Numerical investigation of polyester coextrusion Instabilities for steel coating

Esaform 07

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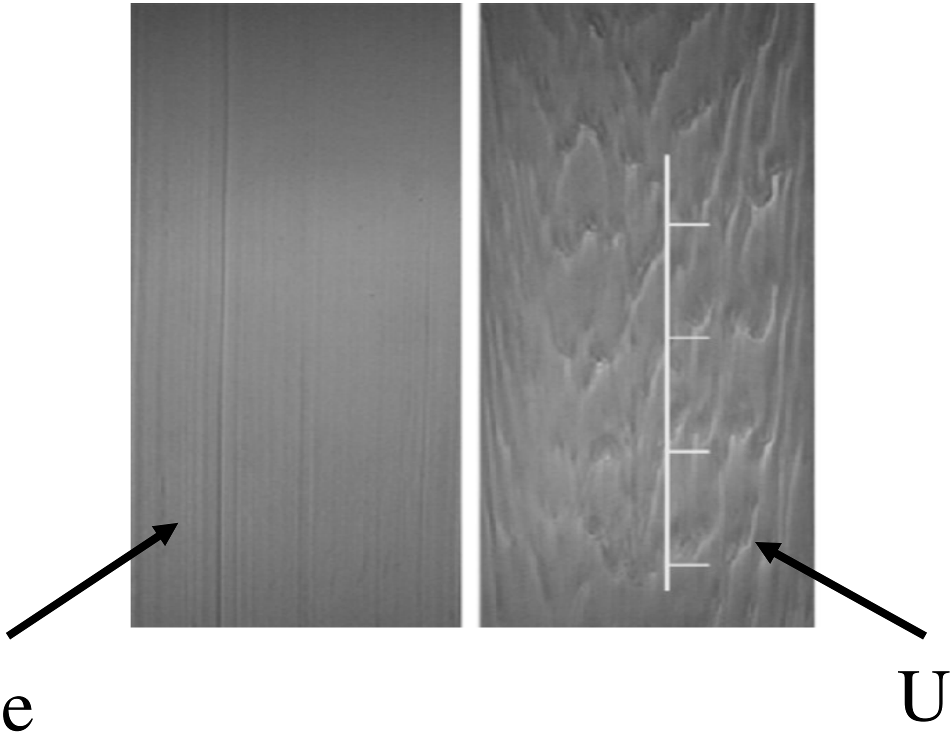
Main problem: Interfacial Instabilities between two coextruded polymers



What governs the appearance of these instabilities

- Viscosity ratio
- Elasticity ratio
- The relative flow rates
- Polymers and die Temperatures

Refering to the literature

H.K Ganpule and B.Khomami. *The effect of viscoelastic properties on interfacial instabilities in superposed pressure driven channel flow, . J. Non-Newtonian Fluid Mech, 80 :217-249, 1999*

R. Valette, P. Laure, Y. Demay and J.-F. Agassant. *Convective Linear Stability analysis of two-layer coextrusion for moltent polymers,* J. Non Newtonian Fluid Mechanics*, 121, 41-53, 2004*

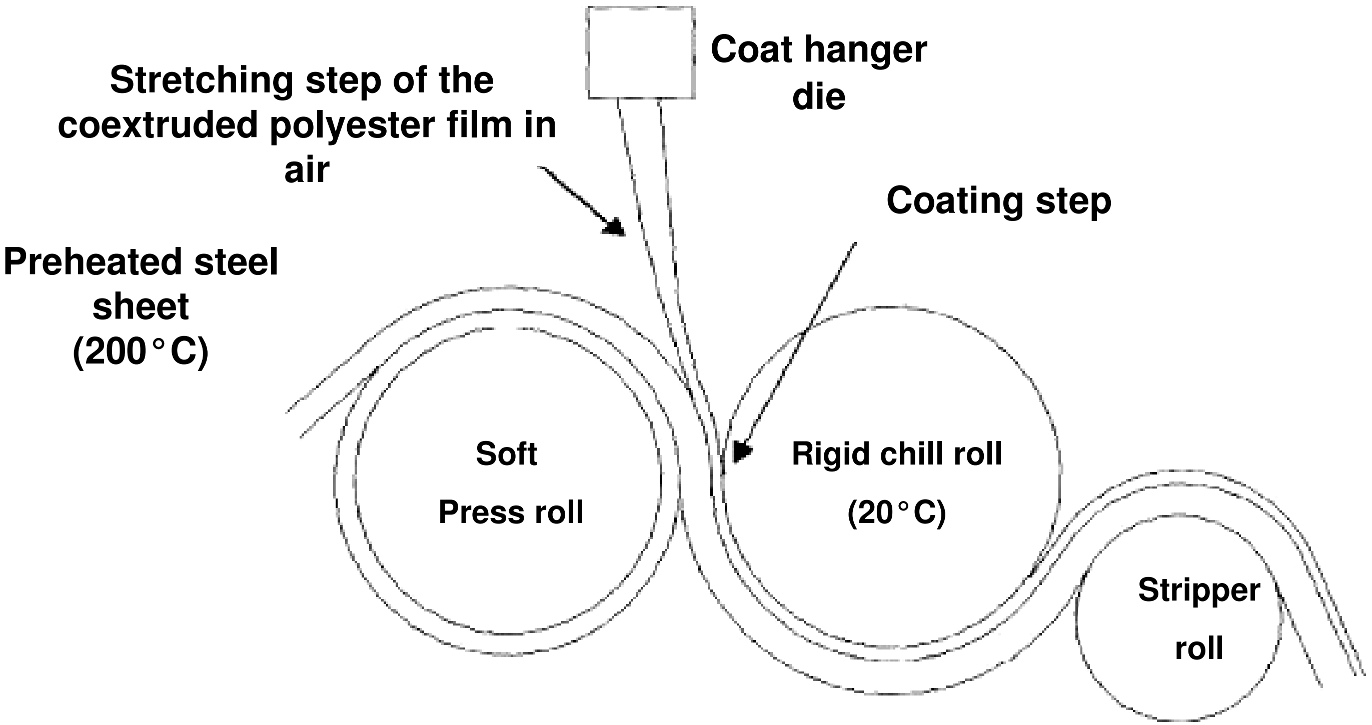
H. Yamaguchi, A. Mishima, T. Yasumoto, T. Ishikawa. *An arbitrary lagranhian-Eulerian approach for simulating viscoelastic fluids* , J. Non-Newtonian Fluid Mech, 251-272, 1999

M. Zatloukal, C. Tzoganakis, J. Vlcek and P. Saha. *Numerical Simulation of Polymer Coextrusion Flows, " Polymer Processing XVI, 198-207, 2001*

