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The Effect of Soluble Surfactants on Liquid Film Flow

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objectives

We investigate experimentally the modifications in the dynamics of liquid film flow, resulting from the addition in water of soluble surfactants such as:

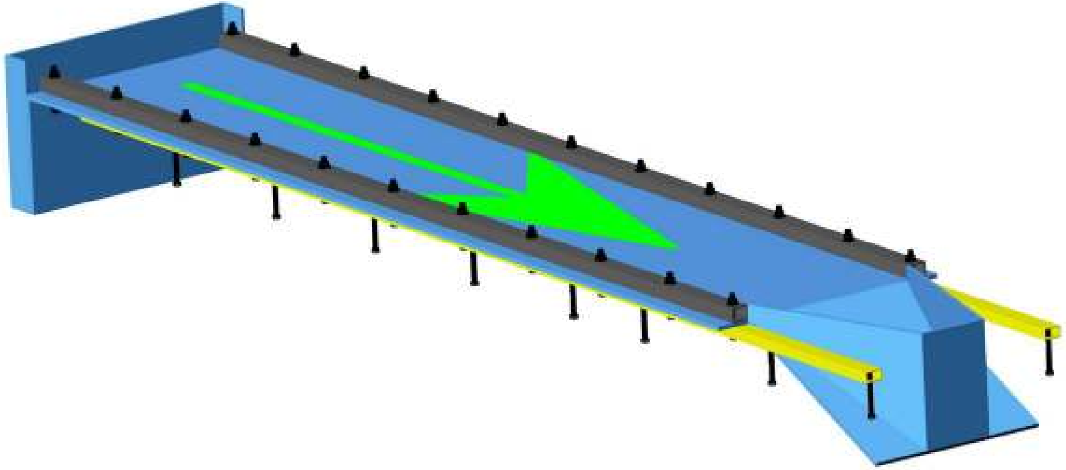
☐ Isopropanol (IP)
☐ Sodium Dodecyl Sulfate (SDS)

Emphasis is placed on: (a) the primary instability
(b) the post threshold dynamics

Experimental Setups

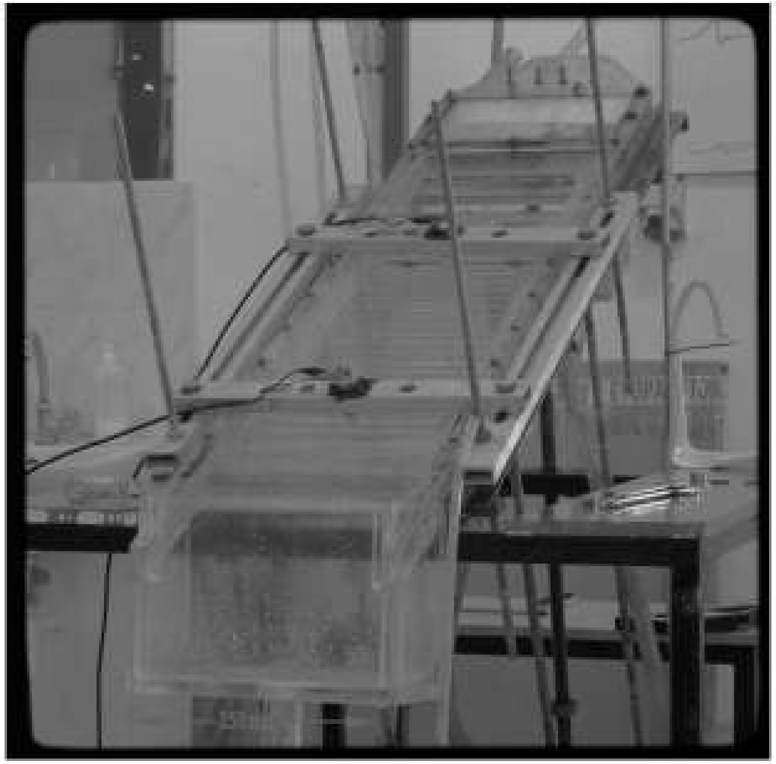
3000 mm long by 450 mm wide

Inclination angles 2-20 degrees

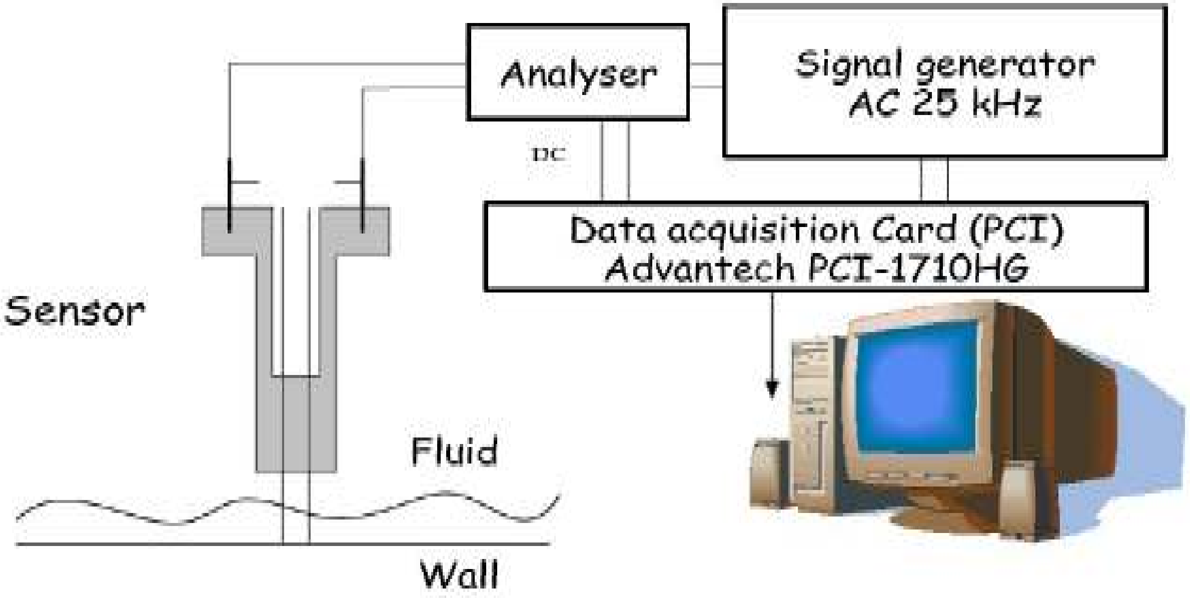


Experimental Setups

800 mm long by 250 mm wide
Inclination angles 0-50 degrees



Time signals of film thickness by conductance probes



Surface tension is measured by maximum bubble pressure and ring method (Du Nouy Method)

We consider two categories of soluble active agents

Isopropanol aqueous solutions

The system behaves as pure liquid

Why?

SDS (Sodium Dodecyl Sulfate) aqueous solutions

The system presents surface elasticity and viscosity

As argued by Lucassen-Reynders (1969) and Lucassen (1982) , this behavior is a result of :

- the considerable solubility of alcohol in water, which - in combination with the low viscosity, i.e. high diffusivity, of the aqueous solution - permits fast diffusional interchange between the surface and the bulk.
- surface tension gradients that would attribute visco-elastic properties to the surface are completely short-circuited, at least for the range of wave frequencies enforced in the present work (0.125 – 1 hz)

Results - IP Solutions

Questions:

- Does surface tension reduction affect the primary instability?
- Are there any changes in the shape of travelling waves?
- Are there any changes in the amplitude of wave height?

