A theoretical and experimental investigation of convective instabilities in a two layer coextrusion flow of molten polymers

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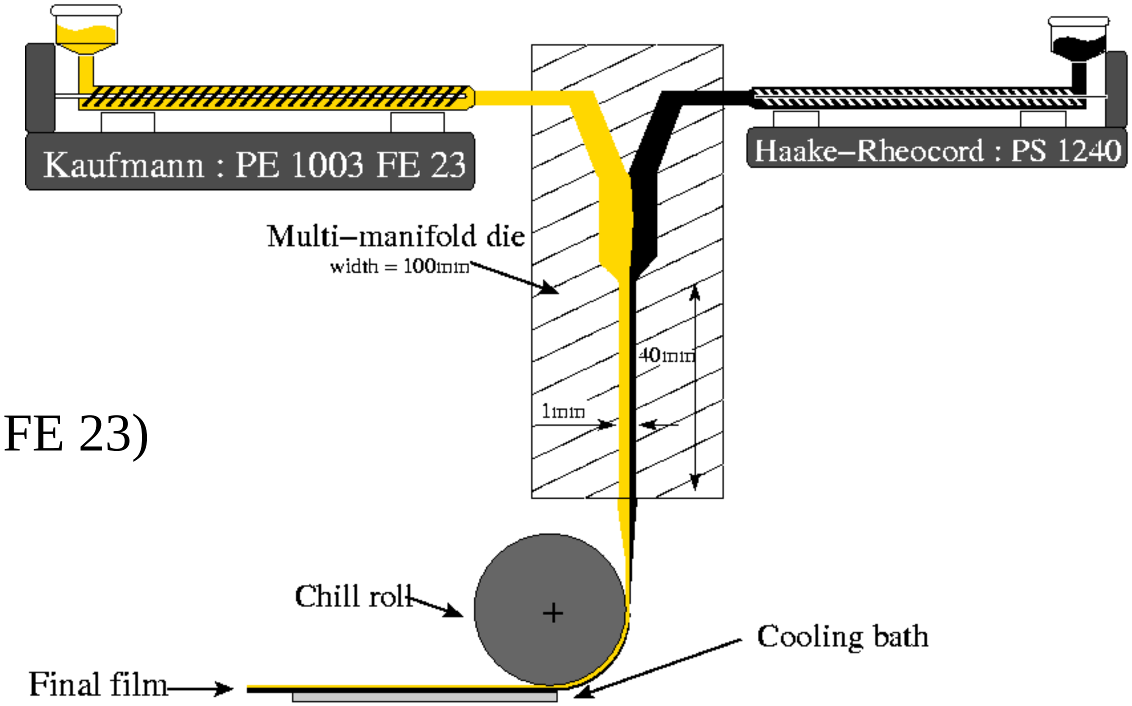
Experimental device



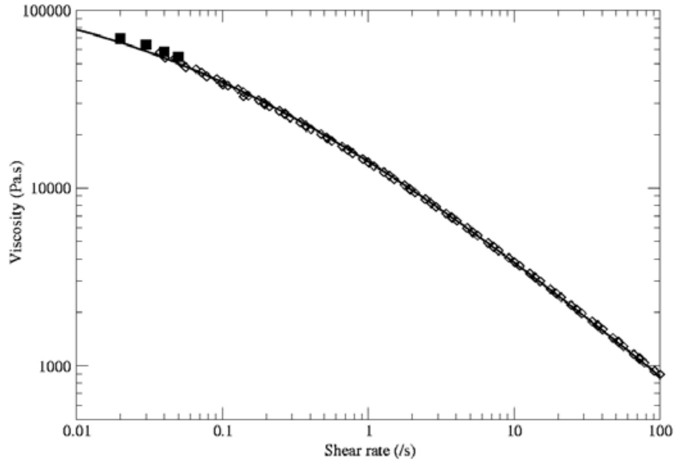
-Multimanifold die :

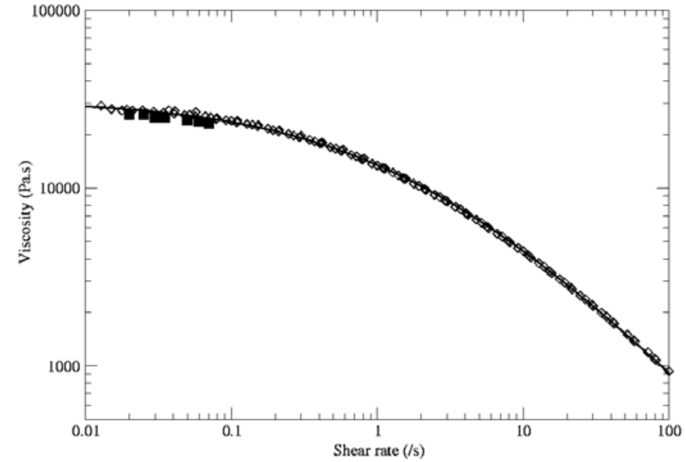
Polyethylene (PE 1003 FE 23)
Polystyrene (PS 1240)

Rheometry PE / PS (master curve)