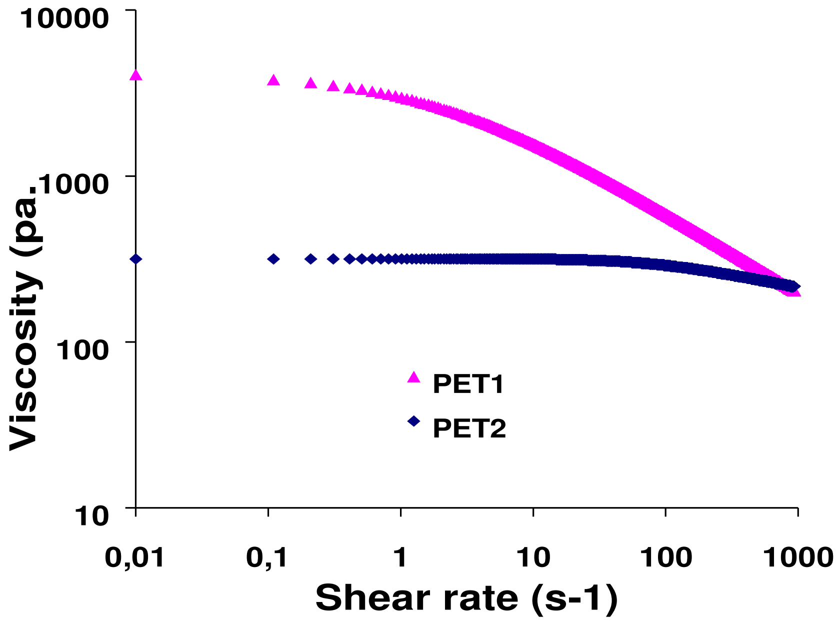
PET coating on steel

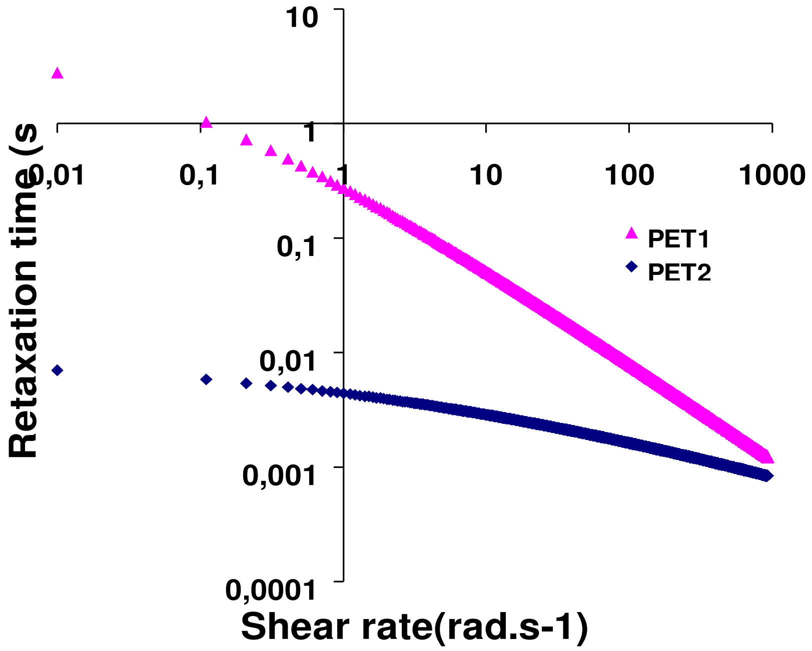
- **Objectives**
  - Good adhesion
  - Mastered cost

Coextrusion of a thin (but expensive) adhesive polyester and a thick (but cheap) polyester



The different Polyester resins


Viscosity curve (T=260°C)


Relaxation time (T=260°C)

PET1:**Viscoelastic** (**E=38 KJ/mol**) and PET2: **Newtonian** (**E=61KJ/mol**)

λ_i (s)	**0.0366**	**0.1408**	**0.5148**	**1.8428**	**5.4390**	**20.371**
η_i(**Pa.s-1)**	**457.6**	**614.97**	**770.55**	**681.61**	**202**	**25.22**

Viscosity/relaxation time distribution for PET1 at 260°C

Dimensionless numbers

- Reynolds number:

$$\mathrm{Re} = \frac{\rho h_{ref} U_{ref}}{\eta} = \frac{\rho Q_i}{\eta L} \Longrightarrow \mathrm{Re} = \frac{\rho h_{ref}^{\,m} (10^{-5} Q_m)^{(2-m)}}{k(36 \rho L h_{ref})^{2-m}}$$

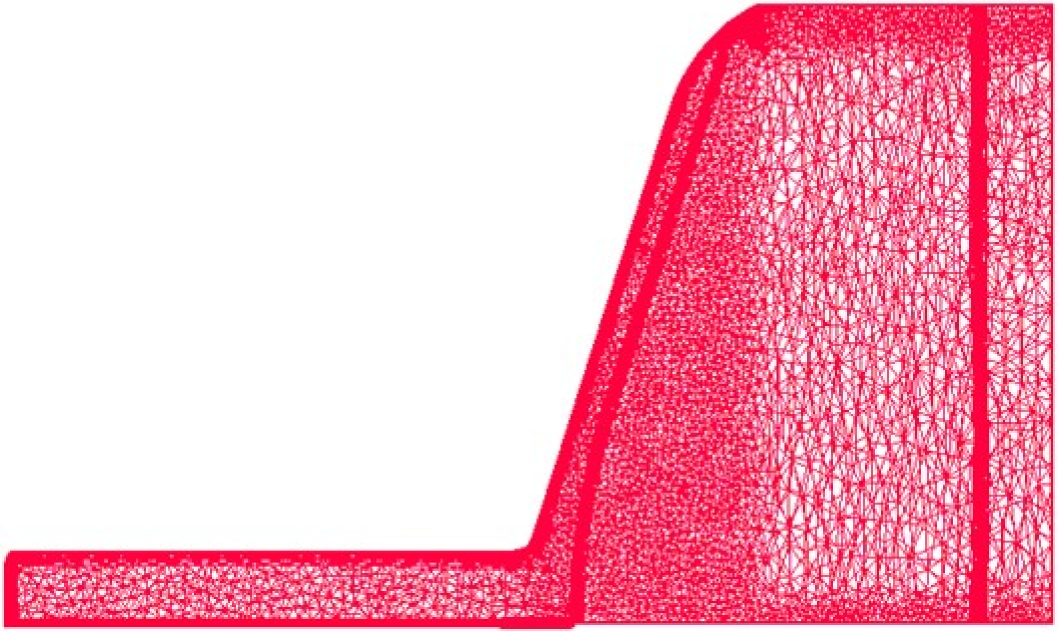
$$Re \approx 10^{-5}$$

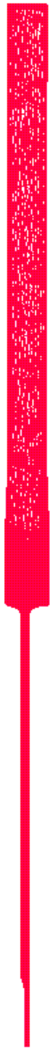
- Weissenberg number :

$$We = \lambda \dot{\gamma} \Longrightarrow We = \lambda \frac{U_{ref}}{h_{ref}} = \lambda \frac{Q}{L h_{ref}^{\,2}}$$

$$0.01 < We < 0.5$$

Basic hypothesis: interfacial instabilities are initiated within the coat hanger die





