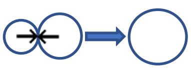
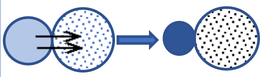
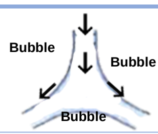
Foamability and Foam Stability with Turbiscan®

Foams are very common in everyday life, constitute many food products, cleaning products, hygiene, and health formulations but are also used for construction materials (heat and noise insulation, shock-absorbers) or for light-weight materials in aerospace/automotive fields. On the other hand, in some cases, foam is the undesired subproduct and must be limited (papermaking, printing). Measuring and analyzing foam remains a challenge due to the diversity of the phenomena involved. This note shows how Turbiscan®, based on SMLS technology, provides relevant and reliable method to fully characterize foam stability: Foam height, bubble size, foamability…

DEFINITION: FOAM

Foam is the union of two-phase systems. It is a dispersion of gas in a condensed phase which is most often an aqueous phase but can be also solid. Adsorbed at the surface of the bubbles, surfactants reduce the surface tension of the interfaces (bubbles/lamellae) and have an important role for foamability, foam stability and foam quality.

Foamability depends on surfactant nature, concentration, and the liquid phase viscosity. Foamability (related to the amount of foam generated) and foam stability are two separate properties to consider. There are three main process of foam destabilization:

Bubble Coalescence	Bubble Ostwald ripening	Water drainage
		
Rupture of a film separating two bubbles within a foam	Because of the Laplace pressure difference, the smallest bubbles empty into the large one by diffusion through the liquid films	Flow of the liquid out of the lamellae

These phenomena, often coupled, lead to an increase in the size of the bubbles and over time phase separation between the liquid and the gas. Indeed, water drainage facilitates coalescence.

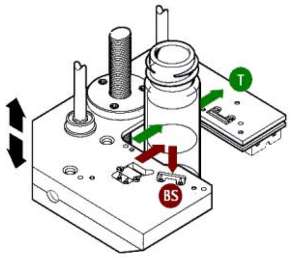
Most used method for foam study is based on visual observation. It is user dependent and not sensitive for such short-lived systems. Some indirect methods also analyze the behavior of an isolated film but it's not always possible to correlate it with the global behavior.

The Turbiscan® is a reliable tool for precise foam study. The foam height (during formation) and the foam destabilization over time can be precisely measured.

TURBISCAN®: HOW IT WORKS

Turbiscan® technology, based on **Static Multiple Light Scattering (SMLS),** consists of sending light pulses (880 nm) into a sample along its height. The reading head scans the sample by moving vertically along the cell's height and acquires data every 20 µm. Scans are made over time and the intensity of backscattered and transmitted light is recorded. The variation in signal intensity translates to sample instability.

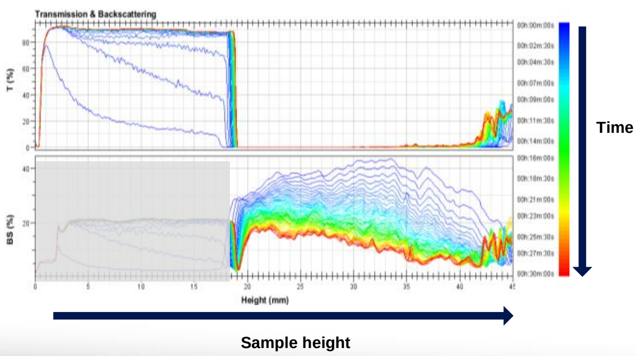
The signal is directly linked to the evolution of particle concentration (φ) and size (d) by the Mie theory.



$$\boldsymbol{BS} = \boldsymbol{f}\,(\varphi, \boldsymbol{d}, \boldsymbol{np}, \boldsymbol{nf})$$

Samples with a particle concentration from 10^{-4} to 95% (v/v) and from 10nm to 1mm in particle size can be measured as is. The instrument enables to monitor changes in physical stability (coalescence, creaming, sedimentation, phase separation, etc...) for any type of dispersion, including foams, **without any dilution or any stress**.

Turbiscan® profiles show the variation in recorded light intensity levels as a function of sample height (in mm) over the time. The bottom of the sample is represented on the left of the graphic and the top of the sample on the right. The color gradient on the time scale corresponds to each scan time lapse with the **first scan in blue** and the **last scan in red**.

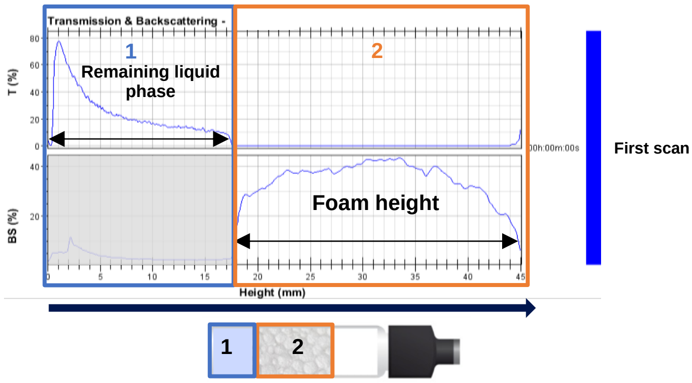


RAPID FOAM ANALYSIS WITH THE TURBISCAN®

The following profiles are an example of a foaming agent (surfactant) analyzed with Turbiscan® which has been previously foamed.

