EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

MATERIALS, PHYSICAL AND NANOSCIENCES
COST ACTION MP1106

COST Action MP1106: Smart and green interfaces
"Multiphase flows with / without phase change"
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Effect of drag reducing polymers on two-phase stratified flow in horizontal and slightly inclined pipes

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University of Thessaly

- Based in Volos, Central Greece, 320 km north of Athens
  [The metropolitan area of Volos has a population of ~140,000]
- Founded in 1984
- 6 Schools, 18 Departments in
  5 cities of Region of Thessaly
- ~7000 undergraduate students
- ~1500 graduate students
- ~500 members of academic staff

Gas-sheared interfaces

- The interaction between a gas and a liquid phase moving concurrently in a duct has been the subject of intense research in the last several decades, mainly due to the importance of such flows in the **chemical, nuclear, geothermal, solar** and **petroleum** industry.
- An inherent complication in two-phase gas-liquid flows is that the interface between the two phases can take various configurations leading to different **flow patterns** or **flow regimes**. Occurrence of a specific regime depends upon: flow rates, physical properties, geometrical characteristics of the pipe etc.
- Flow patterns greatly affect **pressure drop** and **liquid holdup**.

Horizontal Flow: flow patterns

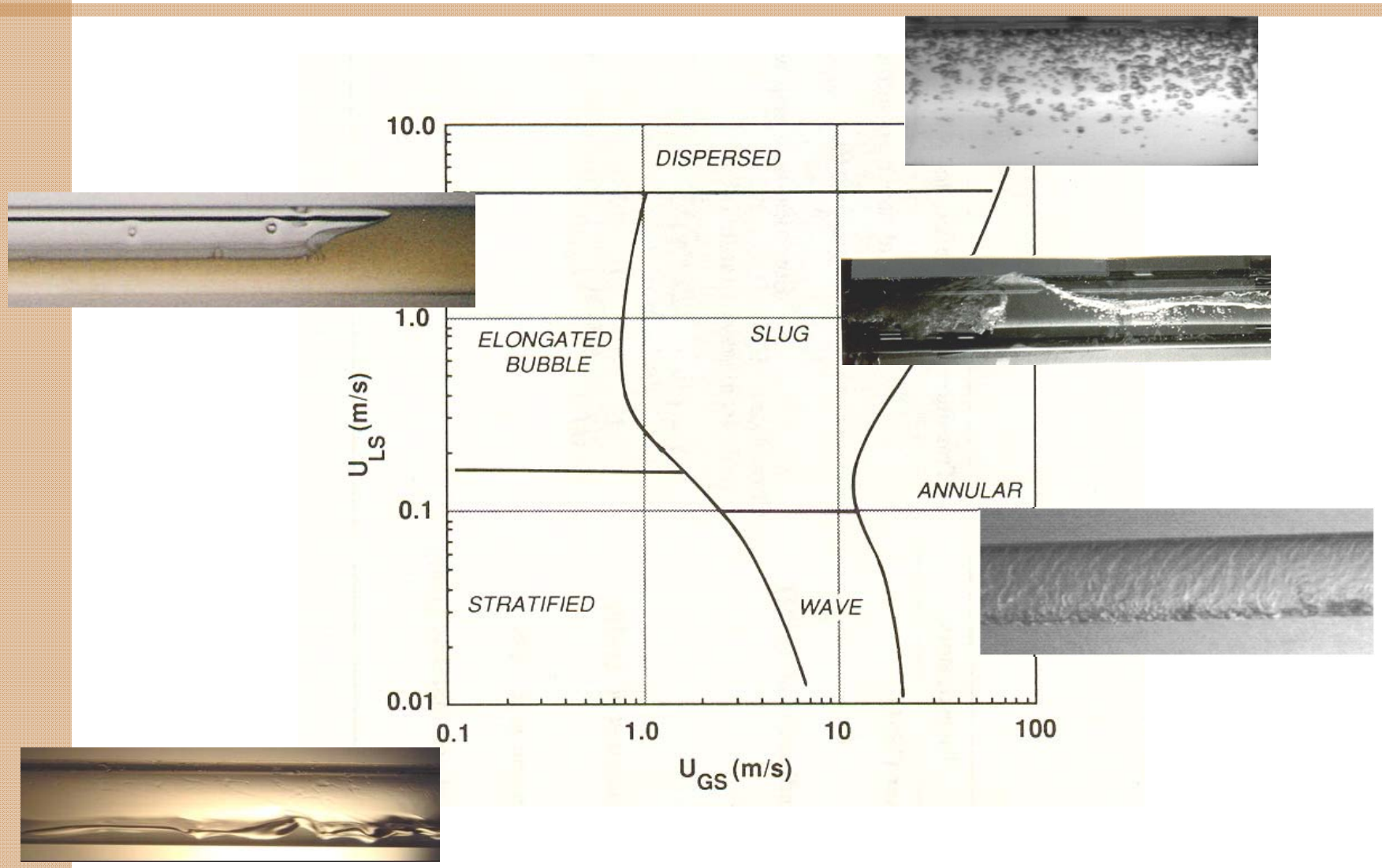
Horizontal two-phase flow is more complicated than the vertical one because of gravity.

