

PULSATING DECAY OF SOME FOAM SYSTEMS

Carlos RODRIGUEZ, José ANDEREZ, and Ana FORGIARINI

Lab. FIRP, Ingeniería Química, Universidad de Los Andes, Mérida, Venezuela

In the typical Bikerman experiment, the height of a foam column reaches a dynamic equilibrium between the formation rate (by bubbling at bottom) and the decay rate (by collapsing at top). In most experiments, the foam column height does not fluctuate more than 10 % about its equilibrium value, which is a measurement of both the system foamability and the foam stability.

The present study shows that in some circumstances a period-like process so-called pulsating decay takes place instead. In such a process, the foam column increases steadily versus time, with no apparent collapse near its top. The foam height versus time plot exhibits a straight line variation until a critical height is reached, at which point most of the foam column (says 90%) collapses in a glance. Immediately after the collapse, the foam column starts again to rise at the same constant rate, which depends upon the formulation and the gas flow rate. After some time it collapses again, and so on.

The cyclical collapse is almost periodical, which is an indication that it corresponds to a critical situation in a metastable process. Interesting applications can be designed if such a behavior can be harnessed.

In the typical Bikerman's experiment, the height of foam column reaches a dynamic equilibrium between the formation rate (by bubbling at bottom) and the decay rate (by collapsing at top). In most experiments, the foam column height does not fluctuate more than 10% about its equilibrium value, which is a measurement of both the system foamability and the foam stability.

The present study shows that in some circumstances a so-called pulsating decay takes place instead. In such a process, the foam column increases steadily versus time, with no apparent collapse near its top. The foam height versus time plot exhibits a straight line variation until a critical height is reached, at which most of the foam column (says 90% of it) collapses in a glance. Immediately after collapsing, the foam column starts to rise again at the same velocity, which depends upon the formulation and the gas flow rate. After some time it collapses again, and so on.

The cyclical collapse is almost periodical, which is an indication that it corresponds to a critical situation in a metastable process. Interesting applications can be thought about whenever such a behavior can be harnessed.

The dynamic behavior of a foam produced by continuous gas injection might be described by an unsteady-state flow balance for the gas phase present inside the foam [3]:

$$(Q_i - Q_o)/(A) = (dH/dt) \quad (1)$$

where

Q_i = incoming gas volume flow rate

Q_o = outgoing gas volume flow rate

= volumetric fraction of gas in the foam

A = cross sectional area of the foam column

H = foam height
t = time

Q_0 depends upon foam stability. The Bikerman's dynamic test is based on the approaching of a steady state, where the foam formation rate equals the foam decay rate, that is $dH/dt = 0$. However, the way of approaching the steady state may be different [4], depending upon the foaming system. Foam persistence is determined by several phenomena, such as gravitational drainage, capillary suction, interbubble diffusion or liquid evaporation. Previous studies have established the influence of formulation (EON, length of hydrophobic group, concentration) on foamability and foam stability [1].

A study of the dynamic behavior of dry foams formed from solutions of non-ionic surfactants is presented. The influence of gas flow, bubble diameter, concentration and viscosity of the solution is analyzed.

MATERIALS:

Nitrogen was used as the bubbling gas. Carboxy Methyl Cellulose was used as water phase viscosifier. Solutions of Sapogenat surfactant series from Hoechst GmbH (Tributyl phenol ethoxylates) in bi-distilled water were used. Some properties of these surfactants are showed in the following table:

SURFACTANT	CMC (weight %)	EON aprox.	HLB
SAPOGENAT-080	0.005	8	11
SAPOGENAT-180	0.015	18	16

EXPERIMENTAL EQUIPMENT:

The main parts of the experimental equipment are a nitrogen tank, manometers, valves, a rotameter for gas flow measurement, a humidity saturator and glass columns of 5 cm OD and 120 cm height, with one or two 1 cm OD and 20 cm long extensions at bottom. Gas is introduced through a 0.5 mm ID injection nozzle. The equipment scheme is showed in Fig. 1

EXPERIMENTAL METHOD:

50 ml of surfactant solution are introduced in the glass column. Nitrogen is passed through the injection nozzle at a constant rate. The variation of foam height with time is measured up to 3500 sec. Experiments were carried out at 23 ± 1 °C and 640 mm Hg (Atmospheric pressure).