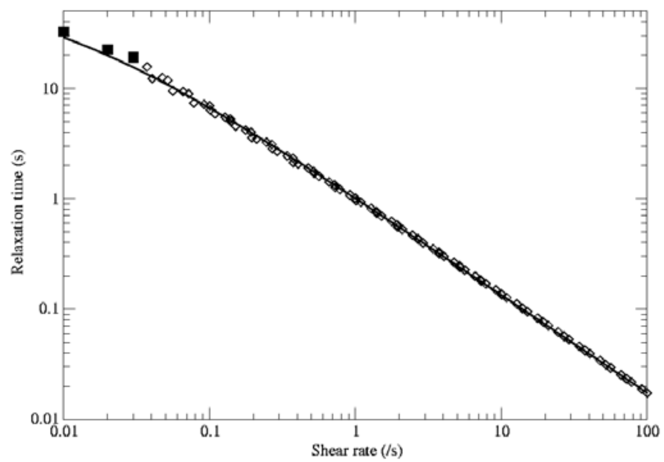
PE PS

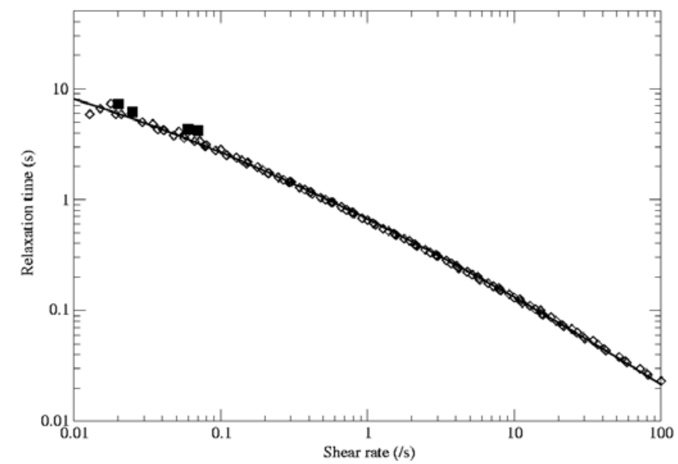
Viscosity



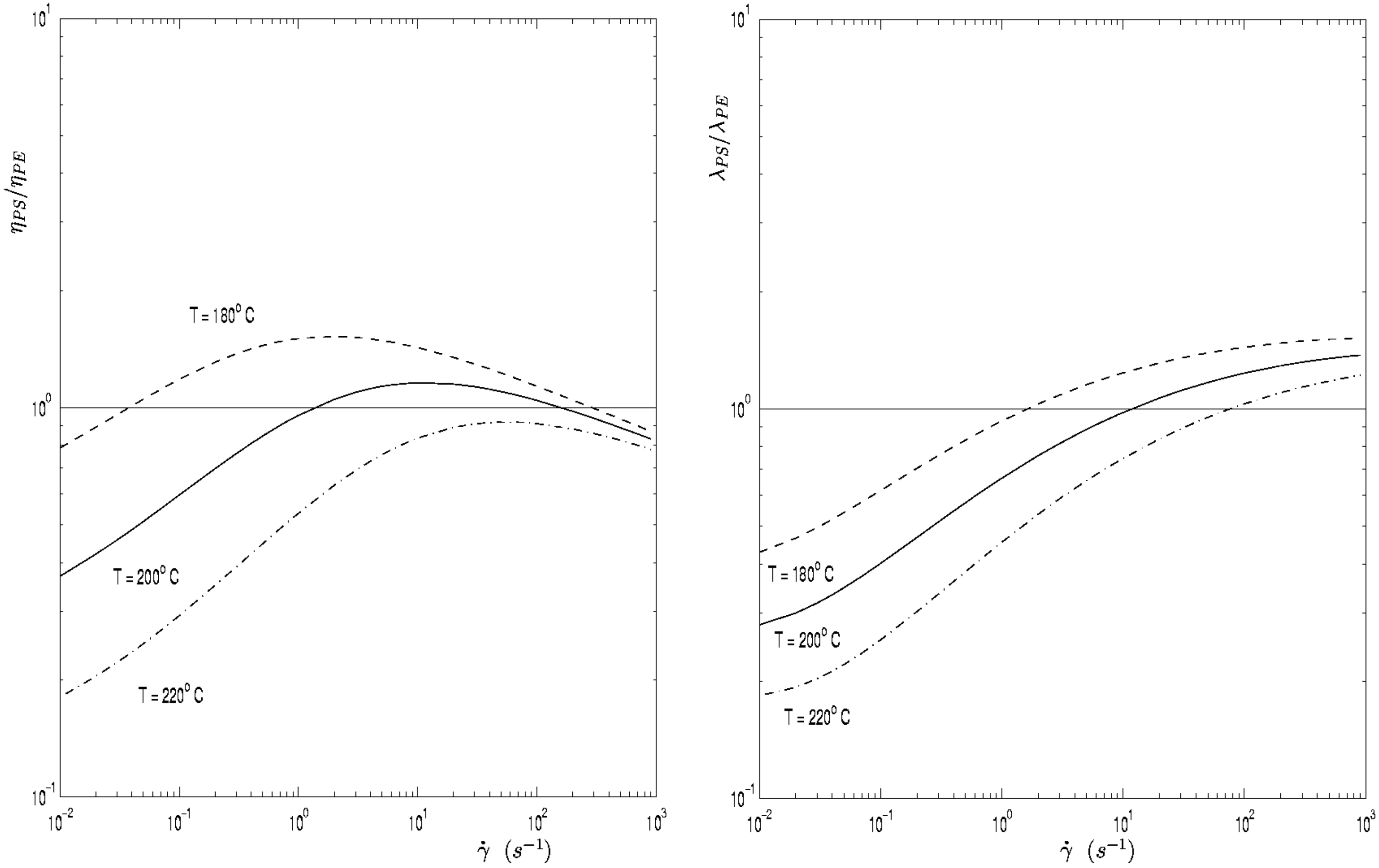


Relaxation time

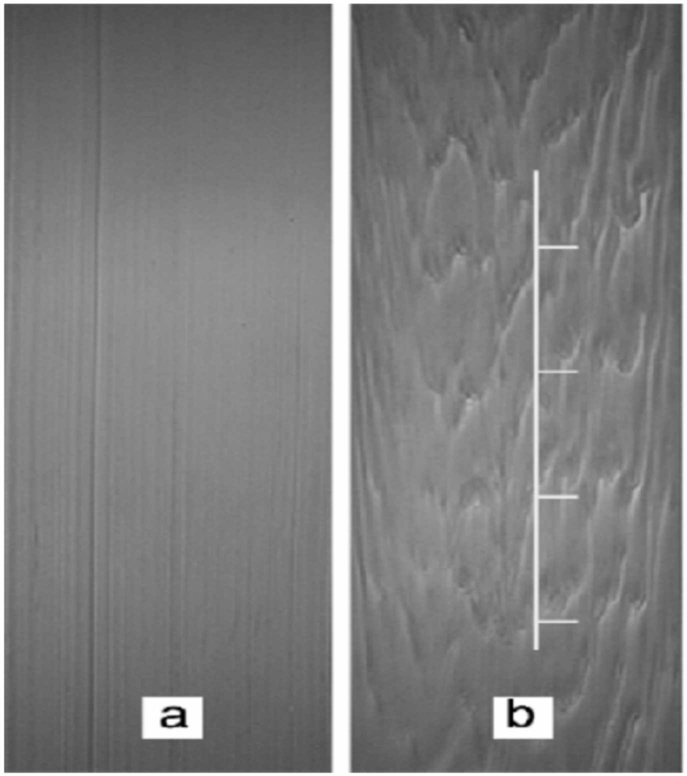


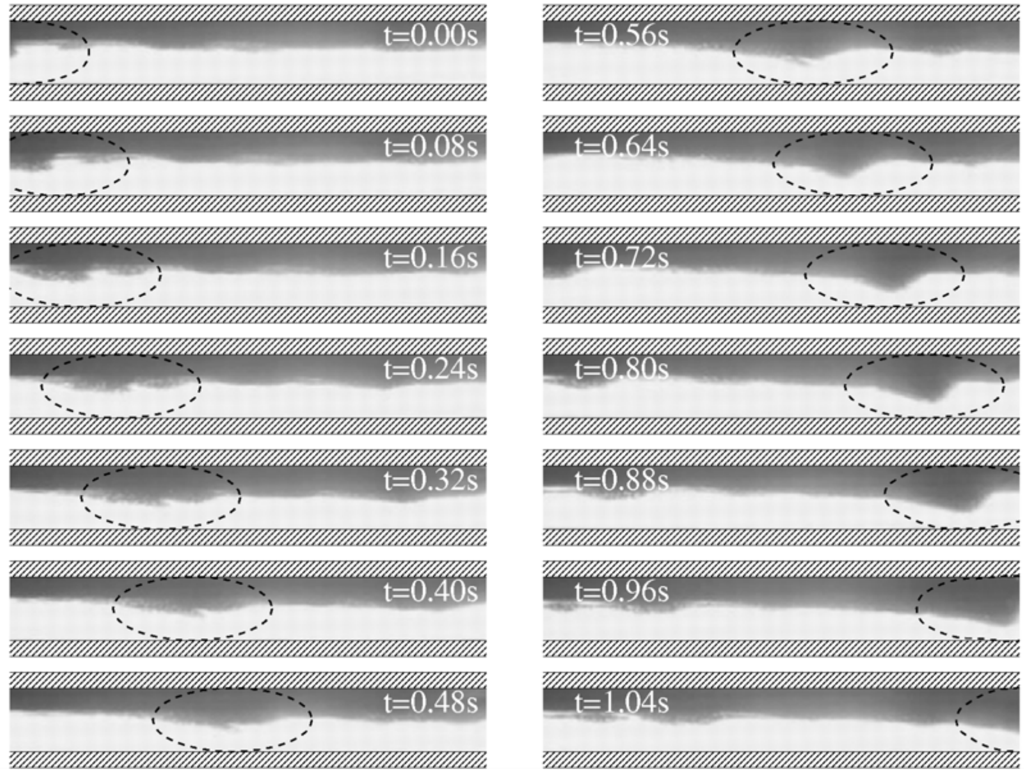


Rheometry PE /PS (relative properties)



Stable (a) / unstable (b) flows





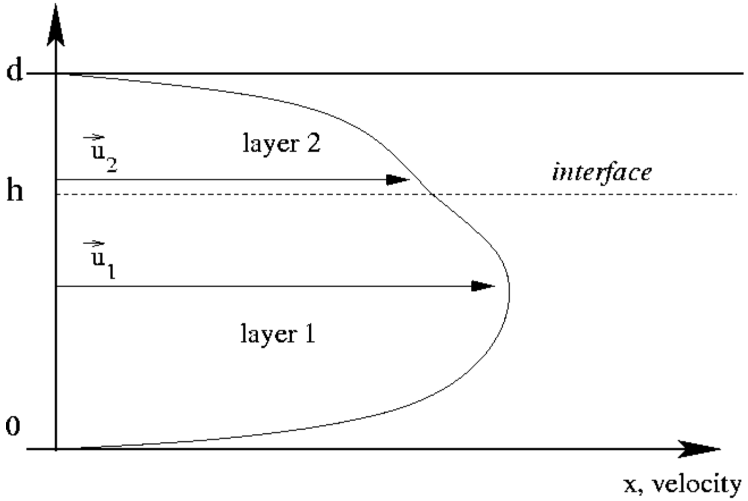
Samples (die exit)

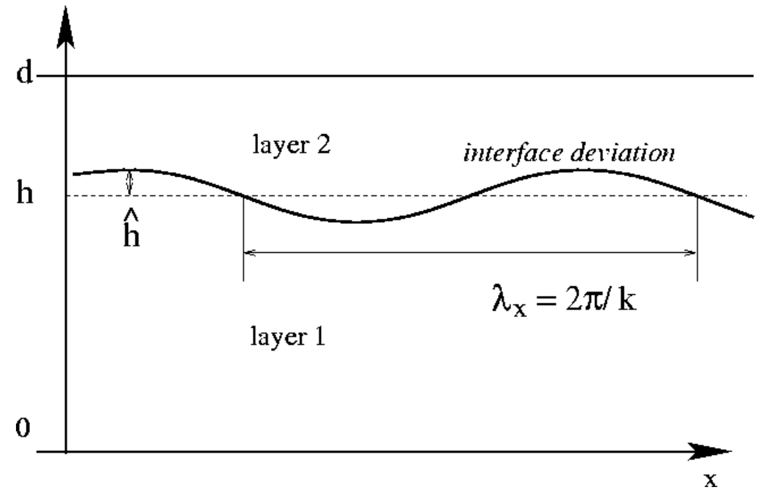
Unstable flow (transparent die)