The following flow regimes can be recognized in horizontal and near-horizontal two-phase gas-liquid flow:

- Stratified smooth
- Two-dimensional (2-D) regular waves
- Irregular, large amplitude (roll) waves
- Atomization
- Annular flow
- Slug flow (or intermittent)
- Pseudo-slug (or wavy-annular)
- Bubbly

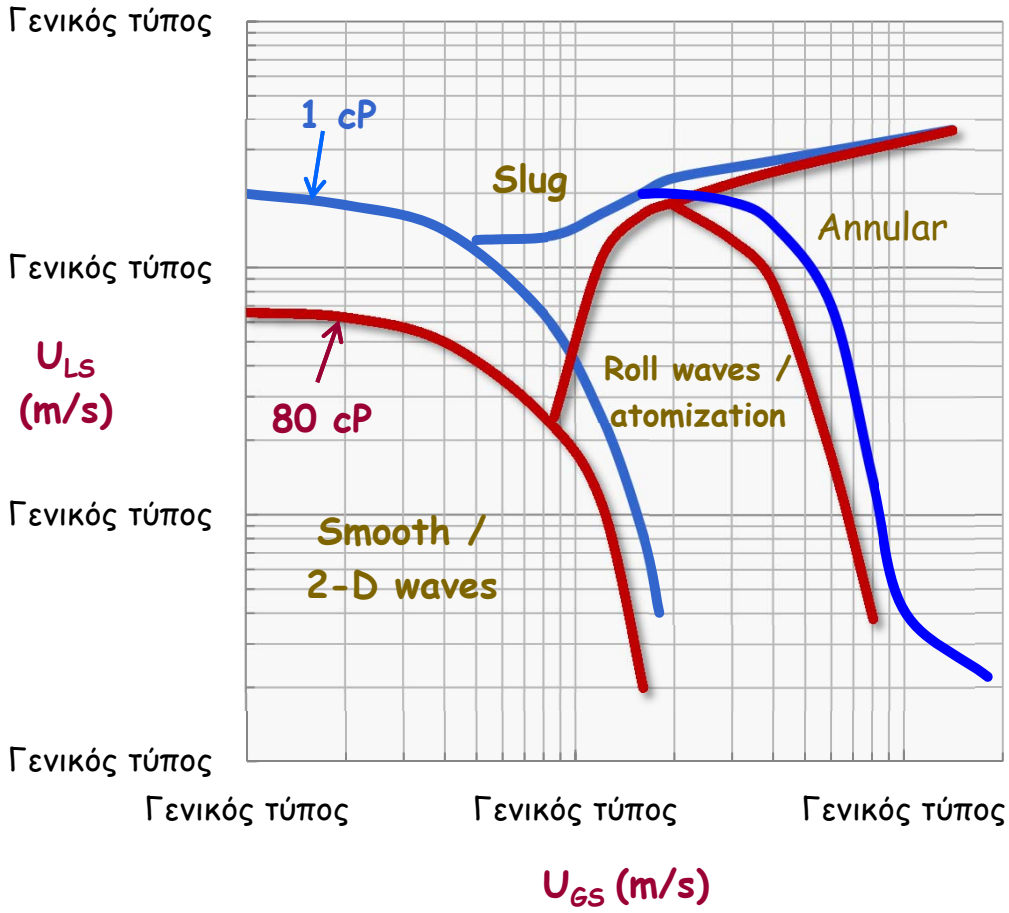
Stratified

Horizontal Flow: empirical flow map



Empirical flow regime map by Mandhane et al. (1974).

Horizontal Flow: experimental flow map



Flow regime map for the systems **air-water** and **air-glycerol solution** in a 95-mm i.d. pipe (Andritsos et al, 1989). A significant decrease in the liquid flow rate for slugging is obvious at low gas rates.

Experimental work at UTh

- Identification of flow patterns, pressure drop & film height measurements in a 24-mm i.d., 13-m long transparent pipe at atmospheric pressure.
- Horizontal and near horizontal (±2°) flow
- Physical properties investigated :
  - gas density (by using CO_2 and He),
  - liquid viscosity (glycerol solutions)
  - surface tension (n-butanol and isopropanol aqueous solutions, and SDS - sodium dodecyl sulphate- solutions)

Tzotzi, C., Bontozoglou, V., Vlachogiannnis, M. and Andritsos, N. Effect of Fluid Properties on Flow Patterns in Two-Phase Gas-Liquid Flow in Horizontal and Downward Pipes. *Ind. Eng. Chem. Res.*, 50 (2), pp 645–655, 2011.

Tzotzi, C. and Andritsos, N. Interfacial Shear Stress in Wavy Stratified Gas-Liquid Flow in Horizontal Pipes. *Int. J. Multiphase Flow*, 54, 43-54, 2013.

Tzotzi, C., Vlachogiannis, M., and Andritsos, N. Effect of fluid properties in small angle gas-liquid upflows. Submitted for publication, 2013.

Drag reduction in stratified two-phase flow