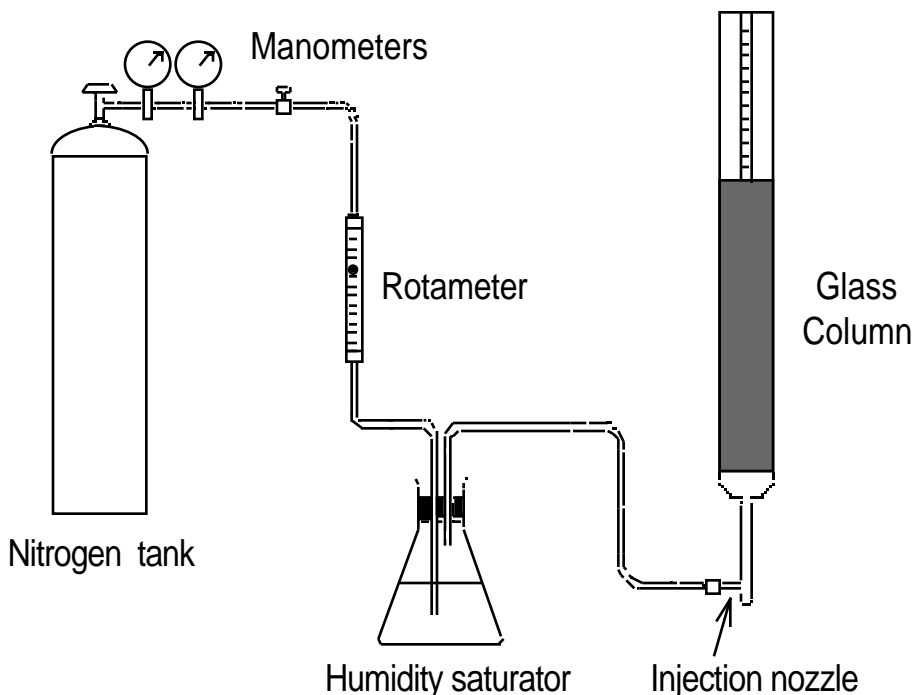


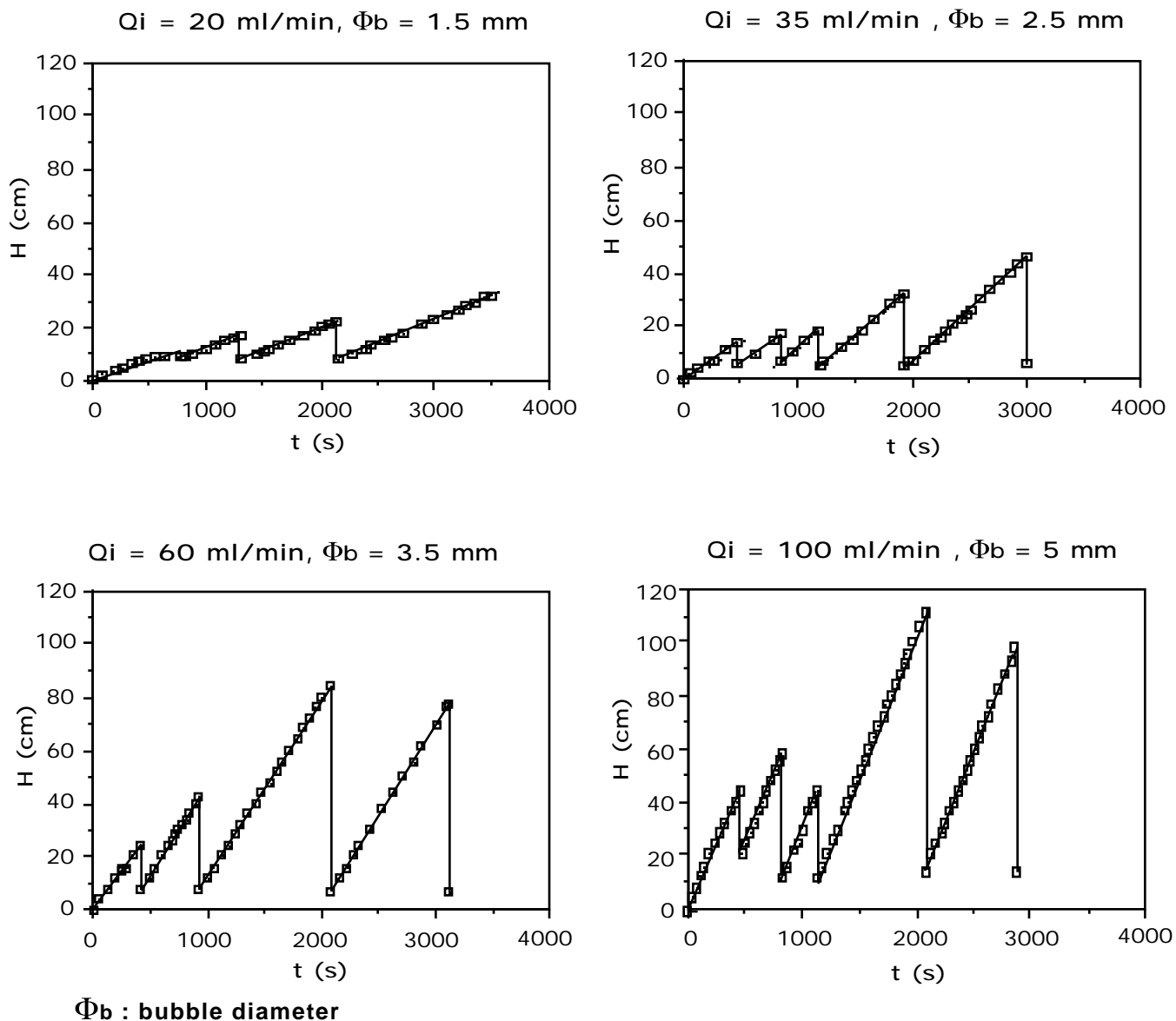
Fig. 1 Equipment scheme

FOAMING DYNAMICS OF SAPOGENAT-080 SOLUTIONS:

Fig. 2 shows that during the foaming up process, the H vs t plot exhibits a straight line variation, which indicates that foam collapse is negligible. This means, according to Eq. (1), that gas retention in the foam is proportional to Q_i . At a certain time, most of the foam column (says 90% of it) suddenly collapses. After this collapse, the foam column starts to rise again at the same constant rate. This phenomenon occurs again and again in the form of a pulsating decay. The remaining height of foam after collapse is almost constant.

