Filling liquid cosmetic products in retail packages – weight-to-volume conversion by means of density measurement

Relevant for: Producers & contract fillers of liquid and paste-like samples (cosmetics, personal care products …) packed in consumer/retail packages

A liquid product is frequently transferred into retail/consumer packages by means of weight. To state the volume on the package or on the label, the density of the filled product is needed for the conversion of weight to volume.

1 How much volume is in the package?

The final step in production is normally the filling of the material in its transport container or more important the consumer-suitable retail package.

Especially for low and high viscous liquids or even paste-like substances from various industries, especially cosmetics and personal care, this is frequently done by transferring product into the empty package until the desired weight is reached.

Customer protection laws and regulations require that the labelling must indicate the volume in the case of liquid products (in e.g. milliliters or liquid ounces). For Europe this is connected with the "℮"-symbol on packages [1, 2] but there are also regulations in other countries [e.g. USA: reference 3 & 4; South Africa: 5].

Producers and fillers of cosmetic products have to fill exactly the amount that is stated on the package or label for two reasons:

- Overfilling means adding too much valuable product, resulting in costly output reduction of readily filled packages.
- Under-filling deceives consumers, is illegal and results in fines.

A reliable procedure to keep the required filling volume within limits and to comply with legal requirements is therefore necessary and economically reasonable.

As density is calculated by dividing the sample's mass by the volume, it takes up at a certain temperature, a conversion to calculate the volume is simple.

$$\rho = \frac{m}{V} \text{ therefore } V = \frac{m}{\rho}$$

2 Digital density measurement short & simple

To measure the density of a solution or pasty goods with a digital density meter, the sample is introduced into the U-shaped tube of the density meter. After being excited the U-tube's oscillations depend on the density of the sample. The lower the density is, the higher is the oscillation frequency. The density is also temperature dependent, so the temperature must be determined precisely.

Anton Paar's density meters measure the true density ρ_{true}, which corresponds to the mass of the sample divided by its volume. The mass of a body is independent of environmental conditions such as buoyancy in air or gravity. However, if the filling volume needs to be calculated based on the determined density, the apparent density is required which corresponds to the sample's weight in air divided by its volume V [for a more detailed explanation see reference 6].

The following formula [7] allows the calculation of the volume V of the sample from its weight $m_{product}$:

$$V = \frac{0.99985 * m_{product}}{\rho_{true} - 0.0012}$$

where ρ_{true} is the true density obtained with an Anton Paar density meter at reference temperature. The constant 0.0012 corresponds to the density of air at 20 °C.

3 Excursion: Why fill by weight and not directly by volume?

3.1 Direct controlled volumetric filling

Directly controlling the filling volume mostly means control via timing of a filling valve. Such measurement highly depends on the flow rate of the product filled and will need separate calibration each time the product properties, specially the viscosity, changes. This action can be difficult and tedious due trapped air bubbles in non-transparent liquids or issues with the leveling to achieve a liquid meniscus in the reference vessel.

3.2 Other means of measuring the filling volume

An alternative way to measure filling volume can be sensors like floating plungers, which pose significant hygiene risks due to possible product carry-overs.

Other sensors in the line based e.g. on the Coriolis force principle are sometimes also used. These need proper, regular calibration, normally lack correlation with a reference instrument in the laboratory and can be expensive to apply in filling lines for less expensive products.

3.3 Benefits of gravimetric filling

Both balances and load cells for weighing deliver precise results, are simple to calibrate and can be used for alternative purposes in the production process as well. Often, they are commonly available in a laboratory or production area and are simply integrated in a filling line.

Additional benefits of weighing a container during its filling are:

- Bubble-prone, non-transparent liquids of various viscosity can be measured easily due to little effect of the bubbles on weight.
- Deviation of the weight of empty container as additional information. Too little mass allows for detection a broken vessel. Exceeding permitted empty weight indicates residues/contamination in the package.
- Monitoring average filling rate, translating into weight change while filling, and deviations of it below a reference pointing to leakages while filling.

