QuantityWare Working Paper

ASTM D1250-08

API MPMS Chapter 11.5

Comparison with table values of API MPMS Chapter 11.1 Volumes XI/XII (ASTM D1250-80 Tables 8, 26 and 56)

Version History

Version	Date	Description
00	2009-05-19	Initial Version
01	2017-08-02	Editorially revised and confirmed
02	2020-06-18	Modern QW document style applied
03	2023-11-01	Editorially revised and confirmed

Contents

1. Introduction

In March 2009, the American Petroleum Institute (API) released the

Manual of Petroleum Measurement Standards

Chapter 11 – Physical Properties Data

Section 5 – Density/Weight/Volume Intraconversion

Adjunct to: ASTM D1250-08 and IP 200/08

First Edition, March 2009

(Referenced as ASTM D1250-08 in this paper)

This new standard is based on equations and is intended to replace the printed tables of

Manual of Petroleum Measurement Standards

Chapter 11.1

Petroleum Measurement Tables

Intraconversion Between Volume Measures and Density Measures

Volume XI and Volume XII

Adjunct to ASTM D1250-80 and IP 200/80

(Referenced as ASTM D1250-80 in this paper)

Many of the ASTM D1250-80 tables are in use worldwide and will continue to be in use for some time, based on agreements between seller and buyer and governmental requirements.

The ASTM D1250 Historical Edition (1952) printed intraconversion tables (referenced as ASTM D1250-52 in this paper) are as well still in use in some parts of the world.

Before any changes to bulk calculations in complex computer networks are made it is necessary to obtain an overview on the differences between those standards and their business impact.

This paper provides a comparison between density in air and inverse density in air values of the most common used tables of ASTM D1250-80 and the corresponding ASTM D1250-08 formula values.

A detailed comparison of the most important printed ASTM D1250 Historical Edition (1952) intraconversion tables with the corresponding printed ASTM D1250-80 table values is not in scope of this document.

The Appendices B to D of this document provides detailed information to the interested reader.

2. Relevance of The ASTM D1250 Intraconversion Tables

Within the Oil & Gas industry, API gravity and relative density are commonly used as density units. Both API gravity (in vacuo) and relative density (in vacuo) can be converted to absolute density values (in vacuo and in air).

This conversion is important, because then a volume quantity value at 60°F can e.g., be converted into a mass (in vacuo) or weight (in air) quantity value.

Example:

For a shipment of gasoline of 10,000 gallons @ 60°F a density of 30 API @60°F is measured. What is the mass of the 10,000 gallons?

Solution:

Convert the 30 API into the absolute density value in pound per gallon, then multiply the 10,000 gallons with the pound per gallon density (in vacuo) and you obtain the mass of the shipment in pounds.

If you multiply the 10,000 gallons with the pound per gallon density (in air) you obtain the weight of the shipment in pounds.

This conversion from API gravity or relative density to absolute density values for all meaningful U.S. customary units of measure is based on well-defined mathematical formulas and includes constants that changed between 1952 and 2009. This made a periodic revision of ASTM D1250 necessary. Thus, small but detectable differences are to be expected when comparing different editions of ASTM D1250.

The following table provides a high-level overview:

ASTM D1250 edition	Implementation formula & constants	Printed table values	Differences to previous edition
1952	See reference [3]	Yes, 4 or 5 significant digits	
1980	Not known to QuantityWare	Yes, 4 or 5 significant digits	yes
2008	See reference [1]	No, formula is the standard	yes

Appendix C provides more detailed information on the historical background.

Since no printed tables are provided with ASTM D1250-08, QuantityWare provides the possibility to print results of the new ASTM D1250-08 formulas in a table format for BCP customers. QuantityWare customers can cross check our findings that we document in this paper using the Petroleum Measurement Cockpit.