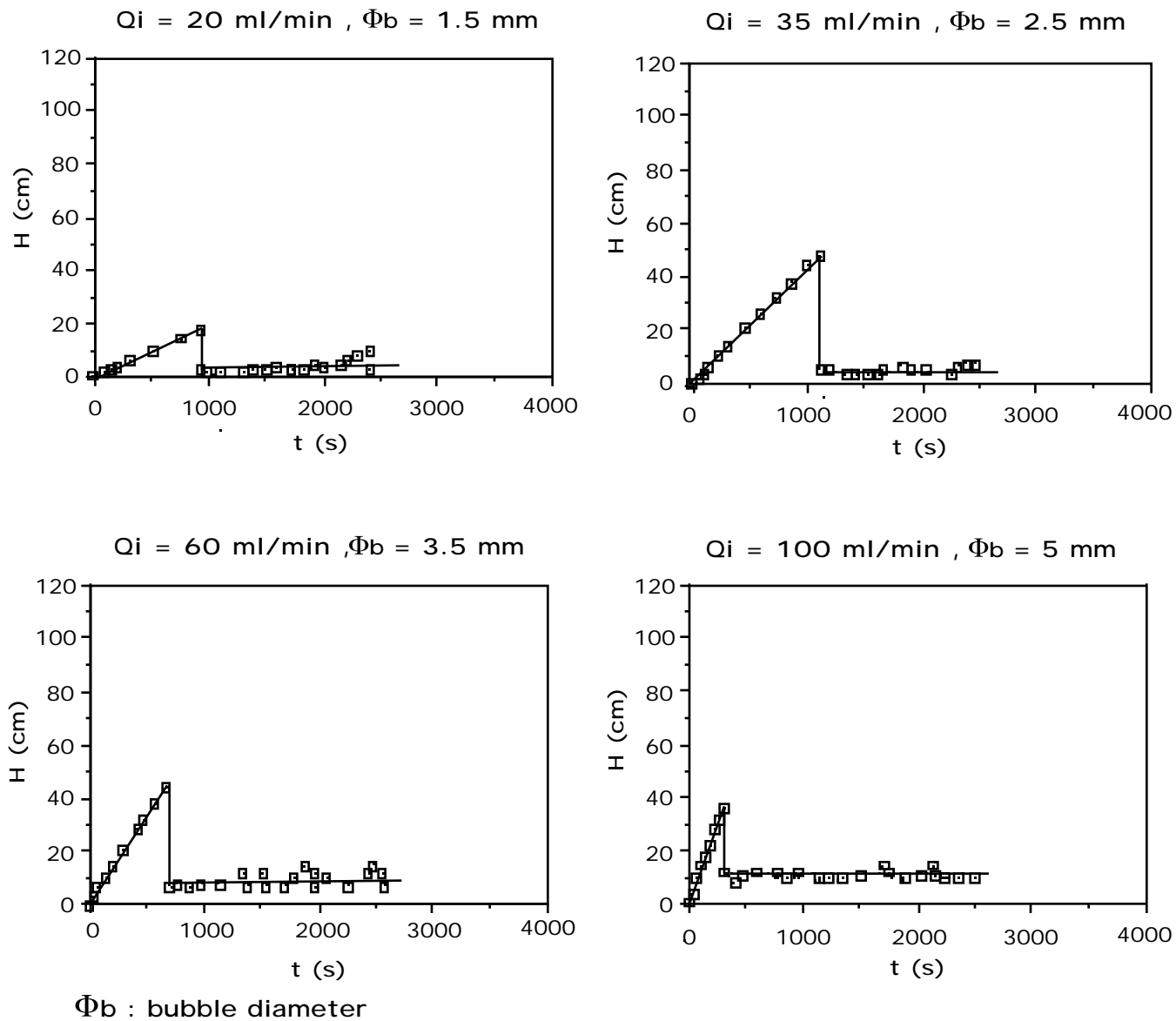
This phenomenon may be explained according to the following interpretation: since the drainage of interbubble liquid is likely to occur without foam collapse, a progressive thinning of interbubble film can take place until a critical thickness is reached. At this moment, interfacial properties are not able to stabilize the film. The breaking of a single bubble might produce a burst strong enough to cause a shock wave that expands and destroys adjacent bubbles with very thin and non elastic films. The lower zone of foam column, with higher liquid content, resists the impact and does not collapse, probably because the films are still thick enough to exhibit elasticity.