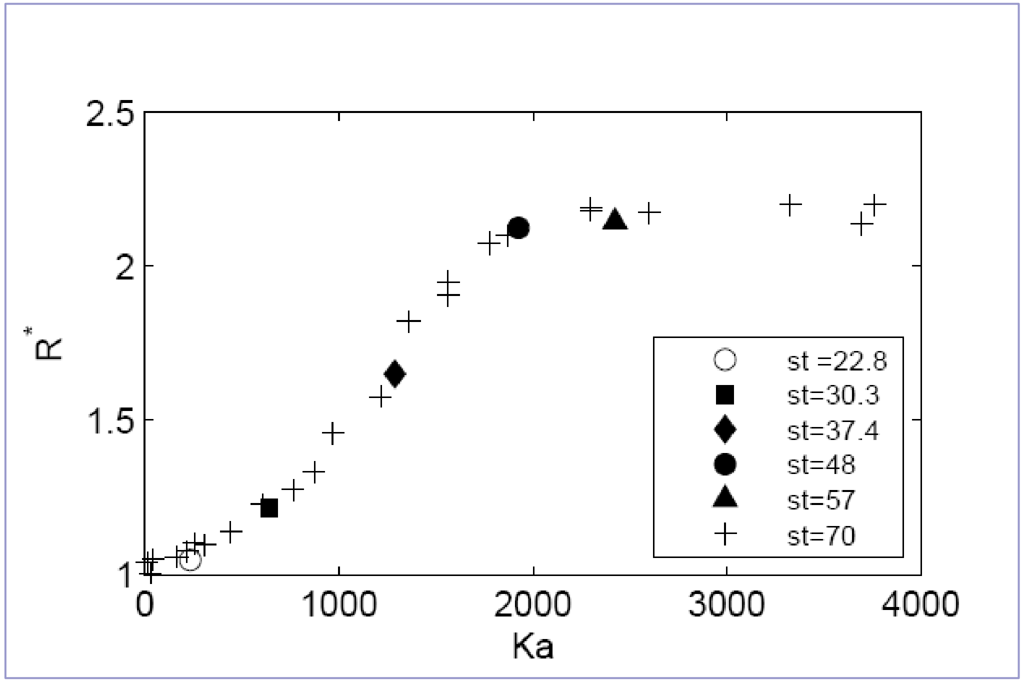
Experimental parameters

Liquids: Isopropanol aqueous solutions : 2.5, 5, 15, 30, 70 % wt

Inlet disturbances Frequencies: 0.167 hz

Experimental Set-up: small

Stability

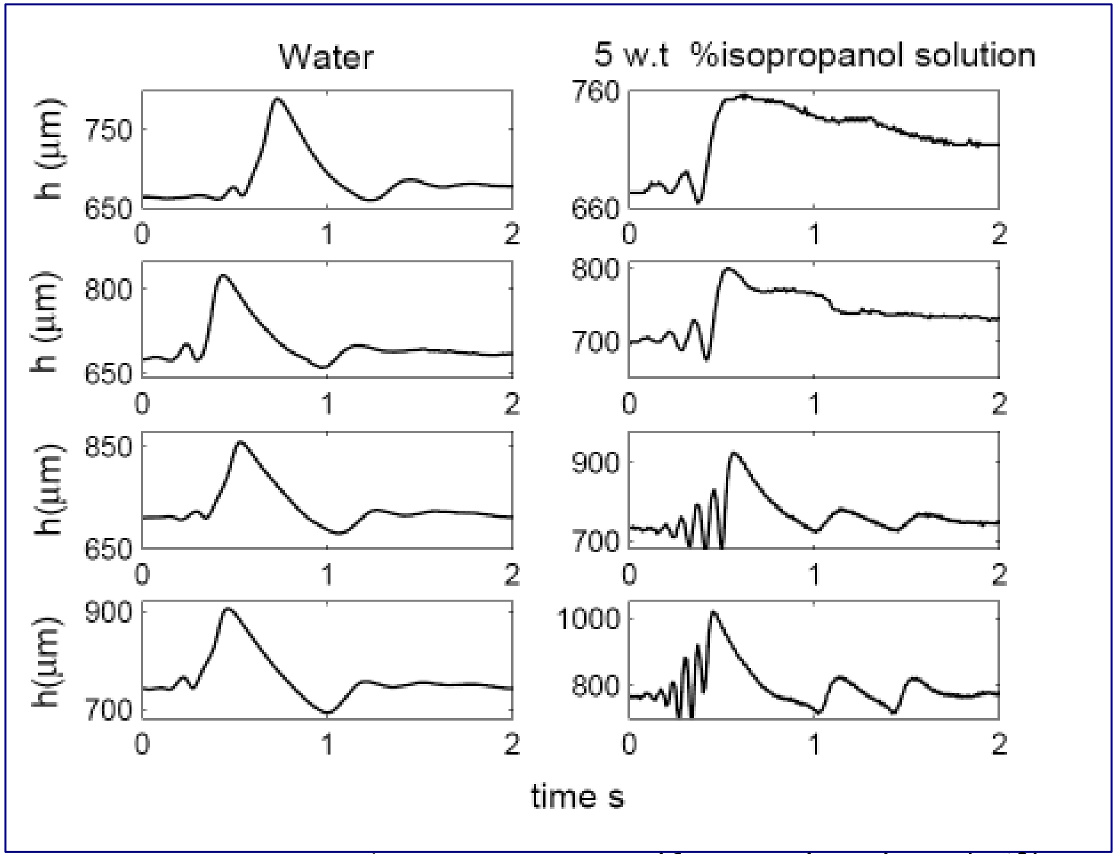


Our recent experimental findings [A. Georgantaki et. al (2011)] render the primary, long-wave, instability as a function of surface tension by correlating data with Kapitza number $Ka=\sigma/\rho g^{1/3}\nu^{4/3}$, which represents the ratio of capillary to viscous stresses.

The addition of IP appears to have no other dynamic effect on the free surface, apart from reducing its surface tension.

Shape - Size

Low - frequency, unstable disturbances evolve into solitary humps with well-defined precursor ripples



Comparison at same δ between water (first column) and 5% w.t IP solution (second column). The corresponding δ of or each line is 18, 20, 25, 28

$\delta = Re^{11/9} 5 Ka^{1/3} 3^{7/9}$ → reduced Reynolds number → introduces the destabilizing and dispersive effects of inertia

Shape - Size

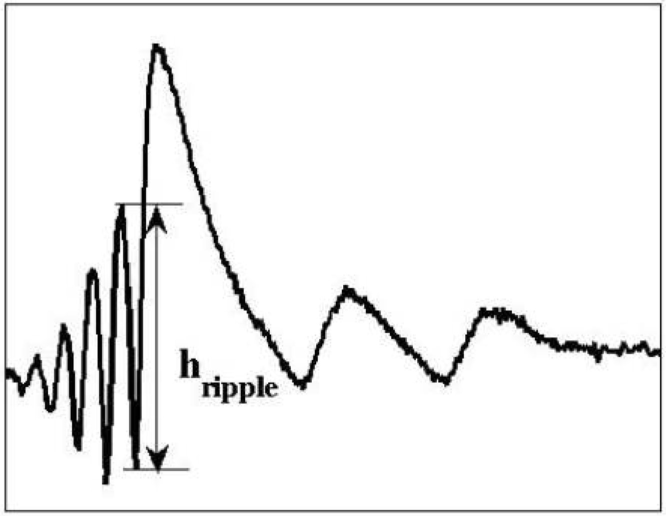
Capillary ripples are higher and better formed in the IP solutions, as compared to plain water, although the former has a lower surface tension than the latter (48 mN/m versus nominally 70 mN/m).

