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Special Documentation
Promass Q: Overrun and density measurement of foamed products

Measurement setup and formulae for calculation

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1 About this document

1.1 Document function

This Special Documentation is intended to help users implement the Promass Q for measuring overrun (the degree of foaming) and density in foamed products.

The topics it addresses include:
- Requirements
- Technical implementation
- Calculation parameters
- Overrun calculation
- Density calculation for foamed products under ambient conditions

This Special Documentation complements the relevant device documentation of the individual components for the overall solution for measuring foamed products. It is **not** intended to replace the Operating Instructions pertaining to the individual components or other device d

1.2 Content and scope

This document describes the formulae for calculating the density of media with entrained gas bubbles such as ice cream or dough. Programming of the calculation unit or the control system is specific and thus not part of this document.

2 Requirements

2.1 Initial situation

Food products are often foamed using gases in order to achieve the desired consistency. This occurs, for example, when ice cream is produced. The gas content is a significant factor in the overall quality of the final product and is an important process parameter. Nowadays, quality control typically takes place by means of a manual density measurement (by weighing a defined volume). The increase in volume of the final product caused by the injected gas is known as overrun. Overrun is product-dependent. Depending on the product, the overrun can be between 20 % and 120 % OR for ice cream and frozen products.

Using the Promass Q with multi-frequency technology (MFT) for overrun measurement enables continuous monitoring of the overrun instead of, or in addition to, what was previously performed as a sample inspection only.

Because the overrun is determined based on the density measurement of the Promass Q, the foaming process must cause a significant change in the density of the liquid mixture.

2.2 Measuring the density of foamed products

The following devices and information form the basis of a correct overrun calculation:

- Promass Q with multi-frequency technology (MFT) for highly accurate measurement of the density of the foamed product
- Pressure measuring cells for measuring the absolute pressure (e.g. Endress+Hauser Cerabar M PMC51/PMP51)
- Information about the density of the non-foamed product (liquid density under process conditions)
- Control system or computer to apply the formulae for overrun calculation

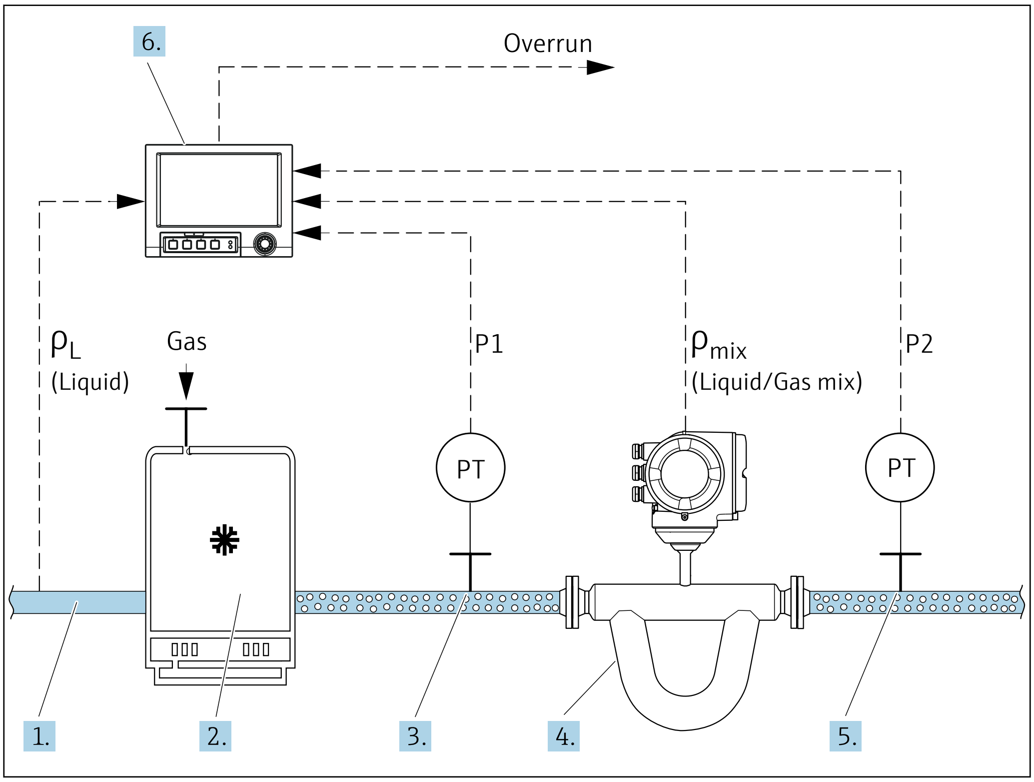
The Promass Q can measure the density of the foamed product (liquid with entrained gas bubbles) correctly thanks to innovative multi-frequency technology (MFT). The increase in volume of the final product at atmospheric pressure (overrun) can be calculated on the basis of this density measurement, information about the pure liquid density before gas is injected and the process pressure.

