Milk volume measurement

Air compensation for different measuring principles

Article

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Contents

1 General Information

This article describes the general problems for verification of volume meters, especially when using milk during the verification.

New MID rules expand the demands of the verification, among these that the same liquid as the plant is intended for is used for the verification as well. This means that milk trucks have to be verified using milk.

1.1 Explanation of the terms used in this article

Accuracy: Specifies correctness = how close a value is to be totally correct. The accuracy is determined by means of the mean value of many measurements compared to the international definition of the unit of the measurement value, for example meter or m^3. A relative accuracy of for example 99.5 % corresponds a relative deviation or error of (100 % - 99.5 %) = 0.5 %.

Deviation: Specifies the difference between the correct value and the value, for example a measurement value. Relative deviation is indicated in % of the actual value or of full scale. The specifications of measuring instruments often use the expression accuracy, where it in fact ought to be deviation.
MID specifies the allowed relative deviation of the measurement in percentage of the actual measurement.

Precision: The fluctuation each individual measurement has, compared to the mean value of many measurements.

Worst case error indication for a single measurement = deviation + fluctuation.

1.2 MID demands

The volume meter is verified separately. A maximum deviation of ±0.3 % is demanded.

The entire measurement system must be verified. The verification must include the parts that may influence the measurement. On a milk truck, this can be for example hose(s), tubes, air separator, flow transmitter, and potentially other mechanical components.

By verification of an entire measurement system with milk a deviation of ±0.5 % is allowed.

Normal practice demands an accuracy of the measuring equipment used for verification being 10 times better compared to the equipment being verified. Thus the demand of the verification equipment is ±0.03 %.

Verification of measuring equipment, which is specified to comply with fluctuations of ±0.25 % when calibrated correctly, demands a verification equipment with a deviation + fluctuation better than ±0.05 % (since 0.3 % – 0.25 % = 0.05 %) to verify to ±0.3 % .

Accuracy and precision of the verification equipment must during verification include influence of air content in the liquid, specific gravity (volume weight), the temperature's influence on the specific gravity, as well as mechanical conditions. It is therefore important to analyze all parameters that may have influence on the verification and its uncertainty.

1.3 Water

The use of water for the verification has the advantage that the air can relatively easier leave the liquid. The specific gravity of water as a function of the temperature is known with a high accuracy.

To have the verification equipment complying with the specified demands for maximum deviation, the test equipment must be designed in such a way that air is minimized as much as possible.

If the water is taken directly from the water works, it isn't necessarily air-free. It is therefore recommended that the water gets a chance of de-airing.

The conductivity of the liquid must be measured and it must be verified that it isn't below the minimum conductivity of the flow transmitter. The best calibration is obtained by adapting the conductivity to the liquid that the meter is supposed to measure at a later stage. It is especially important to pay attention to the fact that water deriving from de-salting or desalination plants has a very low conductivity. This is common in London, among other cities, where water is supplied from such a plant.

1.4 Milk

In the dairy business it is known that air being whipped into the milk, for instance by pumps, agitators etc., is very difficult to get rid of, since the air is split in very small air bubbles. Air whipped into milk won't leave it, even if it is left in an open vessel for a longer time. Whipped cream is an example of this phenomenon.

The air cannot be removed by traditional air separators. In case the milk being used for verification has been collected by a tanker, where milk as well as air is sucked in at end of the process, even more air is whipped into the milk.

In case the SAME MILK is reused for several tests, the content of non-removable air in the milk rises for each test.

The fact that milk used for verification is not available without any air causes that the reference volume used during verification must be compensated for the air content of the milk.

1.5 The air volume's dependency on pressure

The volume meter measures the volume that passes through the meter. When the liquid contains air, the air's volume will be added to the measurement value. The air's volume in the meter is dependent on the pressure of the liquid when it passes through the meter.

The *ideal gas equation* is a mathematical model that describes the relation between volume and pressure.

In simplified form: Pressure * Volume = Constant * Temperature.

For the same liquid, with air at varying pressure, but at the same temperature, the following applies:

$$Pressure_1 * Air\ volume_1 = Constant * Temperature = Pressure_2 * Air\ volume_2$$

$$\boldsymbol{Air\ volume_2 = Air\ volume_1 * Pressure_1 / Pressure_2}$$

The pressure is absolute, meaning relatively to vacuum. The liquid close to the surface of a container, which is ventilated to atmosphere, is exposed to the atmospheric pressure, approximately 100 kPa or 1 bar. The pressure increases down through the liquid.