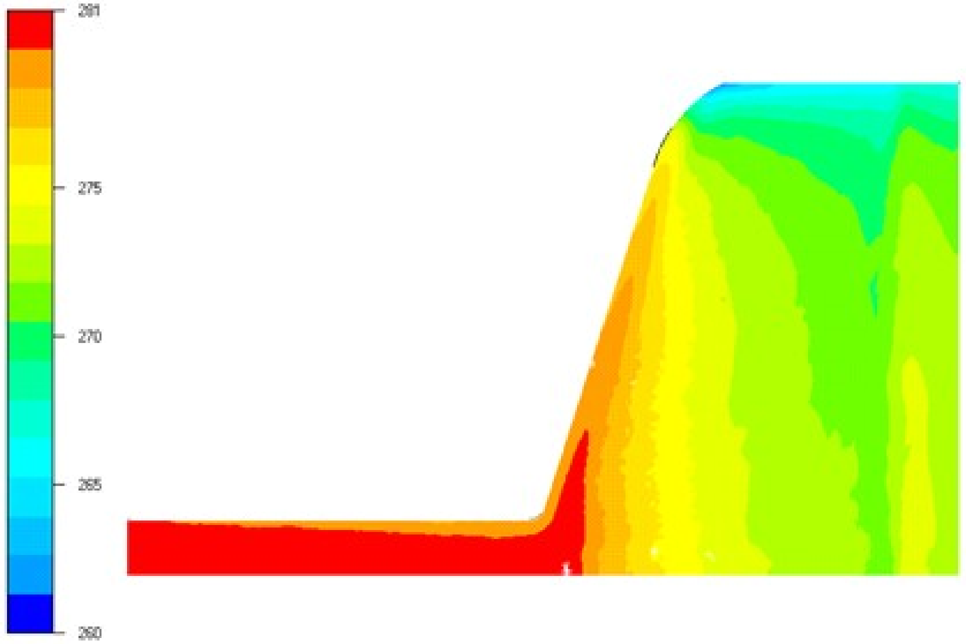
Within
The
thickness

½ die

- anisotropic meshing
- number of nodes : 55739
- number of elements : 315314

Monolayer 3D computation
Temperature distribution (polyester PET1)

- Temperatures: PET 281 °C , die 260 °C
- Flow rate: 46 kg/h

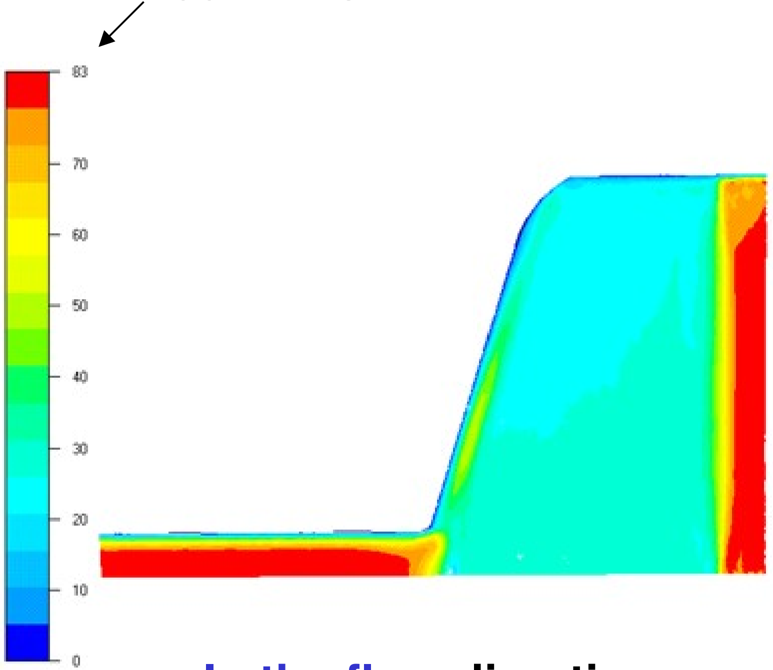


- Significative temperature decrease within the die
- But the die does not impose the final temperature
- The temperature is uniform in the die width

Monolayer 3D computation
Velocity distribution (polyester PET1)

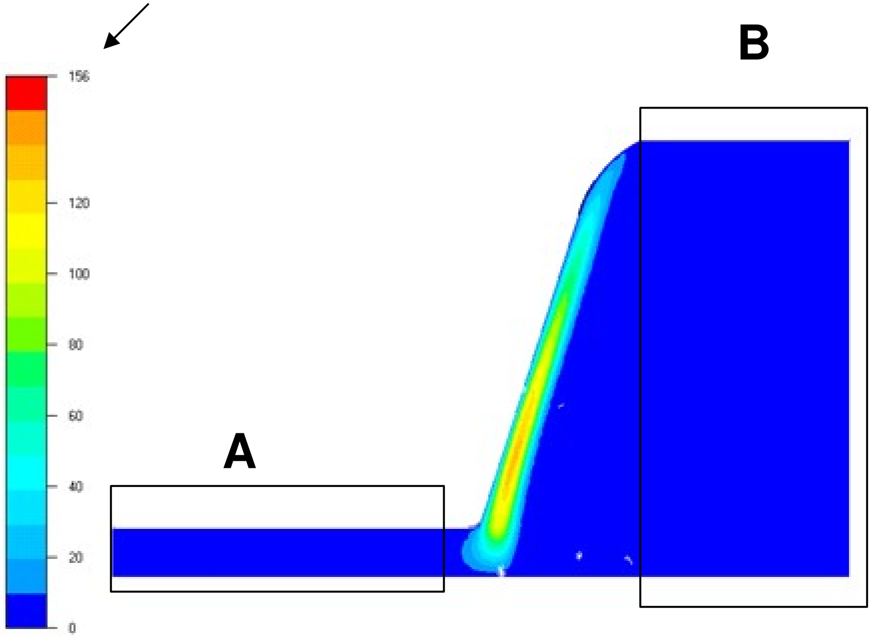
- Temperatures: PET 281 °C , die 260 °C

83 mm/s



In the flow direction

156 mm/s



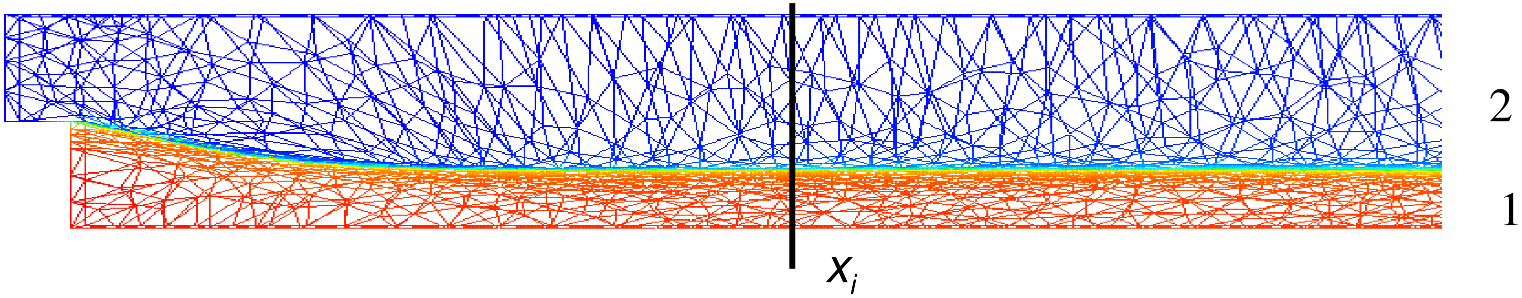
In the transverse direction

- ➢ The die entry zone A
- ➢ The die exit zone B

} One directional flow pattern

2D coextrusion computation

Objective: Capture precisely the interface position between the two polymers



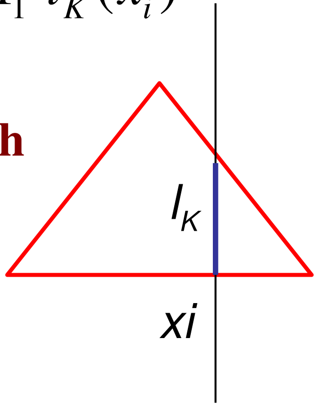
- **Characteristic function :**

$$\Pi_j(x,t)=\begin{cases}1 & x\in\Omega_j\\ 0 & x\notin\Omega_j\end{cases}$$

- **Fluid height 1:**

$$h(x_i)=\int 1_1(y,x_i)dy=\sum_K 1_1^K\, l_K(x_i)$$

- **Needs to determine precisely the line segment which intersect each element**
- **Needs mesh refinement around the interface**