3. Relevant ASTM D1250-80 Tables

The most common tables for intraconversion between volume measures and density measures are:

- Table 8

  Pounds per U.S. gallon at 60 °F and

  U.S. gallons at 60 °F per pound

  against API Gravity at 60 °F

- Table 11

  Long tons per 1000 U.S. gallons at 60 °F and

  long tons per barrel at 60 °F

  against API Gravity at 60 °F

- Table 26

  Pounds per U.S. gallon at 60 °F and

  U.S. gallons at 60 °F per pound

  against relative density 60/60 °F

- Table 56

  Kilograms per litre at 15 °C and

  litres at 15 °C per metric ton

  against density at 15 °C

We compare all printed values of these ASTM D1250-80 tables with the equation-based values of ASTM D1250-08. Since ASTM D1250-80 provides density in air values only, we compare only density in air values. ASTM D1250-08 also provides formula for density in vacuo values.

4. Comparison Between ASTM D1250-08 And ASTM D1250-80

As noted above, we compare all printed values of ASTM D1250-80 tables 8, 11, 26 and 56 with the equation-based ASTM D1250-08 results.

The following comparison is made:

Compare table values ASTM D1250-80 (available with 4 to 5 significant digits) with ASTM D1250-08 computed values rounded to defined decimal values (9 and 10 decimals)

We present the results in a comprehensive table format. The deviation between ASTM D1250-80 table values and calculated ASTM D1250-08 values is calculated based on the value of the new standard.

Example:

Average +% of 0.0020 => The ASTM D1250-80 table value shows in average a value that is by 0.0020% higher than the new ASTM D1250-08 standard value.

4.1. Comparison Results

The following table shows the result of the comparison between ASTM D1250-80 table values and ASTM D1250-08 calculated values, rounded as specified in the standard.

ASTM D1250-80 Table	Number of compared table values	Calculated quantity	Number of differences found	Average +%	Max +%	Average -%	Max -%
Tab8	851	Pounds per U.S. gallon	851	0,0020	0,0049	0,0051-	0,0123-
		U.S. gallon per pound	851	0,0032	0,0069	0,0005-	0,0016-
Tab11	851	Long tons per 1000 U.S. gallons	851	0,0000	0,0000	0,0023-	0,0049-
		Longs ton per barrel	851	0.0008	0,0018	0,0030-	0,0074-
Tab26	422	Pound per U.S. gallon	422	0,0000	0,0000	0,0030-	0,0045-
		U.S. gallons per pound	422	0,0032	0,0066	0,0007-	0,0017-
Tab56	422	Kilograms per cubic metres	379	0.0000	0.0000	0,0038-	0,0058-
		Cubic metres per metric ton	422	0,0033	0,0071	0,0010-	0,0034-

4.2. Analysis of Differences

The result of the comparison shows small differences in the order of approx. +0.003 % to -0.005 %. This result was expected, as explained in detail in Appendix D of this working paper. As noted above and explained in detail in Appendix B, it is a combination of the increased accuracy level (e.g., unit of measure intraconversion factors) and the new accepted value of the density of water at 60 °F, as well of the new standard density of reference weights and the changed density of air value.

4.3. Business Impact – Financial

As a conclusion from the analysis results noted above, the overall differences of +0.003 % to -0.005 % do not impose a major impact on a financial level for oil & gas companies. This is true if existing computer implementations did follow all recommended implementation guidelines available before. See Appendix A for an assessment matrix to support this conclusion.

4.4. Business Impact – Process Disruption

A more important aspect to be considered is the fact that business users will be able to see differences in their business transactions when comparing quantity conversion results of ASTM D1250-80 and ASTM D1250-08 calculations for large transaction quantities, e.g., when loading or unloading a large tanker.

Thus, when changing computer systems to comply with this new standard, as advised by the American Petroleum Institute [1], guidance to business users is required concerning an implementation period to avoid this kind of disruptions.

More specifically, a well-defined migration path and governance process from a legacy calculation process based on ASTM D1250-80 to a calculation process utilizing ASTM D1250-08 is required for each company, to educate business expert users and to be able to clearly explain the slight differences which will be visible e.g., in invoices and supplier bills.

See Appendix A for an assessment matrix to support this conclusion.

5. Conclusion

The new standard API MPMS Chapter 11.5, adjunct to ASTM D1250-08 provides equations instead of printed tables.