❑ Foam Height - Single scan

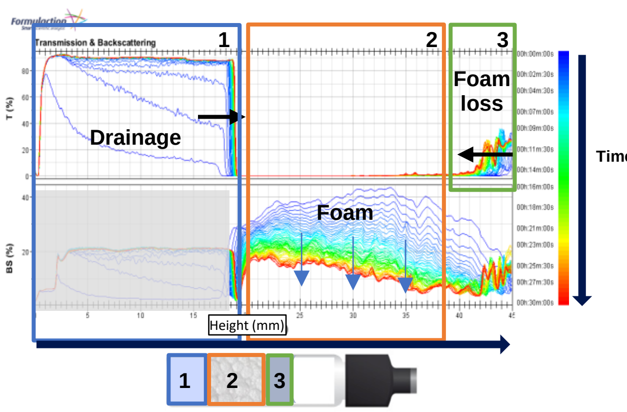
The graph below presents the first scan just after the foaming process (30sec). In only 30 seconds, the Turbiscan can provide information about the foamability (ability of the surfactant to create foam) & foam height as well as the initial bubble size.



- **Zone (1)**: Bottom of the sample - Transmission signal. A peak in transmission is identified corresponding to the remaining water phase
- **Zone (2)**: Top and middle of the sample - Backscattering signal. The incident light is scattered by the air bubbles, the foam is identified on the backscattering signal. The Foam height is easily measured (27.4mm). Finally, knowing the initial liquid height, the foamability can easily be determined (foam volume/ initial liquid volume) as well as the initial bubble size (here 450µm)

❑ Foam stability - Multiple scans over time

The scans are then repeated over time to study evolution of the foam parameters like air bubble size, foam loss, air bubble coalescence rate, … The following graph represents the evolution of foam detected by the Turbiscan during the 30-minute experiment, first scan in blue, last in red.



- **Zone (1):** Bottom of the sample - Transmission signal. The transmission signal increases at the bottom in the left corresponding to the increase of liquid phase at the bottom of the sample (drainage phase).
- **Zone (2):** Middle of the sample - Backscattering signal. Over time, the backscattering signal decreases which corresponds to the increase of the **size** of scatterers (bubbles), i.e: the coalescence of the foam.
- **Zone (3):** Top of the sample. A transmission peak appears on the right (top of the sample) and evolves from the right to the left. This corresponds to the foam collapse. The sample is losing the foam from the top to the middle.

In addition of faster and reliable identification of foam destabilization compared to the visual observation, Turbiscan® technology enables to follow foam stability over time.

Turbiscan® technology is well adapted to study emulsions and suspensions but also the complex foam systems.

DIRECT FOAM STUDIES WITH THE MIXING TOOL

The Turbiscan® Mixing Tool can be used to generate the foam directly inside the measurement cell allowing to characterize the foam properties at every stage.

The direct characterization enables screening of surfactants (type and concentration) and the environment (pH, temperature, water hardness…) to rapidly evaluate the efficiency of various additives and thus to optimize the formulation. In this study, three foaming agents (surfactant A, B, C – 10%wt in water) have been studied. The stability measurement was performed for 10 minutes.

1. Foaming and foamability with Turbiscan®

Once the foam is generated, the foam height and volume can easily be measured with the Turbiscan and the foamability can be determined:

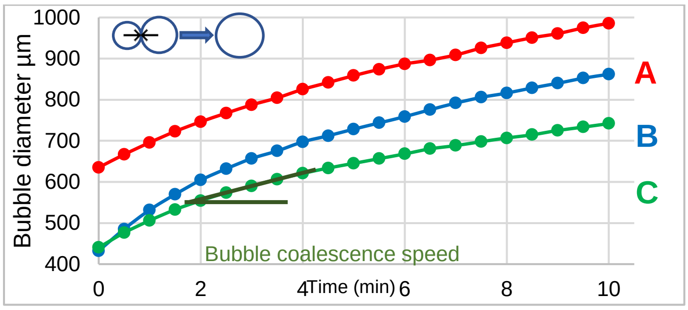
$$\text{Foamability (\%)} = \frac{Volume\ of\ the\ foam}{Initial\ Volume\ of\ the\ liquid}$$

Sample	Initial liquid volume	Foam height	Foam volume	Foamability
Surf.A	10mL	27.4mm	13.4mL	134%
Surf.B	10mL	18.2mm	8.9mL	89%
Surf.C	10mL	17.8mm	8.7mL	87%

The surfactant A generates more foam than the surfactant B and C.

2. Air bubble diameter

Based on the Mie theory and using backscattering measurements, the Turbiscan® enables to calculate the mean diameter of bubbles as a function of time and without any sample preparation. Initial bubble size and coalescence kinetics can be monitored only by the input of 3 parameters (refractive indexes of both phases and volume fraction).