Explanation:

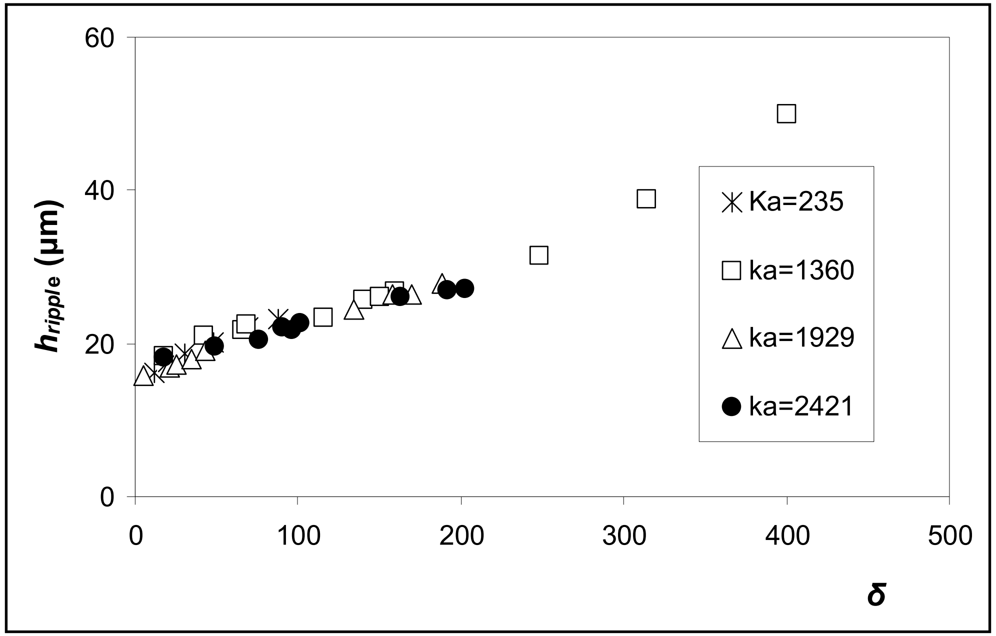
This is attributed to the well - known anomalous behavior of water caused by erratic surface absorption of various impurities and leading to irreproducible results. [B. E. Anshus and A. Acrivos, 1966 and E. H. Lucassen-Reynders, A. Cagna and J. Lucassen, 2001],

Shape - Size

Definition of the size of the ripples as h_{ripple}.



h_{ripple} as a function of δ for various IP solutions



Results - SDS Solutions

Questions:

- How does the addition of surfactant in water affect the size of travelling waves?
- Are there any changes in the shape of travelling waves?
- Is the evolution length important?
- What kind of changes do we observe for the primary instability?

Experimental parameters

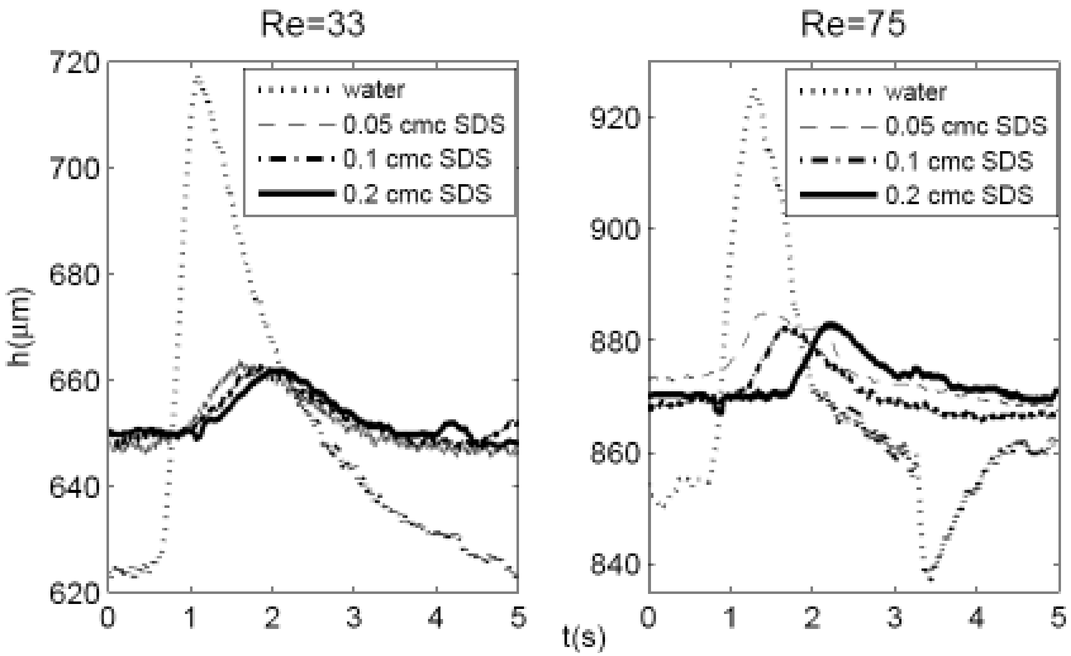
Liquids: SDS aqueous solutions : 0.05, 0.1, 0.2, 0.3, 0.4, 0.5 CMC*

Inlet disturbances Frequencies: 0.125, 0.25, 0.5, 0.75, 1 hz

Experimental Set-up: both

*CMC is critican micelle concentration determined experimentally for SDS by Duangprasert et al. (2007) as 2.75 g/Litter

