THE ROLE OF RIGID PVC RHEOLOGY IN PIPE EXTRUSION

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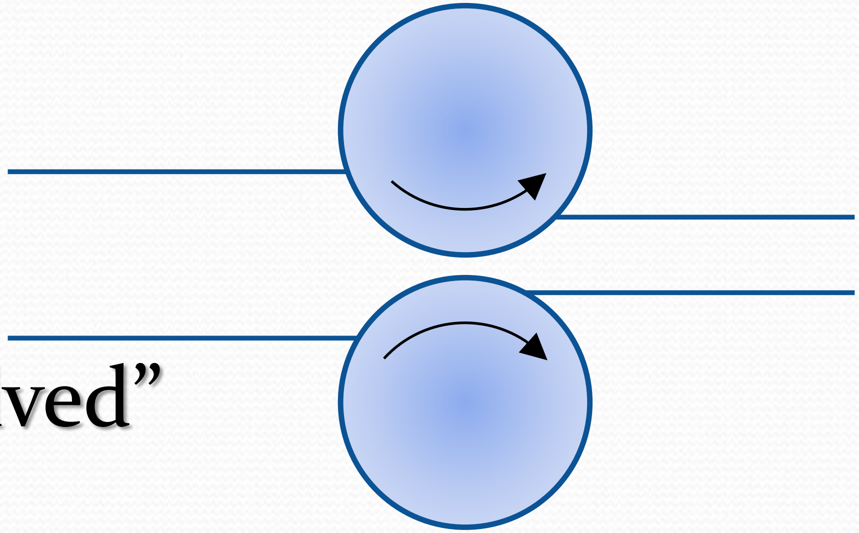
MONTREAL

Society of Rheology Meeting October 1973 MONTREAL

- During a “beer session” on problems of industrial rheology

Calendering
suggested as “unsolved”



- PVC is frequently calendered.

Jean C. Chauffoureaux
SOLVAY, Brussels, Belgium

J.C. Chauffoureaux et al.
"*Flow and Thermal Stability of Rigid PVC*"

- Presented at AIChE Meeting, New York (1977)
- Published J. Rheol. 23, 1-24 (1979)

- Wall slip by optical observations of tracers in a slit die.
- Slip velocity from smooth vs grooved dies.
- Effect of lubricants
- PVC thermal degradation

Jean Chauffoureaux provided me (~ 1978)

- Rheological data for rigid PVC and calendering data (pressure, torque)

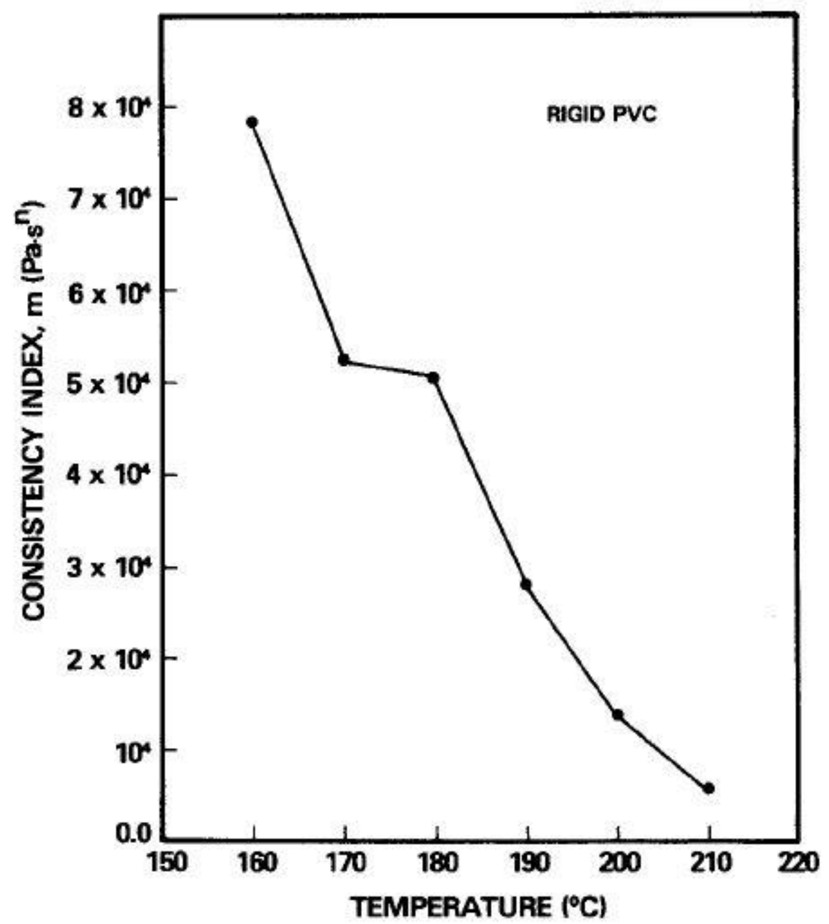
➢ viscosity $\eta = K(T)\dot{\gamma}^{n-1}$ (power-law)