The results obtained with the equations carry more significant digits and are thus more accurate than the rounded printed table values of ASTM D1250-80.

We compared the results provided by the printed tables only and not all possible interpolation values that can be obtained with the table values.

No major fiscal impact is expected if a company moves to the new API MPMS chapter 11.5, adjunct to ASTM D1250-08 calculations. However, business process disruptions can occur if business users and customers are not well prepared and included into the decision process to move to the new ASTM D1250-08 calculation procedures.

QuantityWare delivers a complete implementation of all new API MPMS chapter 11.5 (adjunct to ASTM D1250-08) formulas in Q3 2009.

QuantityWare BCP customers can then define their specific migration path to this new standard.

Via the Petroleum Measurement Cockpit, business users can easily check and compare individual results of ASTM D1250-80 table values and ASTM D1250-08 values, avoiding business process disruptions since they are readily able to explain any small differences that may occur to their customers.

6. References

[1] API Manual of Petroleum Measurement Standards, Chapter 11 – Physical Properties Data

Section 5 – Density/Weight/Volume Intraconversion,

Adjunct to: ASTM D1250-08 and IP 200/08

[2] API Manual of Petroleum Measurement Standards, Chapter 11.1 – 1980, Volume XI/XII,

Adjunct to: ASTM D1250-80 and IP 200/80

[3] Report on the Development, Construction, Calculation and Preparation of the ASTM – IP Petroleum Measurement Tables (ASTM D1250; IP 200), 1960, published by the Institute of Petroleum, 61 New Cavendish Street, London, W.1 and American Society for Testing Materials, 1916 Race Street, Philadelphia 3, Pa

Appendix A. Business Impact Decision Matrix

To make an assessment on the business impact (as done in this paper), QuantityWare uses the following assessment matrix (high level approach).

For a detailed analysis, customer specific business process data must be included, to obtain realistic dollar values e.g., per product and geographical location. Such an analysis requires a much higher effort.

% deviation	Business impact – financials	Explanation	Business impact – process disruptions	Explanation
> 0.2 %	High to massive	Deviations of this magnitude can result in millions to billions of dollars revenue loss, **depending on product value & total company turnover**	Very high risk	Deviations of this magnitude can easily be detected by business users and customers, very high risk of process disruptions
Between 0.01 % and 0.2 %	Medium to high	Deviations of this magnitude can result in hundreds of thousands to millions of dollars revenue loss, **depending on product value & total company turnover**	High risk	Deviations of this magnitude can be detected by business users and customers, high risk of process disruptions
Between 0.001 % and 0.01 %	low to medium	Deviations of this magnitude can result in several thousands of dollars revenue loss, **depending on product value & total company turnover**	Medium risk	Deviations of this magnitude can be detected by business users and customers (large single transaction volume), medium risk of process disruptions
< 0.001 %	Negligible	Deviations of this magnitude do not result in large financial losses.	Negligible to low risk	Deviations of this magnitude cannot easily be detected by business users and customers, low risk of process disruptions, negligible financial impact

Appendix B. Technical Background

The ASTM D1250-80 printed tables are limited in range (density values) and by the number of printed calculation results.

Example: ASTM D1250-80 Table 8 is based on API Gravity @ 60 °F in the range of 0.0 to 85.0 with an increment of 0.1 API. Of course, it is possible to obtain additional values in between by defined interpolation rules.

The pounds per U.S. gallon @ 60 °F density in air is rounded to 3 decimals and thus printed with 3 decimals, carrying an accuracy of 4 significant digits.

The U.S. gallon per pound @ 60 °F “inverse” density in air is rounded to 5 decimals and carries an information of 5 significant digits.

The new equation that replaces Table 8 has no technical limit in the range, the API Gravity can be used with an accuracy that is justified by modern density meters and the pound per U.S. gallon results are rounded to 9 decimal places, the U.S. gallon per pound values are rounded to 10 decimal places accordingly.

Thus, the results of the new and the superseded standard will already be slightly different if the new accuracy levels are applied to computer implementations.