**Fig. 2 Foaming dynamics of 0.02% Sapogenat-080 solutions
EON = 8, CMC = 0.005%.**



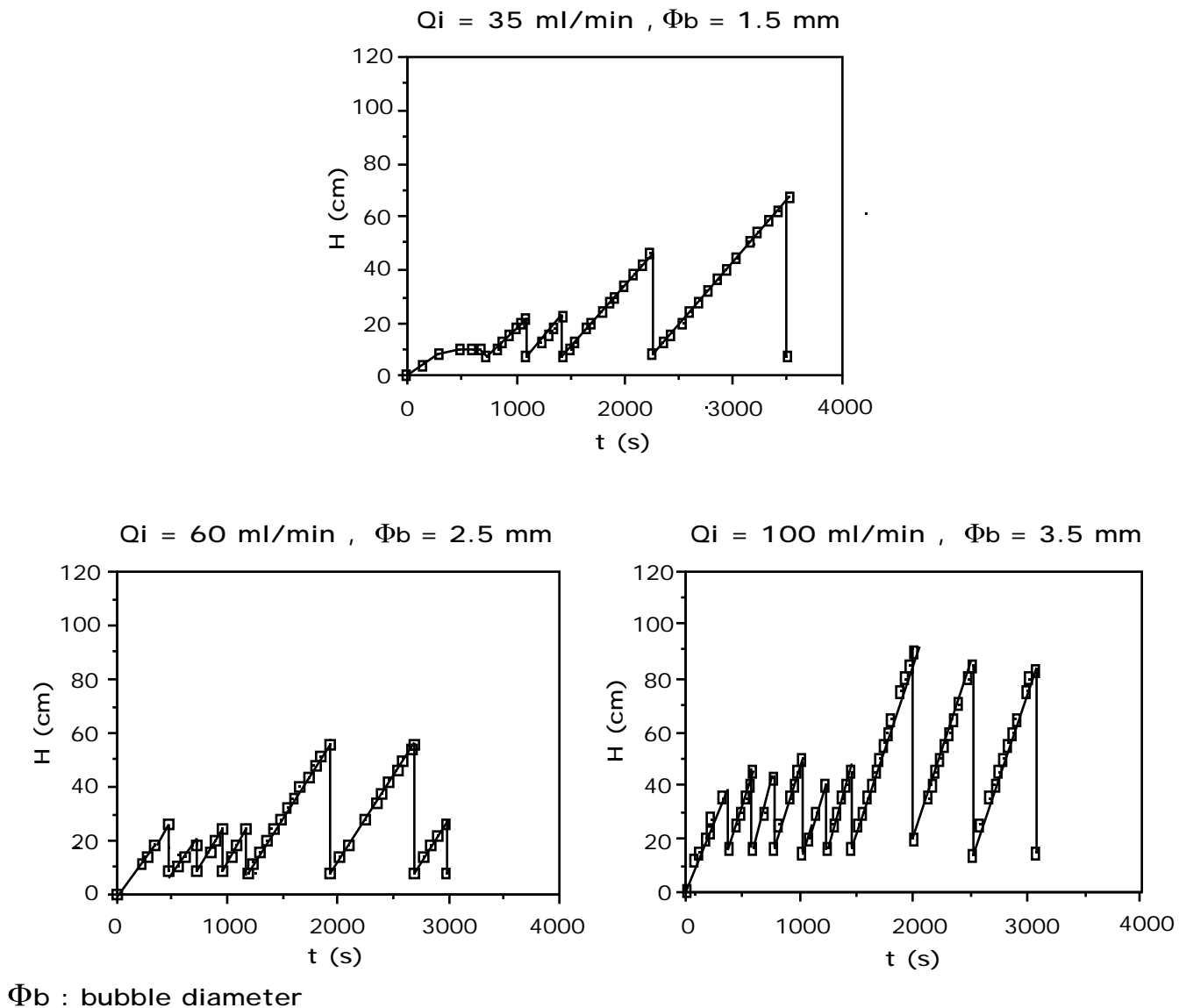
The variation in the stable period between two collapses might be caused by a surfactant fractionation since the surfactant bears a EON distribution. Less hydrophilic species can quickly adsorb as the first bubble surface appears, whereas more hydrophilic species remain in solution. This can alterate the foaming properties of the solution. This may be corroborated by the fact that the higher the gas flow rate is, the longer the bubbles are and the longer the cycle is.