Convective nature of the instability (Khomami *et. al.*, 1992)

Linear stability analysis

(Yih, 1967)





Poiseuille flow
(White-Metzner fluids)

Perturbations $\exp(i(kx-\omega t))$
(waves, temporal growth/decay rate)

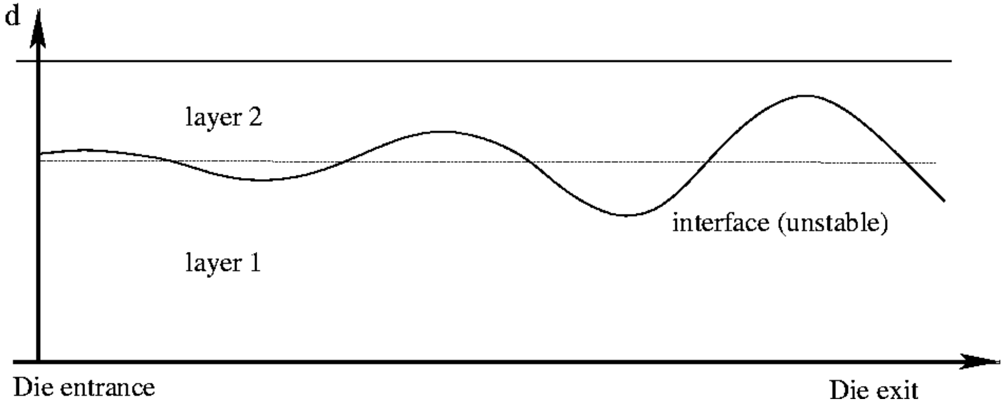
The flow behaves like an oscillator

Growth/decay rate ω_i computed by solving an eigenvalue problem

Spatial stability analysis

(Khomami *et. al.*, 1999)

Perturbations
(spatially growing waves)