2D Dynamic stability analysis

- **Disturbance periodic :**

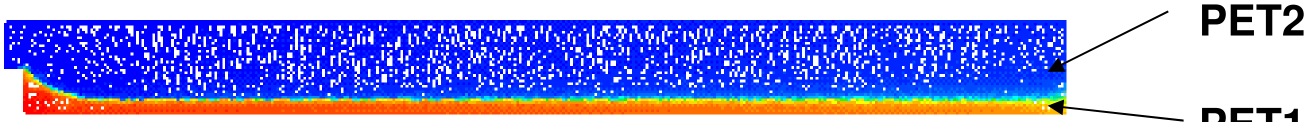
$$Q = Q_0(1 + A\sin(\frac{2\pi}{T}t))$$

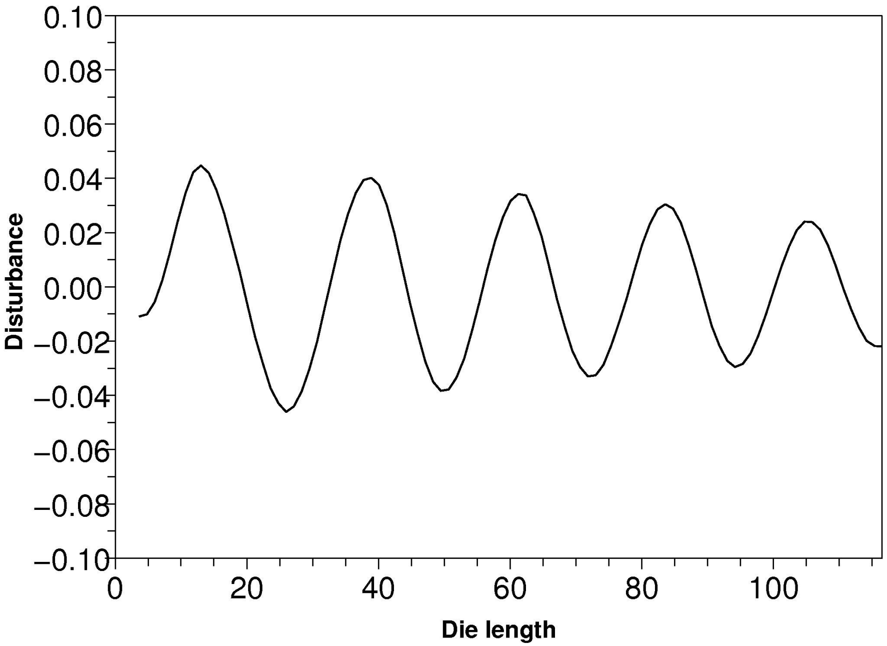
$$h = h(\frac{2\pi}{T}t + kx)$$

2D Dynamic stability analysis

Entrance section of the coat hanger die (flow between parallel plates)

- **Isothermal viscous behaviour**





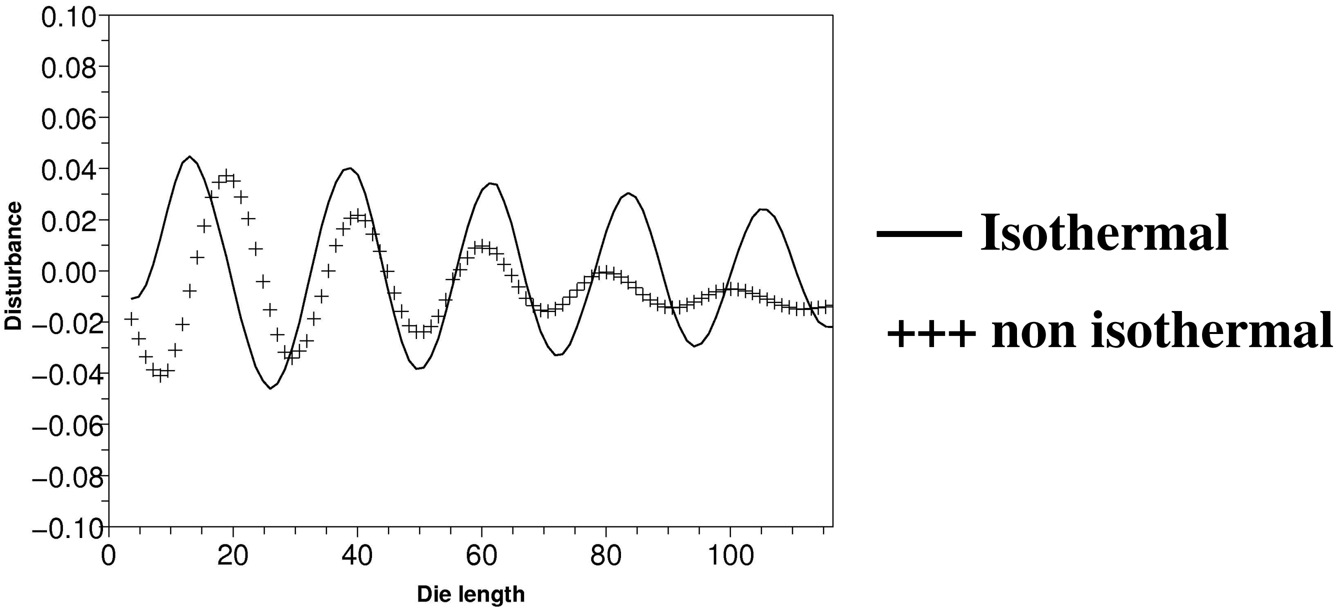
The motor (driving force) for instabilities is the Reynolds number

2D Dynamic stability analysis

Entrance section of the coat hanger die (flow between parallel plates)

- **Non isothermal viscous behaviours**

- **Temperatures: die 260°C, PET1 281°C , PET2 255°C**



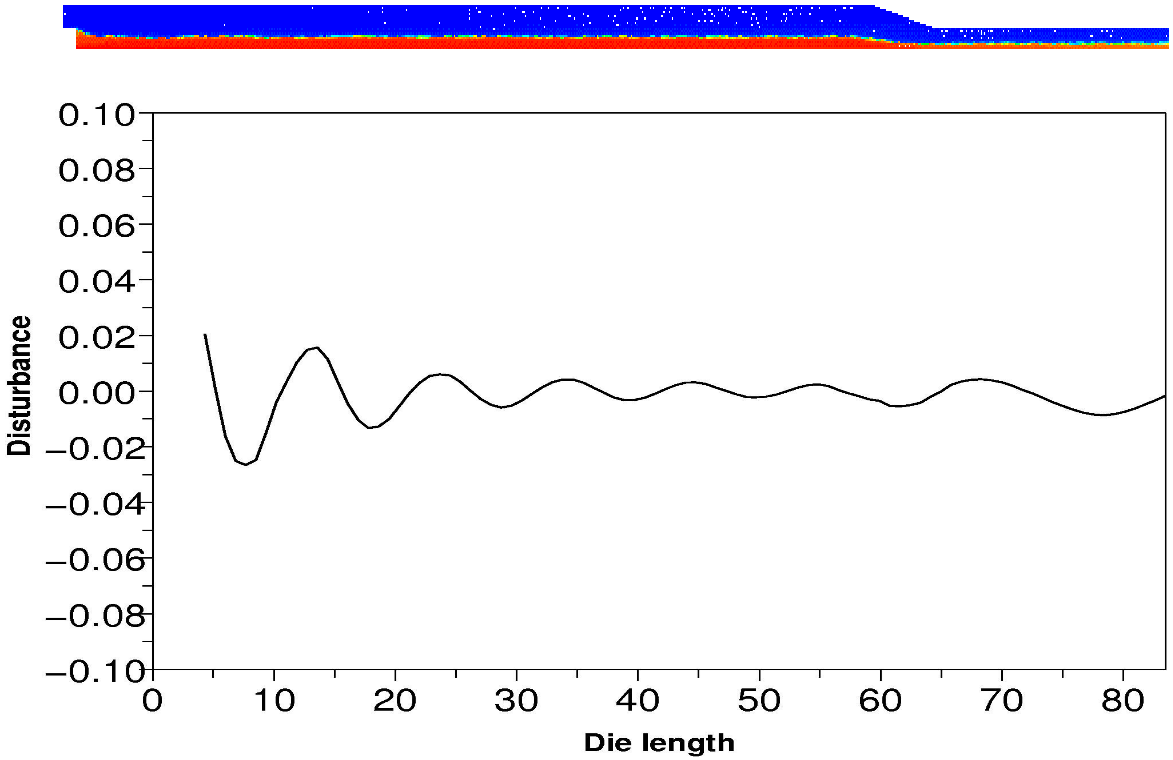
Instabilities: comparison between isothermal and non isothermal behaviours