Air % @ **atmospheric** pressure is used as an indicator for the air content in liquids. When the liquid passes through a volume meter, the pressure $P_{volume\ meter}$ will differ.

$$\boldsymbol{Air\ \%\ in\ volume\ meter = Air\ \%\ @\ atmospheric * P_{atmospheric} / P_{volume\ meter}}$$

If the liquid contains air, the indication of the flow transmitter must be reduced.

$$V_{volume\ meter} = V_{air\text{-}free} + V_{air} = V_{air\text{-}free} *(1 + Air\ \%_{volume\ meter} / 100)$$

$$V_{air\text{-}free} = V_{volume\ meter} / (1 + Air\ \%_{volume\ meter} / 100)$$

$$V_{air\text{-}free} = V_{volume\ meter} / (1 + (Air\ \%_{atmosphere} / 100) * P_{atmospheric} / P_{volume\ meter})$$

For example, if it is assumed that the milk contains 1 % air at atmospheric pressure, and the meter has a working pressure of 2 bar, the correction must therefore only be:

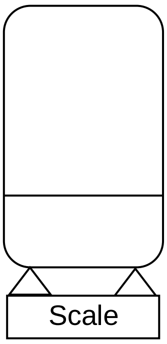
$$\boldsymbol{Air\ volume_2 = Air\ volume_1 * Pressure_1 / Pressure_2}$$

Air volume in the meter @ 2 bar = 1 % * 1 bar/2 bar **= 0.5 %**

In the following sections various forms of reference volumes are described. After that, verification of volume meters separately. Finally, the principles for verification of measuring systems are described.

2 Reference volume based on an electronic mass-meter (scale)

An electronic scale is a mass-meter with built-in force-meter that measures the force [N], by which it is influenced. Force is converted into a mass [kg] by dividing with acceleration due to gravity at the actual location (varies around the globe).



The mass-meter shows the mass [kg] of what is put on the scale.

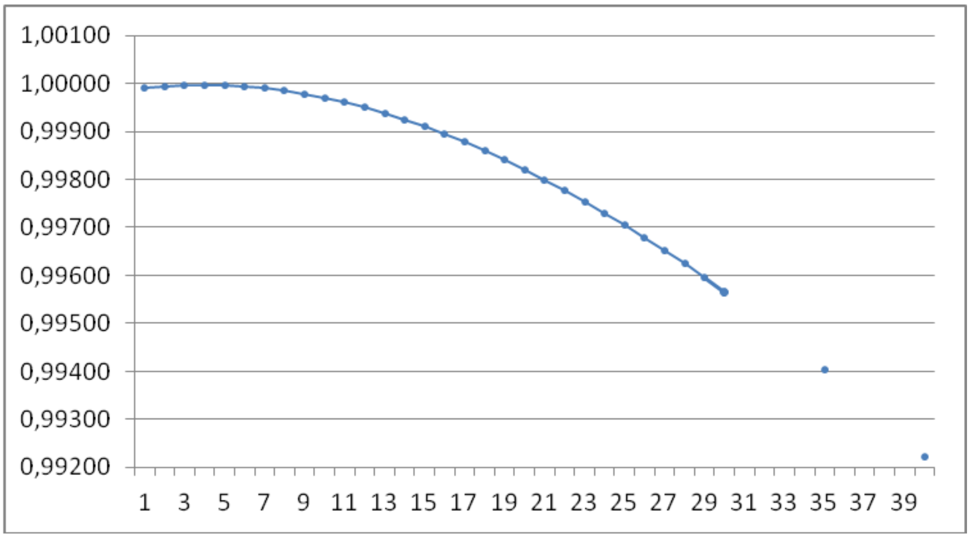
When a verified weight is used to verify the scale, the applied weight has been compensated for the weight of air which it displaces (Archimedes' principle). When a liquid has to be weighted out on a verified scale, the weight must be adjusted for the mass of the displaced air, approximately 1.29 kg/m^3 @ 20 °C corresponding **0.129 %** for liquids with a specific gravity of 1,000 kg/m^3 like for instance water.