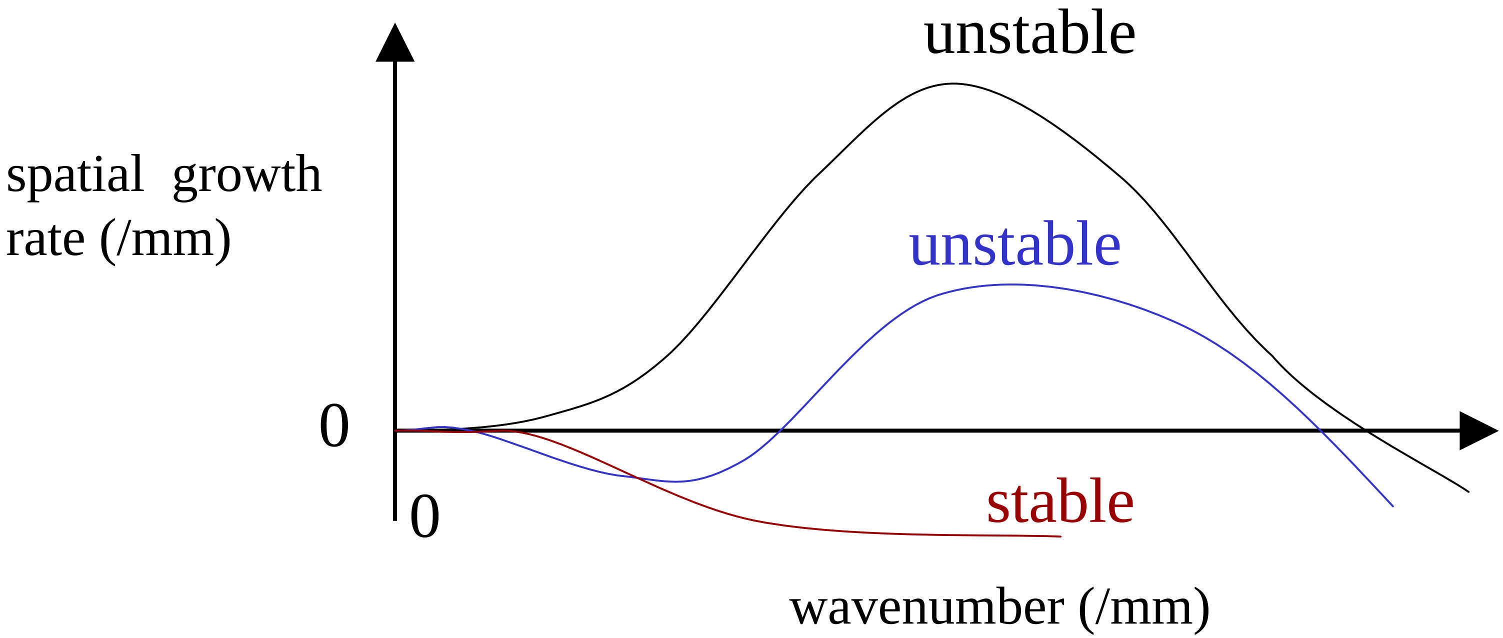


The flow behaves like an amplifier
Spatial growth/decay rate computed by using Gaster's relation

(Gaster, 1962)

Spatial growth rate : $-k_i(S) = \omega_i(T)/V_g$
V_g = group velocity of the perturbations

Spatial stability analysis



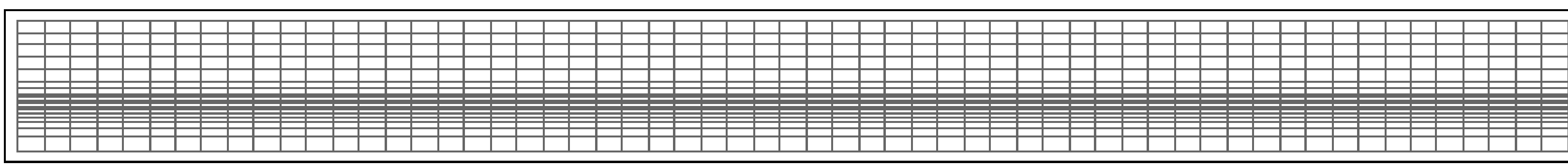
« Transfer function » of the system

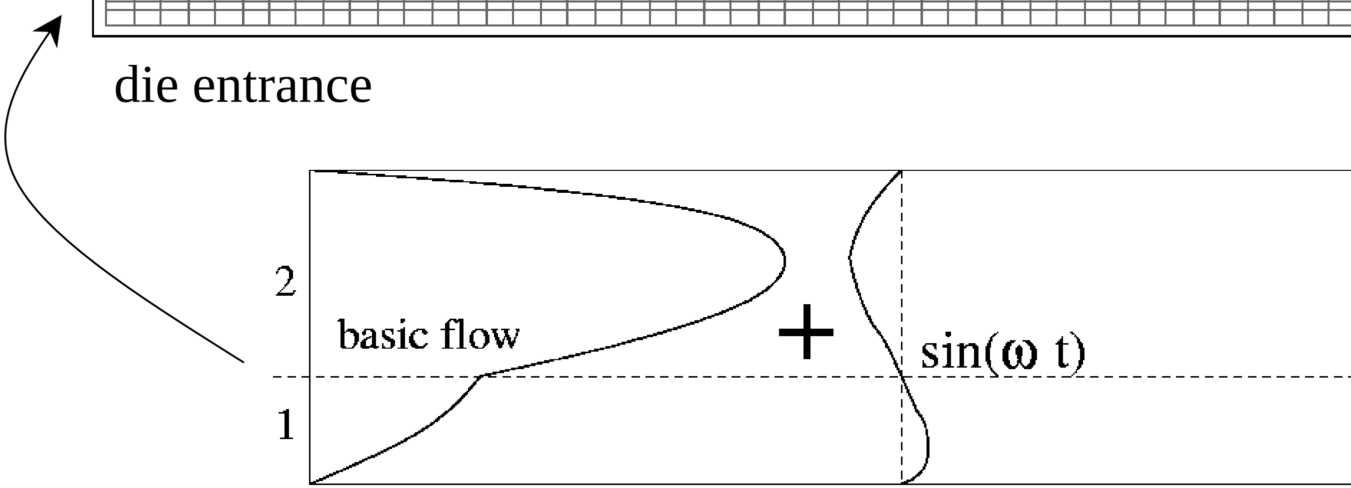
Validation with FE direct simulations

MEF++ finite elements code
GIREF, Univ. Laval, Canada (prof. A. Fortin)

Response to a
t-periodic forcing at $x=0$:

1 – compute the basic flow
2 – perturbation of the flow

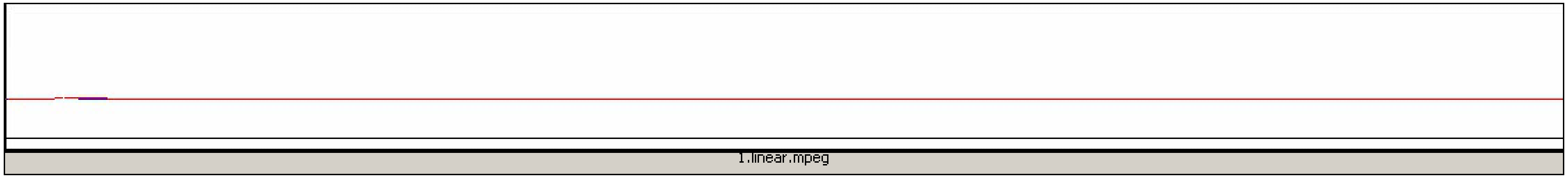




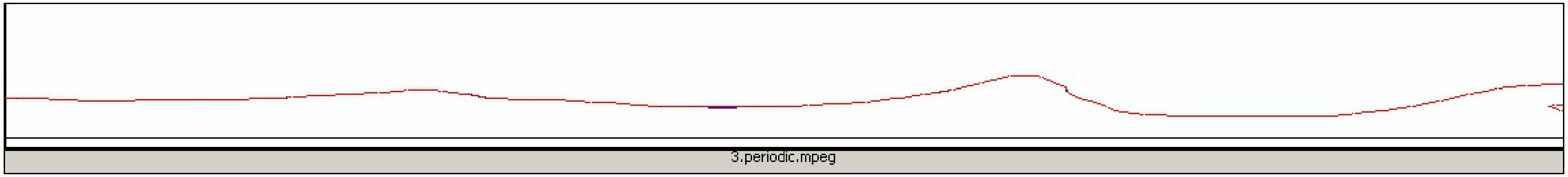
Example of forcing

Maxwell fluid / Newtonian fluid : $\eta_{maxwell} / \eta_{newtonian} = 10$; We = 1
Forcing frequency = 1.0
The flow is convectively unstable

Linear regime



Non-linear regime



die entrance

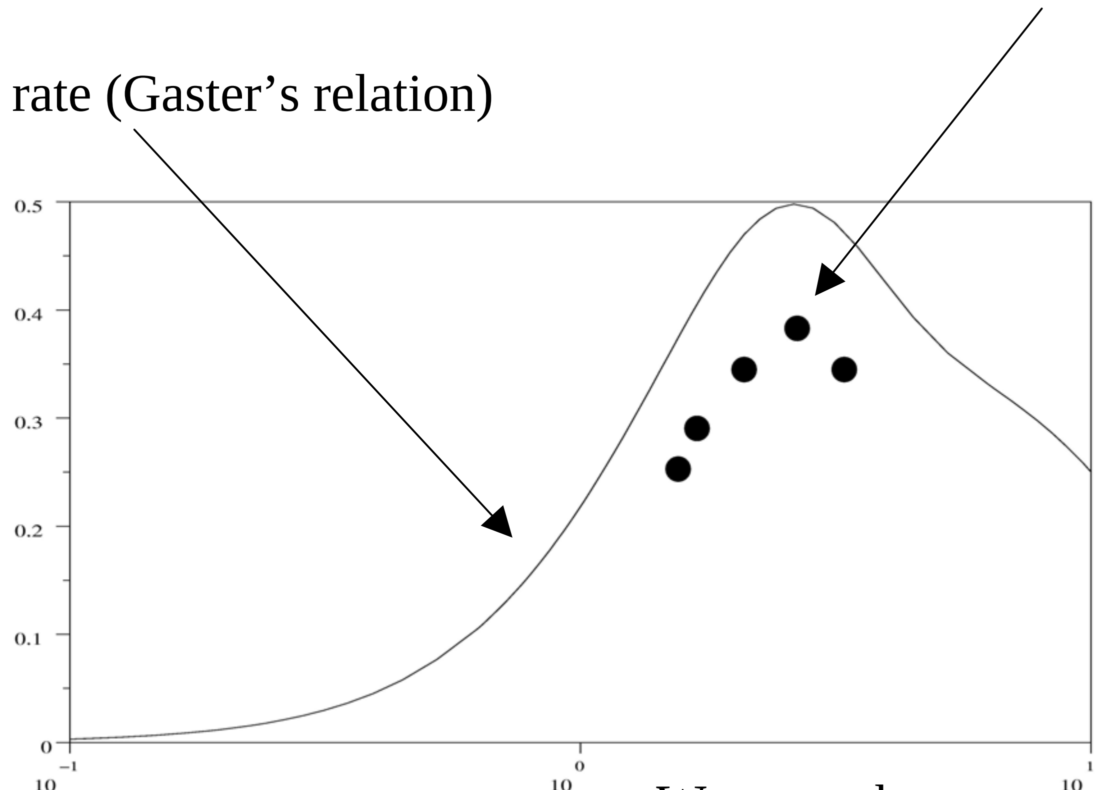
die exit

Comparison with spatial stability analysis

FE simulations spatial growth rate (FFT)

theoretical spatial growth rate (Gaster's relation)

Spatial growth rate



Wavenumber

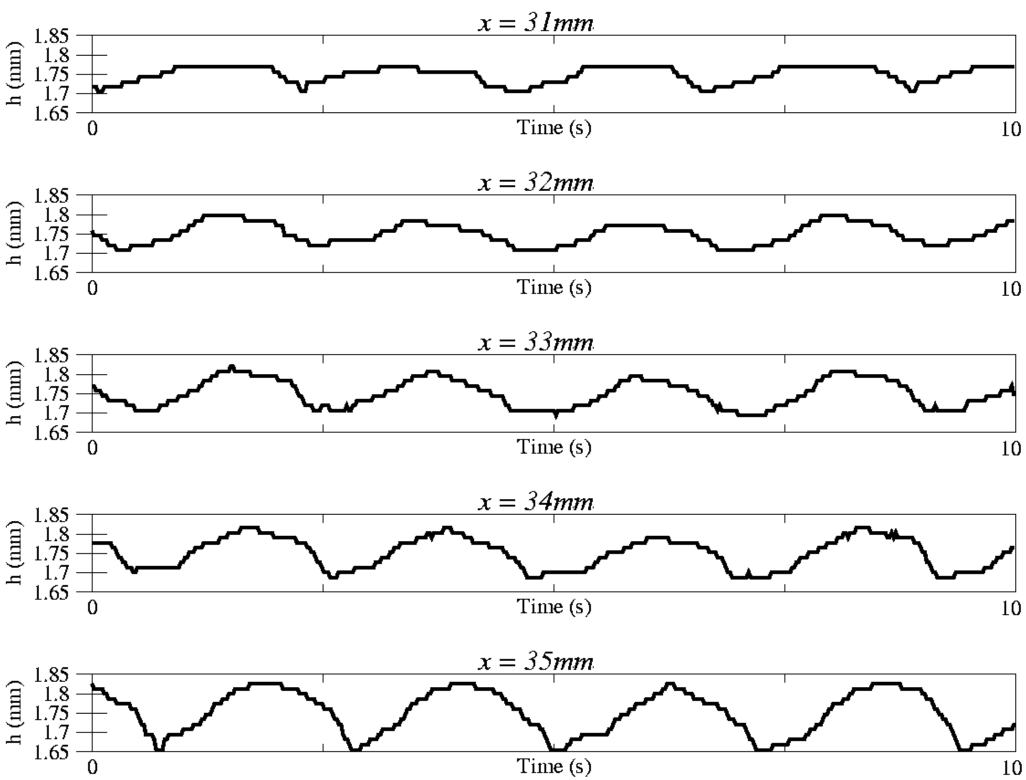
Good qualitative agreement.

