LIQUID FOAMS CHARACTERIZATION

Introduction

Foams possess unique physical properties that make them highly valuable in industrial applications: combining low density, large specific surface area, and the dual behavior of liquids and solids.
These characteristics enable foams to perform a wide range of functions that are difficult to achieve with other fluids.

There are at least seven good reasons why foams are preferable to other fluids in industrial processes:

- **Material efficiency:** Foams reduce the quantity of active ingredients or liquids required, minimizing waste and environmental impact in cleaning or decontamination processes.
- **Rapid volume expansion:** Their high expansion ratio allows foams to quickly fill large areas, as seen in fire-fighting or surface coating applications.
- **Isolation and protection:** Due to their low density and floating capacity, foams effectively smother fires or isolate contaminants.
- **Selective trapping:** Foam interfaces can capture particles, ions, and molecules, making them useful in separation, purification, and mineral flotation.
- **Energy absorption and pressure control:** Foams can dampen explosions, stabilize boreholes during drilling, or apply controlled pressure.
- **Viscosity and structural control:** By imparting solid-like behavior to liquids, foams enable stable coatings and formulations in cosmetics, food, and cleaning applications.
- **Material templating:** Liquid foams act as precursors to solid foams such as polymers, metals, glass, or food products, where the final structure directly reflects the properties of the liquid foam.

	Reducing the use of raw materials	Expansion properties	Insulation properties	Trapping substances of interest	Absorbing or applying pressures	Proving elasticity to a fluid	Providing a foam structure to a solid
Cleaning	•					•	
Surface treatment	•		•			•	
Construction materials							•
Fight against pollution	•	•	•	•		•	
Firefighting		•	•				
Natural resource extraction				•	•	•	
Cosmetics	•					•	
Food	•					•	•

Fig 1: Summary of the different functions of liquid foams in various applications. Adapted from [3]

Therefore, the ability to generate a controlled liquid foam (with a well-defined geometrical structure and liquid fraction) and to understand the mechanisms governing its destabilization is essential for optimizing its performance.

Once the foam is generated, a crucial verification step involves characterizing its key properties using quantitative parameters, among which the liquid fraction and bubble size distribution are the most significant [4].

How to characterize a liquid foam?

A wide range of foam generation techniques have been developed and are used across industries, depending on the desired foam properties. These properties are determined by several key parameters:

- Foam volume/height: the quantity of foam produced
- Liquid fraction: the proportion of liquid relative to the total foam volume
- Bubble size: typically ranging from micrometers to centimeters
- Polydispersity: the distribution of bubble sizes within the foam

To assess foam evolution and stability over time, the following parameters are often used:

- Foamability: time required to reach a defined foam volume
- Foam stability: time needed for a specific fraction of the foam to collapse (typically half)
- Liquid stability: time taken for half of the liquid used to generate the foam to drain out

Several foam characterization methods exist, ranging from simple measurements of foam height to more advanced techniques which enable multiscale analysis of liquid foam properties.

1. Basic used foam characterization methods

- **Ross-Miles method:**

This method is regulated by ASTM D1173 and consists in pouring 200 mL from a height=90 cm into a graduated cylinder already containing 50mL.

LIQUID FOAMS CHARACTERIZATION

The height of the generated foam allows to characterize the foamability of the solution. It allows a quantitative comparison between different foaming solutions. After pouring the solution, monitoring the height of the foam in the cylinder as a function of time gives a rough estimate of the foam's stability.

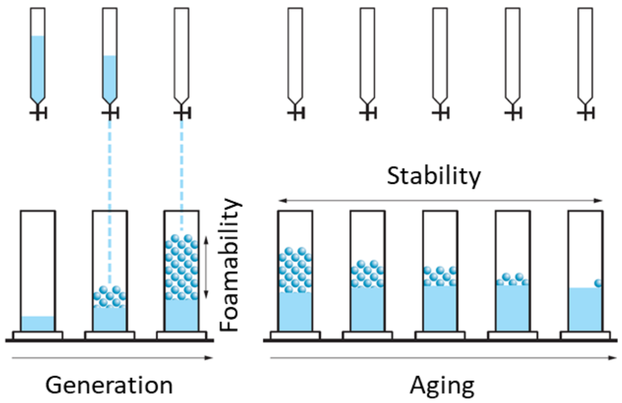


Fig2: Ross-Miles method (adapted from [7])

Pros: easy to implement, Standardized and widely recognized

Cons: Does not reflect foaming behavior under shear, aeration, or continuous gas flow — limiting relevance for industrial foams.
The height of the foam must remain unchanged for long enough time to observe the aging of the foam and structure heterogeneities (between the top and the bottom)

- **Bikerman method:**

This method consists in generating a liquid foam in a cylinder containing a given amount of a solution by gas injection at a constant flow rate through a porous glass frit or any equivalent device generating small bubbles of known size.