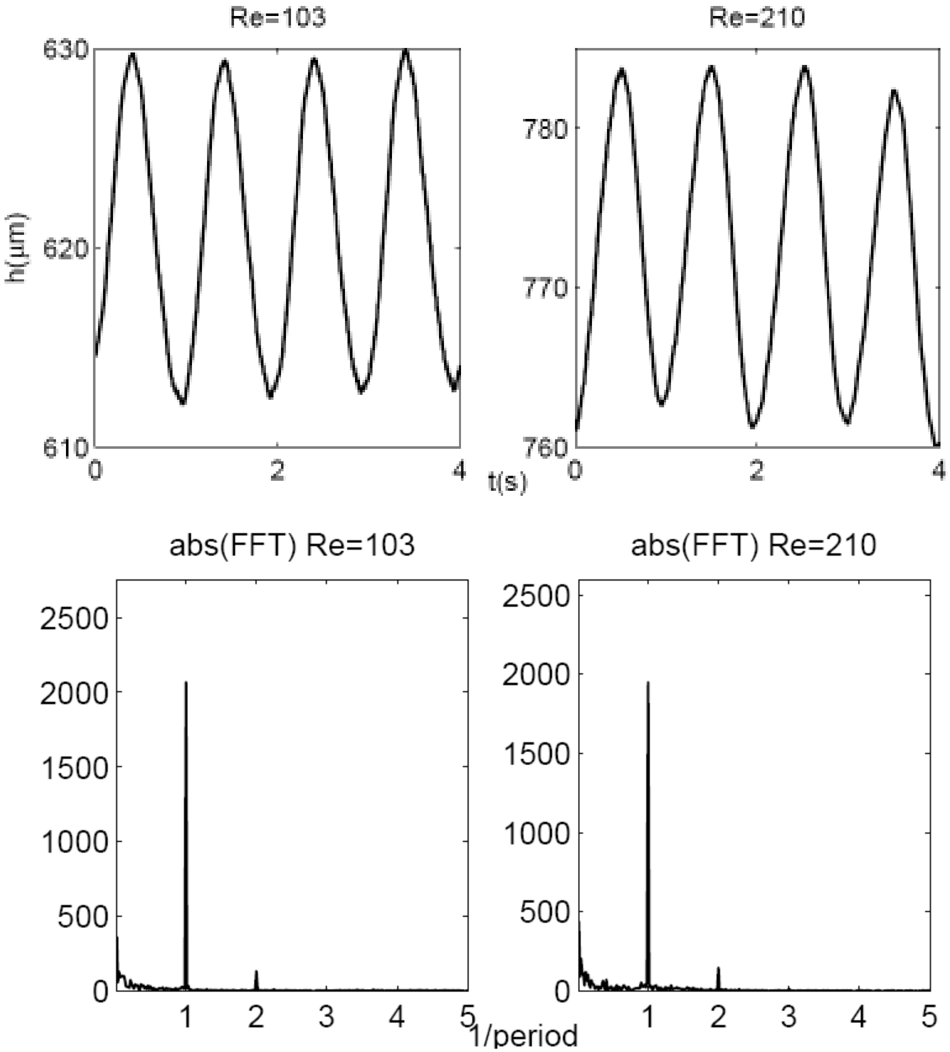
Drastic attenuation of inlet disturbances



Small experimental setup. Inclination angle θ=2°, disturbance frequency f=0.167 Hz. Proble located 50 mm from the film entrance

General Shape

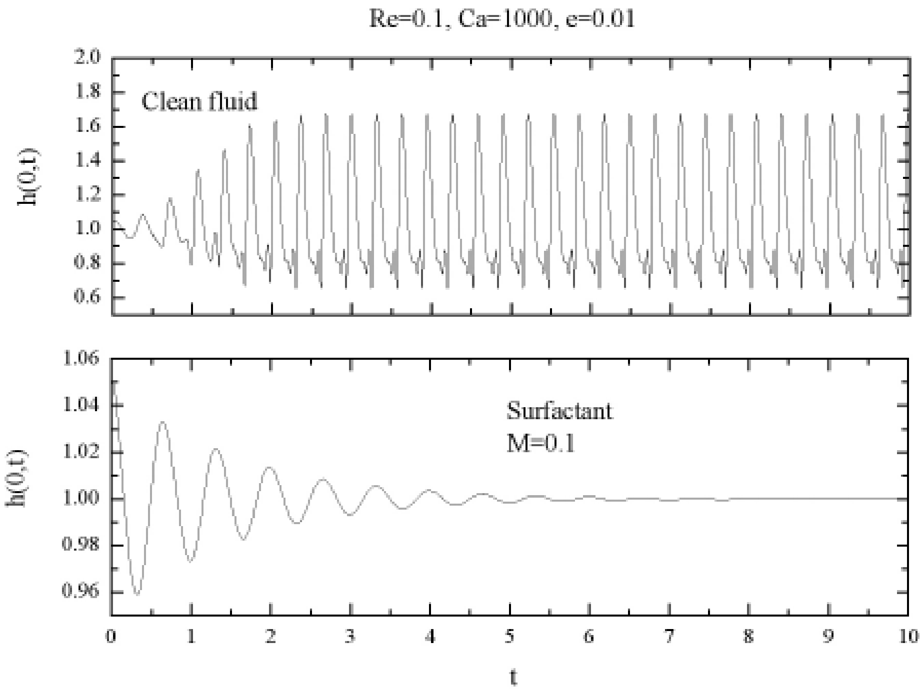
This shape is observed for frequencies 0.5, 0.75, 1 hz for all Re tested

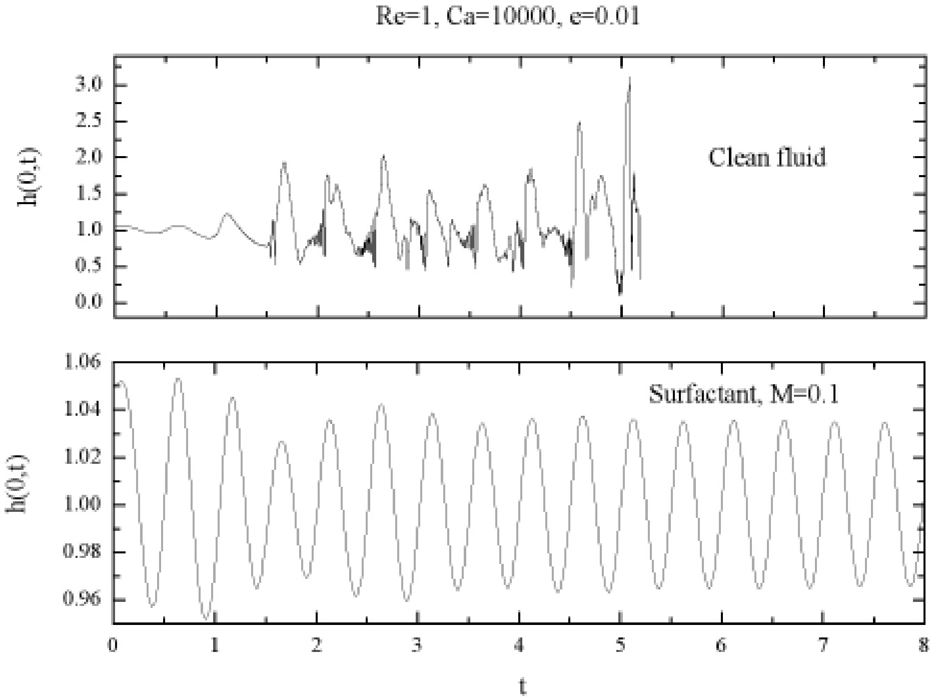


Small experimental setup. θ=7°, disturbance frequency f=1 Hz. Proble located 550 mm from the film entrance. Solution: 0.1 cmc