The liquid has a density [kg/m^3] which specifies mass/volume.

The density of water is temperature dependent, increasing approximately 0.2 % from 4 °C to 20 °C.

In the curve below, the temperature dependency relatively to 4 °C of the density of water is shown.

The X axis specifies the temperature and the Y axis the relative density factor.



Conversion from mass (weight):

*Volume = measured mass / (the liquid's density @ 4 °C * temperature compensation (temperature) – density of the surrounding air @ atmospheric pressure)*

Exactly the same correction must be used when control weighting a truck on a weigh bridge and calculating the contents from the weighing value with full tank minus the weighing value with empty tank.

This also applies to the farmer who weights the milk prior to collection.

2.1 Water with and without air

The mass of liquid on the scale does not change when the liquid contains air.

*Volume = measured mass / (the liquid's density @ 4 °C * temperature compensation (temperature) – density of the surrounding air @ atmospheric pressure)*

The density of water is known with a relatively high accuracy.
Definition of volume by means of weighing can therefore be carried out relatively accurately.

Uncertain factors are:

- Accuracy and precision of the scale
- Accuracy of the specific gravity
- Accuracy of the correction of the specific gravity as a function of temperature
- Density of the air at the temperature at which the measurement takes place
- Air content of the liquid

2.2 Specific gravity of milk

The problem here is that the specific gravity of milk varies ±0.1 % depending of fat percentage, season of the year, etc.

Since air in the milk does not influence on the mass measurement, the specific gravity of the milk without air must be defined.
Specific gravity = density / (volume without air). This demands that the air content is accurately known.

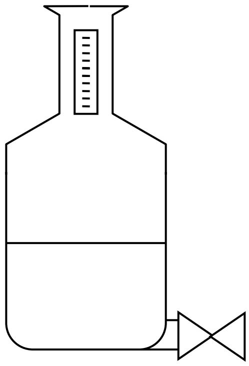
Uncertain factors are:

- Accuracy and precision of the scale
- **Accuracy of the specific gravity**
- **Accuracy of the correction of the specific gravity as a function of temperature**
- Density of the air at the temperature at which the measurement takes place
- **Air content of the liquid**

The specific gravity of the milk must be known with a high accuracy (deviation less than 0.01 %).
Since the specific gravity of air-free milk varies, density measurement cannot be used to determine the air volume.
The required accuracy for the sum of the above mentioned parameters is almost unreachable.

3 Defining reference volume by a verified measurement tank

The tank is verified and has a defined accuracy.



The liquid's **specific gravity without air** does not affect the result.

When the tank is filled with milk to a known reference level, this volume includes air.

$$V_{refence} = V_{air\text{-}free} + V_{air}$$

When the air content in the milk increases, **the air-free volume is reduced,** and thus there is less air-free milk in the reference tank.

The air content must be known when verifying measuring systems that include for example an air separator. An air separator removes air, and it is therefore necessary to know the air content in the measuring tank to calculate the volume of air-free milk.

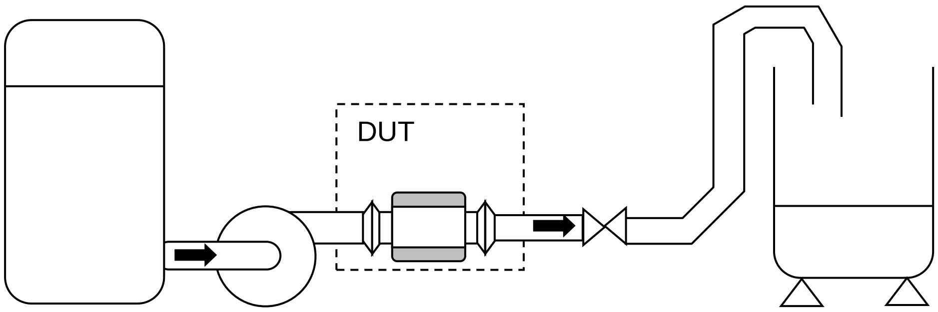
Uncertain factors are:

- Accuracy and precision of the measuring tank
- **Temperature dependency of the measuring tank**
- **Air content**

The air content cannot be calculated from measured specific gravity. See section: 2.2

4 Separate verification of volume meters by means of a reference volume based on an electronic mass-meter (scale)

Verification of a volume meter, during which the meter and the tube are kept filled.