**Fig. 3 Foaming dynamics of 0.2% Sapogenat-080 solutions
EON = 8 , CMC = 0.005%**



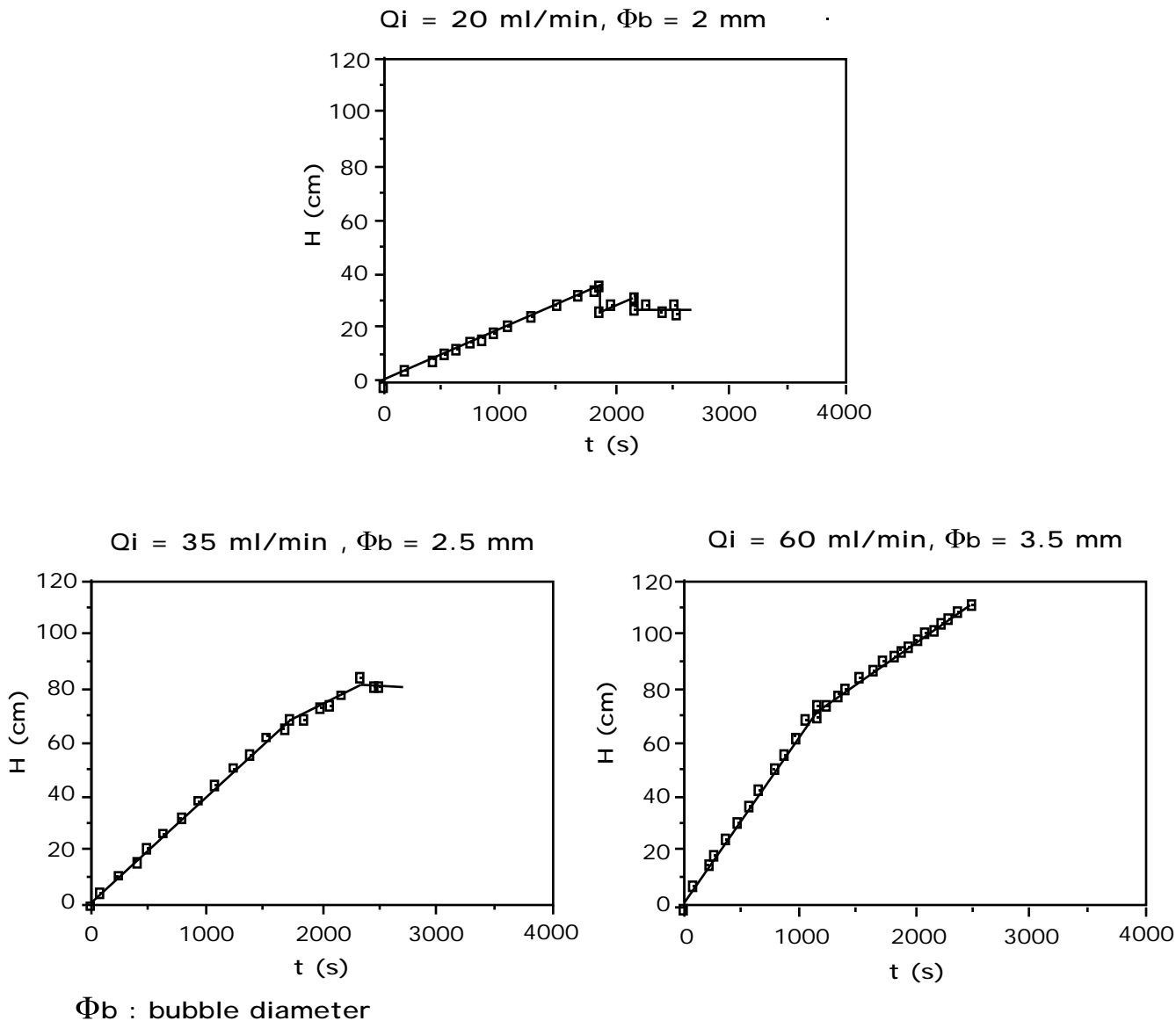
A comparison between Fig. 2 and Fig. 3 illustrates that when surfactant concentration is increased the pulsating decay disappears. A single collapse behavior takes place in which the foam height reaches a maximum value and then decays to a steady-state value. This may be related to the fact that when concentration is increased beyond the CMC, film elasticity decreases. Therefore, foamability also decreases.

