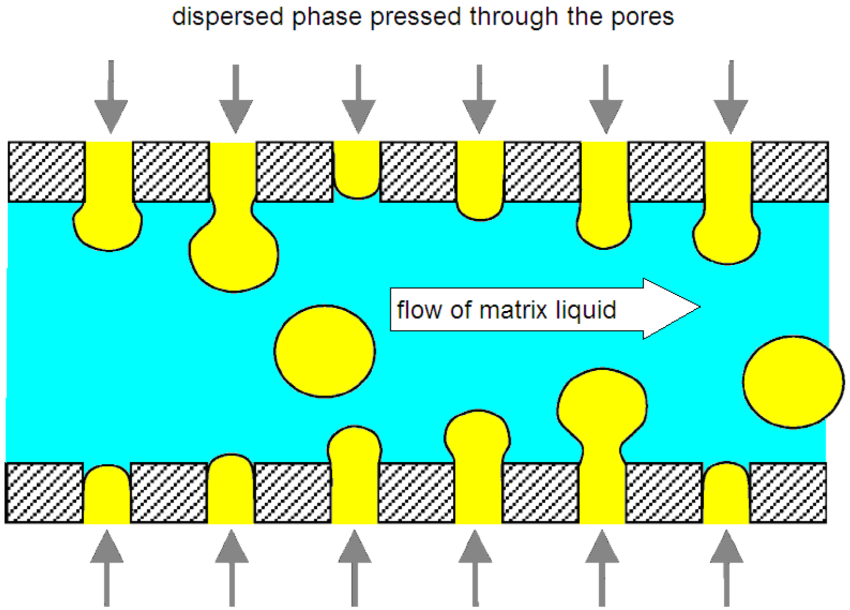
Single Drop/Bubble Experiments to Study the Dynamics of Liquid Interfaces

A. Javadi, N. Mucic, J.Y. Won, M. Born, J. Krägel and R. Miller

MPI Colloids and Interfaces, Potsdam, Germany

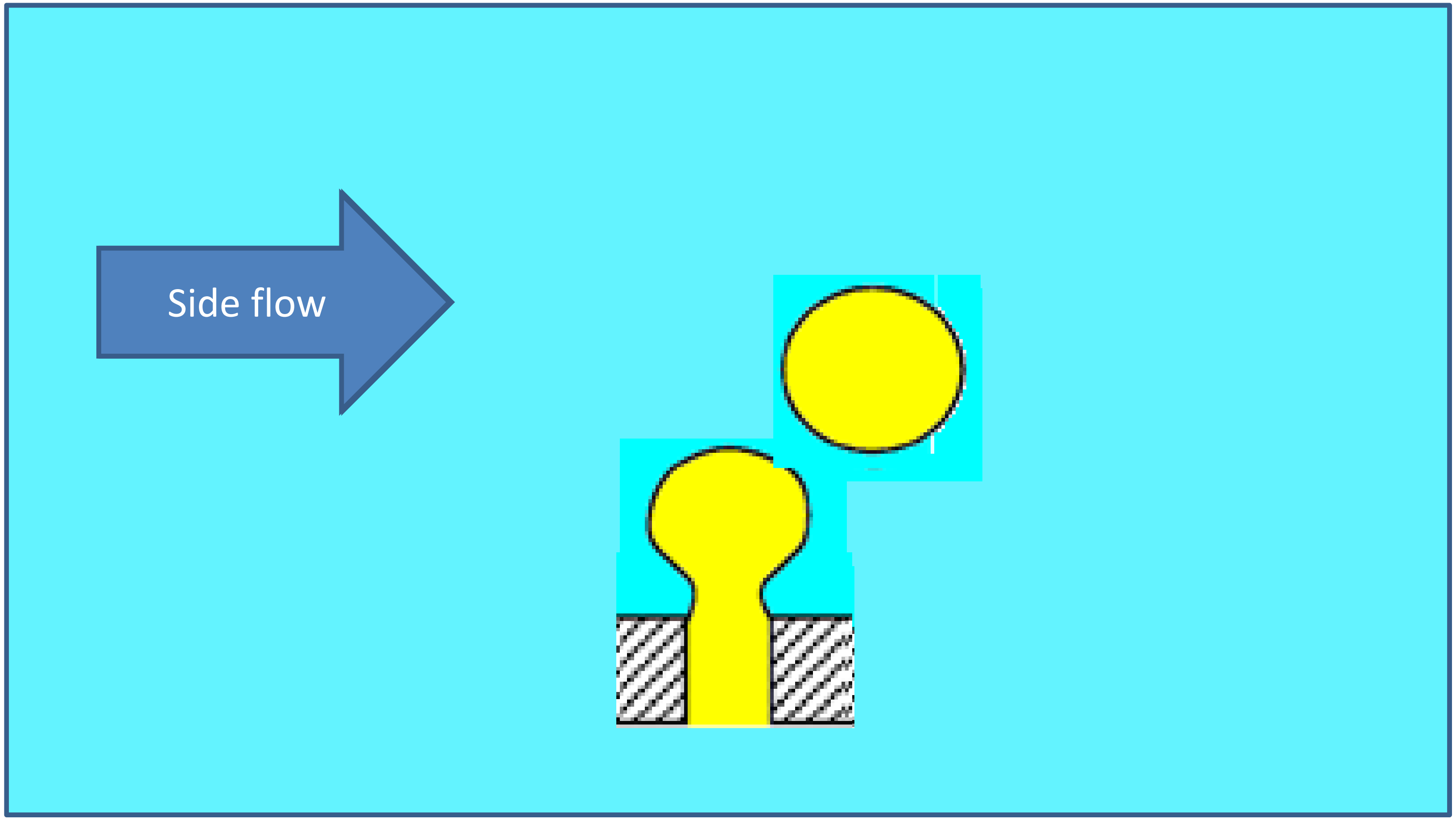
Motivation

Why is knowledge on the dynamics of liquid interfaces essential?



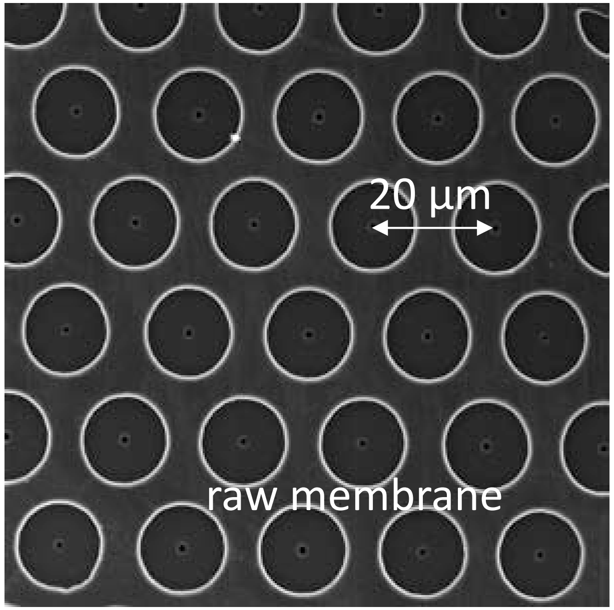
Membrane emulsification is a modern technology to produce emulsions of a narrow droplet size distribution. Also monodispers foams are produced by such a methodology using rotating membranes.

Membrane Emulsification

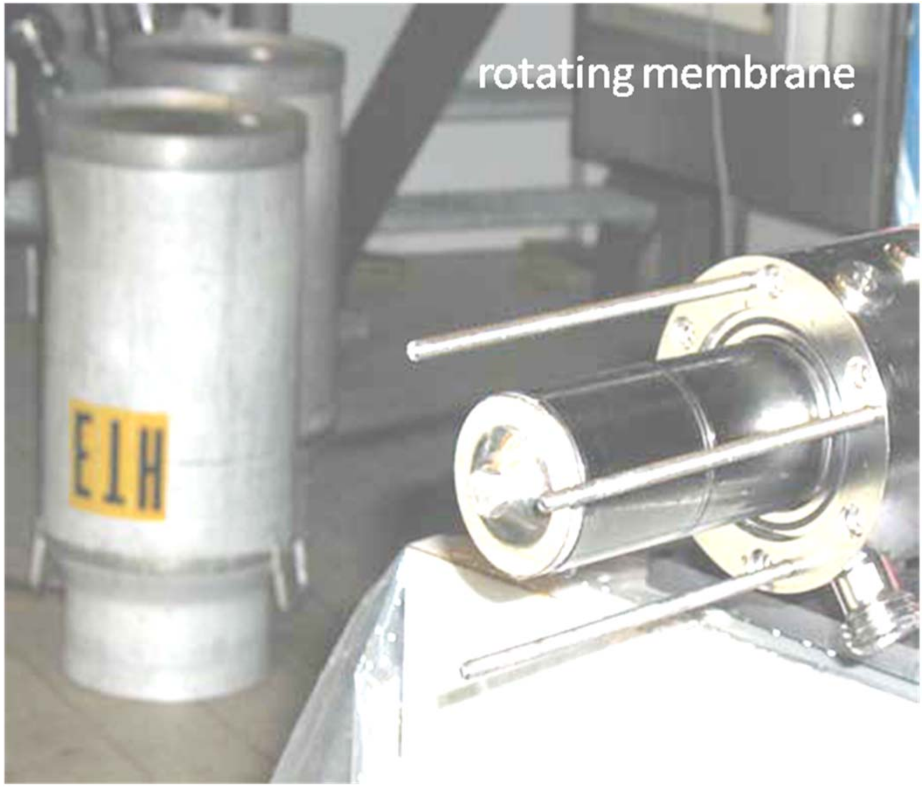


Motivation

Why is knowledge on the dynamics of liquid interfaces essential?