In addition, a small influence of the new accepted density of water value of 999.016 kg/m^3 at 60 °F for °API and relative density conversion formula is expected.

Also, the density of reference weights has been adjusted to the new accepted value, as well as the density of dry air.

Changes that will also lead to small differences are the updated intraconversion factors between units of measurement, e.g., the conversion factor between gallon and liter, which are now given with a higher accuracy in ASTM D1250-08.

The new ASTM D1250-08 also provides a clear distinction between the density in air (apparent density) and density (“in vacuo”) values and thus provides formulas to calculate mass (“weight in vacuo”) and weight (weight in air) quantity values as well as volumes at standard conditions from density, whereas ASTM D1250-80 provided density in air values and inverse density in air values only.

The rounding of the results obtained with the new ASTM D1250-08 formulas is specified to provide the most accurate result that can be replicated on any modern computer system using 64-bit floating point accuracy, considering maximum obtainable measurement accuracy.

Appendix C. Historical Background

In this appendix, we provide a brief historical background on the changes of the intraconversion tables for density, volume and weight measures defined in ASTM D1250, to obtain a good estimate on the order of magnitude of the changes that we should expect when comparing table values of different ASTM D1250 editions.

For ASTM D1250-52, reference [3] is available which lists the formulas and constants that have been used in the development of the printed tables.

ASTM D1250-08 contains all revised constants and formulas in the Appendices.

For ASTM D1250-80 QuantityWare could not find any reference document that lists the formulas and constants that have been used for the development of the tables.

However, for both ASTM D1250-52 and ASTM D1250-80, the printed table values are the standard.

Thus, QuantityWare has developed own formulas based on the approach chosen in [3], which exactly reproduce the ASTM D1250-80 table 8,26 and 56 printed values. These formulas are part of the QuantityWare BCP shipment and can be utilized by BCP customers.

The conversion defined in ASTM D1250 for intraconversion between density, weight and volume is based on well-defined mathematical formulas and includes constants that changed between 1952 and 2009. This made a periodic revision of ASTM D1250 necessary.

This conversion is well defined, via a mathematical equation for API gravity and relative density. These equations contain a physical constant:

- the density of water at 60°F

During the last decades, more precise values for this value have been obtained experimentally. A new refined value for the density of water at 60°F required an update of the intraconversion tables.

The following density of water value changes can be found:

ASTM D1250 edition	Density of water @ 60 °F	Reference
1952	0.9990405 g/mL (Note: This value converted at that time via the conversion factor of 1 Litre = 1.000028 cubic decimetre [3] to a value of 999.01252 kg/m^3)	[3]
1980	Not known to QuantityWare –assume 999.012 kg/m^3 for own formula (also used in 1980 VCF formula)	[2]
2008	999.016 kg/m^3	[1]

If a shipment quantity is determined using a weigh bridge, we obtain the weight in air (not the mass) of the shipment, since the container is surrounded by air, it "swims" in air, thus experiencing a buoyancy effect. For oil products, the difference between weight and mass values for a given quantity is between 0.1% and 0.2%.

This air buoyancy effect is also included into the conversion formulas, via the well-known physical buoyancy model, between API gravity (in vacuum) and relative density (in vacuum) and the absolute density values (in air).

That is why the formulas for the conversion of API gravity and relative density contain additional physical constants, which require experimental determination or international agreement on the values to be used. These constants are:

- The density of standard air
- The density of reference weights (historically brass weights, now changed to generic reference weights)

ASTM D1250 edition	Density of standard air	Reference
1952	0.0012170 g/mL @ 60°F	[3]
1980	Not known to QuantityWare –assume 1952 value	[2]
2008	0.001199228 g/cm^3 @ 20 °C	[1]

ASTM D1250 edition	Density of standard reference weights	Reference
1952	8.393185 g/mL @ 60°F	[3]
1980	Not known to QuantityWare –assume 1952 value	[2]
2008	8.0 g/cm^3 @ 20 °C	[1]

The basic physics model of buoyancy did not change between 1952 and today. For the standard reference weight density and the standard air density a common standard temperature of 20°C is now internationally accepted and utilized in ASTM D1250-08.