- Recently, we started to examine the effect of drag reducing polymers (DRP) on two-phase stratified flow.
- It is well known that the addition of a minute amount of polymers to a turbulent single flow in a pipe or a channel can result in a **large reduction of the frictional drag**. Drag reduction can be obtained also with certain surfactants. [Simultaneous reduction of heat & mass transfer coefficients.]
- Although this phenomenon (drag reduction, DR) has been known since the late 40s and it has been extensively studied, our **understanding** of the physical mechanisms and the **predicting capabilities** of polymer drag reduction are still **rather incomplete**.
- Work on DR in two-phase flows has been carried out since the late 60s, but new interest has emerged in the past 10-15 years for both gas-liquid and liquid-liquid systems.

Scope of the work

- This work aims at investigating the effect of the addition of minute quantities of DRP on the "shape" of the interface in air-water two-phase flow in slightly inclined and horizontal pipes in two pipelines, 24 and 100 mm in diameter. More interest on the experiments in the 100-mm pipe.
- The addition DRP affects both the transition to various flow regimes and subregimes (pseudo-slug, 2-D waves, roll waves and atomization) and on the **interfacial friction factor** and the **pressure drop** in the system.
- Hope that relations for the interfacial friction factor can be established
- Only preliminary experiments have been so far carried out in the 24-mm pipeline. A brief literature review of the topic follows.

Literature review

Toms (1948) first reported a large reduction in frictional pressure drop for turbulent flow past a surface.