In the illustrated model the liquid is pumped through the volume meter via a constant pressure valve into a tank on a calibrated scale. The weight indication must be compensated for the water's specific gravity, the temperature, etc. See section 2.

4.1 Without air

When calibrating air-free water, the indication of the volume meter must be calibrated in order to display the compensated volume of the scale.

4.2 With air

The scale does not register air, but the flow transmitter measures the volume including air.

The air % @ atmospheric pressure is measured manually. The measured value must be adjusted for the pressure in the flow meter. See section 1.5

$$V_{air\text{-}free} = V_{volume\ meter} / (1 + (Air\ \% * P_{atmospheric} / P_{flowmeter} * 100))$$

The meter is calibrated so that the calculated $V_{air\text{-}free}$ in the flow meter equals the compensated reference volume.

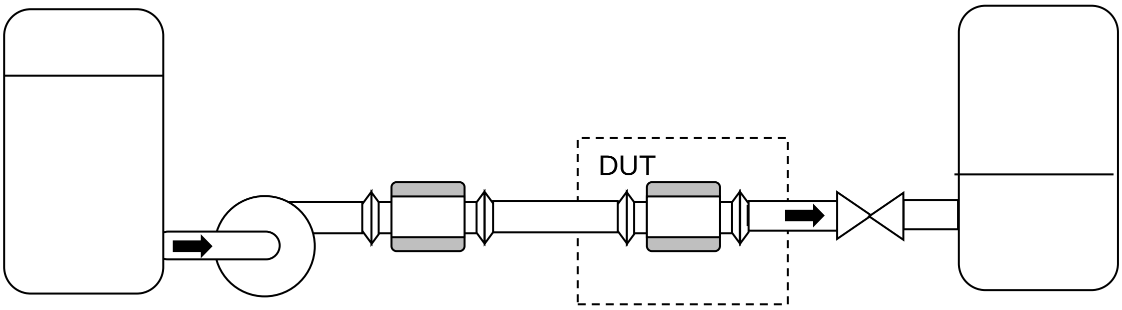
Uncertain factors are:

- Deviation of scale-based reference volume
- Air content (combined and free) in the liquid when it passes through the flow transmitter

The air content should be measured **after** the flow meter, since leaks at connections and axel gaskets are not visible, but do influence the measurement.

Conclusion: This type of verification demands an accurate and precise air measurement.

5 Verification of volume meters with a reference volume meter



The illustrated arrangement pumps water from a tank through a verified volume meter, followed by the flow transmitter that requires verification (DUT = Device Under Test), through the counter-pressure valve and into a tank.

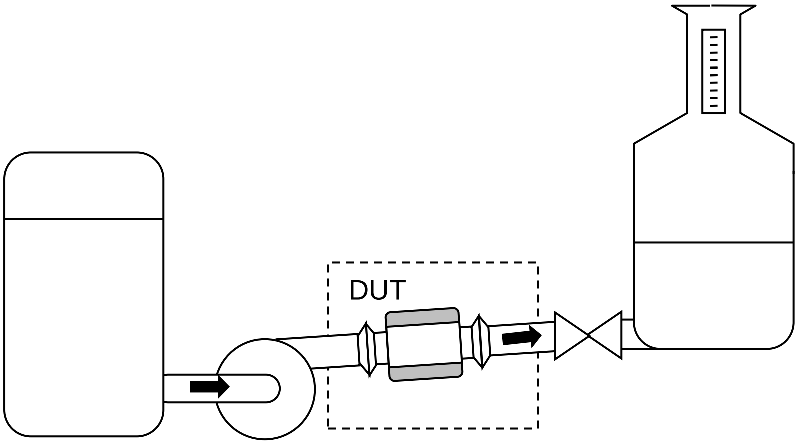
This construction removes many uncertainties.

The liquid's air content does not affect the measurement, since the same quantity of air flows though both meters, however on condition that the pressure in the two meters is the same. Neither the specific gravity nor the temperature of the liquid has any affect. It is only the accuracy and the precision of the reference meter that affect the accuracy of the verification. Accuracy and precision of the best flow transmitters on the marked correspond a verified scale. This test model is especially suitable for mobile verification equipment.

