranges			
Quantity compared:	Volume correction factor : observed to base, **5** decimals		
	A - crude oil	**B - products**	**D - lubricants**
all temperatures			
Maximum difference (complete/90%)	0,00006 / 0,00006	0,00036 / 0,00016	0,00005 / 0,00005
complete grid	85,1%	69,4%	50,0%
90 % grid	65,8%	59,8%	47,6%
temperatures below base			
Maximum difference (complete/90%)	0,00006 / 0,00006	0,00020 / 0,00016	0,00005 / 0,00005
complete grid	90,0%	90,3%	90,0%
90 % grid	90,0%	90,3%	90,1%
temperatures equal or above base			
Maximum difference (complete/90%)	0,00006 / 0,00002	0,00036 / 0,00013	0,00002 / 0,00001
complete grid	83,4%	61,2%	39,6%
90 % grid	41,6%	29,3%	5,1%

ASTM D1250-80 Table 54 :			
% differences found - 1980 grid, within 1980 ranges			
Quantity compared:	Volume correction factor : observed to base, **4** decimals		
	A - crude oil	**B - products**	**D - lubricants**
all temperatures			
Maximum difference (complete/90%)	0,0001 / 0,0001	0,0004 / 0,0002	0,0001 / 0,0001
complete grid	13,6%	7,6%	1,7%
90 % grid	2,7%	3,6%	0,2%
temperatures below base			
Maximum difference (complete/90%)	0,0001 / 0,0001	0,0002 / 0,0002	0,0001 / 0,0001
complete grid	4,8%	4,8%	0,5%
90 % grid	3,8%	4,0%	0,4%
temperatures equal or above base			
Maximum difference (complete/90%)	0,0001 / 0,0001	0,0004 / 0,0002	0,0001 / 0,0001
complete grid	16,5%	8,7%	5,1%
90 % grid	1,7%	3,3%	**0%**

The results for the complete 1980 grid show a slightly higher % value of differences, which partially reverses within the 90% “real life” grid, This is apparently a combined effect of the different input rounding and increasing number of differences when calculating far away from the base temperature. Note that the ASTM D1250-80 “German rounding” implementation results for both grids are basically identical with these 1980 grid results.

Based on our business impact decision matrix (see Annex C), the financial impact of a change from ASTM D1250-80 to the ASTM D1250-04 version is <u>medium to low</u> for ASTM D1250-80 tables 54. Business users should be informed that differences can occur with the probabilities given in the table above, to avoid business process disruptions.

5.11. Result analysis - tables 60 A, B and D – 1980 and 2004 grid

ASTM D1250-80 Table 60 :			
% differences found - 2004 grid, within 1980 ranges			
Quantity compared:	Volume correction factor : observed to base, **5** decimals		
	A - crude oil	**B - products**	**D - lubricants**
all temperatures			
Maximum difference (complete/90%)	0,00011 / 0,0008	0,00052 / 0,00023	0,00006 / 0,00006
complete grid	76,2%	68,7%	58,6%
90 % grid	64,7%	61,5%	50,6%
temperatures below base			
Maximum difference (complete/90%)	0,00009 / 0,0008	0,00032 / 0,00023	0,00006 / 0,00006
complete grid	90,0%	90,3%	90,0%
90 % grid	90,0%	90,3%	90,1%
temperatures equal or above base			
Maximum difference (complete/90%)	0,00011 / 0,0004	0,00052 / 0,00019	0,00004 / 0,00001
complete grid	70,6%	58,3%	48,9%
90 % grid	39,3%	32,8%	11,1%

ASTM D1250-80 Table 60 :			
% differences found - 2004 grid, within 1980 ranges			
compared quantity:	Volume correction factor : observed to base, **4** decimals		
	A - crude oil	**B - products**	**D - lubricants**
all temperatures			
Maximum difference (complete/90%)	0,0002 / 0,0001	0,0006 / 0,0002	0,0001 / 0,0001
complete grid	13,0%	9,2%	3,7%
90 % grid	3,4%	4,6%	0,5%
temperatures below base			
Maximum difference (complete/90%)	0,0001 / 0,0001	0,0003 / 0,0002	0,0001 / 0,0001
complete grid	6,1%	7,2%	1,7%
90 % grid	4,1%	5,2%	1,1%
temperatures equal or above base			
Maximum difference (complete/90%)	0,0002 / 0,0001	0,0006 / 0,0002	0,0001 / 0,0001
complete grid	15,9%	10,2%	4,3%
90 % grid	2,7%	4,0%	0,0%

The two tables above summarize our findings for the ASTM D1250-80 tables 60. Although ASTM D1250-04 does not contain the recommendation to round the final volume correction factor to four decimals, we also compared these values with the ASTM D1250-80 four decimal volume correction factors (VCF).