Mechanisms: damping of turbulent bursts and reduction of Reynolds stresses and velocity fluctuations normal to the wall.

TWO-PHASE FLOWS

Greskovich and Shrier (1971) – plug/slug horizontal flow

- Mainly air-water, D=1.5 in, polyethylene oxide
- Up to 45% drag reduction for slug flow

Sylvester and Brill (1976) – annular flow

- air–water in a 6-m horizontal pipe, D=1.27 cm
- polyethylene oxide solution of 100 ppm
- 0-37% drag reduction

Literature review

Manfield et al. (1999) – annular flow

- drag reduction with additives in multiphase flows is reviewed
- understanding of the influence of DRP not satisfactory

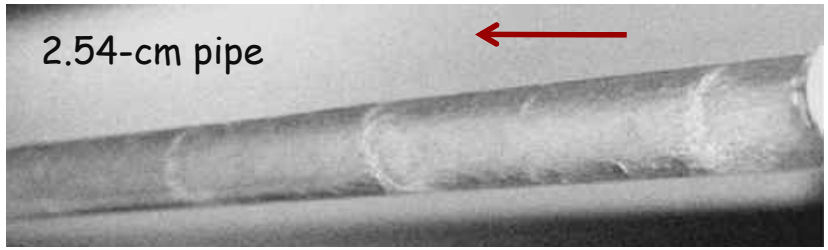
Al-Sarkhi and Hanratty (2001a and b), annular flow

- Co-polymer: polyacrylamide and sodium-acrylate
- D=9.53 cm, the annular pattern changed to a stratified flow
  Drag reduction up to 48%. ΔR increases with increasing U_{SL}.
- D=2.54 cm, similar results, drag reduction as high as 63%.

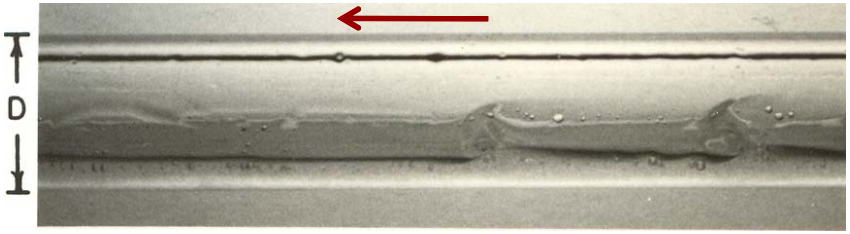
Baik and Hanratty (2003), stratified/slug flow

- D=95.3 mm, hydrolysed poly-acrylamide (HPAM)
- Wave amplitude decreases with DRPs
- No effect on the transition to slugging (at low/medium U_{SL})
- DRPs cause a damping of waves and a reduction of turbulence in the liquid

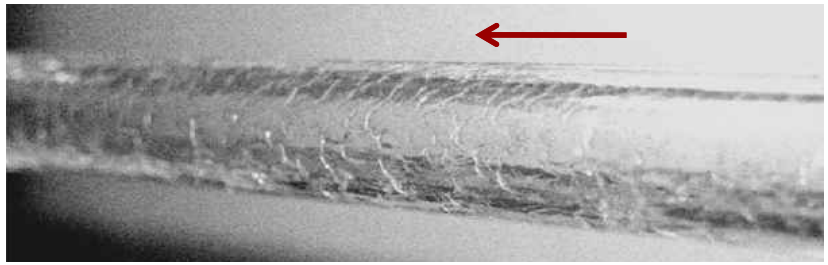
Literature review



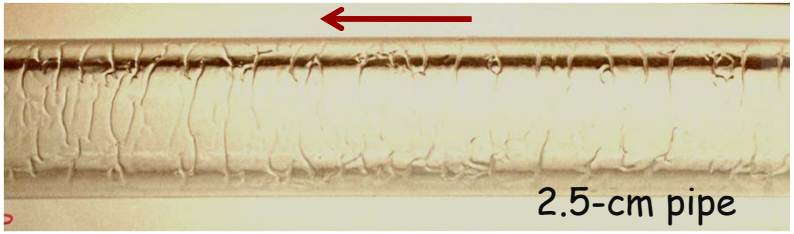
(a) Annular flow of air-water at U_{GS} = 52 m/s and U_{LS} = 0.02 m/s