If one analyzes the basic conversion formula, which is unchanged, we can obtain a rough estimate on the order of magnitude of differences to be expected based on these changes.

See appendix D for some details.

Since the above noted three physical constants are determined experimentally, the values are reported in SI units (e.g., the densities in kg/m^3). All science laboratories in the world report their results in SI units.

To convert the values in SI units to U.S. customary units (e.g., from kg/m^3 to lb/gal),

- the conversion factors from SI units to U.S. customary units

must be well defined (value & numerical precision if no exact value can be given).

These unit conversion factors are defined in ASTM D1250, but also changed between 1952 and 2009, typically the precision has been increased due to the overall availability of floating-point math processors in modern computer system.

One important change of a unit conversion factor was the definition of the liter L conversion to the cubic decimeter [3], see also comment above.

QuantityWare calls these unit conversion factors generically ASTM Table 1 factors, since D1250-80 listed these factors under the table designation Table 1.

The above listed three constants and unit conversion factors have changed between 1952 and 2009, thus making revisions of the ASTM D1250 intraconversion tables necessary. In addition, the standard temperature for the reference weights has changed as well, leading to negligible changes for that value as well. However, in high precision calculations, these changes can become visible.

The pound per gallon values (as well as all other business relevant values like long ton per barrel, short ton per barrel etc.) provided by the intraconversion tables of ASTM D1250-52 and ASTM D1250-80 are the density in air values, whereas the API gravity and relative density always are the density in vacuum values. The intraconversion tables of ASTM D1250-52 and ASTM D1250-80 also provide the inverse density in air values, e.g., gallon per pound, long ton per pound etc. Since the U.S. customary units are not related to each other with conversion factors that are a multiple of 10, for each relevant combination of absolute density units and API gravity and relative density, a table had been developed, for convenience of the business users applying the table values in their calculations.

The API MPMS Chapter 11.5 formulas which are adjunct to ASTM D1250-08 now provide both the conversion formulas into density in air and density in vacuum, so that both mass and weight can be calculated using this new standard.

Appendix D. Details - Understanding The Differences

In this appendix, we provide some details how we can understand the deviation in % between the ASTM D1250-80 table values and the ASTM D1250-09 computed values, and how we can make a rough estimate on the magnitude of the % deviations that we calculate for each specific table.

For the 1952 versions of the weight & volume intraconversion tables, the report from 1960 mentioned in reference [3] provides the conversion formulas that have been utilized to construct the 1952 table values. In this appendix, these formulas are referenced as **1960 formulas**.