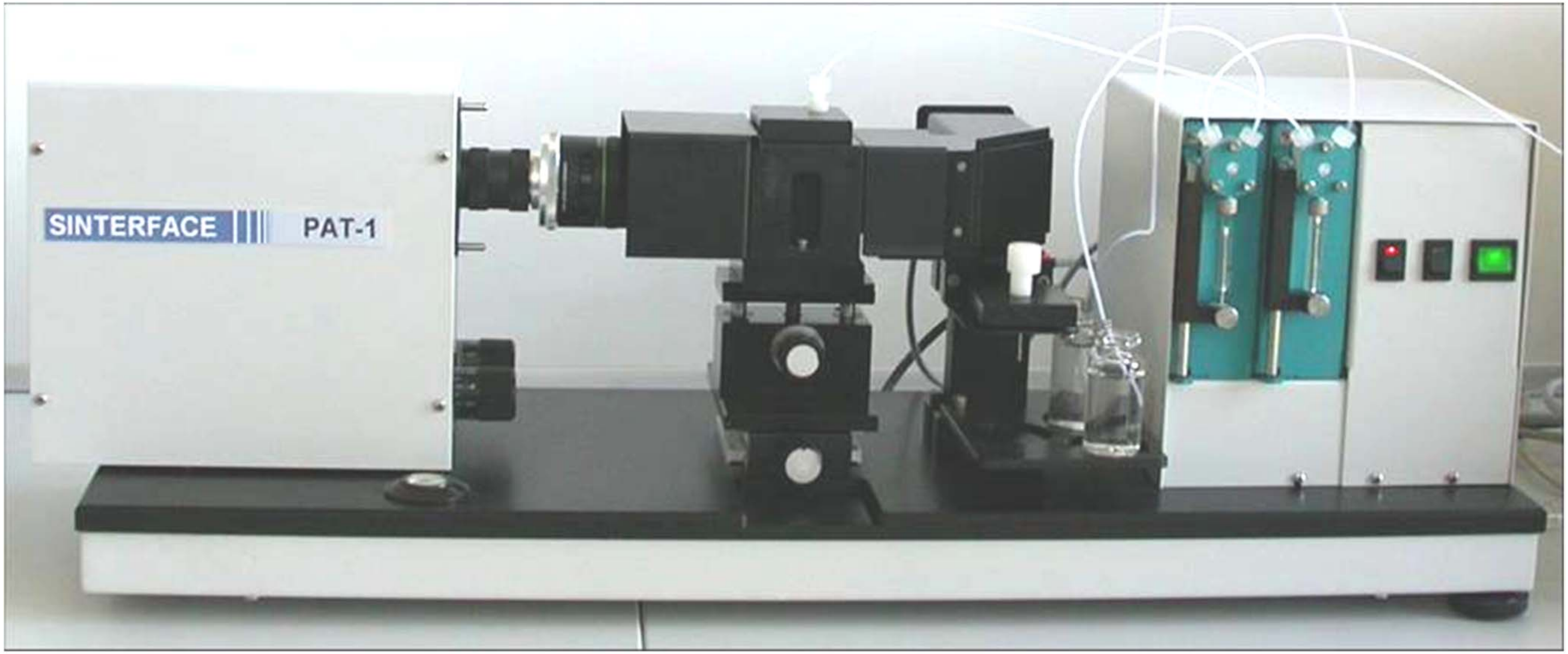


Erich Windhab, ETH Zurich (DE 10307568 A1)



Also monodisperse foams are produced by a membrane technology using rotating membranes.

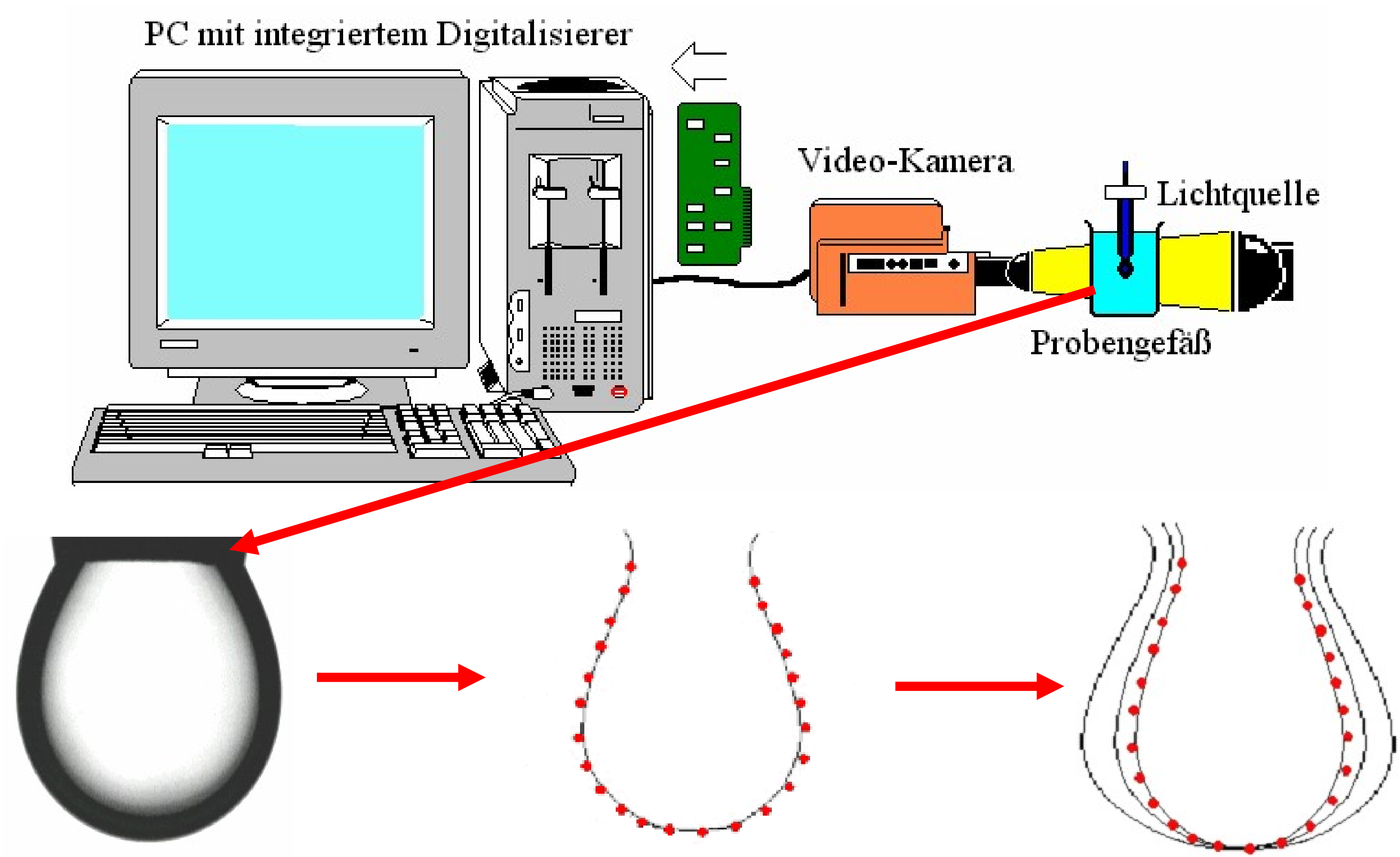
Drop Profile Tensiometry



Drop and Bubble Profile Tensiometer PAT1 of SINTERFACE Technologies, Berlin

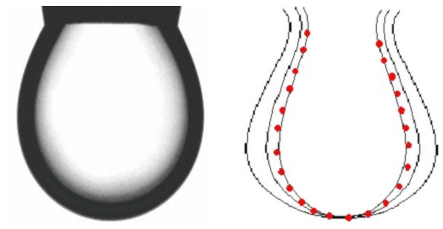
Drop and bubble profile analysis is the most versatile method and the working horse in many interfacial laboratories.

Drop Profile Tensiometry



The coordinates of the drop profiles are determined from a video image.

Drop Profile Tensiometry

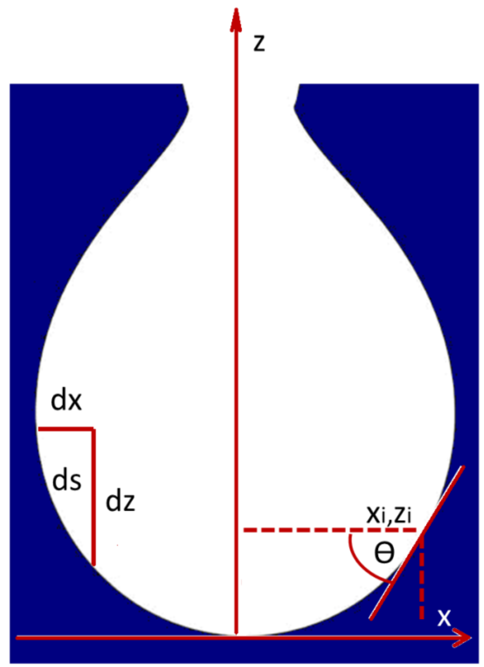


Gauss Laplace Equation

$$\frac{dx}{ds} = \cos\theta$$

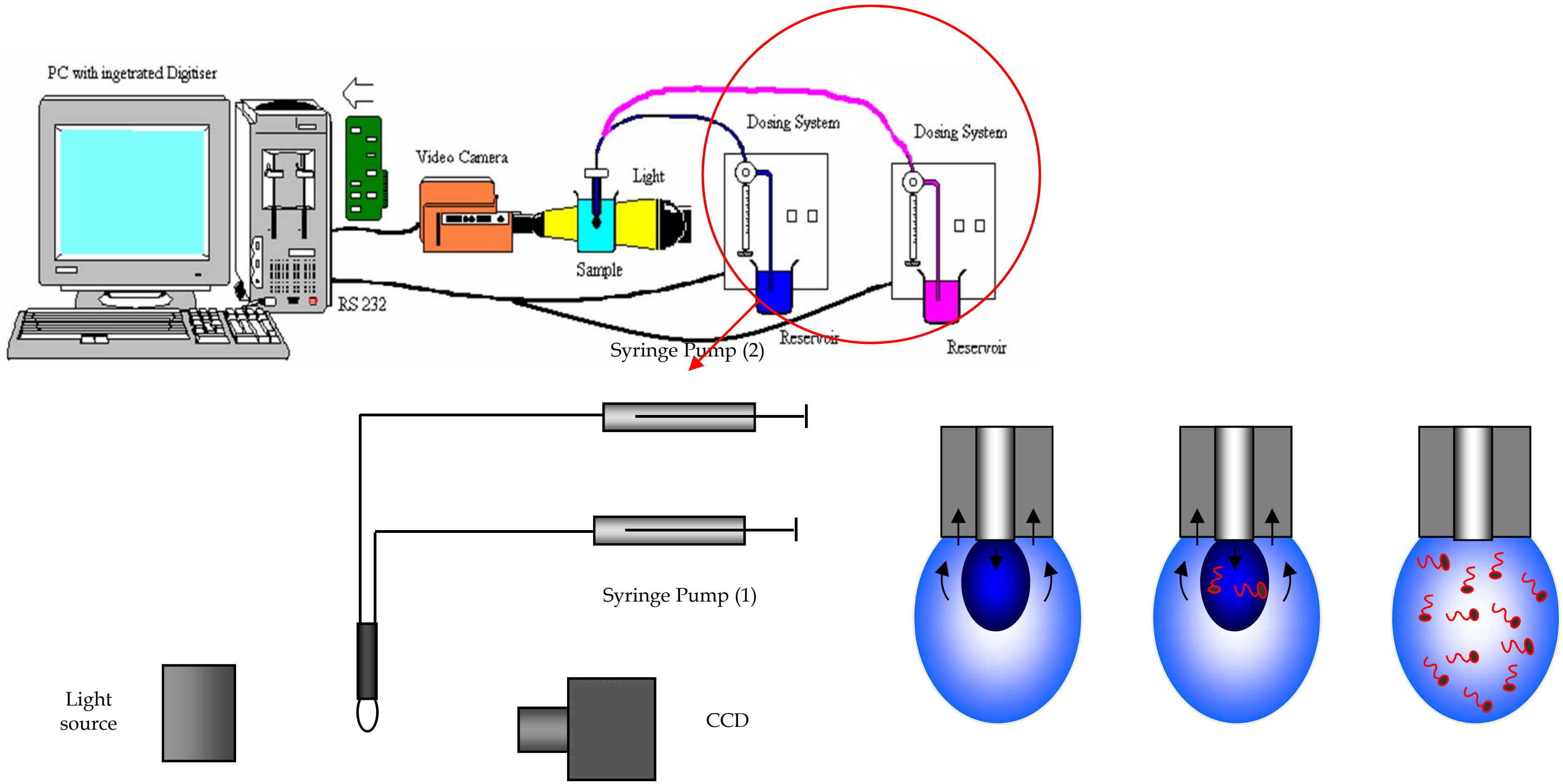
$$\frac{dz}{ds} = \sin\theta$$

$$\frac{d\theta}{ds} = \frac{2}{R_0} - \frac{\Delta\rho g z}{\gamma} - \frac{\sin\theta}{x}$$