Roll waves in a viscous liquid (μ_L=70 cP)



(b) Annular-Stratified flow at U_{GS} = 52 m/s and U_{LS} = 0.02 m/s



Annular flow with a viscous liquid (μ_L=70 cP) at U_{GS} = 40 m/s and U_{LS} = 0.004 m/s

Al-Sarkhi and Hanratty (2001b)

Andritsos and Hanratty (1987)

Literature review

Vlachogiannis et al (2003): Drag Reduction is also a function of "degradation" time of the polymer used. Degradation is not accompanied by significant changes in the molecular weight distributions.

Daas and Bleyle (2006) horizontal slug flow, oil-CO_2

- D=100 mm, L=20 m, μ_L=2.5 and 50 cP, CDR WS 500 M flow improver
- DR effectiveness greater for the 2.5-cP oil (for the same U_{SL})
- Slug frequency decreases

What we have learnt

- Maximum DR when certain flow regimes (slug, annular, roll waves) are converted to a stratified-type flow.
- In slug flow DR is also due to the decreasing slug frequency and damping of waves.
- DR starts after a minimum DRP concentration and usually exhibits a plateau.

BUT:

Which comes first?

Drag reduction is due to regime change or a regime change is the result of a decreased pressure drop?

What we have learnt

The effectiveness of a DRP depends upon:

- Pipe diameter
- Flow regime
- Liquid phase physical properties
- DRP concentration
- Type of DRP
  [e.g. partially hydrolyzed poly-acrylamide (HPAM), poly-acrylamide (PAM), and poly-ethylene oxide (PEO)]
- History of DRP solution
- Pipe roughness
- .....

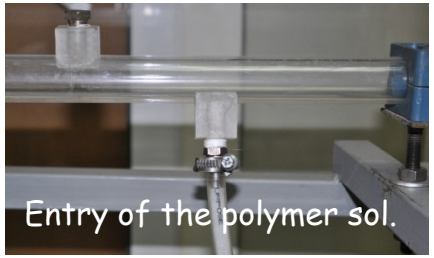
Experimental Facility and Techniques

Experiments are/will be carried out in two near-horizontal transparent pipelines at atmospheric conditions:

(1) D=0.024 m, 13-m long (inclination ±3°)

(2) D= 0.10 m, 23-m long (under construction)

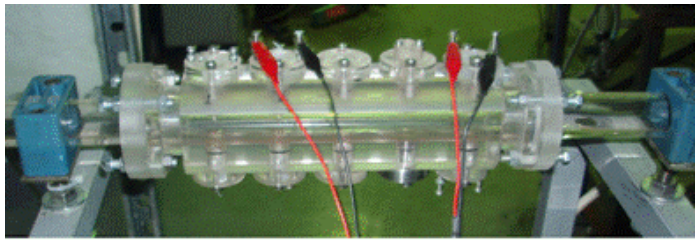
System to introduce the polymer sol. with pressurized air.



Entry of the polymer sol.