Validation with forced experiments

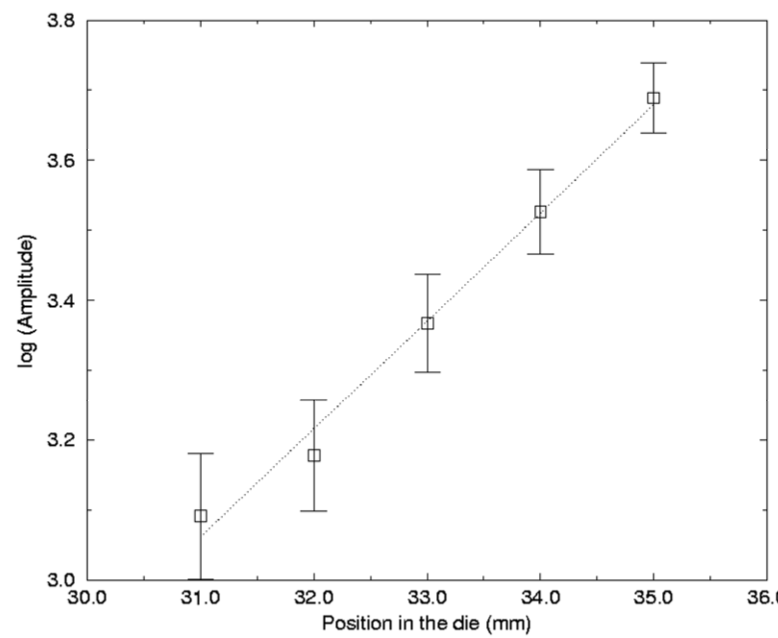
(Khomami *et. al.*, 1992)

Forcing by imposing a periodic screw rotation rate on the extruder.
Measurement of spatial growth rate for various forcing conditions.

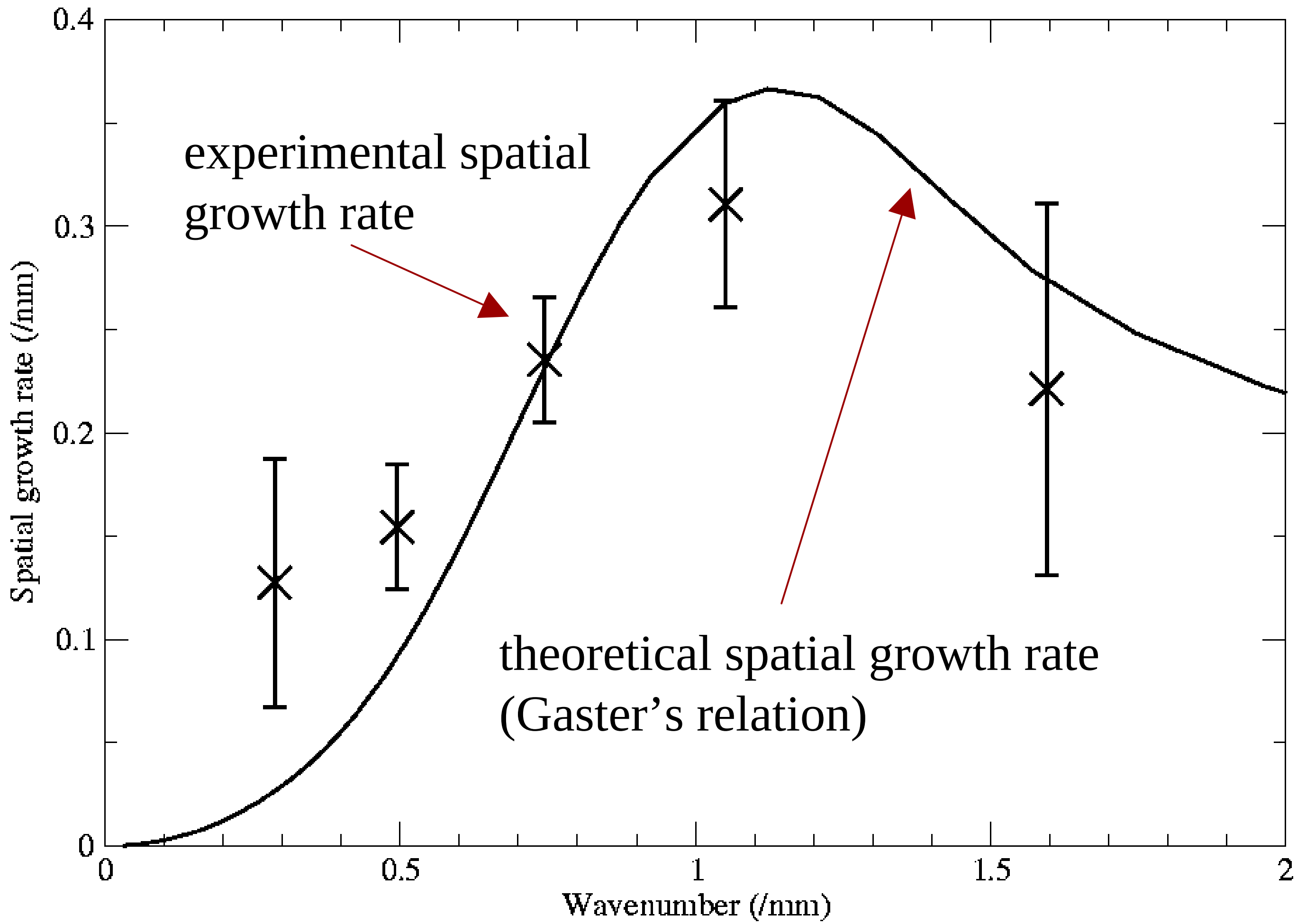
Interface deviation for different *x* :



Fit of the spatial growth rate :



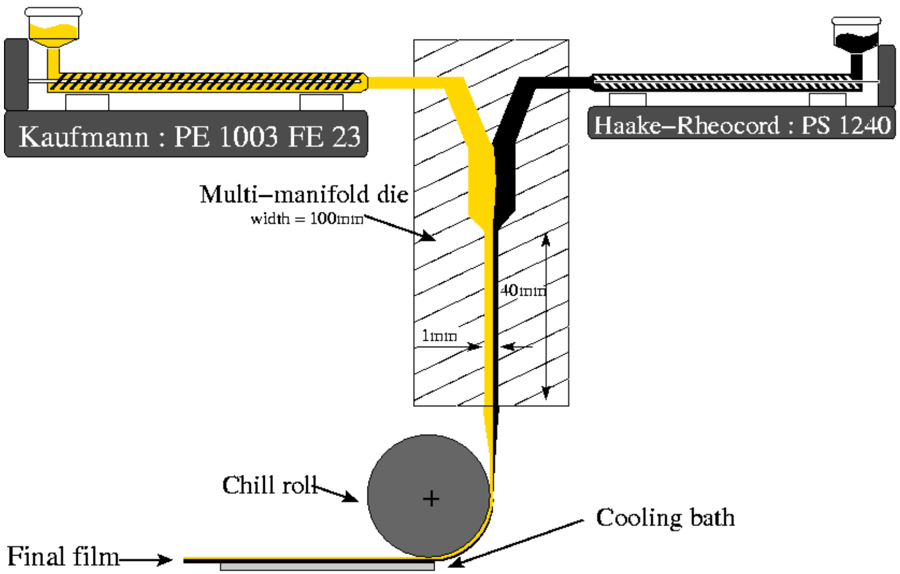
Comparison with spatial stability analysis