The height of the foam increases as gas is injected. The upper portion of the foam ages while new bubbles are generated in the bottom of the cylinder. At a given point, the upper portion of the foam starts breaking and the overall height of the foam stops increasing and reaches a plateau value (when the breaking speed at the top is equal to the generation speed in the bottom).

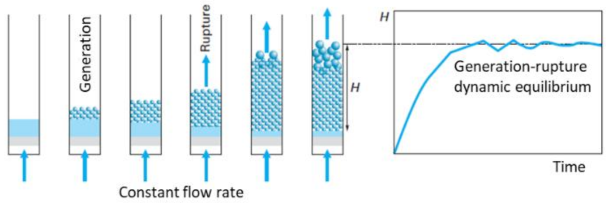


Fig3: Bikerman method (adapted from [7])

Bikerman stated that the volume of foam V on top of the liquid slag layer is linearly related to the volumetric flow of rising gasses Qg as is shown in equation:

$$V = Qg\Sigma$$

Σ is the Bikerman constant or foaming index. It has the dimension of time and acts as a quantity that expresses the inherent foaming stability of the foam forming liquid.

Pros: The Bikerman method is valuable whenever you need to quantify foam generation and stability under dynamic conditions, i.e. when gas is continuously injected into a liquid.
By deriving an index (foaming index), the method allows comparison between different liquids, surfactant solutions, foaming agents under controlled gas flow conditions.

Cons: the Bikerman method is only valid for foam, formed by freely rising gas bubbles. This means that there always must be a dispersed gas layer present under the foam layer in which the injected gas bubbles can rise exclusively due to buoyancy.

2. Advanced foam characterization methods

The behavior of a liquid foam depends strongly on several factors: the **foam generation technique** (gas injection, mechanical stirring, etc.), the **physicochemical properties** of the foaming solution (type of surfactant — ionic or nonionic — salinity, water hardness), and the **nature of the gas** used (air, nitrogen, CO_2).

- **FOAMSCAN™ foam analyzer and defoamer tester**

The method consists in generating a liquid foam in a glass cylinder under different controlled conditions:

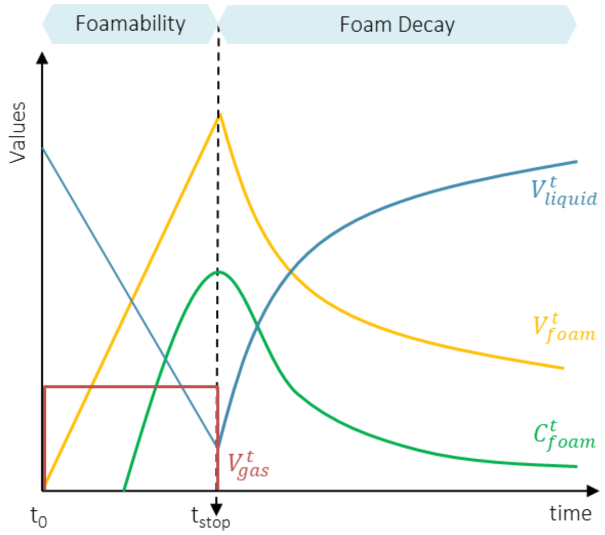
LIQUID FOAMS CHARACTERIZATION

- **Gas sparging:** gas is injected into the liquid through a porous glass frit at a precisely controlled flow rate.
- **Mechanical stirring:** foam is produced by agitating the liquid at a controlled rotational speed.
- **External source:** foam generated by an external device can be directly transferred into the measurement cell for analysis.

The glass cylinder is equipped with electrodes and prisms to combine image analysis and liquid conductance measurement.