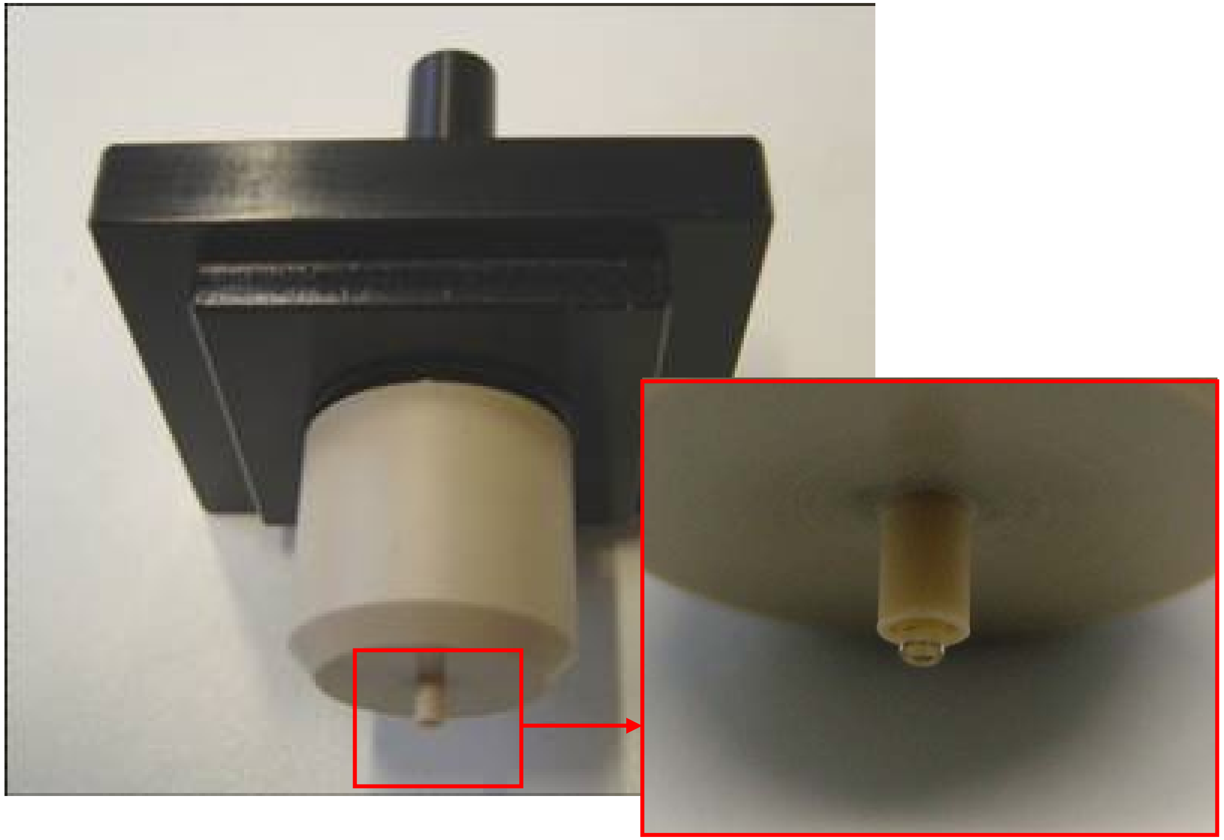
The experimental coordinates are then compared with the „theoretical shape“ of a drop calculated from the Gauss Laplace Equation. The “best fit” provides the interfacial tension value γ..

Drop profile Analysis Tensiometry
PAT-1 with coaxial capillary and double dosing system

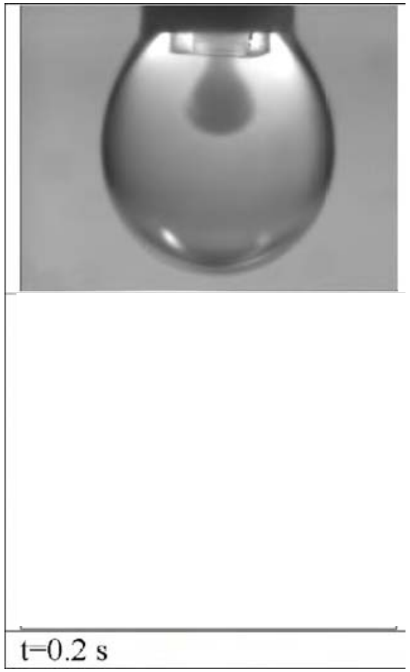


Wege, H. A.; Holgado-Terriza, J. A.; Neumann, A. W.; Cabrerizo-Vilchez, M. A. *Colloids Surf. A* 1999, *156*, 509.
Ferri, J. K.; Gorevski, N.; Kotsmar, Cs.; Leser, M. E.; Miller, R. *Colloids Surf., A* 2008, *319*, 13.

Coaxial double capillary

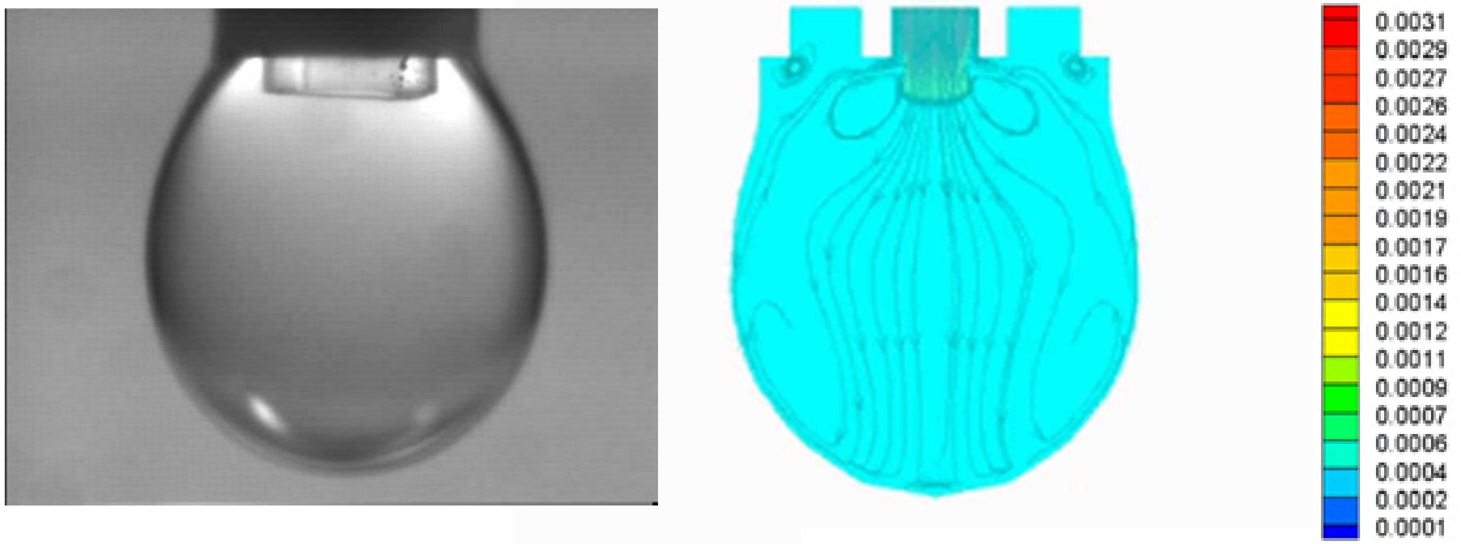


Drop profile Analysis Tensiometry
PAT-1 with coaxial capillary and double dosing system



A. Javadi, J.K. Ferri, T.D. Karapantsios and R. Miller, Interface and bulk exchange:
Single drop experiments and CFD simulations, Colloids Surfaces A, 365 (2010) 145

Drop profile analysis tensiometry with drop bulk exchange



Drop exchange rate dt = 0.1, dv = 0.1, V = 30mm3, t = 65 s

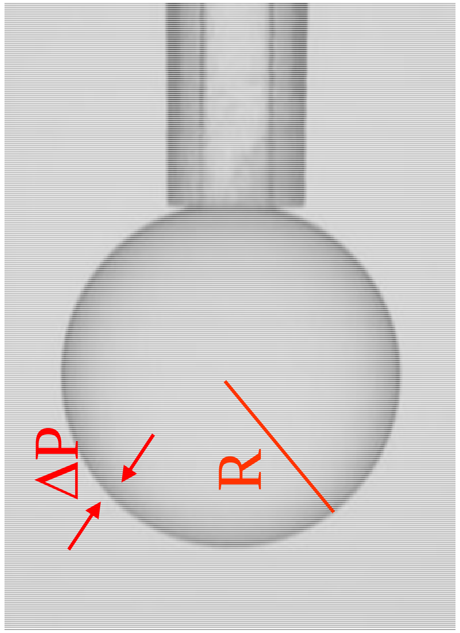
A. Javadi, J.K. Ferri, T.D. Karapantsios and R. Miller, Interface and bulk exchange: Single drop experiments and CFD simulations, Colloids Surfaces A, 365 (2010) 145

Capillary pressure technique for fast dynamic Interfacial tension measurements

Fast dynamics (<0.01 s)