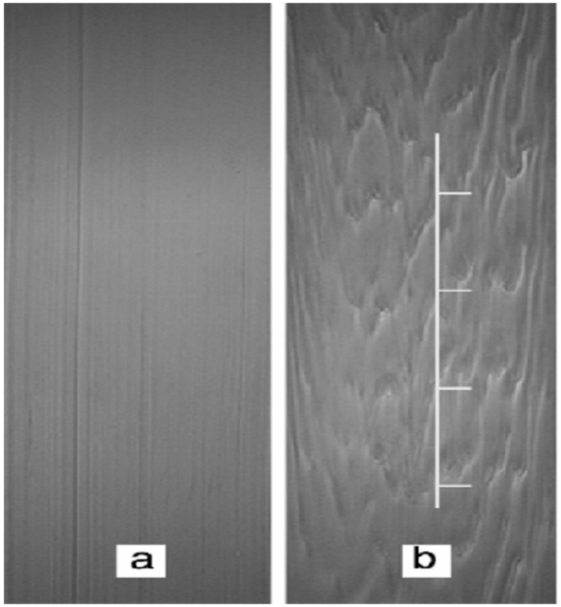


Good quantitative agreement.

Industrial application

Experiments for various flow rates and temperatures.
Existence of a stable/unstable transition observed on the extrudates.



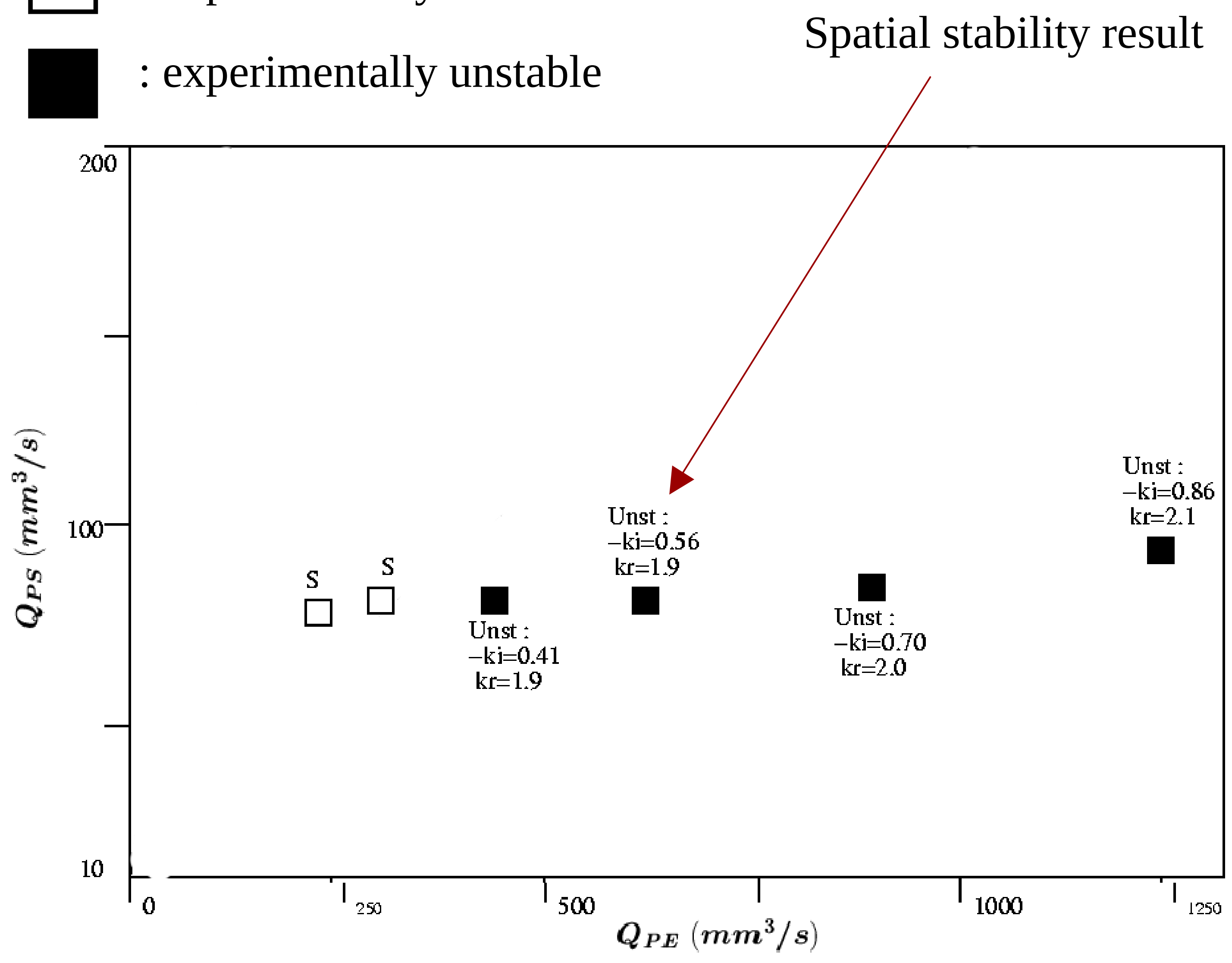


Comparison with the value of the growth rate of the dominant mode of the spatial stability analysis.

Temperature : 180°C.