The analysis typically consists of two main phases:

1. Foaming phase: foam is generated either for a defined duration or until a specified foam volume is reached.
2. Foam decay phase: after foam generation stops, or when externally produced foam is introduced.



Macro-Scale analysis

During measurement:

- **Foam volume** (mL) is calculated by images analysis
  - The Foaming capacity is measured by the quantity of foam produced by a limited volume of liquid during a time.
  - The « Foamability» is measured by the time to reach a targeted volume of foam
- **Liquid volume** (mL) is calculated by conductance and determines the drainage rate and the quantity of liquid in the foam:

$$V_{liq}^{in\ the\ foam} = V_{liq}^{at\ t0} - V_{liq}^{at\ t}$$

- **Foam/ Liquid conductance** (µS) is measured by the electrodes
- **Liquid Fraction** (%) is calculated from the relationship between Liquid conductance and Liquid volume
- **Volume of gas** injected (mL) and Bikerman Index (sec.) are calculated by the Gas flow rate F^t_{gas}

At the end of the foaming phase, the Foaming properties are calculated:

- **Foaming capacity** $\boldsymbol{FC} = \frac{V^t_{foam}}{V^t_{gas}}$ is the ability of a gas to be trapped by the liquid.
- **Foam expansion** $\boldsymbol{FE} = \frac{V^t_{foam}}{V^0_{liquid} - V^t_{liquid}}$ is the ability of a formulation to produce foam.
- **Foam Density** $\boldsymbol{FD(t)} = \frac{V^0_{liquid} - V^t_{liquid}}{V^t_{foam}}$ refers to the global liquid fraction composing the foam.
- **Bikerman Index** BI= $\frac{V_{foam}}{F_{gas}}$ is used to compare foam generation and stability under dynamic conditions.

When the foam production stops or after pouring foam generated by an external device, **foam stability properties** are measured until the end of the measurement:

- **Foam volume half-life time** is the time required for the maximum foam volume to decrease by 50%
- **Liquid stability half-life time** is the time required for 50% of the **liquid** trapped in the foam **to drain**
- **Foam volume stability (FVS)** represents the foam volume normalized by the maximal foam volume obtained when foaming stops.
- **Foam liquid stability (FLS)** represents the global foam density stability.
- **Foam Density Stability (FDS)** differs from the FLS by the region of analysis. FDS represents the local foam density stability.

LIQUID FOAMS CHARACTERIZATION

Micro-Scale analysis

The statistical analysis of the foam structure is performed through **image analysis**, providing quantitative data on several key parameters:

- **Bubble size:** minimum, maximum, and mean diameter, mean radius, perimeter, area, elliptical ratio, eccentricity, and circularity.
- **Bubble distribution:** bubble count and density, Sauter mean diameter, bubble and liquid areas, and the polydispersity index.
- **Liquid fraction:** proportion of liquid within the foam.

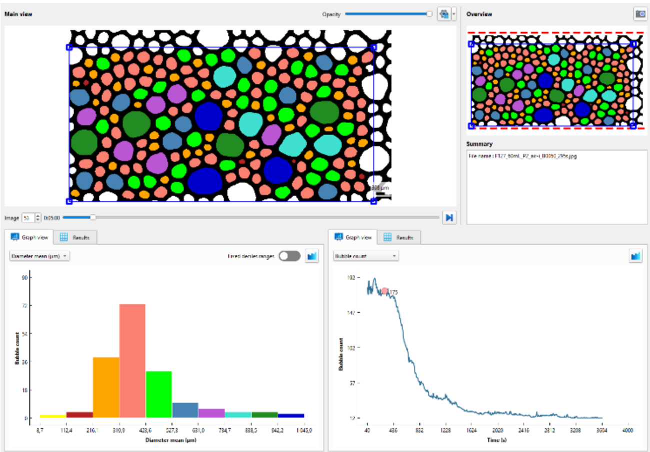


Fig4: Foam structure analysis with BubblesStatistics™ software

Foam structure analysis provides **quantitative and qualitative insights** into how a foam evolves over time, helping to understand its **stability, drainage, and aging mechanisms**.
It typically delivers information in three main categories:

1. Bubble Size and Geometry

- **Average bubble diameter / mean radius** indicates the typical bubble size. Smaller, uniform bubbles usually mean a more stable foam.
- **Minimum and maximum diameter** show the size range present in the foam.
- **Perimeter, area, circularity, eccentricity, and elliptical ratio** describe the bubble shape; deviations from circularity can reveal deformation or coalescence events.