Low density differences

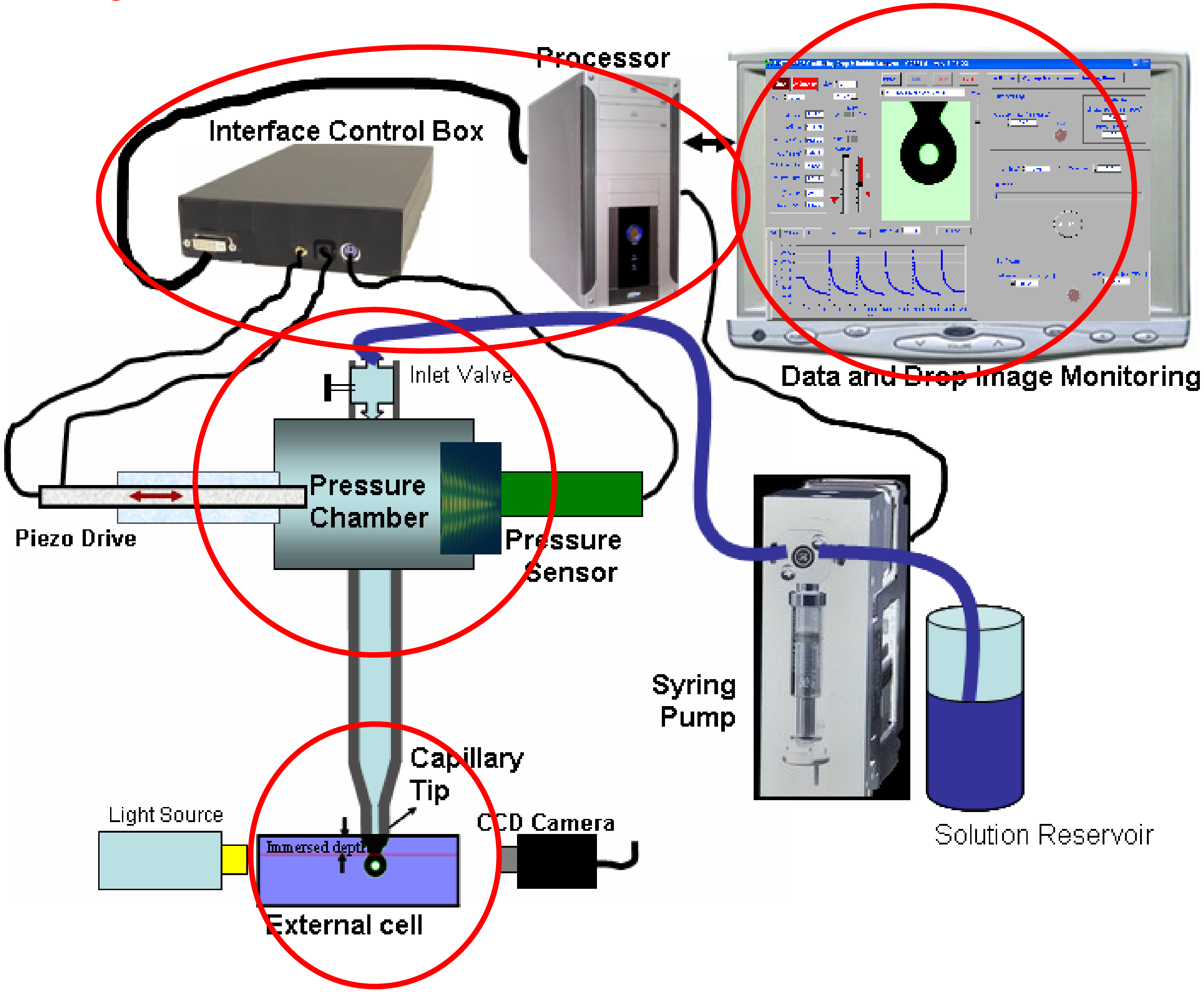
Microgravity conditions



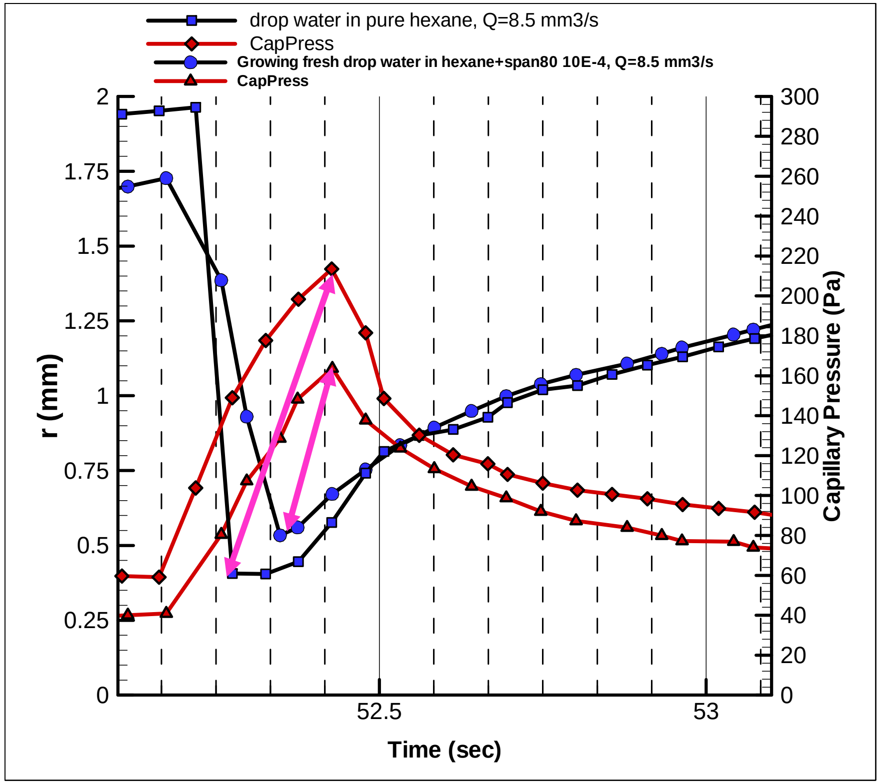
$$\Delta P(t) = 2\frac{\gamma(t)}{R(t)}$$

A. Passerone, L. Liggieri, N. Rando, F. Ravera, E.Ricci, J. Colloid Interface Sci., 146 (1991) 152.
R. Nagarajan, D.T. Wasan, J. Colloid Interface Sci., 159 (1993) 164.
C. A. Macleod, C. J. Radke, J. Colloid Interface Sci., 166 (1994) 73.
X. Zhang, M.T. Harris, O.A. Basaran, J. Colloid Interface Sci., 168 (1994) 47.
L. Liggieri, F. Ravera, A. Passerone, J. Colloid Interface Science, 169 (1995) 226.

Capillary pressure technique for fast dynamic Interfacial tension measurements

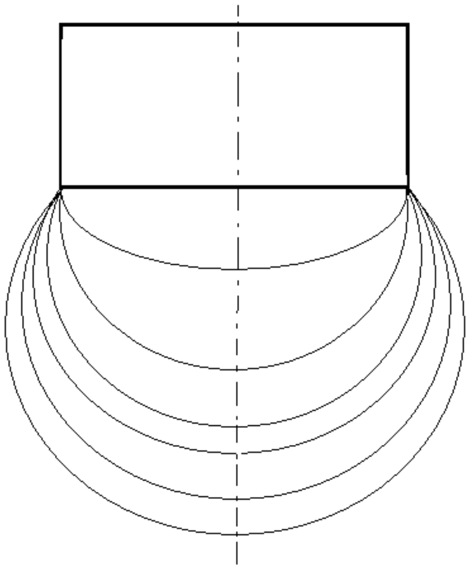


Continuously Growing Drop (CGD)



There can be various reasons for the time shift between maximum capillary pressure and minimum drop radius at high liquid flow rates

Adsorption on Growing Drop Surfaces



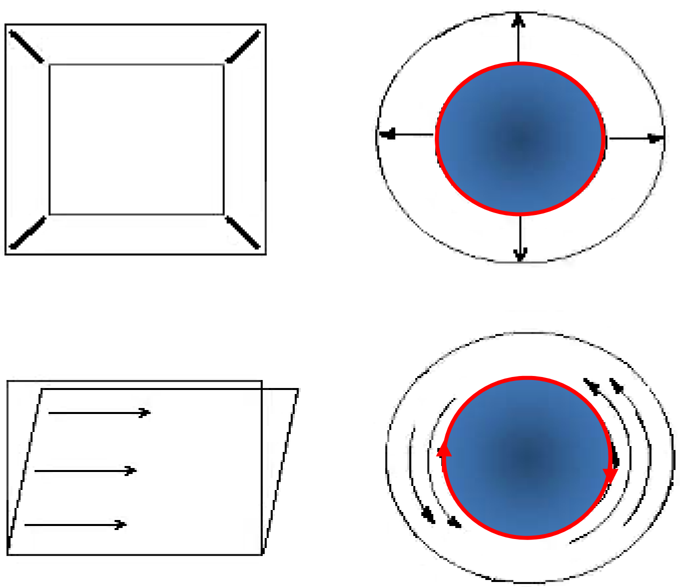
$$\Gamma(t) = \Gamma(0) + \frac{1}{R^2(t)}\sqrt{\frac{D}{\pi}}\int_0^t \frac{R^4(t)(c_0 - c(\tau))}{\left[\int_\tau^t R^4(\xi)d\xi\right]^{1/2}}d\tau$$

$\Gamma(t)$ - time dependence of adsorption
c - surfactant bulk concentration
$\Gamma(0)$ - initial load of the drop surface
R(t) - change of drop radius with time

18 years old but yet the best that we have to describe the adsorption at a growing drop.

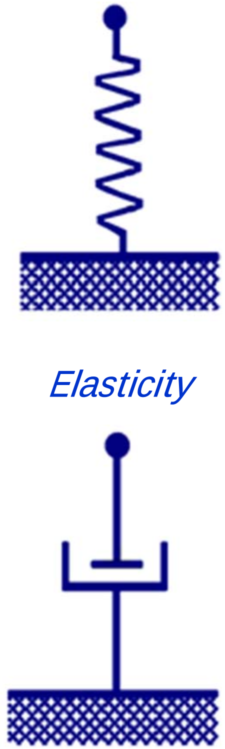
C.A. MacLeod and C.J. Radke, J. Colloid Interface Sci., vol. 166, pp. 73-78 (1994)