□ : experimentally stable

■ : experimentally unstable

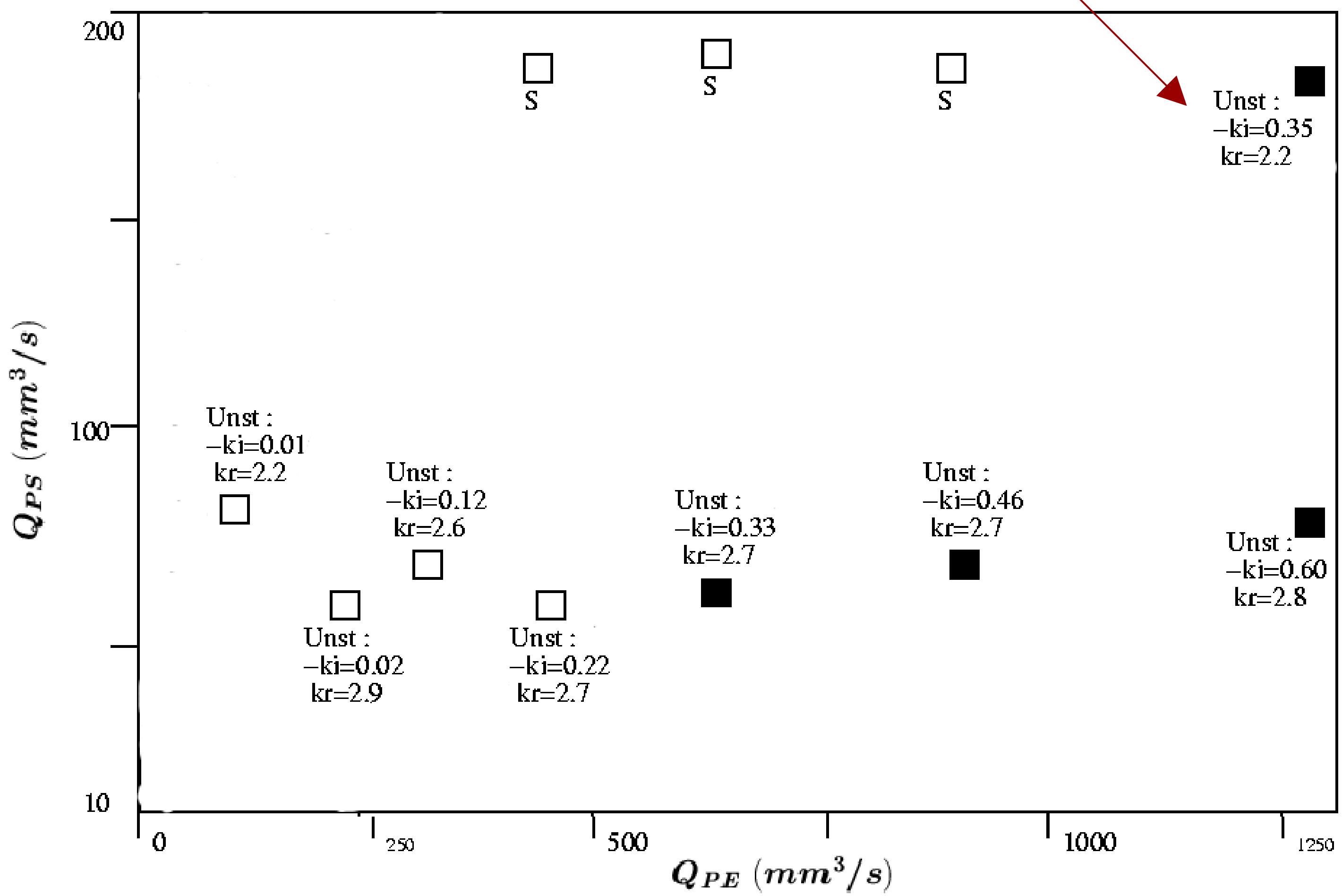


Temperature : 200°C.

: experimentally stable

: experimentally unstable

Spatial stability result

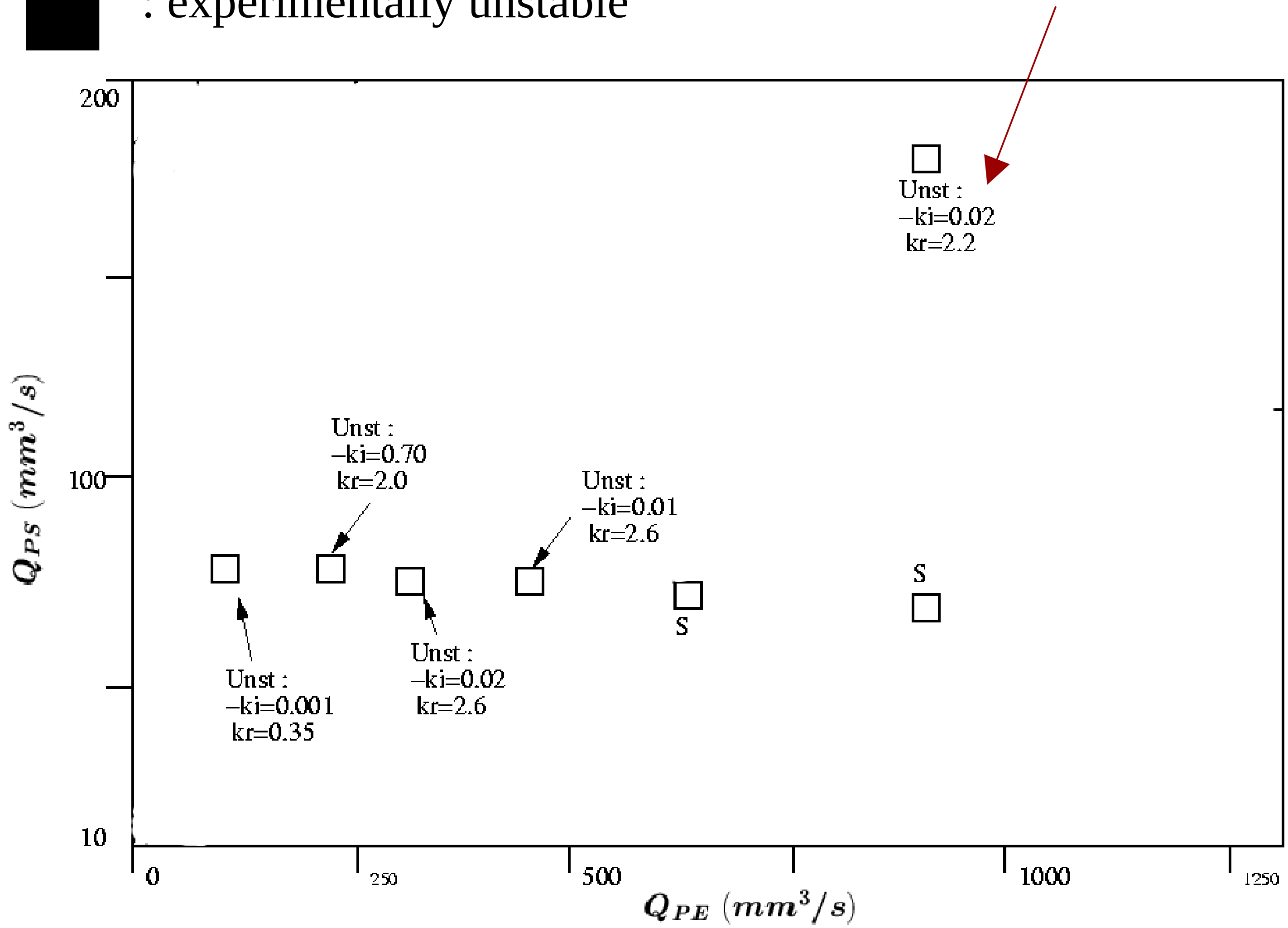


Temperature : 220°C.

□ : experimentally stable

■ : experimentally unstable

Spatial stability result



Conclusion.

Direct simulation

More realistic constitutive equations

Influence of non isothermal conditions

Complex die geometries