**Fig. 4 Foaming dynamics of 0.02% Sapogenat-080 solutions
EON = 8 , CMC = 0.005% . Double gas injection**



A comparison between Fig. 2 and Fig. 4 shows that the decreasing of the bubble diameter causes an increase in the number of foam breaking cycles. It may be caused by an increase in the pressure differential between foam bubbles. However, no significant influence of the bubble size on the foam dynamic behavior is observed.

Fig. 5 Foaming dynamics of 0.02% Sapogenat-080 solutions
EON = 8 , CMC = 0.005%
Solution viscosity = 10 cp
Additive: Carboxy Methyl Cellulose (0.1%)

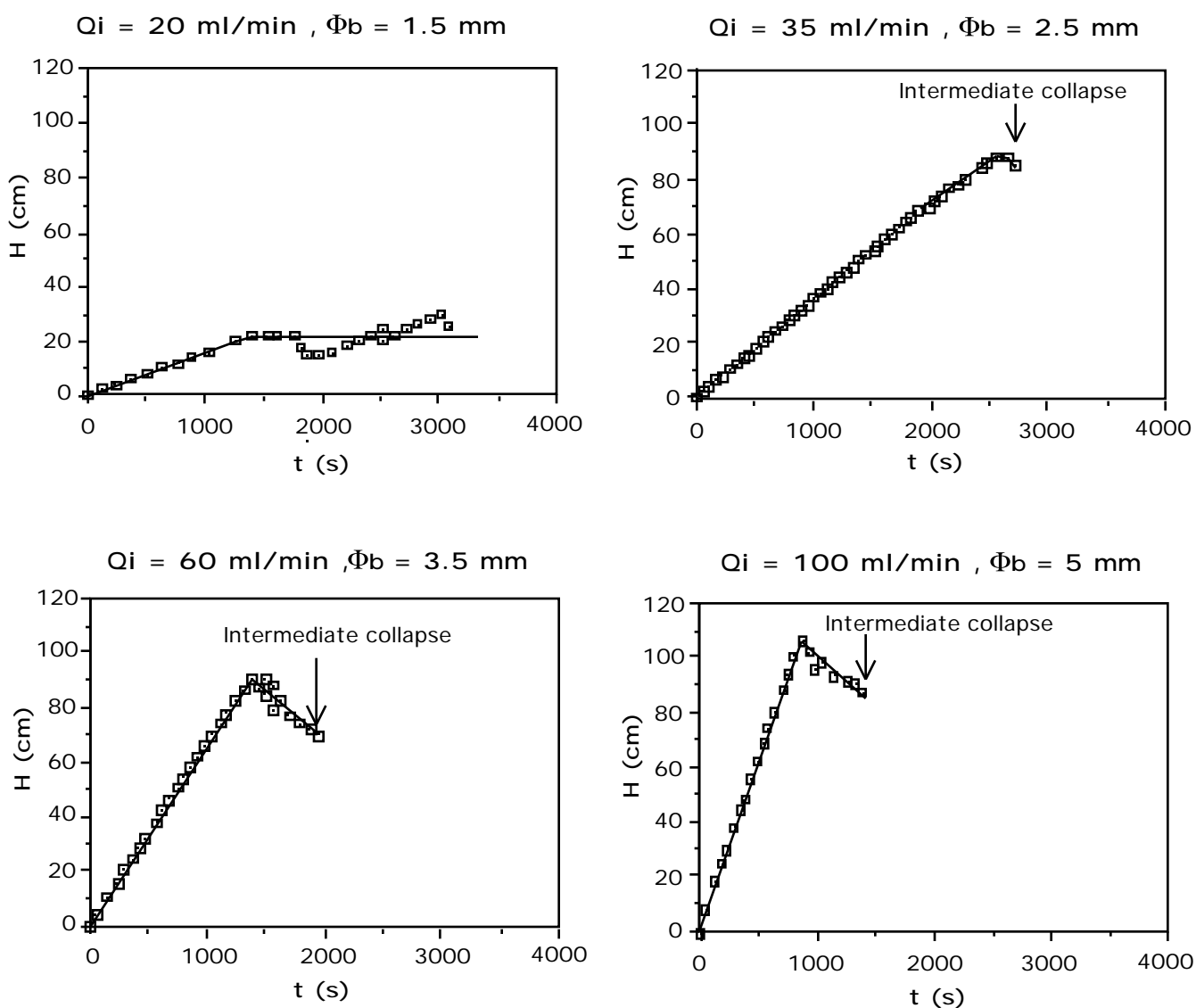


Since the liquid drainage determines the foam behavior, an increase in solution viscosity may delay the drainage and avoid the conditions of foam complete collapse (see Fig. 5), resulting in an asymptotic dynamic behavior.