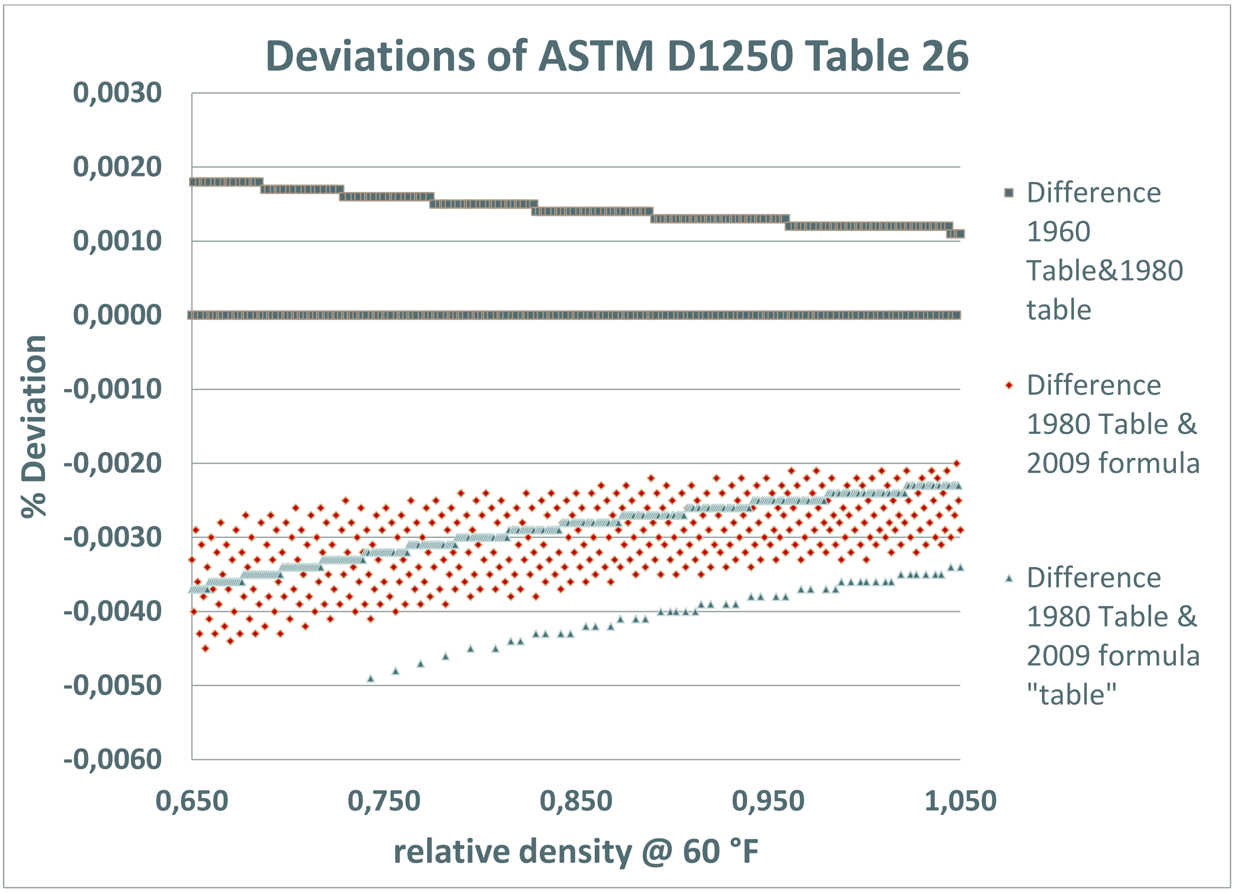
For the 1980 table values [2], no specific report has been made available to our knowledge how the values have been calculated. It can be assumed that the formulas have been adjusted to the then (1980) new value of the density of water of 999.012 kg/m3.

Thus, QuantityWare delivers with BCP 10A a solution for the 1980 table values which directly reads all printed table values for tables 8, 11, 26 and 56.