In that case temperature dependence seems to damp down instabilities

2D Dynamic stability analysis

Exit section of the Coat hanger die
(Convergent geometry)

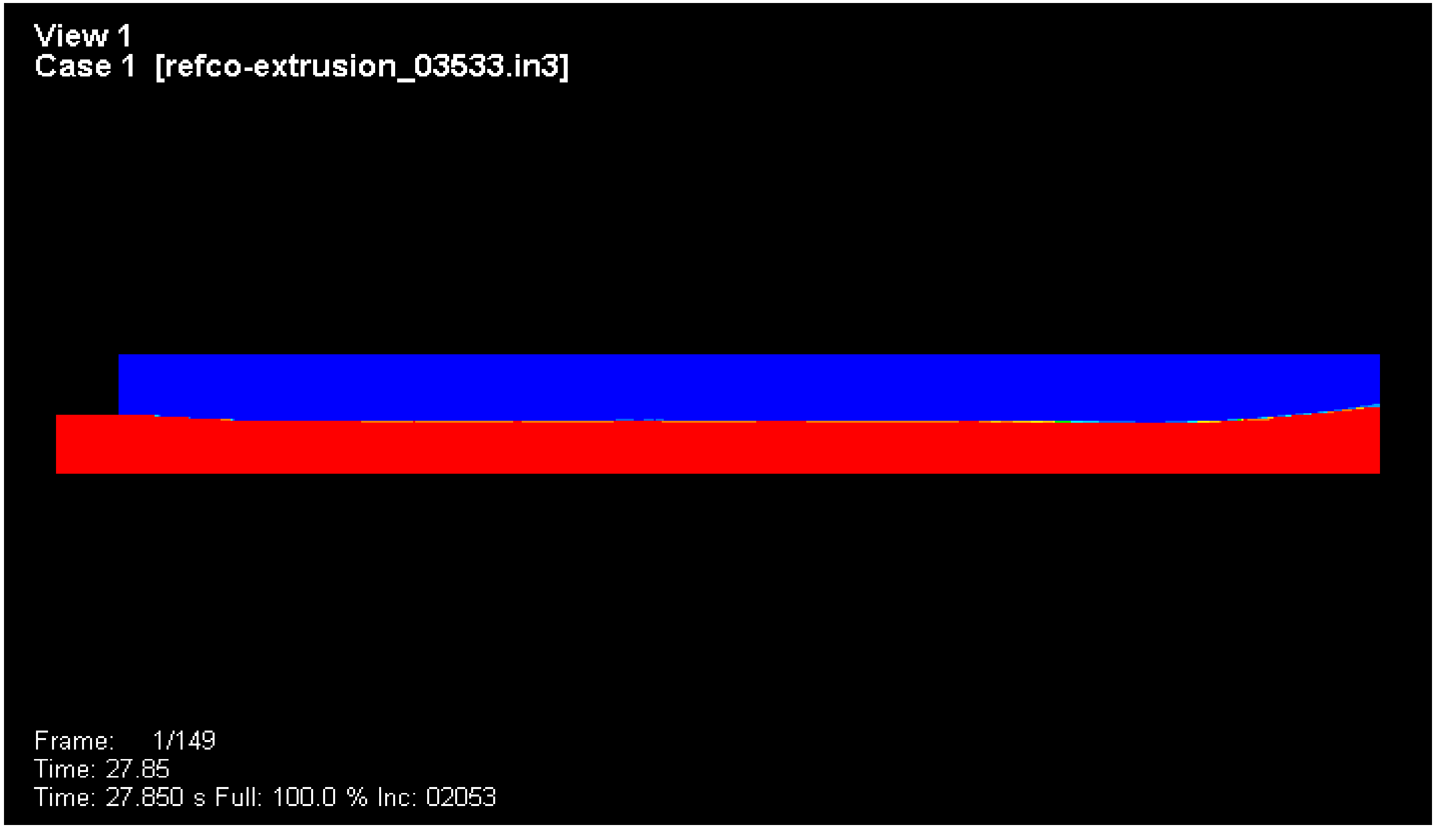
- **Isothermal viscous behaviour**



The convergent geometry seems to damp down instabilities

Towards the viscoelastic behaviour
Feasibility test

Artificial boundary conditions : P1 = 2000 Pa ; P2 = 2300 Pa


View 1
Case 1 [refco-extrusion_03533.in3]

Frame: 1/149
Time: 27.85
Time: 27.850 s Full: 100.0 % Inc: 02053

The driving force is the Weissemberg number

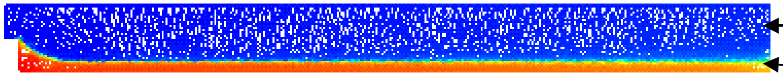
Some experimental conditions (Freville report)

cas	PET1 Vit. vis B25)(tr/min	PET2 Vit. vis B30)(tr/min	note défaut /5
1	20	25	0
2	20	50	1
3	**20**	**90**	**2**
4	50	25	0
5	**50**	**50**	**0**
6	**50**	**90**	**1**