As expected, since ASTM D1250-80 VCFs - for temperatures below the base temperature – are calculated with four decimals only, we observe 90 % differences in that range. Above the base temperature, within the complete 1980 range, we observe an average of 706 (crude), 583 (products) to 489 (lubricants) calculations out of 1.000 calculations that show a maximum difference of 0,00052; Within the 90 % grid, these values drop considerably as expected.

The four decimal results list the differences one has to expect when considering running an ASTM D1250-04 implementation where the VCF is still rounded to four decimals.

ASTM D1250-80 Table 60 :			
% differences found - 1980 grid, within 1980 ranges			
Quantity compared:	Volume correction factor : observed to base, **5** decimals		
	A - crude oil	**B - products**	**D - lubricants**
all temperatures			
Maximum difference (complete/90%)	0,00007 / 0,0006	0,00036 / 0,00017	0,00005 / 0,00005
complete grid	84,8%	69,5%	40,5%
90 % grid	66,2%	60,7%	47,0%
temperatures below base			
Maximum difference (complete/90%)	0,00007 / 0,0006	0,00024 / 0,00017	0,00005 / 0,00005
complete grid	90,0%	90,3%	90,0%
90 % grid	90,0%	90,3%	90,1%
temperatures equal or above base			
Maximum difference (complete/90%)	0,00007 / 0,0002	0,00036 / 0,00013	0,00002 / 0,00001
complete grid	82,7%	59,4%	25,3%
90 % grid	42,5%	31,0%	3,8%

ASTM D1250-80 Table 60 :			
% differences found - 1980 grid, within 1980 ranges			
Quantity compared:	Volume correction factor : observed to base, **4** decimals		
	A - crude oil	**B - products**	**D - lubricants**
all temperatures			
Maximum difference (complete/90%)	0,0001 / 0,0001	0,0004 / 0,0002	0,0001 / 0,0001
complete grid	12,9%	7,6%	0,7%
90 % grid	2,9%	3,9%	0,2%
temperatures below base			
Maximum difference (complete/90%)	0,0001 / 0,0001	0,0002 / 0,0002	0,0001 / 0,0001
complete grid	5,7%	5,7%	0,6%
90 % grid	3,9%	4,3%	0,4%
temperatures equal or above base			
Maximum difference (complete/90%)	0,0001 / 0,0001	0,0004 / 0,0002	0,0001 / 0,0001
complete grid	15,9%	8,5%	0,8%
90 % grid	1,9%	3,5%	**0%**

The results for the complete 1980 grid show a slightly higher % value of differences, which partially reverses within the 90% “real life” grid, This is apparently a combined effect of the differing input rounding and increasing number of differences when calculating far away from the base temperature. Note that the ASTM D1250-80 “German rounding” implementation results for both grids are basically identical with these 1980 grid results.

Based on our business impact decision matrix (see Annex C), the financial impact of a change from ASTM D1250-80 to the ASTM D1250-04 version is <u>medium to low</u> for ASTM D1250-80 tables 60. Business users should be informed that differences can occur with the probabilities given in the table above, to avoid business process disruptions.

5.12. Additional recommendation for even ASTM D1250-80 tables

> ⚠ ***If you are running your system using an ASTM D1250-80 implementation with the five-decimal volume correction factor for values below 1 and the four decimal volume correction factors for values above 1, we also recommend that you educate business users about the following fact: With ASTM D1250-04 one will observe more accurate five decimal VCF values for all observed temperature values below the respective base temperature.***

6. Comparison of ASTM D1250-52 data with ASTM D1250-80/04 procedures

The 1952 version of ASTM D1250 is only available as printed tables for a different product classification, thus we performed a statistical analysis for approx. 100 data points for temperature and compared the results with the ASTM D1250-04 version.

On average, the differences are in the order of 0,05 %, which represents a difference up to the 4th digit of a quantity value when taking rounding into account

We then also started a full comparison run for the computerized version of API/IP Table 6 (1952) with the corresponding 1980 and 2004 implementations, based on our proven 2008 comparison analysis:

Gravity: 0 °API to 100 °API
Temperature: 0 °F to150 °F
Number of calls: 19.890

Standard #	Differences	Average+%	Maximum+%	Average-%	Maximum -%
1980(4)	17140	0,0399	0,0626	0,0806-	0,9930-
1980(5)	18072	0,0400	0,0626	0,0806-	0,9930-
2004	19500	0,0399	0,0626	0,0811-	0,9930-

This detailed analysis confirms our statistical finding above. Large differences (Maximum - %) are noticeable for temperature values further away from the base temperature of 60 °F. These findings are also in agreement with the data provided in [2]: Table A-10-Average Error in the 1952 Table 6.