Interfacial Rheology



Expansion /
Compression

Shear

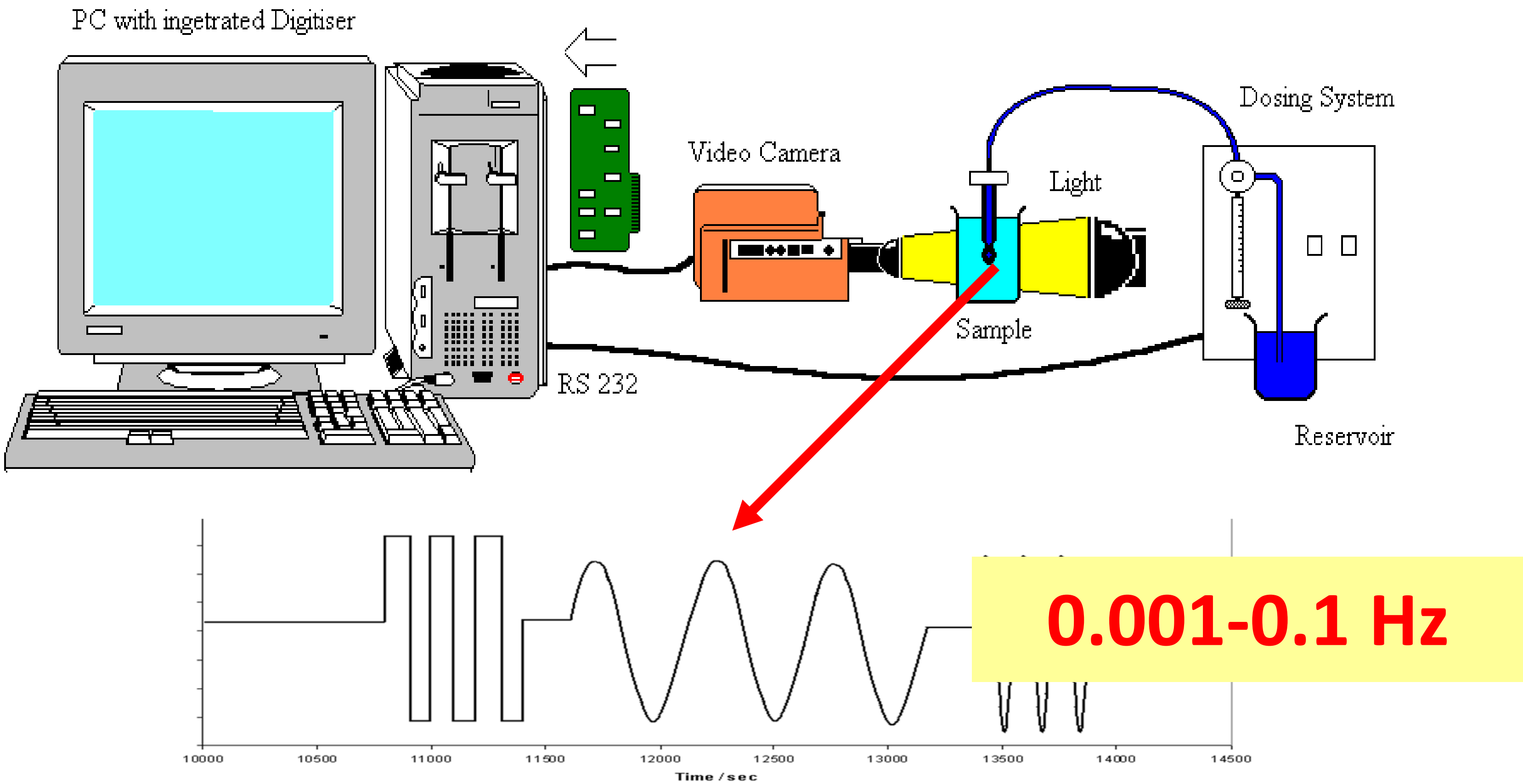


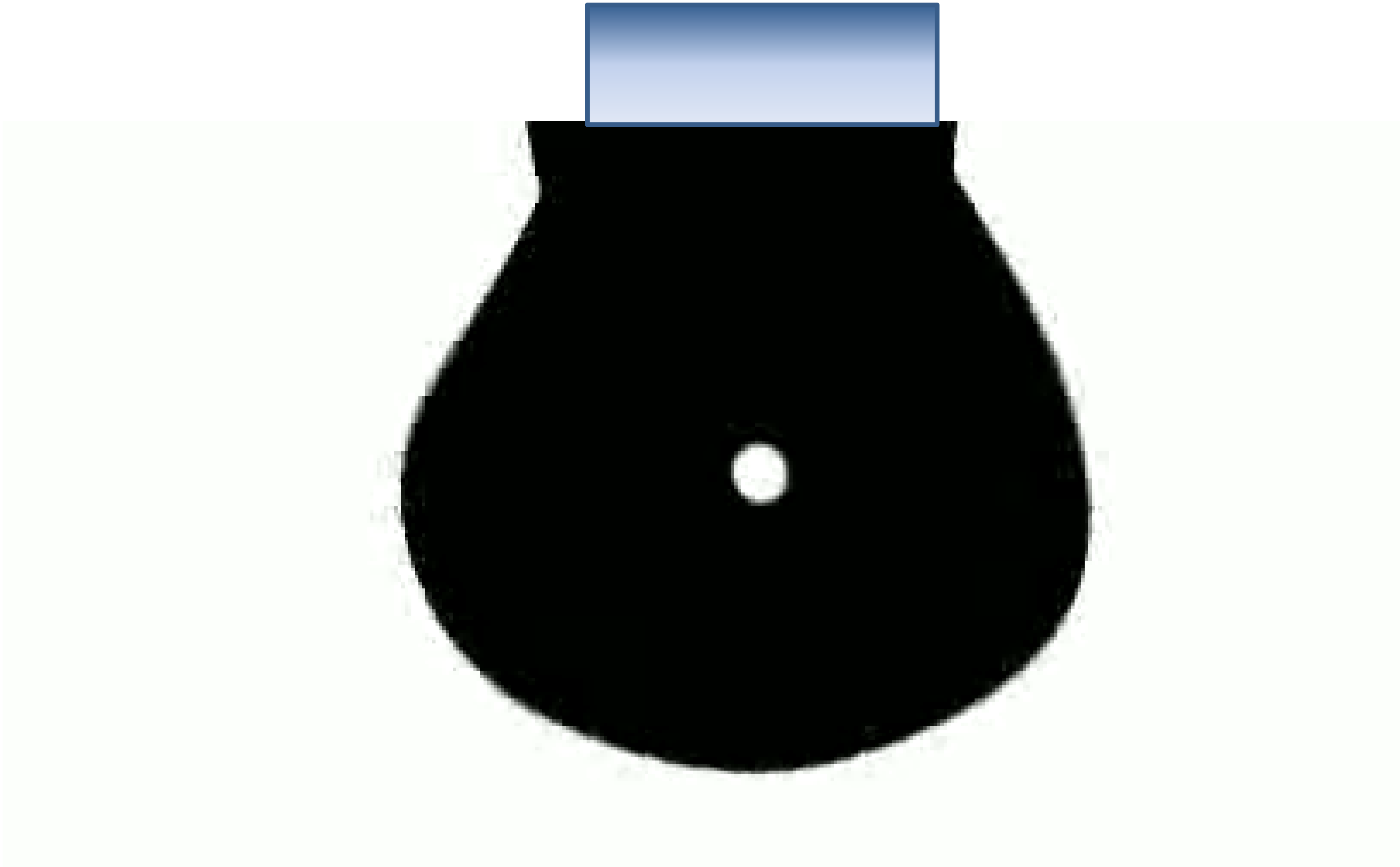
Elasticity

Viscosity

Drop Profile Analysis Tensiometer PAT-1

Drop/ Bubble Oscillations generated via the Dosing System



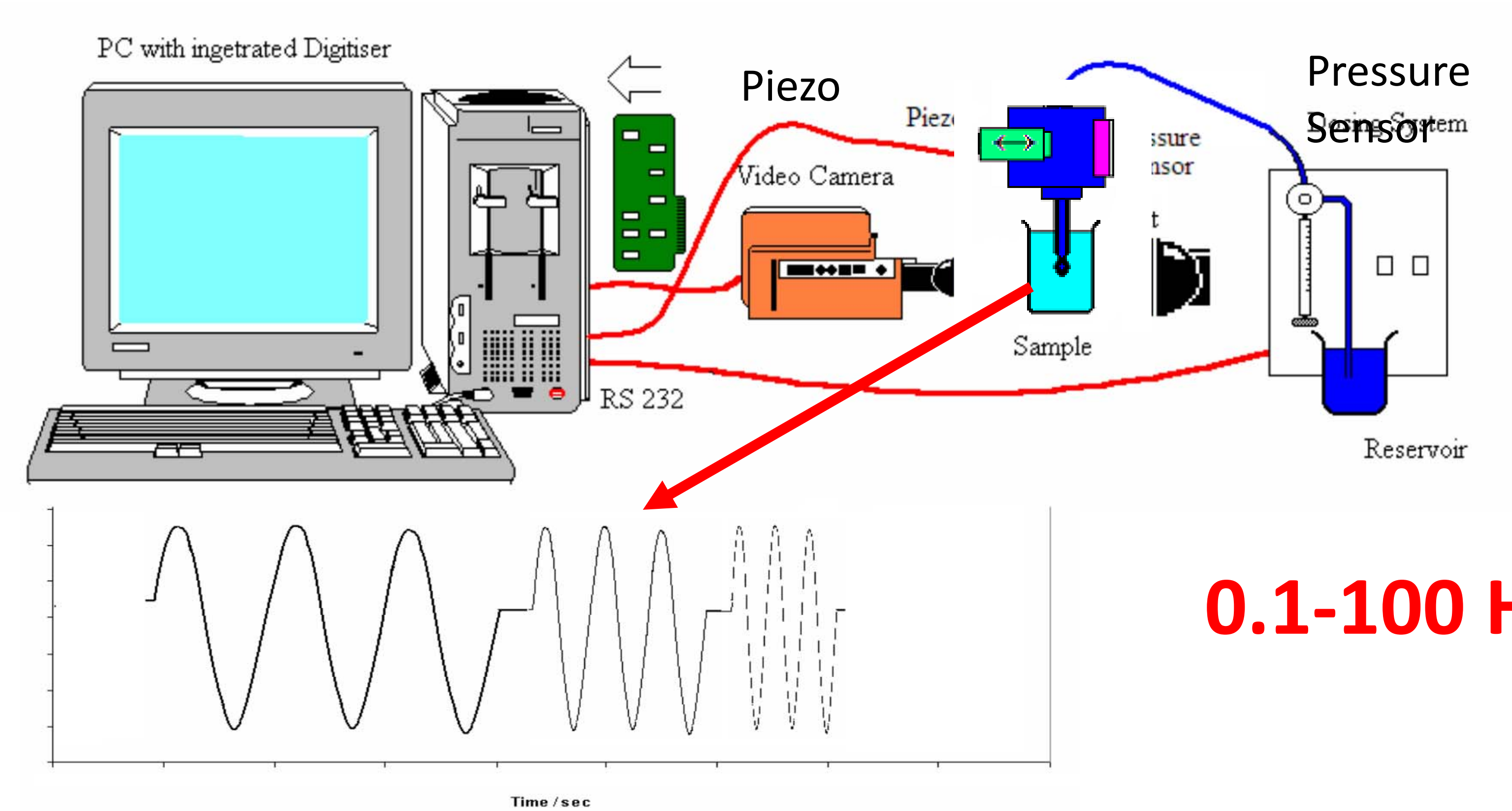


Large drops or bubbles perform complex oscillating modes.

Looks nice but is useless from a scientific point of view.