The conductivity of the liquid has to be measured and it must be checked that it is not below the minimum conductivity value for the flow. The best calibration is obtained by adapting to the liquid that the transmitter is intended to measure at a later stage.

To obtain the best calibration, the verification should be carried out at normal flow speed.

6 Verification of volume meters using a calibrated volume tank



The illustrated arrangement pumps water from a tank through the volume meter to be verified, through the counter-pressure valve, and into a tank.

First tube, pump and transmitter are filled entirely. After that, the pump is started, and secondly the valve is opened. The sequence is important to avoid air in the transmitter. The flow transmitter is placed in a tilted position to ensure that no air pocket gets stuck in it.

There has to be compensated for the air content and the pressure in the transmitter.

Combined air takes up space in the measuring tank. If necessary, free air can be bled from the measuring tank. Free as well as combined air passes through the flow transmitter. The air volume in the flow transmitter differs from the air volume at atmospheric pressure and must therefore be compensated for the pressure of the liquid when it passes the transmitter, according to a phenomenon known as the Venturi Effect.

The air content in the flow transmitter and the tank must be measured separately, since a part of the air may escape from the verified reference tank.

If the liquid contains air, the indication of the flow transmitter has to be reduced.

$$V_{air\text{-}free} = V_{volume\ meter} / (1 + Air\ \% /100)$$

Air % @ atmospheric pressure must be adjusted for the pressure in the flow transmitter, see section 1.5

$$V_{air\text{-}free} = V_{volume\ meter} / (1 + (Air\ \% * P_{atmospheric} / P_{flowmeter} *100))$$

The transmitter is calibrated so that the calculated $V_{air\text{-}free}$ in the flow transmitter equals the compensated reference volume.

Uncertain factors are:

- Deviation of reference based on volume. See section 2.
- Air content (combined and free) in the liquid when it passes through the flow transmitter. The air is not included in the weight, but in the volume measurement it is.

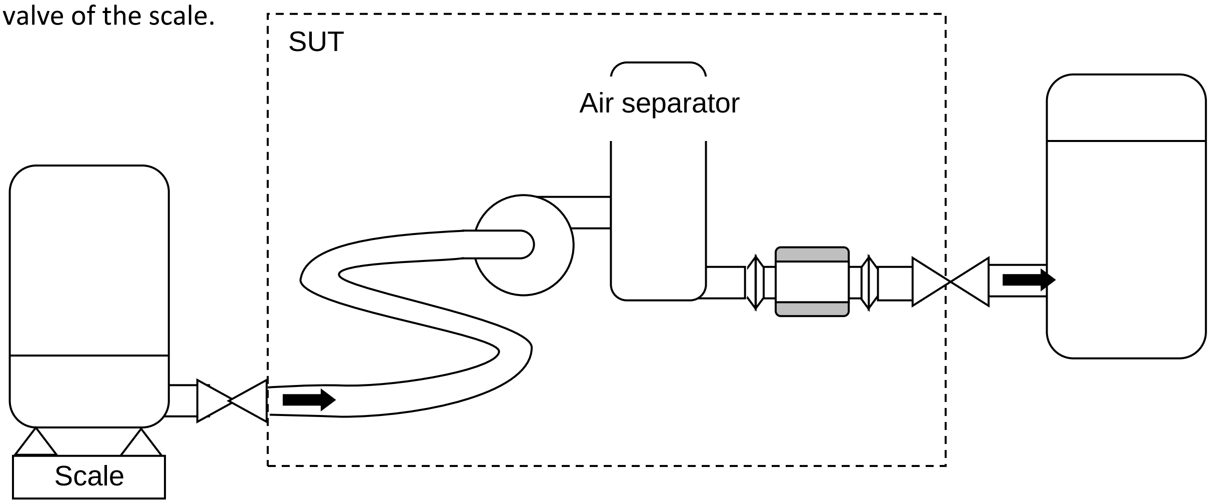
The air content should be measured **after** the flow transmitter, since especially leaks on the suction side including axel gaskets may cause the liquid to contain air, which is included in the result of the volume meter, but which on the other hand is completely or partly bled from the calibrated tank and thus does not appear in its volume.