Computations

Preliminary Computations by George Karapetsas



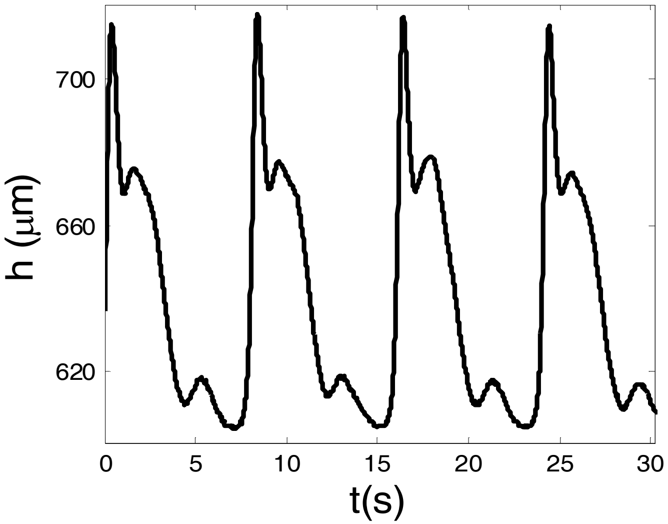


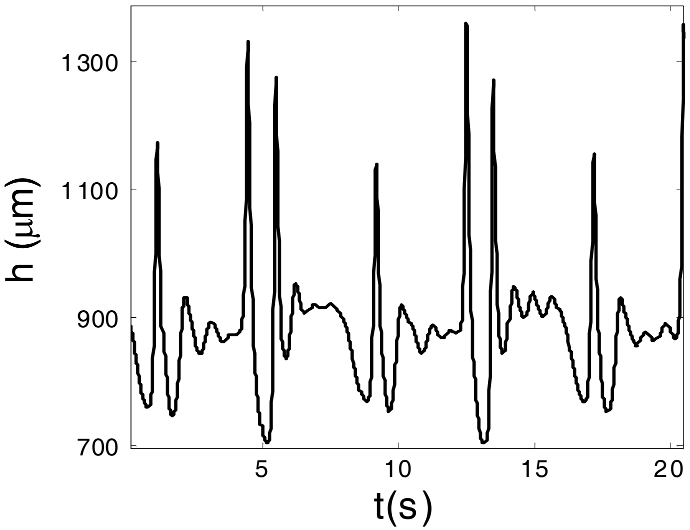
$$\mathrm{Re} = \frac{\varepsilon \rho U H}{\mu} \qquad Ca = \frac{\mu U}{\varepsilon^3 \sigma} \qquad \varepsilon = \mathrm{H} / L$$

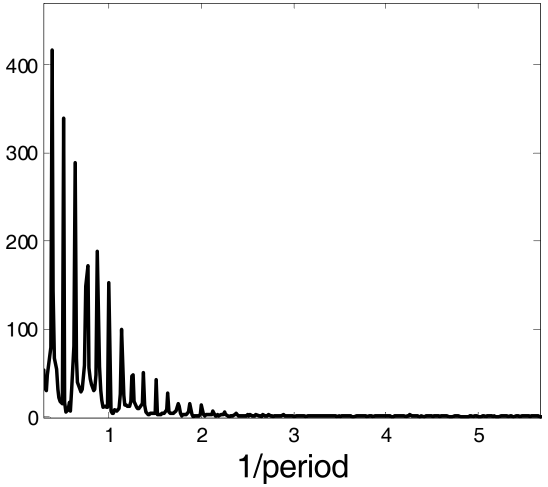
M is the total mass of the surfactant

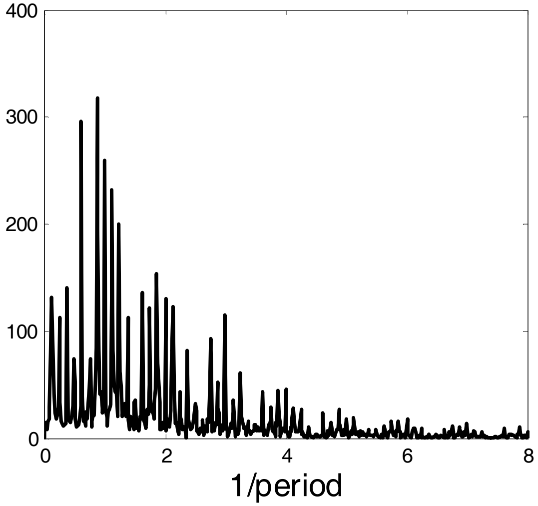
Deviation in shape

Observed for frequencies 0.125, 0.25 Hz:
0.125 Hz →from the transition to the unstable regime
0.25 Hz → at Re 30% higher than the critical