Extra Equipment for PAT-1

Fast Drop/ Bubble Oscillations with ODBA-1



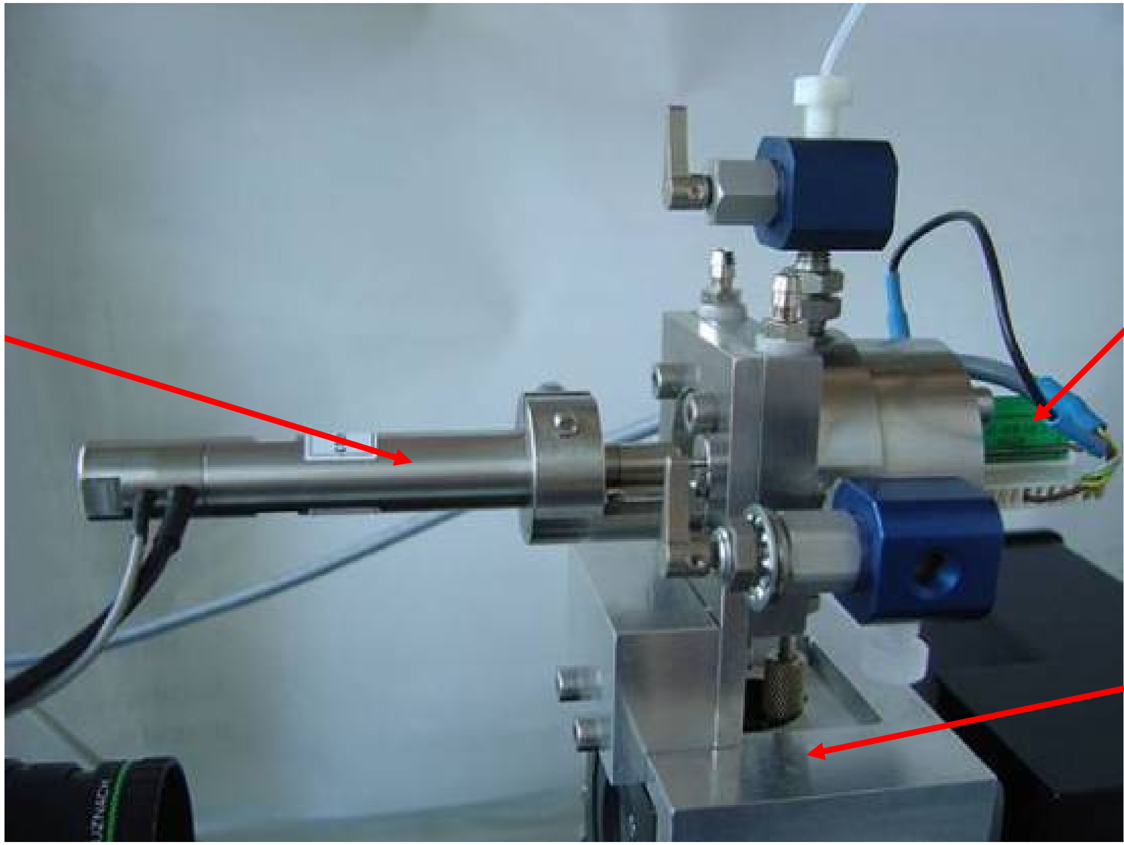
0.1-100 Hz

A piezo system allows fast drop oscillations up to 100 Hz and more.
The change in surface tension is monitored by capillary pressure measurements

Extra Equipment for PAT-1

Fast Drop/ Bubble Oscillations with ODBA-1

Piezo actuator

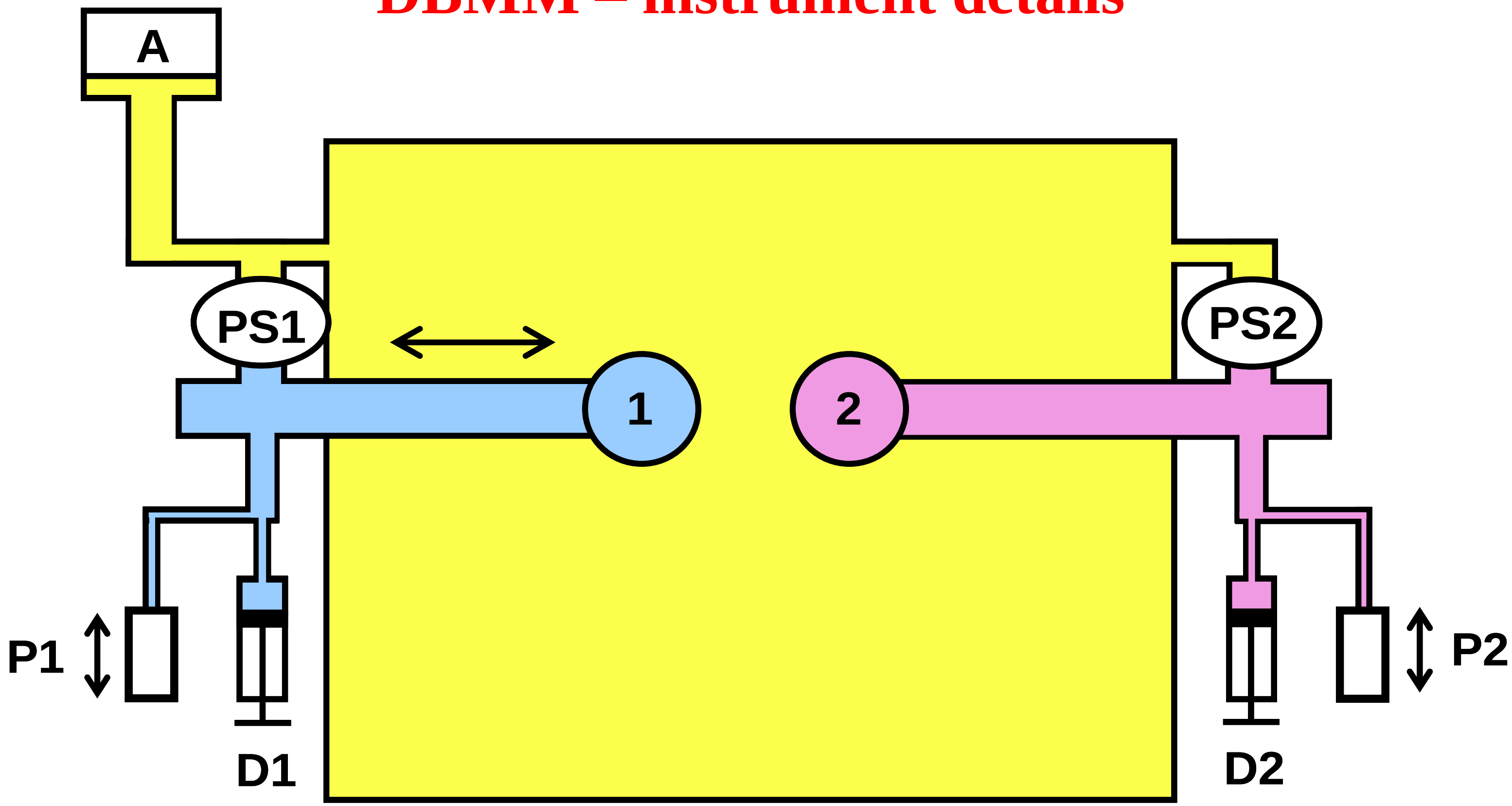


Pressure sensor

Capillary

Oscillating Drop and Bubble Analyser as extra module for PAT1 from SINTERFACE Technologies Berlin

DBMM – instrument details



Schematic of the Drop Bubble Micro Manipulator DBMM with its main elements

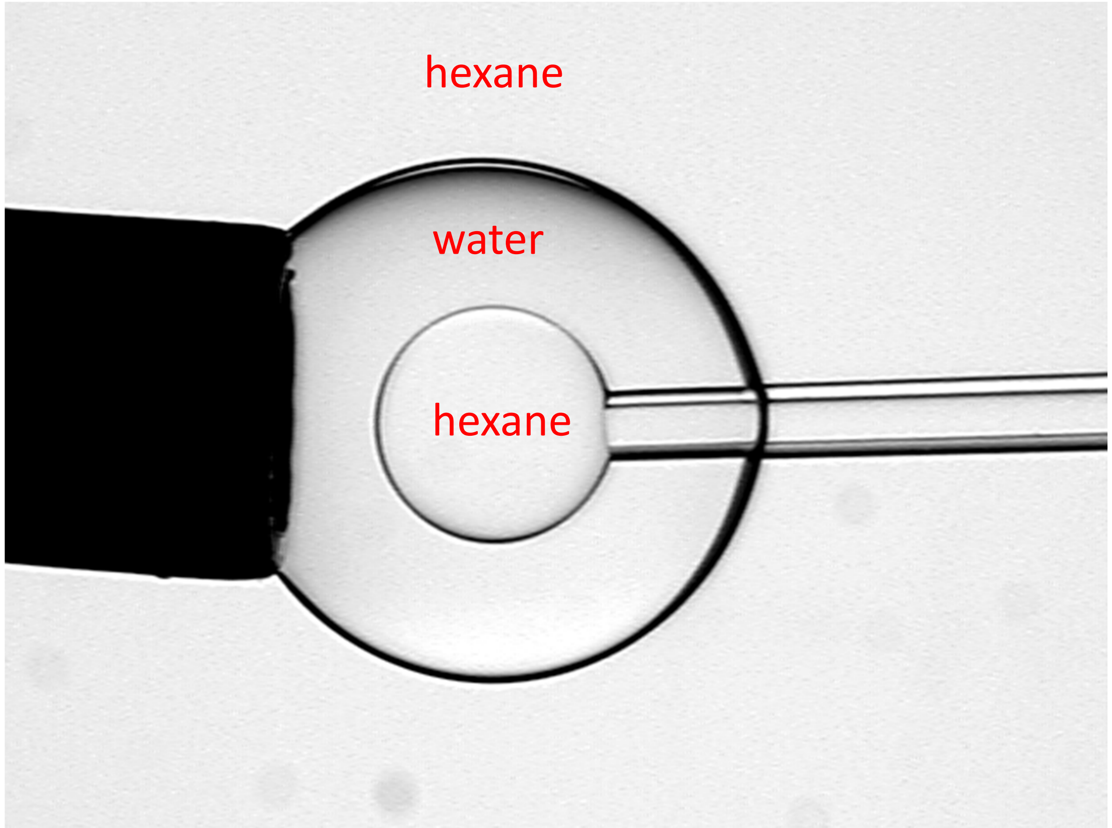
$10e^{-4}$ CTAB in water drops in air
real time - 0.003s
Running time : 30s

$10e^{-4}$ CTAB in water drops in hexane
real time - 0.002s
Running time : 20s

Pure water drops in hexane
real time - 0.002s
Running time : 20s

Coalescence of droplets in air or hexane

Extended to Droplet/Bubble inside of droplet/bubble – Water droplet in hexane droplet in water



Suitable tool for *investigations with two drops (or bubbles)*
for a quantitative analysis of the role of emulsifiers in "multiple emulsions"