Conclusion: This type of verification demands an accurate and precise air measurement.

7 Verification of a volume meter system using a scale

When verifying a volume measurement system that includes an air eliminator or similar, it is demanded that the reference volume is measured on the suction side of the system. It is not possible only to verify the quantity coming out of the system, since the system may be filled to a varying degree when the measurement is ended, leading to a varying level in the air separator. The quantity entering the system is what has to be verified.

The verification includes the quantity that passes the connection at the hose at the bottom valve of the scale.



A tank on a scale is here used with a bottom valve as reference, corresponding a farm tank.

The weighing tank is filled with water and the scale is tared. After that, a hose is connected to the weighing tank. The valve is opened, the weighing tank is emptied, and finally the hose is dismantled and rolled up, or placed in accordance with the enclosed instruction.

The weight change is converted to volume by means of the table for temperature and specific gravity etc. See section 2.

Conversion from weight change to reference volume:

*Reference volume = (Weight change [kg] / (The liquid's specific gravity @ 4 °C [kg/m^3] * specific gravity correction (temperature) – Specific gravity of the surrounding air @atmospheric pressure[kg/m^3])*

The system must be calibrated to indicate correctly for liquids without combined air. During verification, it must therefore be compensated for potential combined air in the liquid, which cannot be separated in the air separator.

When the air content in the weighing tank increases, the volume of the liquid also increases, but without influencing the weight. The air content in the milk, which is not bled in the air separator, will affect the measurement depending of the pressure of the milk when it passes the flow transmitter.

The system must be calibrated to an adjusted indication. The air correction is calculated from the measured air content in the milk ***coming out of the measurement system*** and the pressure of the milk *when it passes the flow transmitter*. The air that once has been removed in the air separator does not pass the flow transmitter.

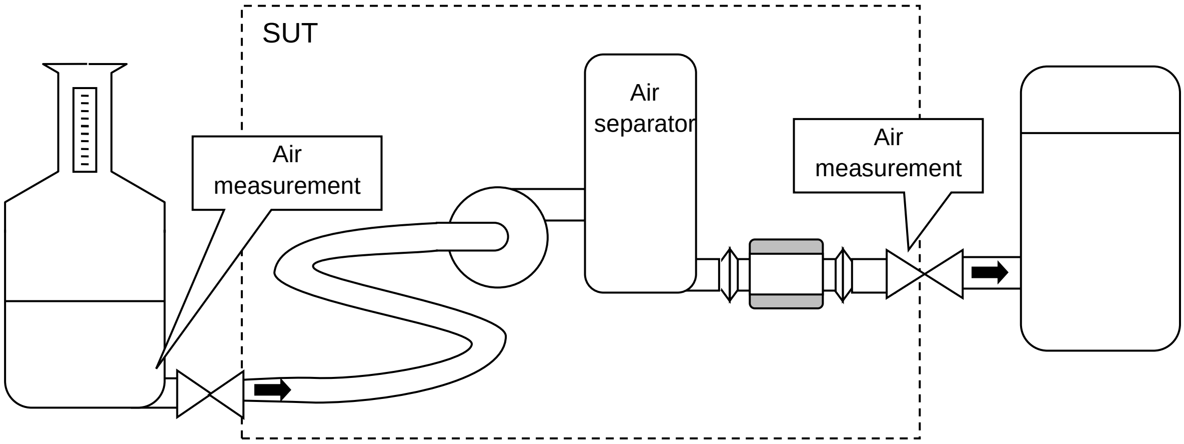
See section 1.5

Uncertain factors that have to be summed up:

- Uncertainty of reference volume based on weight. See section 2
- Uncertainty of measurement of combined air in the liquid.
- Liquid in the inlet hose, caused by a hose not having been rolled up or by another instruction that has not been followed in accordance with the description.

=> To carry out calibration and verification with milk, the air content of the milk must be known precisely.

8 Verification of a volume measurement system using a tank with calibrated volume



The reference tank is filled with water to a known volume including the valve. After that, a hose is connected to the weighing tank. The valve is opened, the tank is emptied, and finally the hose is dismantled and rolled up, or placed in accordance with the enclosed instruction.