Experimental Facility and Techniques

- Visual observations
- Pressure drop measurements
- Film thickness measurements (conductance probes)
- PIV experiments (hopefully): determination of the relative motion of the polymer filaments, filament breakup and turbulence changes
- Visualization experiments: doping the polymer solution with a fluorescent dye and applying the fluorescence imaging technique to detect polymer filaments/aggregates in the flow



Some results in the 24-mm pipe

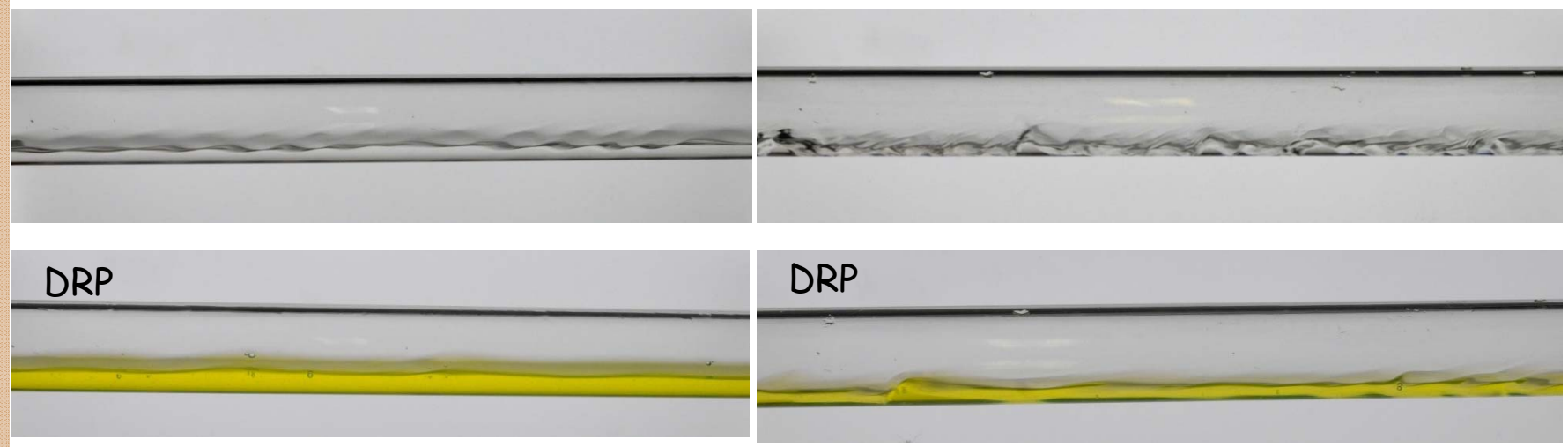
- **Polymer used: HPAM**
- **Concentration of initial polymer solution**

  (α) 500 ppm, mixing time 8 h, relaxing time 8 h

  (β) 1000 ppm, mixing time 12 h, relaxing time 12 h
- **Final polymer concentration in the liquid: 0-20 ppm**