4 The right density meter for every application

4.1 DMA 35

The portable density meter DMA 35 with three decimal places opens up the series of devices best suitable for this application.

Figure 2: The portable density meter DMA 35

DMA 35 measures the true density at sample temperature, determined directly at the density U-tube.

To convert the density to a reference temperature different to the measuring temperature, knowledge of the temperature coefficient is required, which can be determined in a simple way.

$$Temperature\ coefficient = \left|\frac{\rho_1 - \rho_2}{T_1 - T_2}\right|$$

Practically, the true density of a sample is measured at two different temperatures, the difference between them is divided by the difference between the two temperature values. The result is the temperature coefficient, which always has a positive sign. Next enter the desired reference temperature and the appropriate temperature coefficient in the “Density@” function.

Entering an offset (density of air at 20 °C = 0.0012 g/cm³) to compensate for the buoyancy will lead to the apparent density ρ_{app}, which is needed for the determination of the correct volume.

Tip: The measuring cell of DMA 35 can also be filled with a syringe. This is especially useful in case of high viscous and pasty samples.

4.2 DMA 501 & DMA 1001

The two density meters DMA 501 and DMA 1001 are suitable, compact benchtop instruments which also allow for thermostatisation of the sample. They are built for operation even in production spaces.

Figure 3: The DMA 501 density meter

The apparent density of the sample can be displayed and printed (in g/cm³, g/mL, kg/m³ and lb/gal).

5 How to determine the accuracy of the calculated filling volume?

The accuracy of the used instrumentation, the measurement and as well the sample itself contribute to the minimal detectable filing error. Therefore, the density meter's accuracy is relevant.

The deviation range of the calculated filling volume ΔV depends on the density of the solution and the accuracy of the instrument Δρ.

$$\Delta V = \frac{\Delta\rho}{\rho_{app,sample} + \Delta\rho} * 100\% \approx \frac{\Delta\rho}{\rho_{app,sample}} * 100\%$$

Table 1 lists the specified accuracies of various DMA density meters.

Instrument	Specified instrument accuracy Δρ
DMA 35	±0.001 g/cm³
DMA 501	±0.001 g/cm³
DMA 1001	±0.0001 g/cm³

Table 1: Accuracies of various DMA density meters

Example:

The accuracy of the calculated filling volume ΔV for a density value of 0.7 g/cm³, obtained with DMA 35 or DMA 501, amounts to

$$\Delta V \approx \pm \frac{0.001\ g/cm^3}{0.7\ g/cm^3} * 100\% = \pm 0.143\%\,.$$

If better accuracies are required, DMA 1001 is recommended.

6 Summary

Regulations require the volume of a product to be stated directly or on the label of retail or consumer packages containing liquid or semi-solid products.

Producers and contract fillers frequently fill products based on weight determination as weighing versus volumetric determination of such goods offers numerous advantages. Weighing can be done fast and is non-destructive when the average tare is known.

All these considerations show that density measurement with Anton Paar density meters is the suitable way to go for weight-to-volume conversion when checking the quantity of a filled product, e.g. prior to delivery, and specifying the correct volume on label or package. Additionally, density is a versatile quality control parameter throughout the whole production process. This offers multiple uses of the instrument in your process.

7 References

[1] Verordnung über Fertigpackungen (Fertigpackungsverordnung) FertigPackV 1981 § 7 Kennzeichnung der Füllmenge bei Fertigpackungen mit bestimmten Erzeugnissen

[2] EUR-Lex Labelling of pre-packed products Dec 14, 2015

[3] Electronic Code of Federal Regulations e-CFR data current as of February 3, 2020 PART 500—REGULATIONS UNDER SECTION 4 OF THE FAIR PACKAGING AND LABELING ACT § 500.7 Net quantity of contents, method of expression

[4] NIST Handbook 130 & 133 (2020)

[5] SANS 1841:2015 & SANS 289:2016

[6] Anton Paar Application report "Determining filling volumes based on density measurement" XDLIA023EN

[7] WELMEC 6.4, 2015 Guide for packers and importers of ℮-marked pre-packed products

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