FOAMING DYNAMICS OF SAPOGENAT-180 SOLUTIONS:

Fig. 6 shows that for EON = 18 and a concentration of 0.02% the pulsating decay does not occur anymore. When the foam height reaches a value between 90 and 110 cm, an intermediate collapse takes place; that is, a foam column fragmentation at 10 cm from the bottom. Before this collapse, foam top decay appears, which indicates that foam generation rate is less than foam destruction rate. Because intermediate collapse takes place at an almost constant height, a surfactant depletion might have occurred, which is corroborated by surface tension measurements before and after foaming.

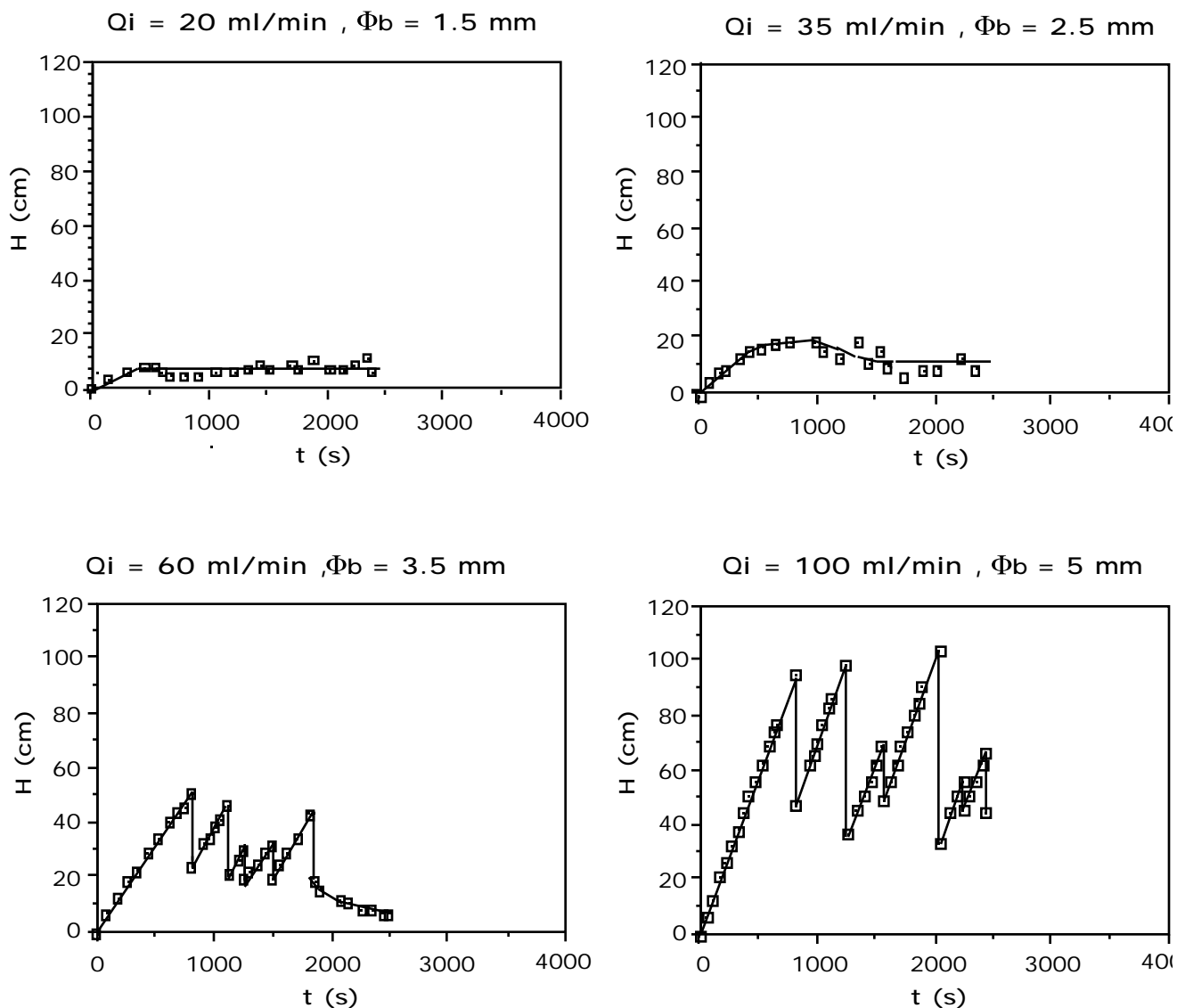
**Fig. 6 Foaming dynamics of 0.02%. Sapogenat-180 solutions
EON = 18 , CMC = 0.015%**



Φ_b : bubble diameter

When surfactant concentration is increased (see Fig. 7) the effect of gas flow rate can be clearly observed. At low gas flow rates asymptotic behavior occurs, and at high gas flow rates, pulsating decay occurs. This confirms the existence of a surfactant fractionation, which causes a variation in foam properties with time.