2D Dynamic stability analysis

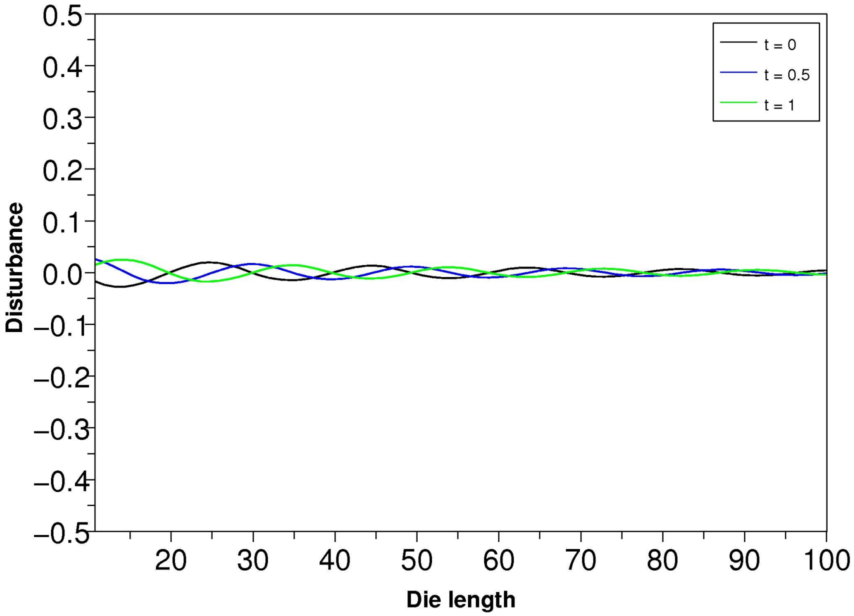
Entry section of the coat hanger die

- <u>Isothermal viscoelastic behaviour</u>

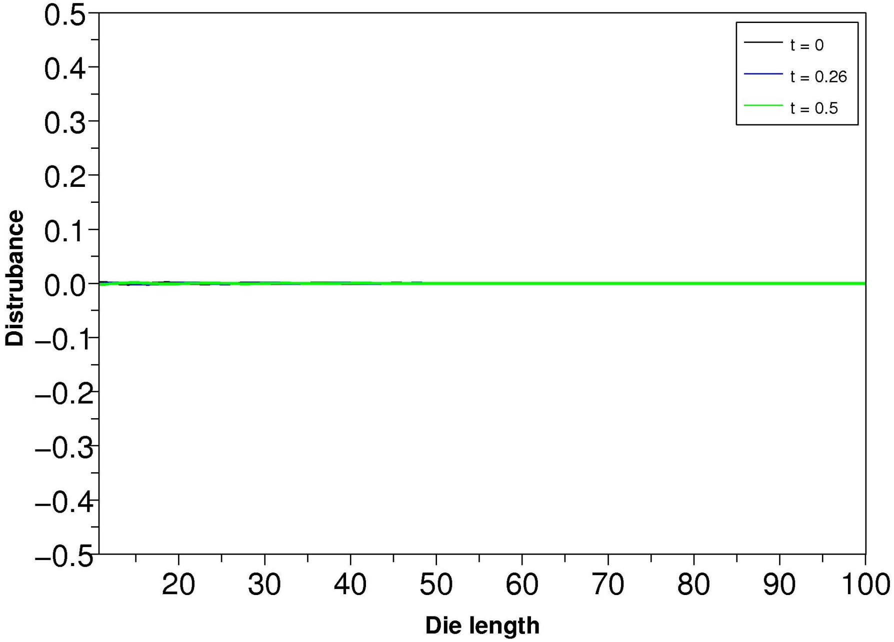


Newtonian (PET2)

Viscoelastic (PET1)



frequency forcing 0.5 Hz



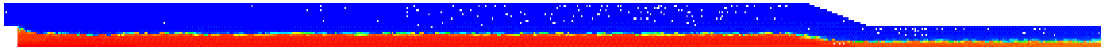
frequency forcing 1 Hz

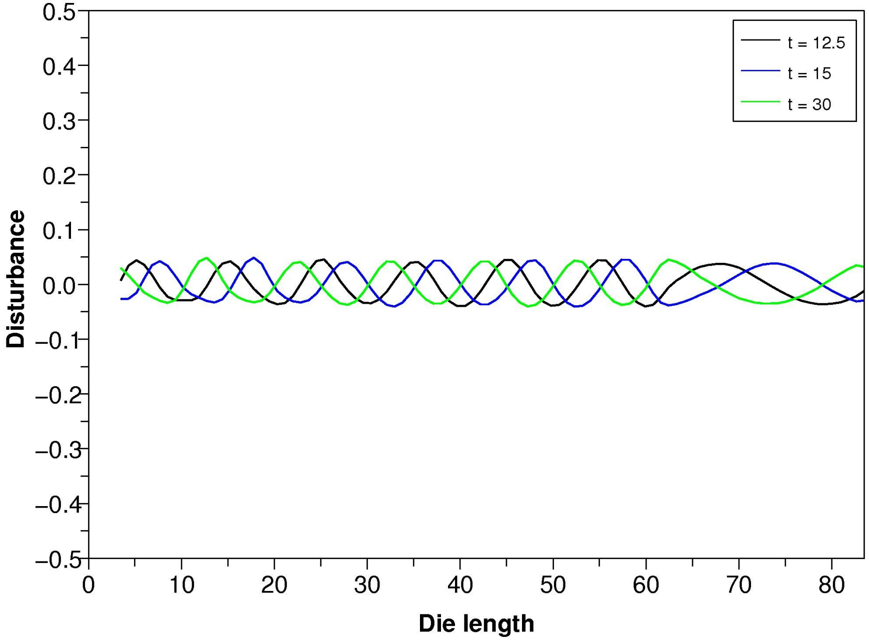
Case 5 (<u>stable</u> experimentally)