Drops under dynamic conditions – high liquid inflow

150mm³/s flowing water in air through a 0.45mm cylindrical capillary

On ground

Under microgravity Conditions

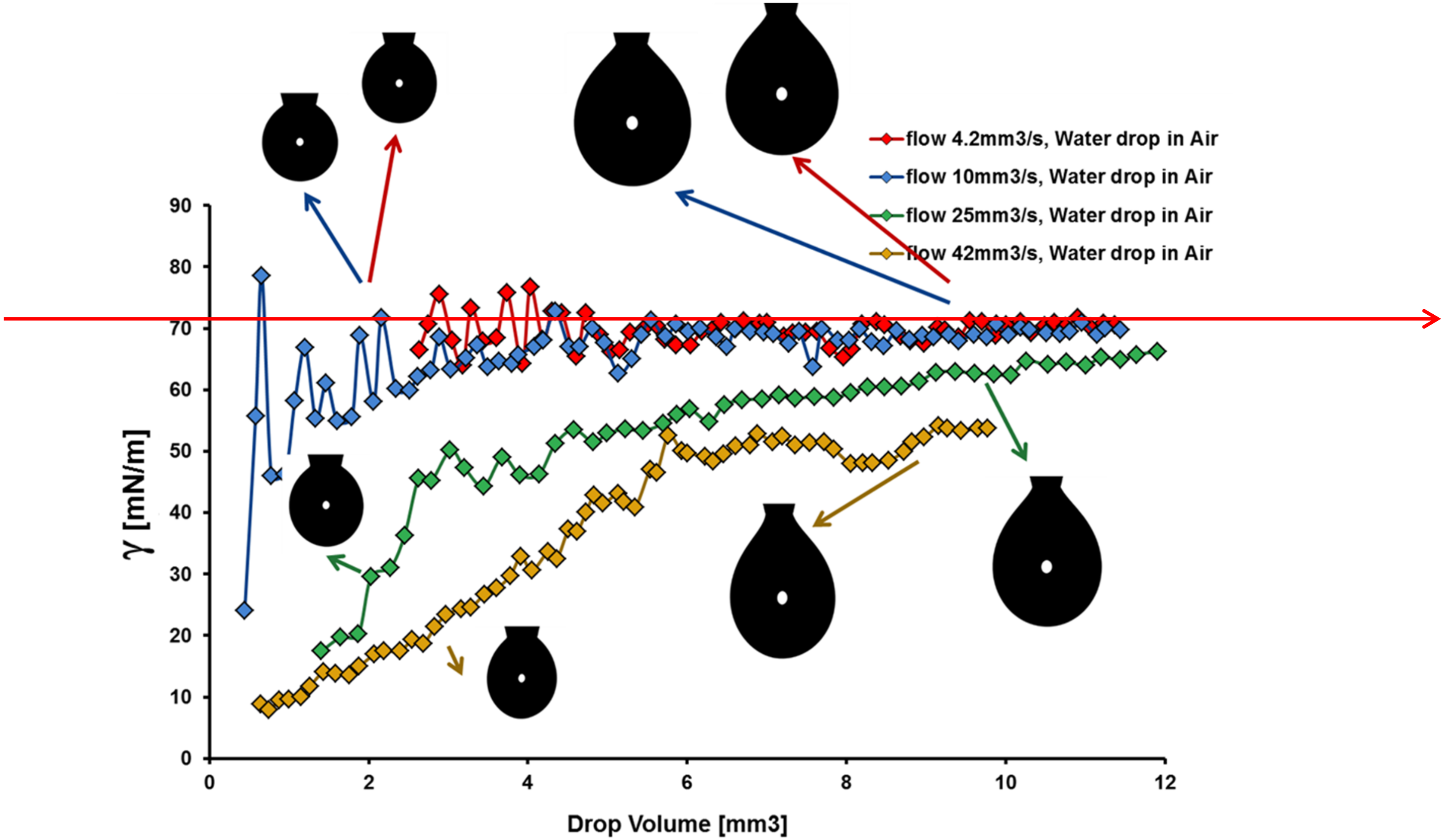
Drop Tower Bremen

83mm³/s flowing water in air through a 0.45mm cylindrical capillary

On ground

Under microgravity Conditions

Profile Analysis Tensiometry applied under dynamic conditions

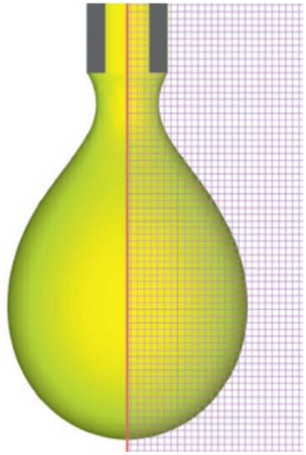


The obtained surface tension values extracted from dynamic drop profiles depend on the flow rate.

Computational Fluid Dynamics simulations (VOF)

The complete Navier-Stokes equations should be solved in conjunction with relevant equations regarding multiphase systems and surface forces

$$\frac{D\rho}{Dt} + \rho\nabla . \vec{u} = 0 \qquad \rho\frac{D\vec{u}}{Dt} = -\nabla P + \mu\nabla^2\vec{u} + \rho\vec{g} \qquad \frac{DC_i}{Dt} = D_i\nabla^2 C_i$$



Volume of Fluid technique applied to describe multiphase systems

$$\varphi = \frac{V_{Fluid,II}}{V_{Fluid,II} + V_{Fluid,I}} \qquad \frac{\partial\varphi}{\partial t} + \frac{\partial}{\partial x_i}(u_i\varphi) = 0$$

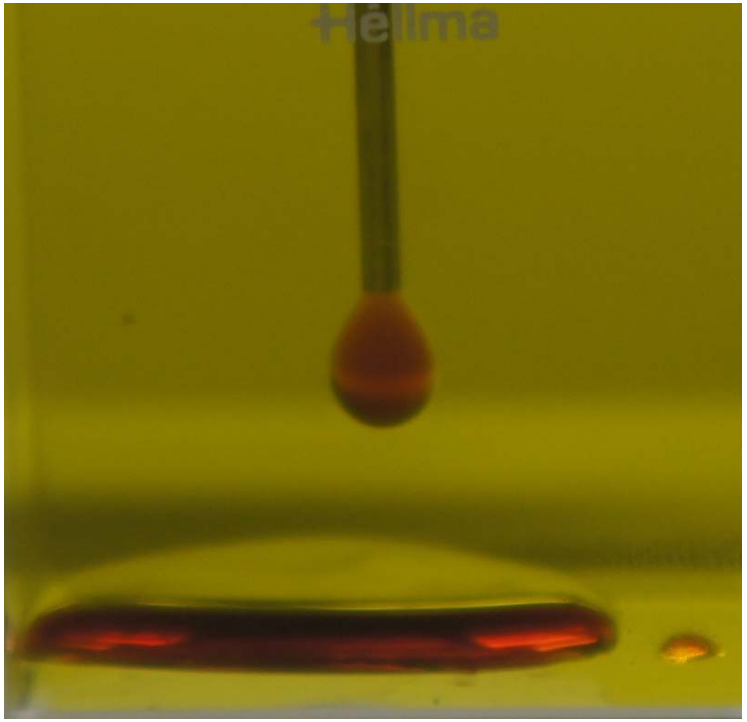
$$\rho = \rho_{Fluid,II}\varphi + \rho_{Fluid,I}(1-\varphi) \qquad \frac{1}{\mu} = \frac{\varphi}{\mu_{Fluid,II}} + \frac{1-\varphi}{\mu_{Fluid,I}}$$

Continuum Surface Force Model for surface tension effects

$$F_{sv}(x) = -\gamma\kappa\underline{n}\delta(\varphi) \qquad \kappa = -\nabla\cdot\underline{n} \qquad \underline{n} = \nabla\varphi / |\nabla\varphi|$$

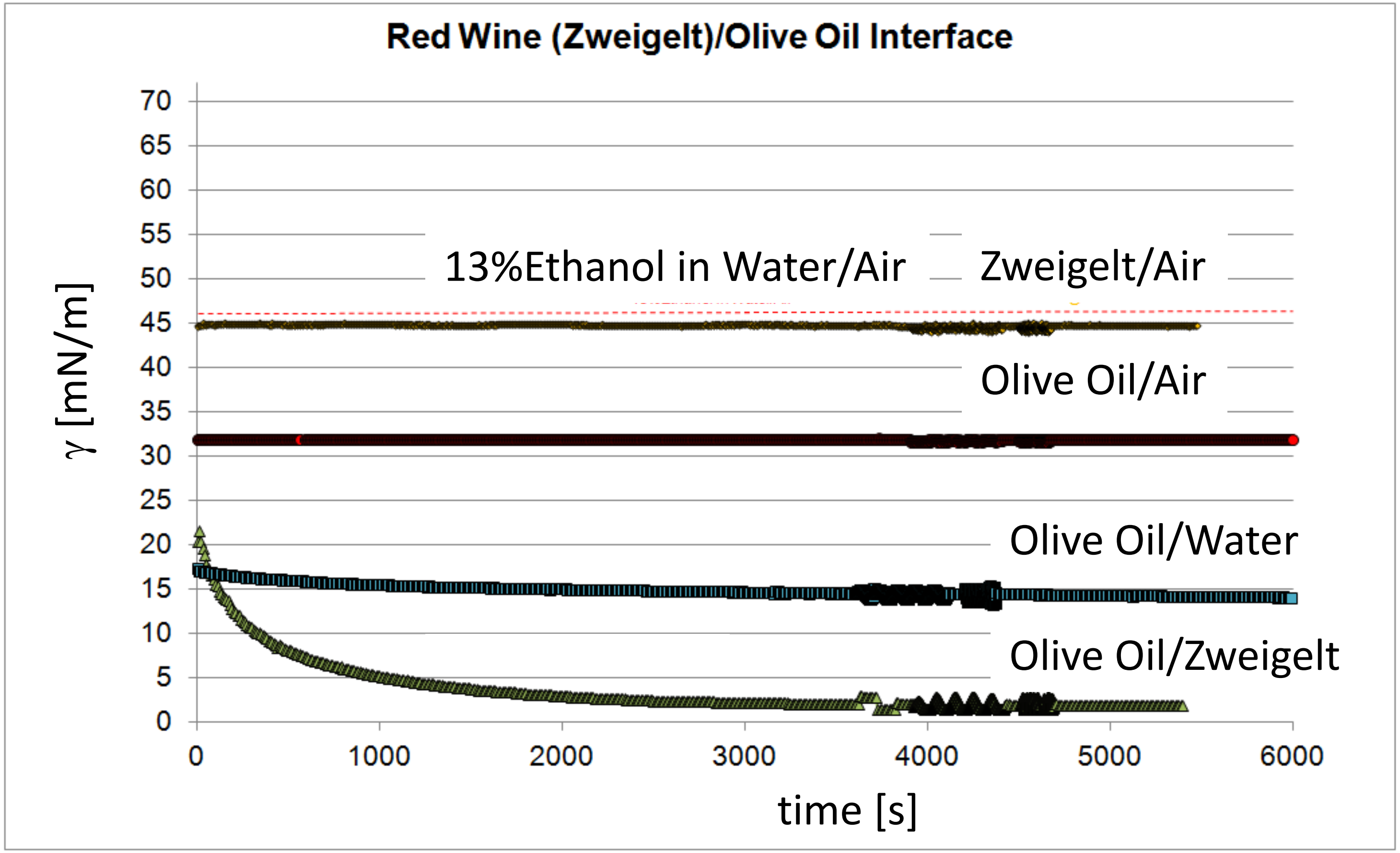
A real example in daily life

Interfacial studies of an aqueous solution in oil



Red wine (Zweigelt, Austria) in olive oil (extra virgin, Spain)

A real example in daily life



Aqueous solution in oil: red wine (Zweigelt, Austria) in olive oil (extra virgin, Spain)