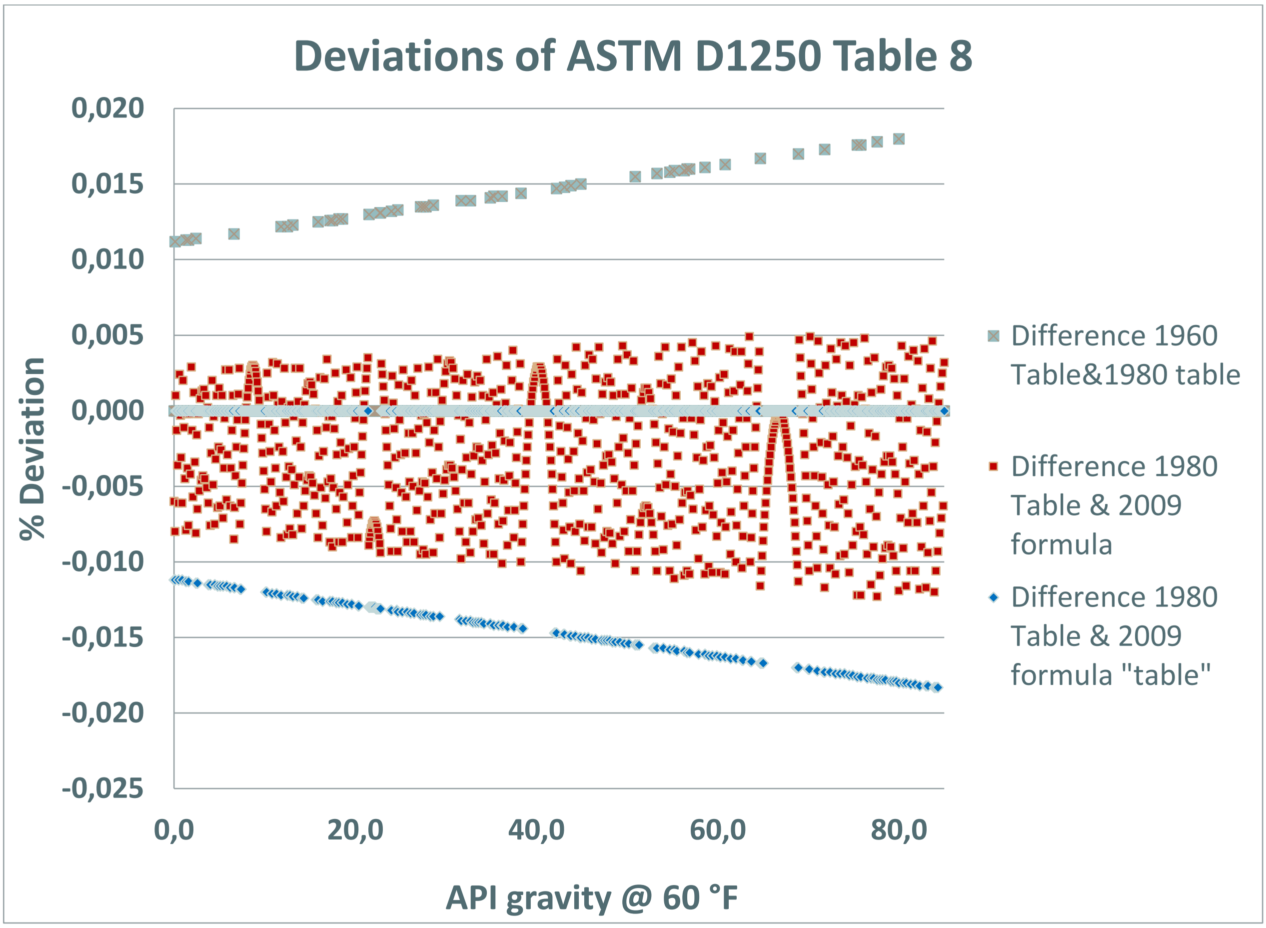
The solution also contains a heuristic formula (**1980 QW formula**) based solution which reproduces all the 1980 table values. Customers can choose which of these two possible implementations are to be utilized in their calculations. The formulas are based on the established 190 formulas, with updated constants and unit of measure conversion factors, to reproduce all printed table values. For some tables, heuristic shifts had to be introduced, to achieve 100% mapping with the printed standard values.

The new 2008/2009 values are not made available as printed tables but provide the clearly defined implementation formulas [1]. Down below these formulas are references as **2009 formulas** (since the API MPMS 11.5. that specifies the adjunct to ASTM D1250-08) has been published in 2009).

The 1952 and 1980 table values are both printed with a limited accuracy of 4 or 5 significant digits (densities in air) or 5 significant digits (inverse densities).



Deviations of ASTM D1250 Table 26
% Deviation
0,0030
0,0020
0,0010
0,0000
-0,0010
-0,0020
-0,0030
-0,0040
-0,0050
-0,0060
0,650
0,750
0,850
0,950
1,050
relative density @ 60 °F
Difference 1960 Table&1980 table
Difference 1980 Table & 2009 formula
Difference 1980 Table & 2009 formula "table"


Deviations of ASTM D1250 Table 8
0,020
0,015
0,010
0,005
0,000
-0,005
-0,010
-0,015
-0,020
-0,025
% Deviation
0,0
20,0
40,0
60,0
80,0
API gravity @ 60 °F
Difference 1960 Table&1980 table
Difference 1980 Table & 2009 formula
Difference 1980 Table & 2009 formula "table"

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