2D Dynamic stability analysis

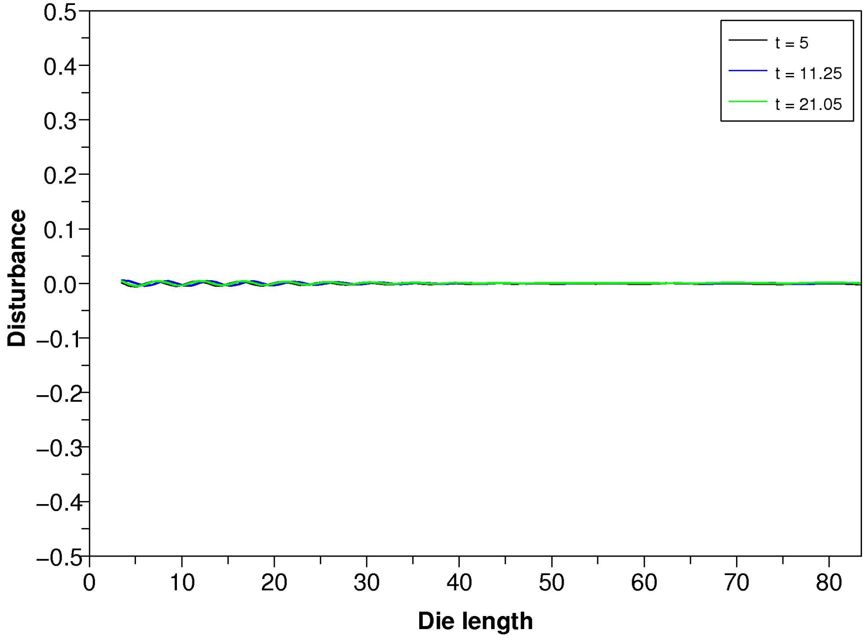
Exit section of the coat hanger die

- **Isothermal viscoelastic behaviour**





frequency forcing 0.5 Hz



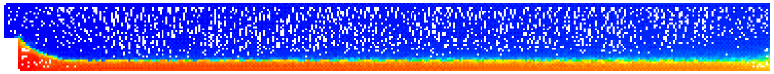
frequency forcing 1 Hz

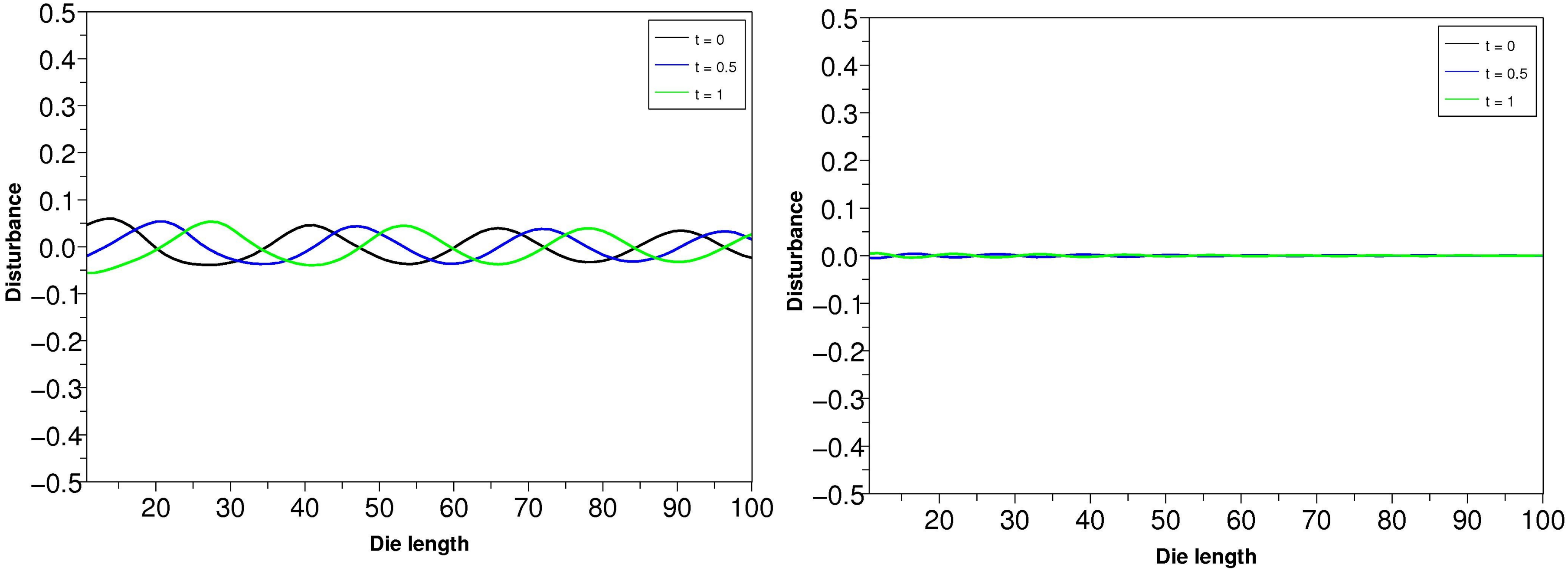
Case 5 (stable experimentally)

2D Dynamic stability analysis

Entry section of the coat hanger die

- **<u>Isothermal viscoelastic behaviour</u>**





frequency forcing **0.5 Hz**

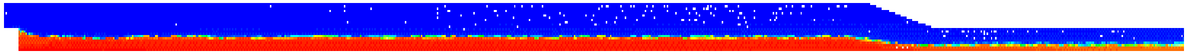
frequency forcing **1 Hz**

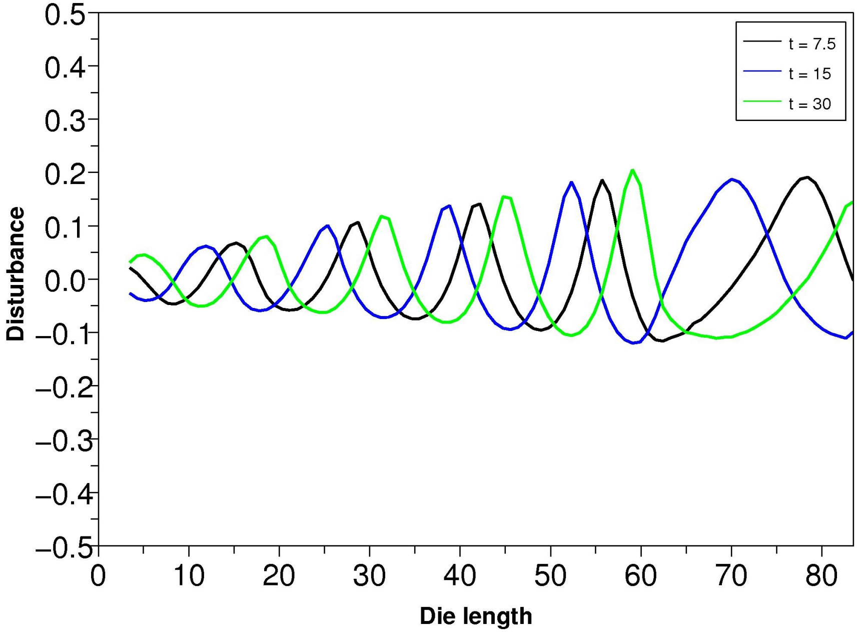
Case 6 (<u>unstable</u> experimentally)