The measurement of the process pressure (as the average of pressure measurements upstream and downstream of the Promass Q) takes into account the compressibility of the added gas, whose effect on the volume increase of the product is significantly greater under atmospheric conditions than at higher process pressures. The formulae for overrun and density calculation described in this document can either be used in the control system/process control system or an external computer (e.g. Endress+Hauser Memograph).

3 Technical implementation

3.1 Measurement setup

- From the point of view of the measuring technology, either horizontal (as per the diagram) or vertical orientation of the Promass Q is permitted where foam formation is stable. Since media with low viscosity (less than 50 cP) tend to separate, vertical installation with flow from the bottom to top is recommended. Please refer to the Operating Instructions for the Promass Q for further information on installation.
- Maintaining a minimum speed of more than 0.5 m/s is recommended for foamed products. This recommendation can be undershot for applications with a viscosity of more than 50 cP, but should nevertheless be greater than 0.3 m/s.
- The pressure measuring cells must be installed symmetrically and as close as possible to the process connections of the Promass. No additional components such as valves or pumps, for example, should be located between the Promass Q and the pressure measuring cells as otherwise the measured pressure will deviate considerably from the conditions in the Promass.
- MFT must be enabled in the Promass Q and, depending on the orientation, the pitch angle and roll angle must also be set (see the Promass Q Operating Instructions).
- Significant output values for overrun calculation are density ρ_{mix} (Promass Q) and absolute pressure P1 and P2 of the pressure measuring cells.
- The density of the liquid ρ_L must be known from calculations, laboratory data or corresponding process measurements before foaming.
- Specification of the default value 1013 hPa is usually sufficient for atmospheric pressure P_A. If required, this value can be adapted to the relevant ambient conditions.



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1. The process upstream of foaming
2. Foaming (and freezing) of the mixture
3. First sensor for absolute pressure measurement
4. Promass Q

5. Second sensor for absolute pressure measurement
6. Calculation unit (e.g. PLC)

4 Calculation base

4.1 Atmospheric pressure: P_A

In many cases, a standard value for the average barometric pressure (1013 hPa for MSL) is sufficient for calculation purposes. In this case, site altitude and fluctuations in the air pressure are disregarded.

4.2 Process pressure in the Promass Q: P_P

In order to determine the process pressure in the Promass Q, the average value of two sensors installed close to the entrance and exit of the Promass Q is calculated (please also refer to the diagram in the "Technical implementation" section → 🗎 6):

$$P_P = \frac{P_1 + P_2}{2}$$

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Two sensors are required for this purpose to measure the absolute pressure. Where possible, they should be installed directly upstream and directly downstream of the Promass Q.

4.3 Density of the liquid/gas mix: ρ_{mix}

ρ_{mix} is determined by the Promass Q.

It is assumed for the purpose of overrun calculation that the gas is dispersed in the liquid phase as micro-bubbles. Volume expansion under atmospheric conditions is thus only based on expansion of these gas bubbles. However, if the gas is present in a dissolved form in the Promass due to increased pressure, the method described here for overrun calculation does not work.

4.4 Density of the liquid: ρ_L

The liquid density ρ_L before foaming can be based on laboratory values, calculations or a corresponding process measurement (e.g. with the Promass before gas is added).

The accuracy of the overrun calculation depends significantly on the accuracy of the specified density of the liquid. If the product changes, then the value ρ_L for the liquid density must also be adapted accordingly.

5 Calculation of relevant values

5.1 Volumetric gas content under process conditions: α_P

The first step of the calculation determines the volumetric gas content under process conditions α_P:

$$\alpha_p = \frac{\rho_L - \rho_{mix_P}}{\rho_L} \cdot 100\%$$

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In this case, ρ_{mixp} is the density of the mixture determined by the Promass while ρ_L is the liquid density. The index P refers to process conditions in each case. In general, liquids can be seen as incompressible such that their density is not dependent on the process pressure ($\rho_{LP}= \rho_L$).

Please remember to use the same units (e.g kg/m^3) for the different density values.

5.2 Overrun: % OR

The second step calculates the "overrun" **OR** for atmospheric conditions using the following equation:

$$\% \text{ OR} = \frac{\alpha_p \cdot \frac{P_P}{P_A}}{(100\% - \alpha_p)} \cdot 100\%$$

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P_P refers to the process pressure (absolute) and P_A the atmospheric pressure (please also refer to section 4 on "Calculation parameters" → 📄 8).

Please remember to use the same units for the different density values.

5.3 Volumetric gas content under ambient conditions

The gas content at ambient conditions is an important parameter for determining the density of the foamed product and is calculated as follows:

$$\alpha_a = \frac{1}{1 + \frac{P_a}{P_p}\left(\frac{\rho_L}{\rho_L - \rho_{mix,p}} - 1\right)} \cdot 100\%$$

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5.4 Density under ambient conditions

The density of the foamed product at atmospheric pressure is calculated as follows:

$$\rho_{mix,a} = \frac{(100\% - \alpha_a)}{100\%}\ \rho_L = \frac{\rho_L}{\frac{P_p}{P_a}\left(\frac{\rho_L - \rho_{mix,p}}{\rho_{mix,p}}\right) + 1}$$

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