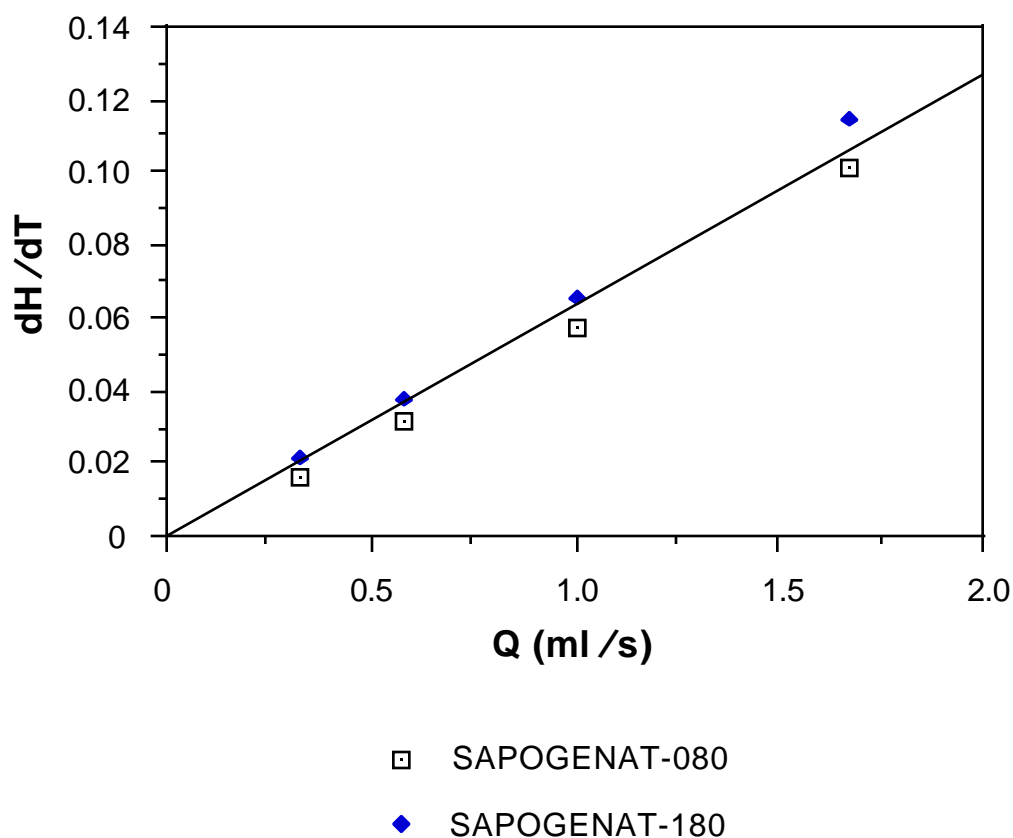
Fig. 7 Foaming dynamics of 0.2% Sapogenat-180 solutions
EON = 18 , CMC = 0.015%



Φ_b : bubble diameter

Fig. 8 shows that foaming rate, that is H vs t plot slope, is proportional to the gas flow rate and almost independent on EON. This means that the maximum height that might be attained depends upon the foam stability.

Fig. 8. Foaming rate vs Q_i for 0.02% Sapogenat solutions



The following factors contribute to decrease foam stability:

- High gas flow rates.
- Low surfactant concentrations (near CMC)
- Low EON values.
- Low viscosities.

These factors affect dynamic foam behavior, because they have an influence on Q_0 . This term may be continuous or discontinuous. In the second case, a pulsating decay may occur,

and foam collapse might correspond to a critical situation in a metastable process. Interesting applications can be designed if such a behavior can be harnessed.

[1] ANDERER, J. e IGLESIAS, E. (1993). Acción antiespumante. Informe técnico FIRP No.9302.

[2] GARRET, P.R. (1993) . Recent developments in the understanding of foam generation and stability. Chemical Engineering Science. 48. 367-392

[3] JEELANI, S.A.K, FIDI, N. and HARTLAND, S. (1990) .Foam formation during CO₂ desorption from agitated supersaturated aqueous surfactant solutions. Chemical Engineering Science. 45. 1043-1048

[4] SZEKRENYESY, T. , LIKTOR, K. and SANDOR, N. (1992) Characterization of foam stability by the use of foam models. Colloids and Surfaces. 68 .267-273.