2D Dynamic stability analysis

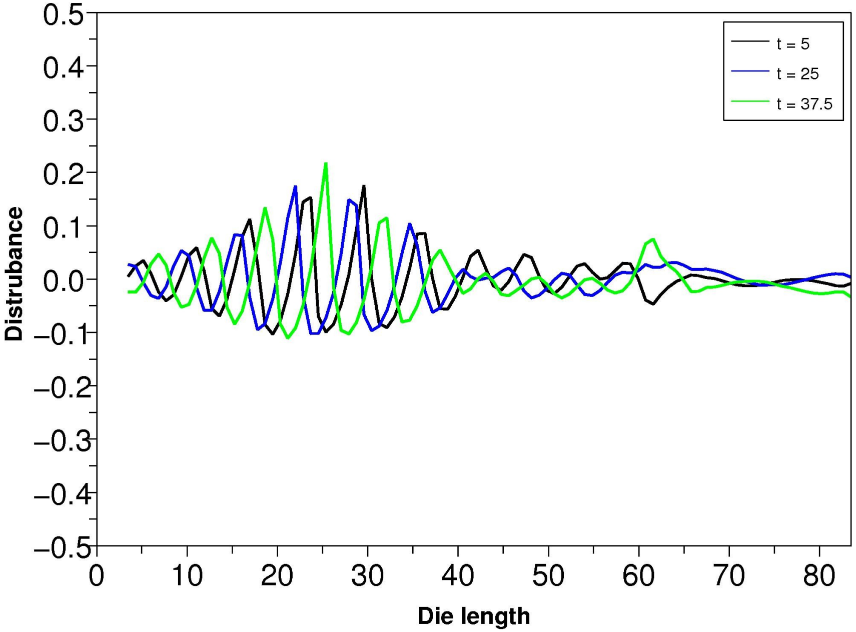
Exit section of the coat hanger die

- **Isothermal viscoelastic behaviour**





frequency forcing 0.5 Hz



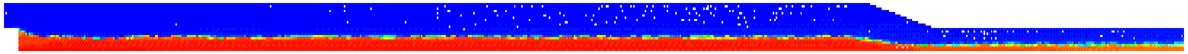
frequency forcing 1 Hz

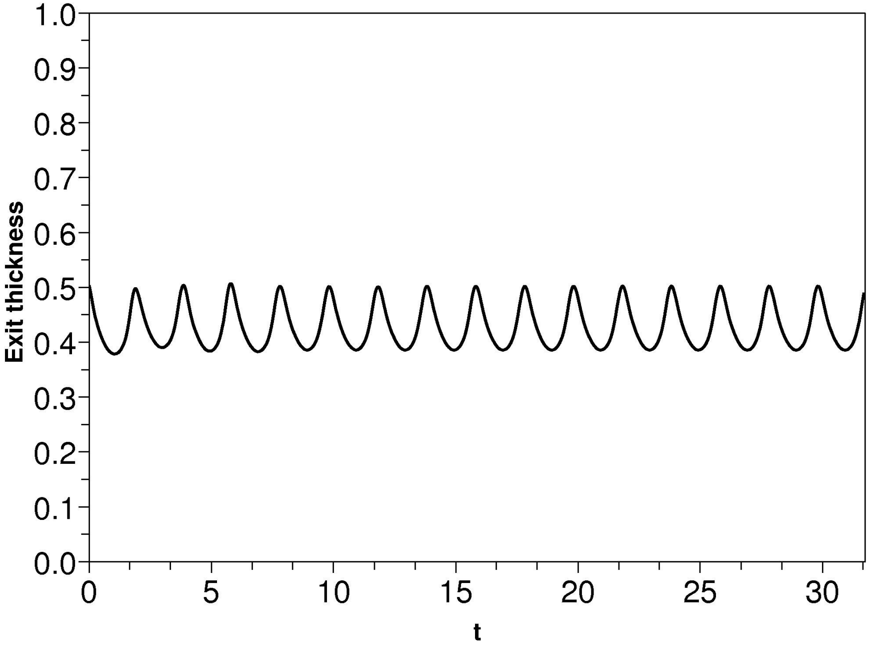
Case 6 (unstable experimentally)

2D Dynamic stability analysis

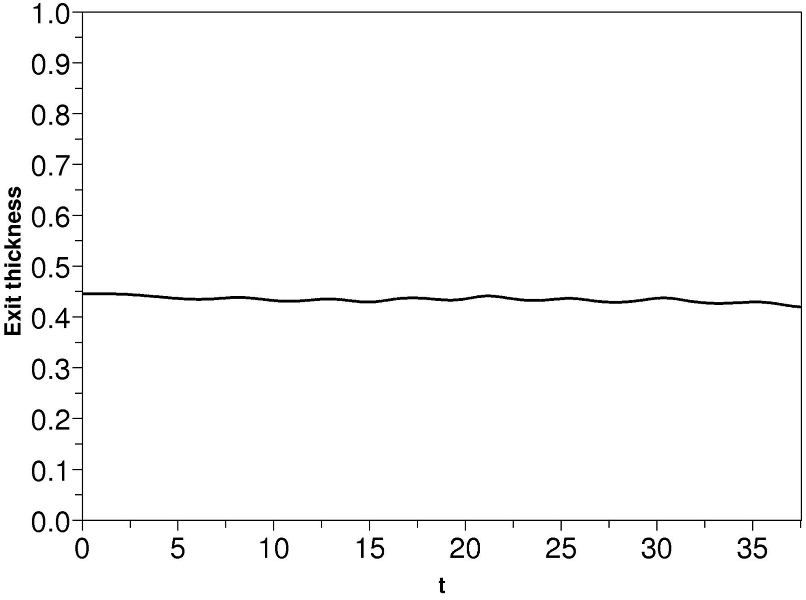
Exit section of the coat hanger die

- **Isothermal viscoelastic behaviour**





frequency forcing 0.5 Hz



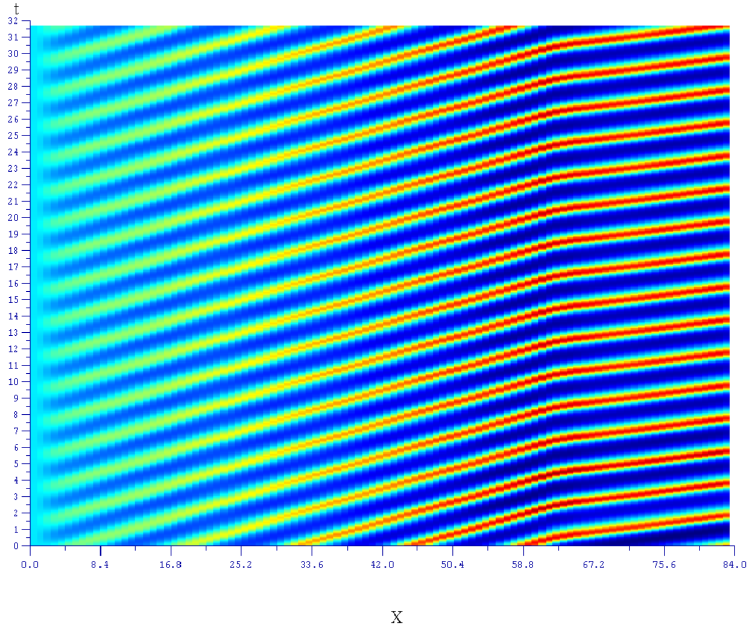
frequency forcing 1 Hz

Case 6 (unstable experimentally)

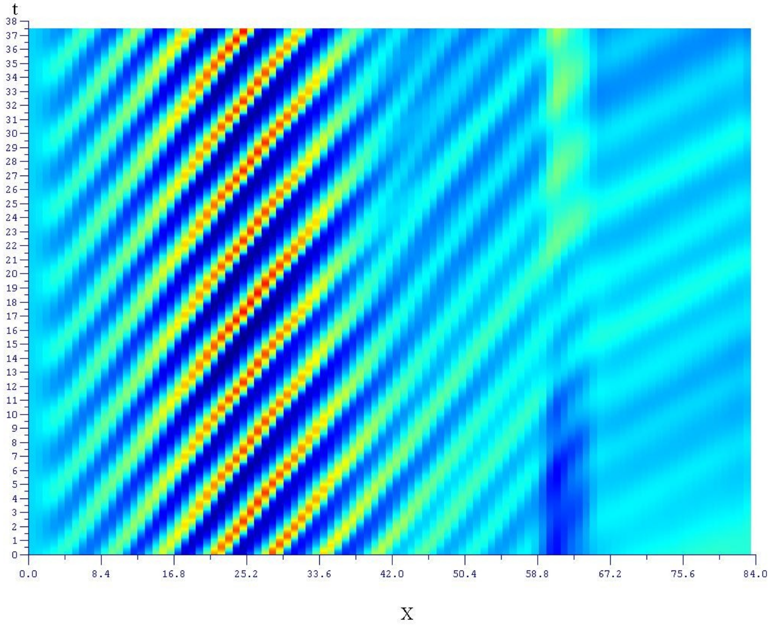
2D Dynamic stability analysis

Exit section of the coat hanger die

- **Isothermal viscoelastic behaviour**



frequency forcing 0.5 Hz



frequency forcing 1 Hz

Case 6 (unstable experimentally)

Comparison
numerical computations/experiments

				Zone A		Zone B	
cas	PET1 Vit. vis B25 (tr/min)	PET 2 Vit. vis B30 (tr/min)	note défaut /5	frequency 0.5 Hz	frequency 1 Hz	frequency 0.5 Hz	frequency 1 Hz
1	20	25	0	stable	stable	stable	
2	20	50	1	stable	stable	unstable	
3	20	90	2	stable	stable	unstable	unstable
4	50	25	0	unstable	stable	stable	stable
5	50	50	0	stable	stable	unstable	stable
6	50	90	1	stable	stable	unstable	unstable

Conclusion

- In the purely viscous case :
  - Reynolds number is the driving number but is very law
  - The amplitude of these waves always decreases along the die
- In the viscoelastic case:
  - Weissenberg number is the driving number: may be much more important than the Reynolds number
  - The amplitude of the progressive waves may increase towards the die exit
  - The agreement between dynamic computation and experiments is surprisingly good

Open questions

- 2 D coextrusion temperature dependant viscoelastic computation
- Why instabilities appear initially in the die center?

Spatial amplification rate of perturbation