The read-out volume in the reference tank = the sum of air and air-free milk. This means that higher air content equals less quantity of air-free milk. The volume indication of the reference tank includes air, **free air as well as combined air**. The air separator removes the free air, whereas the combined air passes the flow transmitter.

To adjust for air in the reference tank, the air content must be measured in the **outlet of the reference tank.**

The volume indication of the reference tank must first be reduced with the air percentage measured in the tank. If 1 % air remains in the reference tank, the volume of the reference tank must be multiplied by 0.99 to get the quantity of the air-free milk.

The milk's content of combined air **that cannot be removed** in the air separator will affect the measuring system depending of the pressure of the milk when it passes the flow transmitter. It must be adjusted by means of the pressure in the volume meter and the air content just after the flow transmitter. See section 1.5.

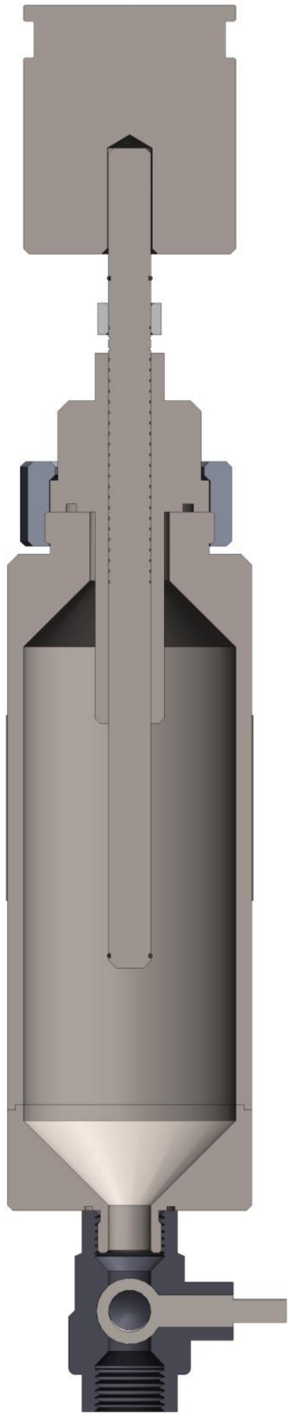
The system must be calibrated and verified to be exact and precise for liquids without combined air. If it is accepted that milk does always contain for example 0.5 % air when collected at the farmer, the calculated calibration factor can be multiplied by 0.995.

Uncertain factors that have to be summed up:

- Exactness and precision of the reference tank.
- Measurement of air % in the reference tank.
- Measurement of air % after the system.

- Liquid in the inlet hose, caused by a hose not having been rolled up or by another instruction that has not been followed in accordance with the description.

9 Air content meter



In the previous sections the importance of knowing the air content of the milk very precisely has been described. At the right-hand side an ”Air content meter” is illustrated, which in a simple way can indicate the liquid’s air content.

The mode of operation is based on the *Ideal gas equation*, which describes the relations between volume and pressure.

Pressure_1 * air volume_1 = Pressure_2 * air volume_2 = Constant (provided that the temperature does not change).

The measuring chamber is filled with milk from the bottom through the ball valve, while the upper part with cylinder and piston is disassembled. When the chamber is filled, the valve is closed, and the upper part with cylinder and piston is assembled while the piston is kept up. The chamber is now filled with a mixture of liquid and air. The milk has entered directly into the measuring chamber, with the least possible influence of the air content.

The weight of the piston increases the pressure in the chamber slightly. The volume in the liquid is hereby reduced a little. On the piston rod a small plastic ring is located, which is pushed downwards and touches the cylinder.

After that, the matching weight is carefully placed on the piston rod, causing the air in the liquid to be squeezed more, and the piston is moved an equivalent distance. The weight is then removed, and the piston lifts itself back. The distance between the plastic ring and the cylinder indicates the air content. The piston rod has an indication for each 0.2 % air.

Up to 5 % air can be measured.

The accuracy and the precision are very high. The measuring chamber is cut on a numerically controlled milling machine. The inexactness derives from the tolerances of what the milling machine can achieve and the accuracy of the weight.

The measurement indicates the volume of the air at atmospheric pressure and at the actual temperature.

The illustrated ”Air content meter” has been developed and manufactured by PROCES-DATA A/S.