These parameters help identify coarsening (bubbles growing larger over time) and film rupture.

2. Bubble Distribution and Population

- **Bubble count and density** (number of bubbles per unit area or volume): a decrease over time reflects coalescence or foam collapse.
- **Sauter mean diameter (D_{32})**, relates surface area to volume, useful to track gas–liquid interface evolution.
- **Polydispersity index (PDI)** measures the uniformity of bubble sizes.
    - Low PDI → homogeneous, likely stable foam.
    - Increasing PDI → bubble coalescence or instability.
- **Gas–liquid area ratio** is the proportion of gas phase versus liquid phase.

These metrics reveal how the bubble population evolves and how uniform the foam remains during aging.

3. Liquid Fraction and Drainage Behavior

- **Liquid fraction (%)** quantifies the proportion of liquid in the foam, a key indicator of wetness and mechanical strength.
- **Drainage rate** measures how quickly liquid leaves the foam structure; high drainage correlates with faster collapse.

Tracking liquid fraction over time helps understand foam stability, rigidity, and how surfactant properties influence aging.

Conclusion

Understanding and quantifying the behavior of liquid foams is essential for optimizing their performance across a wide range of applications.

The various characterization techniques, from simple methods such as Ross–Miles and Bikerman to advanced automated systems like **FOAMSCAN™**, provide complementary information on foam formation, evolution, and stability.

While traditional approaches offer valuable comparative data under controlled conditions, advanced automated systems like **FOAMSCAN™** now

LIQUID FOAMS CHARACTERIZATION

enable **multi-scale analysis**, combining **macroscopic measurements** (foam height, liquid fraction, drainage) with **microscopic insights** (bubble size, distribution, and polydispersity).

Such integrated characterization is key to linking **formulation parameters** with **foam performance**, allowing researchers and engineers to design and control foaming processes more efficiently.

Ultimately, advanced analysis tools like FOAMSCAN™ provide a robust and reproducible framework for **understanding, predicting, and optimizing foam behavior** in both academic research and industrial development.

Bibliography

[1] Olivier Dauchot, Douglas J Durian, and Martin van Hecke. Dynamical heterogeneities in grains and foams. *Dynamical Heterogeneities in Glasses, Colloids, and Granular Media*, 150 :203, 2011.

[2] Langevin, Dominique. "Aqueous foams and foam films stabilized by surfactants. Gravity-free studies." *Comptes Rendus Mécanique* 345.1 (2017): 47-55

[3] Cantat, Isabelle, et al. Foams: structure and dynamics. 2010.

[4] Drenckhan, Wiebke, and Stefan Hutzler. "Structure and energy of liquid foams." *Advances in colloid and interface science* 224 (2015): 1-16.

[5] Weaire D, Phelan R. A counterexample to Kelvin's conjecture on minimal surfaces. Philos Mag Lett 1994; 69:107–10.

[6] Marangoni, Carlo. "Sul principio della viscosita'superficiale dei liquidi stabilito dalsig. J. Plateau." *Il Nuovo Cimento (1869-1876)* 5.1 (1871): 239-273.

[7] Salager, Jean-Louis, and Lionel Choplin. "Mousses Formation, formulation et propriétés." (2008).

[8] Arnaud Saint-Jalmes and Dominique Langevin. Time evolution of aqueous foams: drainage and coarsening. Journal of Physics: Condensed Matter, 14(40) :9397, 2002.

[9] J. W. Gibbs. The scientific papers of J. Willard Gibbs. Oxbow press, Woodridge, 1993

[10] V Carrier and A Colin. Coalescence in draining foams. Langmuir, 19(11) :4535–4538, 2003.

[11] Khidas, Yacine, Benjamin Haffner, and Olivier Pitois. "Capture-induced transition in foamy suspensions." Soft matter 10.23 (2014): 4137-4141.

[12] Denkov, Nikolai D., and Krastanka G. Marinova. "Antifoam effects of solid particles, oil drops and oil-solid compounds in aqueous foams." Colloidal particles at liquid interfaces (2006) : 383-444.

[13] Anthony Hutin, Rhéologie interfaciale: compression et dilatation