Re=104


Re=277

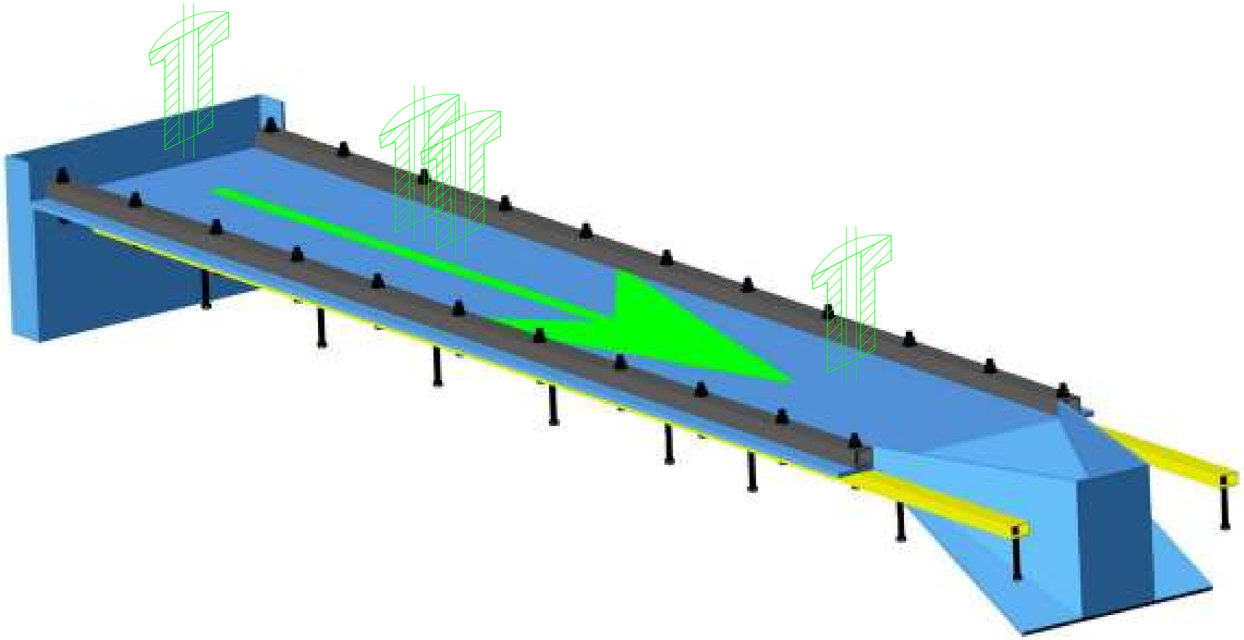

abs(FFT)Re=104


abs(FFT) Re=277

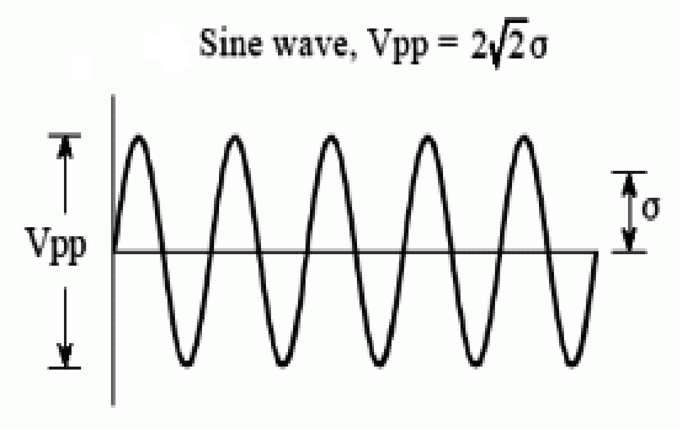
0.3 cmc,
0.125 hz,
θ=5°

Evolution Length

Small:channel→no information

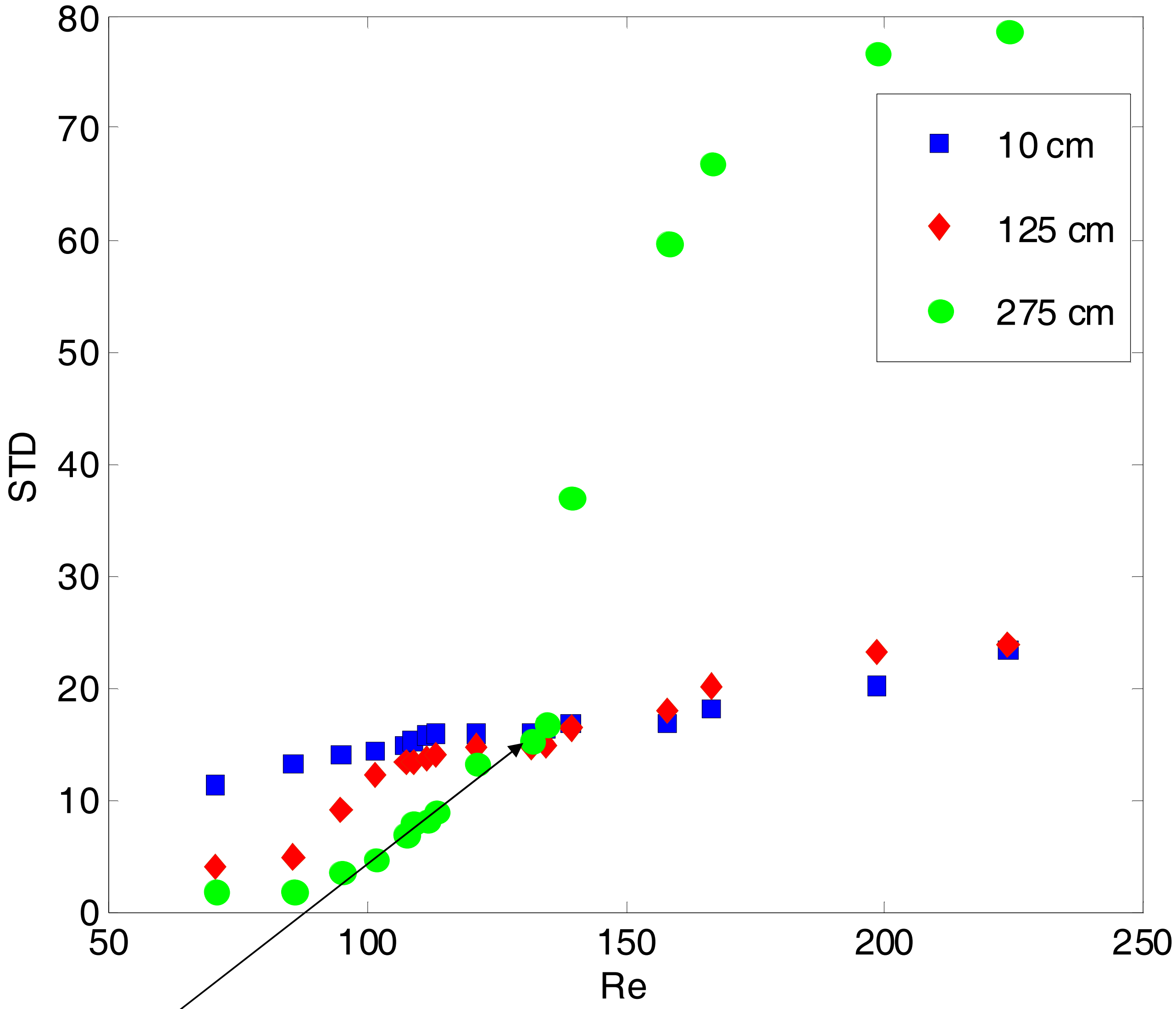


Probe1 : 0.1 m
Probe2 : 1.1 m
Probe3 : 1.25 m
Probe4 : 2.75 m
(from the film entrance)



Since the shape of the waves in all cases tested is sinusoidal, we compute Standard Deviation in order to estimate film amplitude

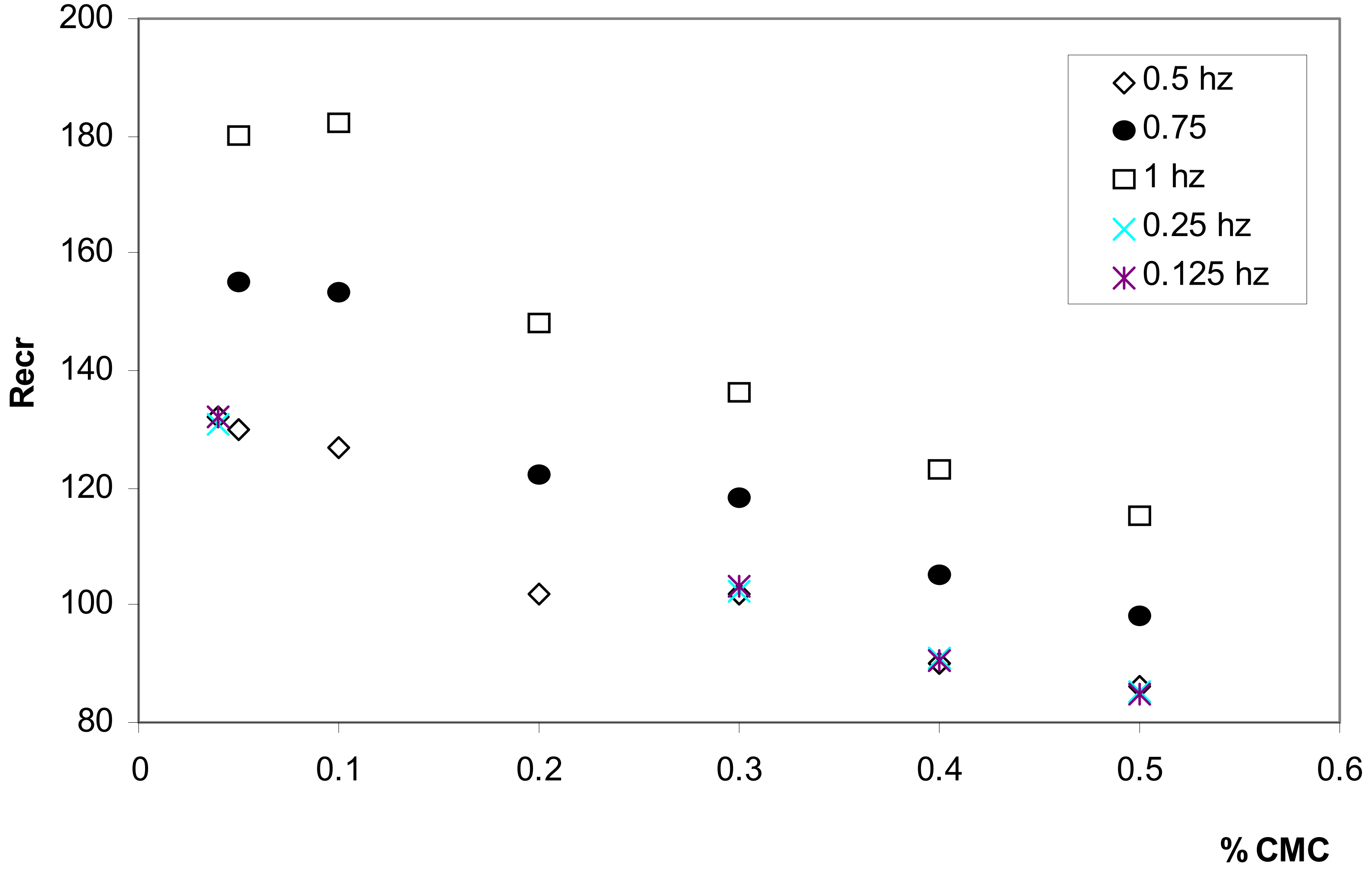
Evolution of film height - Stability criterion