2-D waves, U_{GS}~6 m/s, U_{LS}=0,015 m/s

Roll waves, U_{GS}~10 m/s, U_{LS}=0,015 m/s

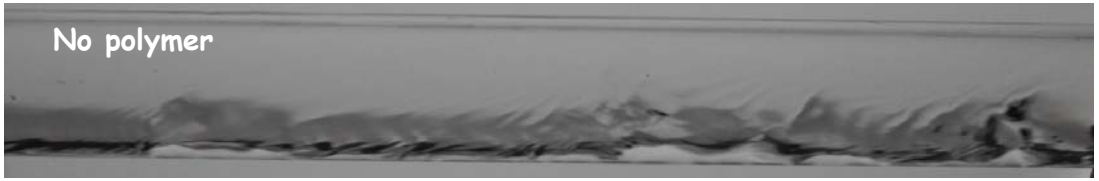


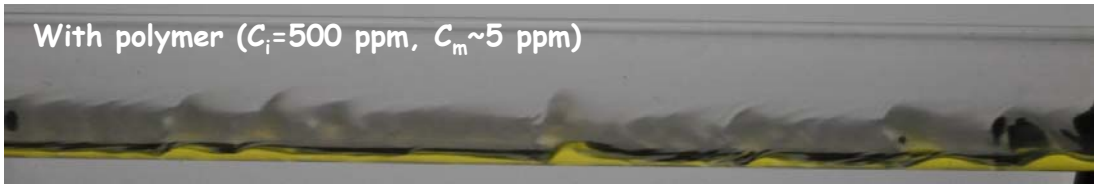
~ 10 ppm HPAM, drag reduction 30-40%

Some results in the 24-mm pipe

roll waves

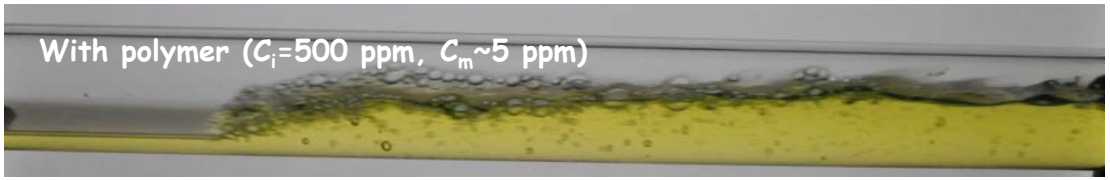
U_{LS}=0.03 m/s, U_{GS}= 10 m/s



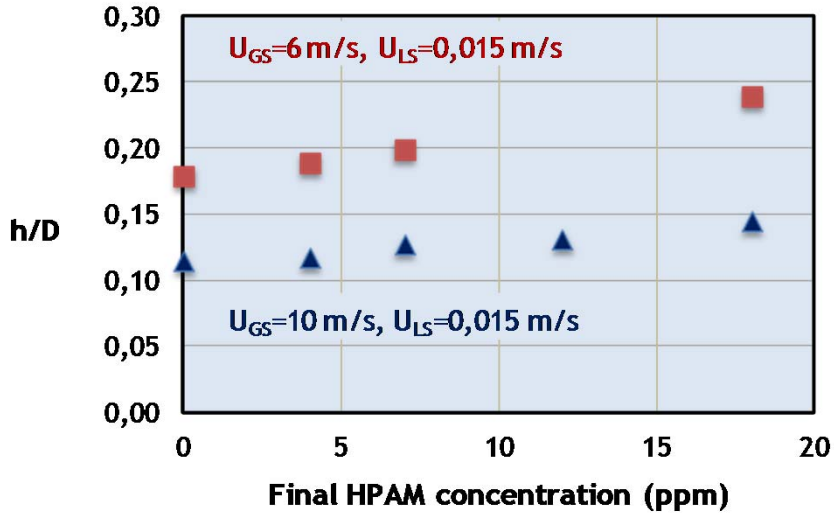


slug flow

U_{LS}=0.15 m/s, U_{GS}= 4 m/s



Some results in the 24-mm pipe



Increase of film height with the final polymer concentration.

Despite the film height increase a drag reduction is observed due to a "smoother" interface.

Preliminary conclusions

- The addition of HPAM in stratified flow in a horizontal pipe results in:

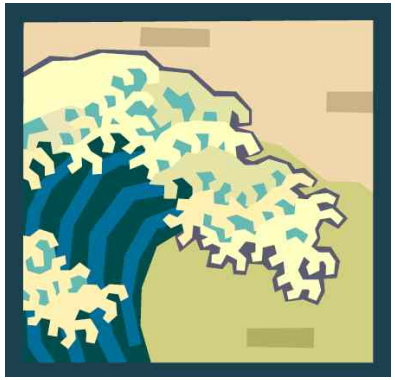
  (a) Delaying the onset of 2-D waves

  (b) Damping (to a significant degree) of the waves (both 2-D and roll waves). Damping of waves is also obvious in slug flow.

- Wave damping results in the reduction of interfacial frictions factor and the frictional pressure drop. In these experiments DR approached 40%.

- It seems that the DR percentage decreases with increasing the gas superficial velocity and increases with liquid velocity.

- The addition of a DRP expands somehow the stratified flow regime at the expense of slug/pseudo-slug flow and annular flow.

- There are some indications that the initial polymer solution affects DR.

Thanks for your attention !