7. Summary of ASTM D1250 comparison analysis – business view

The following tables summarize our results:

ASTM D1250 version	Available as printed table book	Available with implementation guidelines	Average difference compared to 1980	Average difference compared to 2004
1952	yes	no	0,05 %	0,05%
1980	yes	yes	same	table dependent
2004	no	yes	table dependent	same

The American Petroleum Institute states in the 2004 MPMS Chapter 11.1 implementation guidelines:

“Due to the nature of the changes in this Revised Standard (ASTM D1250-04), it is recognized that guidance concerning an implementation period may be needed in order to avoid business disruptions within the industry and ensure proper application.”

Within the Industry, and across the Internet, we found no guidance document. Thus, in this paper we provide table dependent recommendations (see chapter 5) to make such guidance available to organizations wishing to migrate to the new ASTM D1250-04 standard. Overall, the total average observable difference between an ASTM D1250-80 and ASTM D1250-04 implementation is about 0,001%, which can be considered as a low to negligible business risk from a financial impact point of view (see our annex C business impact decision matrix). However, since the differences depend on the measurement data accuracy and rounding, as well as on the specific table in use, a closer look at individual organizational business and measurement practices combined with a possible “Safe Passage” project approach is advisable.

8. Conclusion

We compared the differences in the results of the 2004 and 1980 versions of the ASTM D1250 standard. This massive effort using a "Brute-Force" approach resulted in detailed table-dependent recommendations and % deviation data. Form this basis business users can see the degree of difference that is likely to be observed between the two standards, and in what order of magnitude these differences will appear.
Differences between the printed 1952 version (not available as a formula-based implementation procedure) and these two versions (1980 and 2004) have been statistically examined and are found to be in a range of 0,05%, i.e. up to the 4th significant digit with respect to rounding.

In any case, it is a business decision based on company internal governance as well as legal and contractual requirements, if these differences are acceptable or not.
There are additional major technical differences between the implementations of ASTM D1250-80 and ASTM D1250-04 that should be taken in consideration.

The QuantityWare Recommendation:

ASTM D1250-04 has been extremely well designed, is reliable and fulfils all business needs. Unless legal requirements or business concerns require the further usage of ASTM D1250-52 or ASTM D1250-80 within an organization, we recommend the adoption and implementation of ASTM D1250-04, especially within new implementation projects.
QuantityWare also delivers full versions of the ASTM D1250-80 implementation, which is still required due to contractual or governmental regulations in many countries. Implementations of the ASTM D1250-52 tables are available for selected tables as well.
The QuantityWare Petroleum Measurement Cockpit can be used to print detailed lists for all ASTM D1250-XX implementations, allowing business users to analyze differences between different versions in greater detail, if this is required.
For customers that are still running their ERP system with an ASTM D1250-80 implementation, a specific "Safe Passage" project should be considered.

9. References

[1]: THE USE OF THE PETROLEUM MEASUREMENT TABLES – Manual of Petroleum Measurement Standards, Chapter 11.1 (API Std. 2540, ASTM D1250, IP200, ISO 91-1), revised October 1995, API 1995

[2]: 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, API 2004

[3]: Manual of Petroleum Measurement Standards Chapter 11.1, Volume X – Background, Development and Program Documentation, First Edition, August 1980

[4]: ASTM D1250-04: Standard Guide for the Use of the Petroleum Measurement Tables

[5]: ASTM D1250-07: Standard Guide for the Use of the Petroleum Measurement Tables

[6]: ASTM D1250-08: Standard Guide for the Use of the Petroleum Measurement Tables

[7]: ASTM D1250 – Historical Edition 1952

[8]: DIN 51757-94: Testing of mineral oils and related materials – Determination of Density

Annex A: Detailed results – complete calculation grid

For technical reasons, the results are provided as a separate annex A document, which can be found in our Knowledge Base at www.quantityware.com as well.

Annex B: Detailed results – 90 % calculation grid

For technical reasons, the results are provided as a separate annex B document, which can be found in our Knowledge Base at www.quantityware.com as well.

Annex C: Business impact decision matrix

QuantityWare uses the following assessment matrix when performing high-level business impact assessments:

% Deviation	Business impact – financials	Explanation	Business impact – process disruptions	Explanation
> 0,2 %	Massive to high	Billions to millions of dollar revenue loss.	Very high risk	Deviations of this magnitude are obvious, even to industry-external observers.
Between 0,01 % and 0,2 %	High to medium	Millions to hundreds of thousands of dollar revenue loss.	High risk	Deviations of this magnitude will be detected by controlling bodies, business users and customers.
Between 0,001 % and 0,01 %	Medium to low	Several thousands of dollar revenue loss.	Medium risk	Deviations of this magnitude in large single transaction volumes will be detected by controlling bodies, business users and customers.
< 0,001 %	Negligible	Negligible revenue impact.	Negligible to low risk	Deviations of this magnitude will only be realized by controlling bodies and cannot easily be detected by business users or customers.

It is important to note that a detailed analysis is advisable for each company that wishes to migrate to the new ASTM D1250-04 standard implementation. For a detailed analysis and to obtain realistic dollar values, customer specific business process data has to be included, e.g. per product and geographical location.