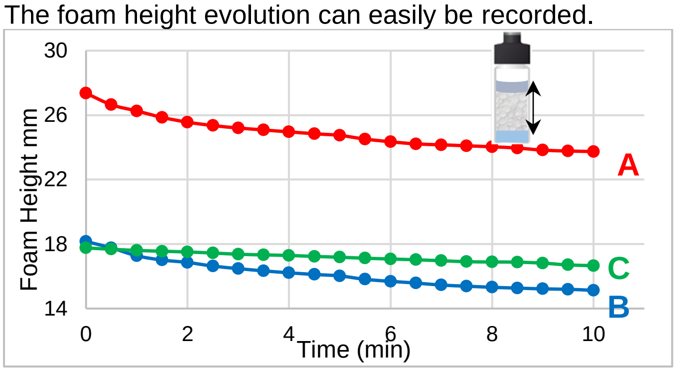
The bubble coalescence rate can easily be obtained by determining the slope of the kinetics:

Sample	Initial bubble size	Coalescence speed
Surf.A	635µm	31,6 µm/min
Surf.B	432µm	38,6 µm/min
Surf.C	440µm	27,4 µm/min

The initial bubble sizes are different for surfactant B and C compared to the surfactant A (~430µm vs 630µm) and different foam quality can be expected. Furthermore, the foam made of the surfactant C show the slowest coalescence speed.

3. Foam stability & half-life

The foam height evolution can easily be recorded.



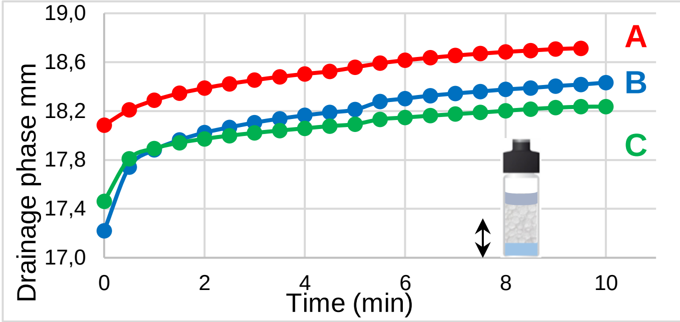
From the previous graph, the initial amount of foam can also be determined as well as the speed of foam loss (slope of the curve), thus the foams stability can be easily evaluated.

Sample	Initial foam height	Foam loss rate
Surf.A	27.4 mm	-0.30 mm/min
Surf.B	18.2 mm	-0.27 mm/min
Surf.C	17.8 mm	-0.10 mm/min

Note: Foam stability can be expressed in terms of foam half-life. Half-life is defined as the time required for half of the initial foam volume/height has collapsed and can easily be determined using this technique.

4. Drainage phase

With time, the liquid phase is drained, which increases the volume of the liquid phase at the bottom, so called drainage. This phase is precisely and quickly measured by following the thickness of the peak in transmission at the bottom of the sample over time:

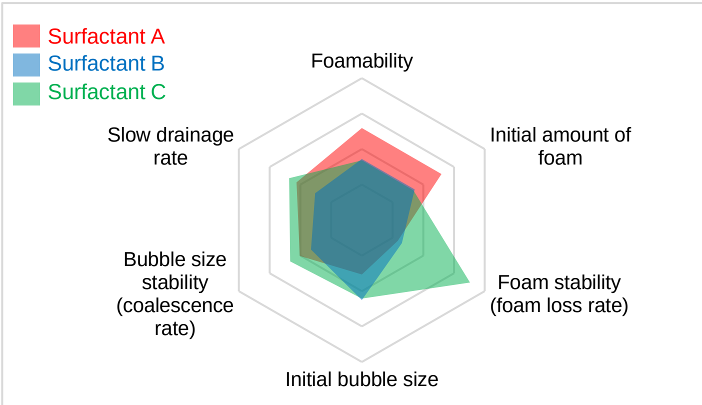


Sample	Initial drainage phase	Drainage speed
Surf.A	18.1 mm	3.42 mm/hr
Surf.B	17.2 mm	4.8 mm/hr
Surf.C	17.5 mm	3.1 mm/hr

The foam generated by the surfactant C has the slowest drainage speed, which must be related to the bubble size (the smallest) and the stability of the foam.

5. Data interpretation

Foam analysis with the SMLS technology provides a broad range of precise metric for foam: from foamability, to bubble size, and foam stability measurement. All the data can be summarized in the radar chart for comparing the different formulations and select the best formulation.



Surfactant B is surpassed in all the parameters by the surfactant A and C and can be considered as the least efficient foaming agent. For **foam generation**, **surfactant A** is the most appropriate foaming agent, it generates the most amount of foam, However the foam is not as **fine** and as **stable** as the foam generated by the **surfactant C**. So, for stability and for the finest foam, surfactant C is the surfactant of choice.

The Turbiscan® allows to study the entire foam life, from the generation to its collapse and monitor key parameters: stability, air bubble size, coalescence rate... Thus, it is perfectly adapted to accurately evaluate the quality of foam products and take the right decision to optimize product efficiency and quality