Stability Threshold

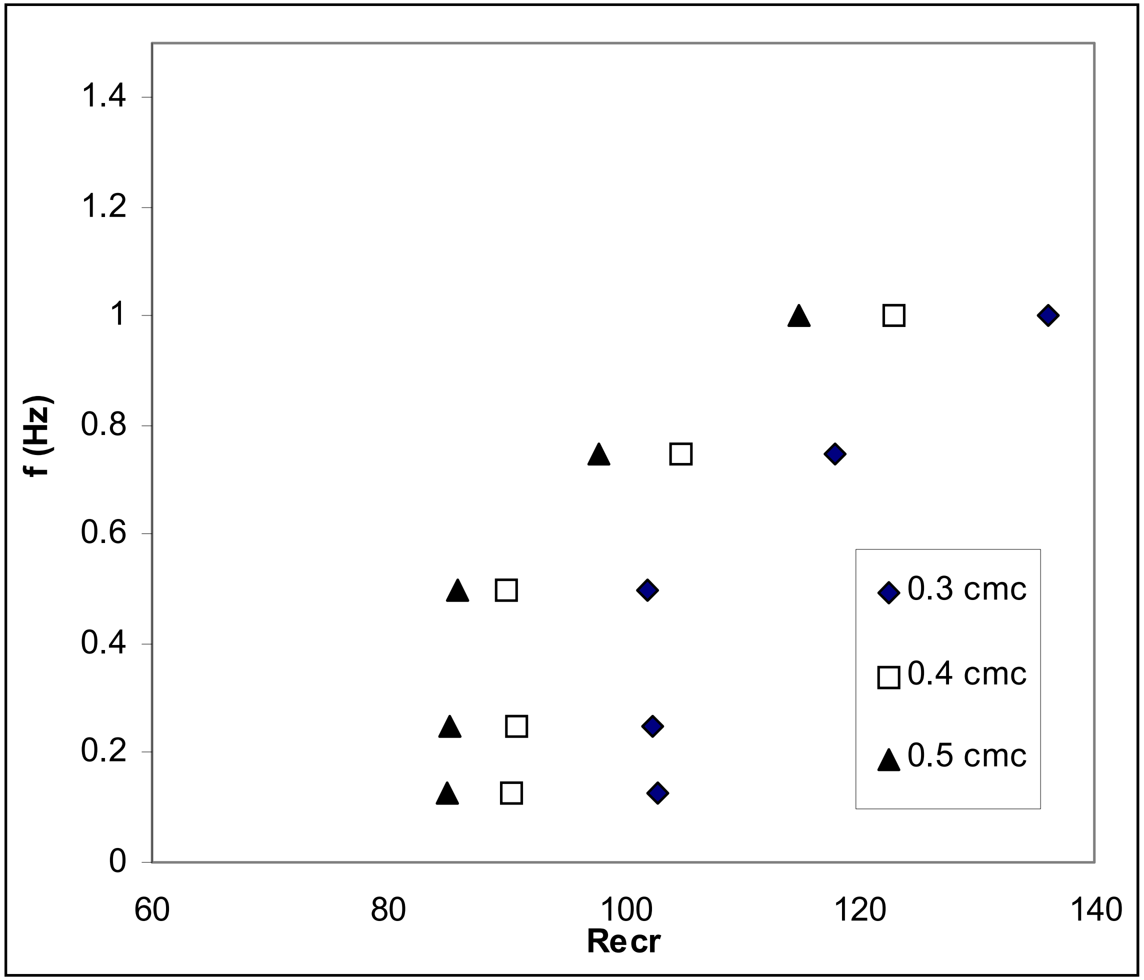
Example of 0.05 cmc,
f=0,5 hz

Stability Results

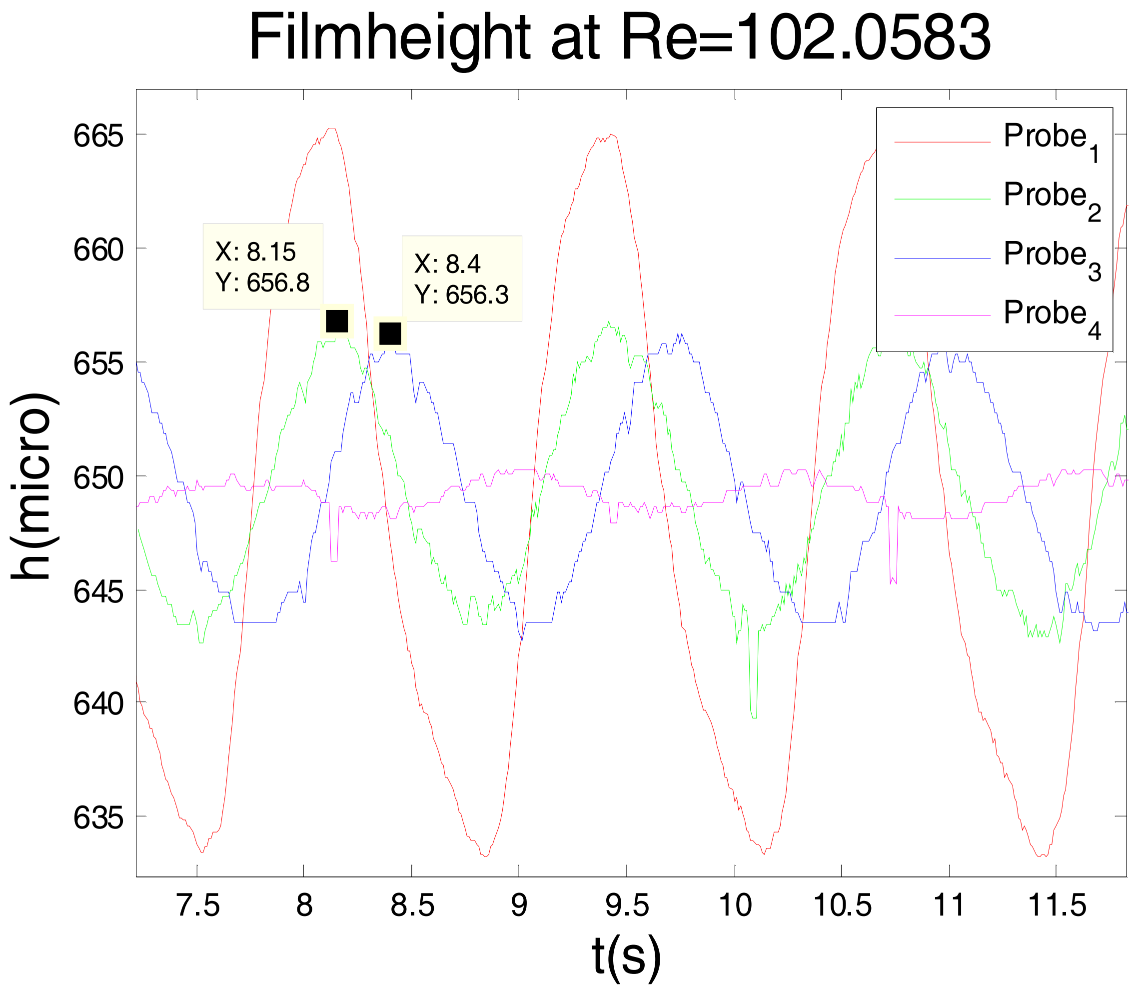


Re_{cr} for water ≈ 16

Stability Results



Wave velocity - wavelength

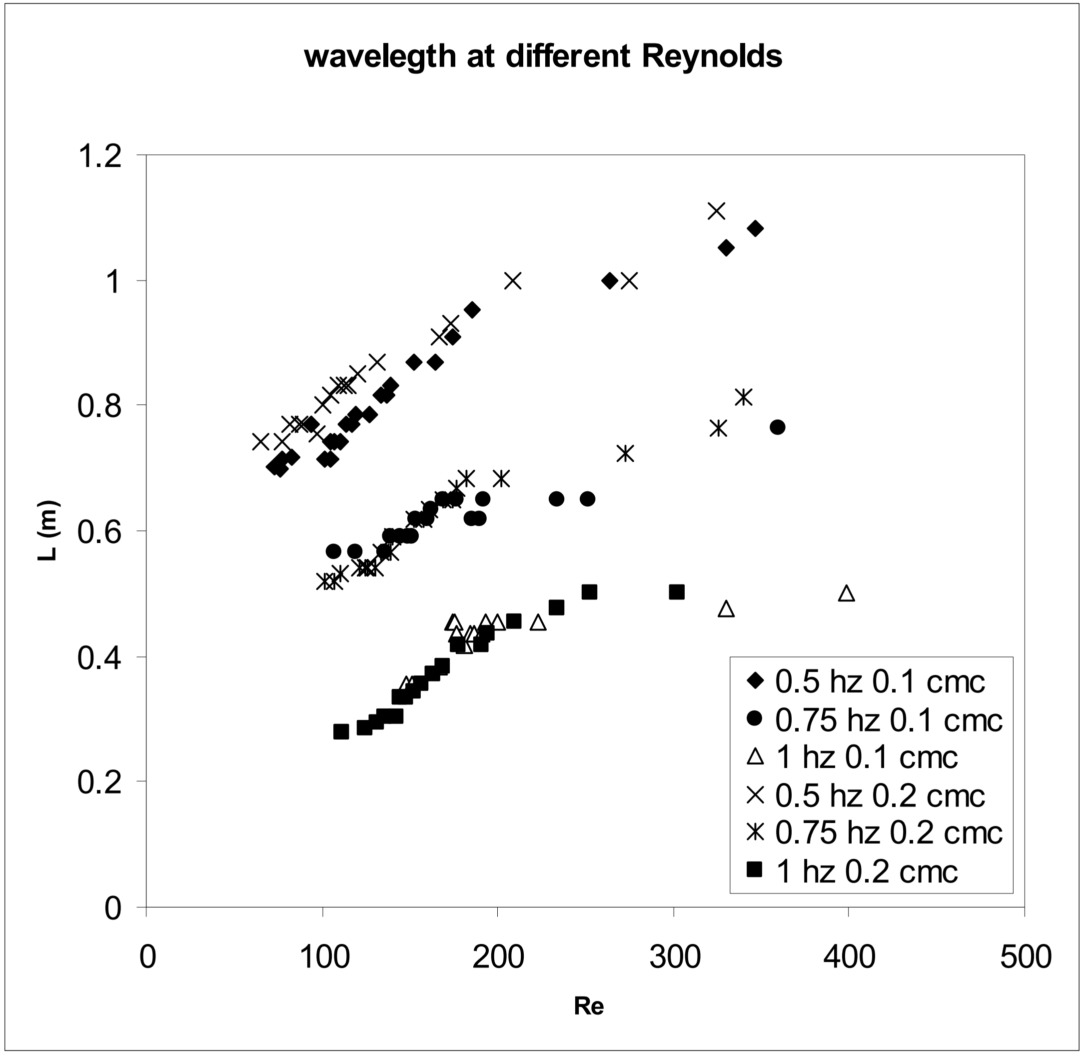


Wave velocity
C = Probe distance / time delay

time delay → cross correlation between signal 2 and 3

L = C /f

Wavelength



Irrespective of surfactant concentration
average wave length > 0.5 m → long wave instability

Stability Results

Isopropanol Solutions:

The system behaves as a simple liquid

- Formulation of precursor ripples
- Ripples scale with the reduce Reynolds number δ

SDS Solutions:

- Strong damping at all inlet disturbances
- Dominant structures → sinusoidal traveling waves of very small amplitude – some exceptions at small inlet frequencies
- The amplitude of the wave evolves very **intense** at the end of the channel
- Generally the flow is almost 8 – 10 times more stable comparing with water
- The stability threshold is inversely proportional to the surfactant concentration
- At very low inlet disturbances (0.125, 0.25, 0.5 Hz) there is no difference at the transition point
- Long wave instability

Acknowledgements

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European Union
European Social Fund

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EDUCATION AND LIFELONG LEARNING
investing in knowledge society
MINISTRY OF EDUCATION, LIFELONG LEARNING AND RELIGIOUS AFFAIRS
MANAGING AUTHORITY

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There are several theoretical studies of the hydrodynamic stability of falling liquid films [1–5] indicating that surfactants can be very effective in retarding, if not completely suppressing the onset of waves.

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Surface instabilities can be enhanced by assuming a soluble and volatile surfactant

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- [7] Kim K J, Berman N S and Wood B 1996 Int. J. Refrig. 19 322
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