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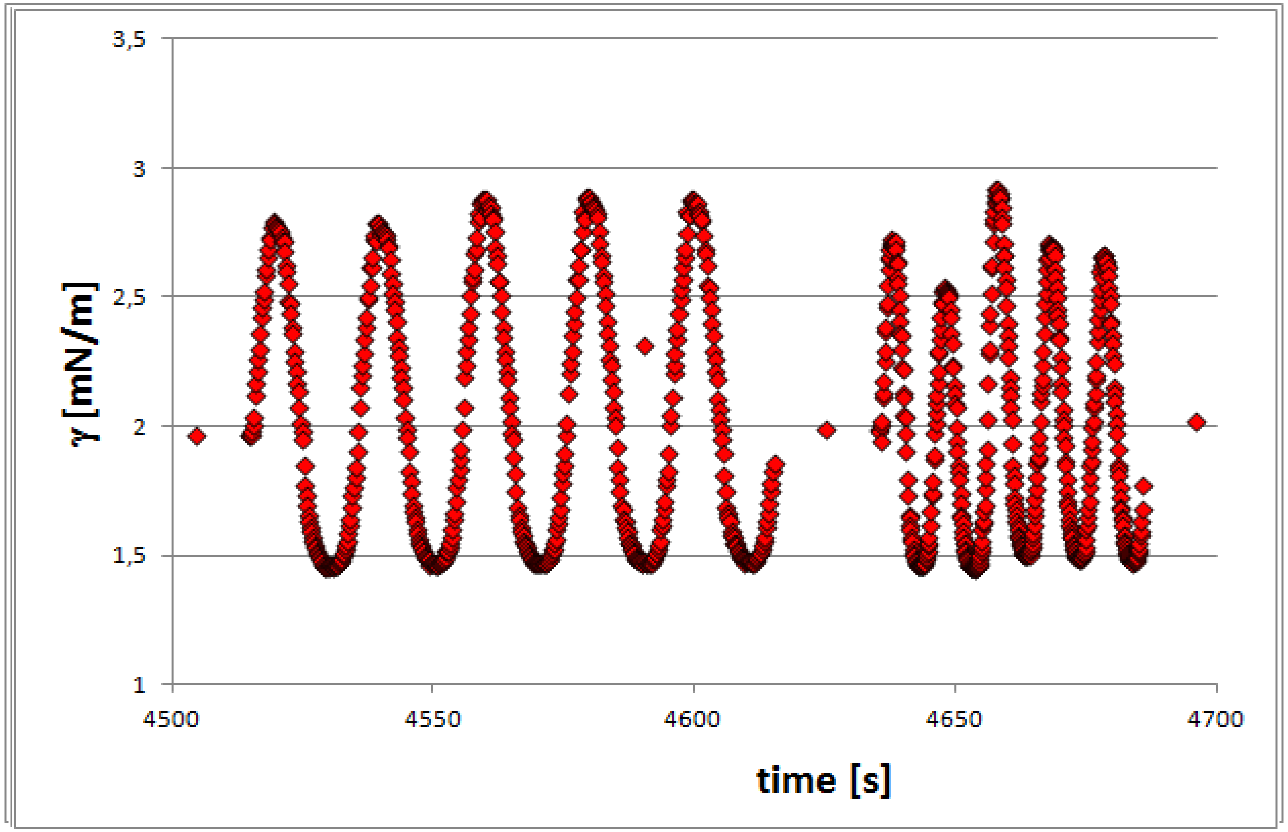
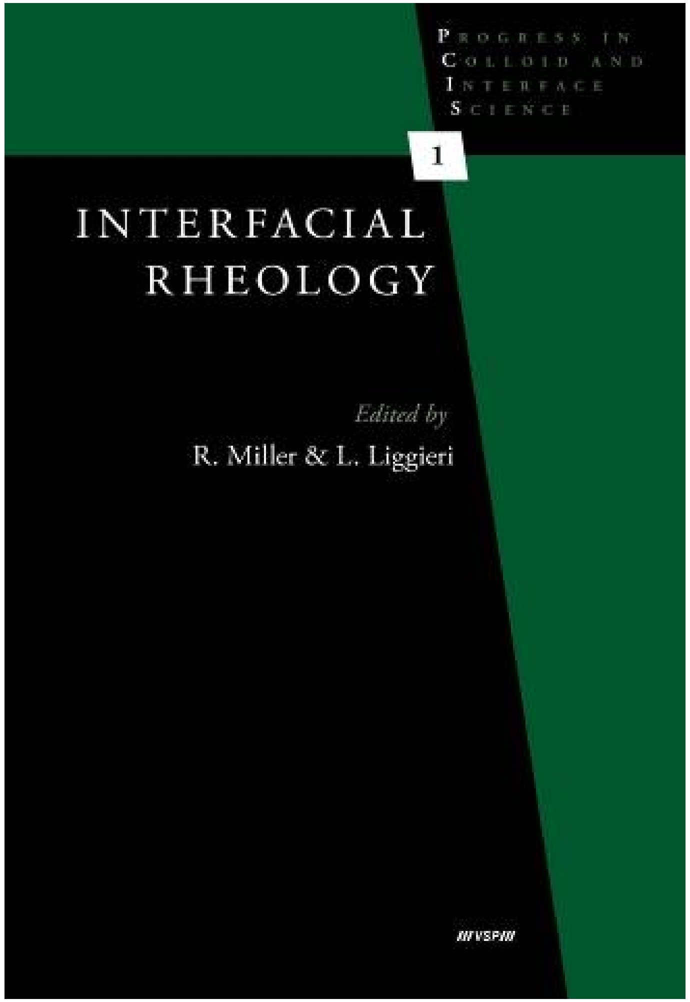


Aqueous solution in oil: red wine (Zweigelt, Austria) in olive oil (extra virgin, Spain)

Recently published books on the topic



Interfacial Rheology

R. Miller and L. Liggieri (eds.)

Progress in Colloid and Interface Science

Volume 1
VSP, Brill Publ.
ISBN 978 90 04 17586 0
Leiden 2009

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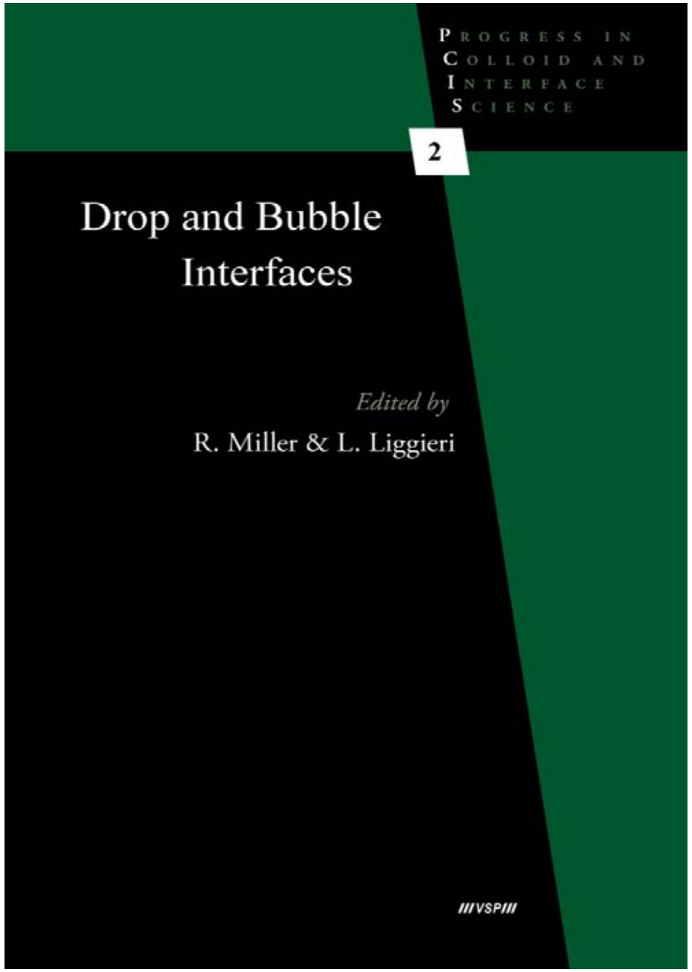


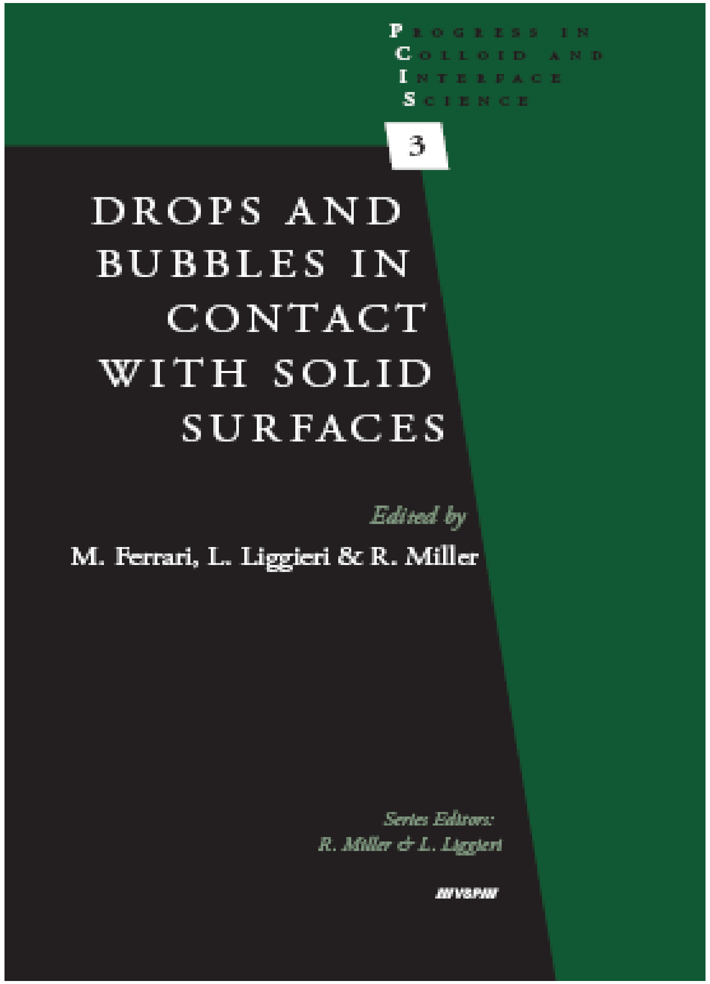
Drop and Bubble Interfaces

R. Miller and L. Liggieri (Eds.)

Progress in Colloid and Interface Science

Volume 2
VSP, Brill Publ.
ISBN 978 90 04 17495 5
Leiden 2011

Recently published books on the topic



Drops and Bubbles in Contact with Solid Surfaces

M. Ferrari, L. Liggieri and R. Miller (eds.)

Progress in Colloid and Interface Science

Volume 3,
VSP, Brill Publ.
ISBN 9789004203198
Leiden 2012

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Thank you for your attention!