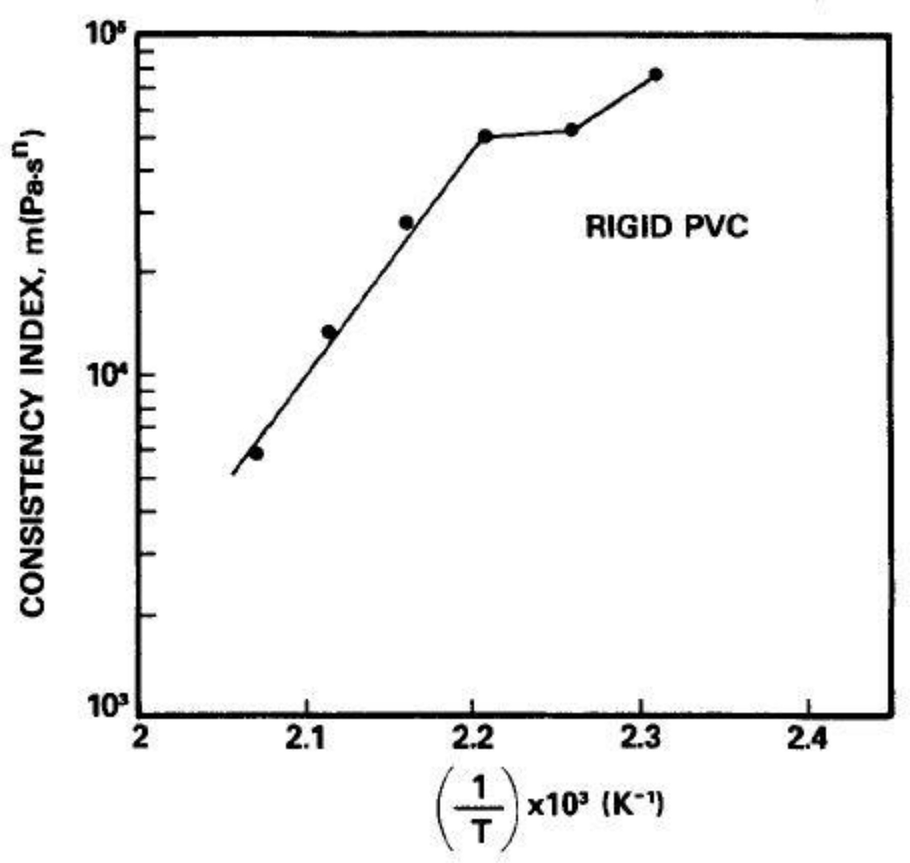
➢ Wall slip velocity $U_s = A\tau^b + c$

Predictions of <u>pressure</u> and <u>torque</u> compared well with lubrication flow analysis of calendering.

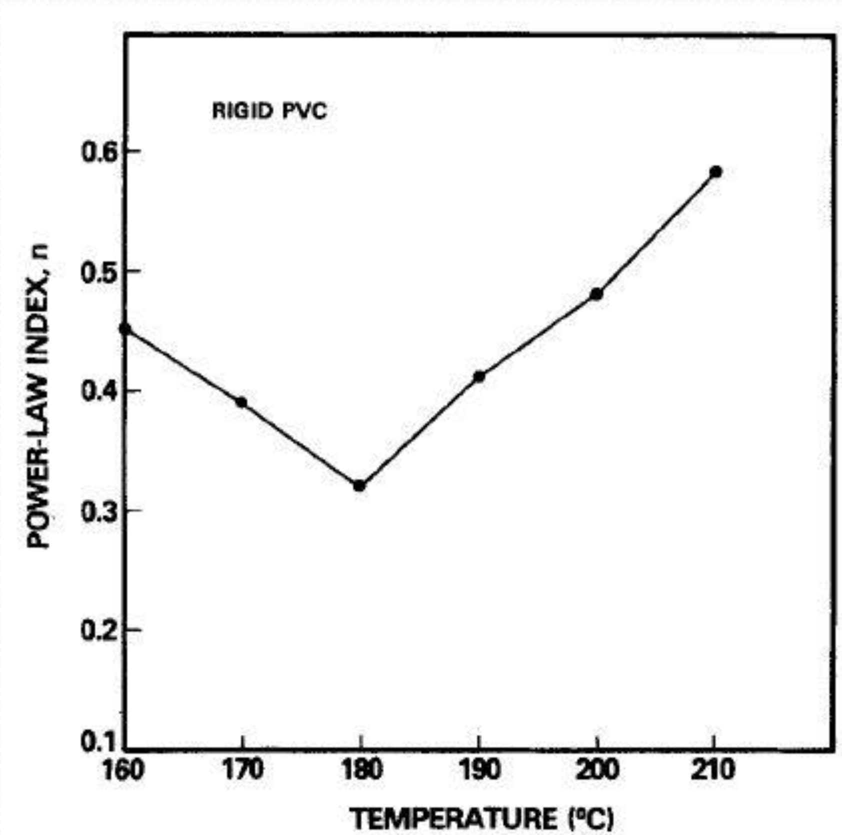
J. Vlachopoulos and A.N. Hrymak, Pol. Eng. Sci. <u>20</u>, 725-731 (1980).

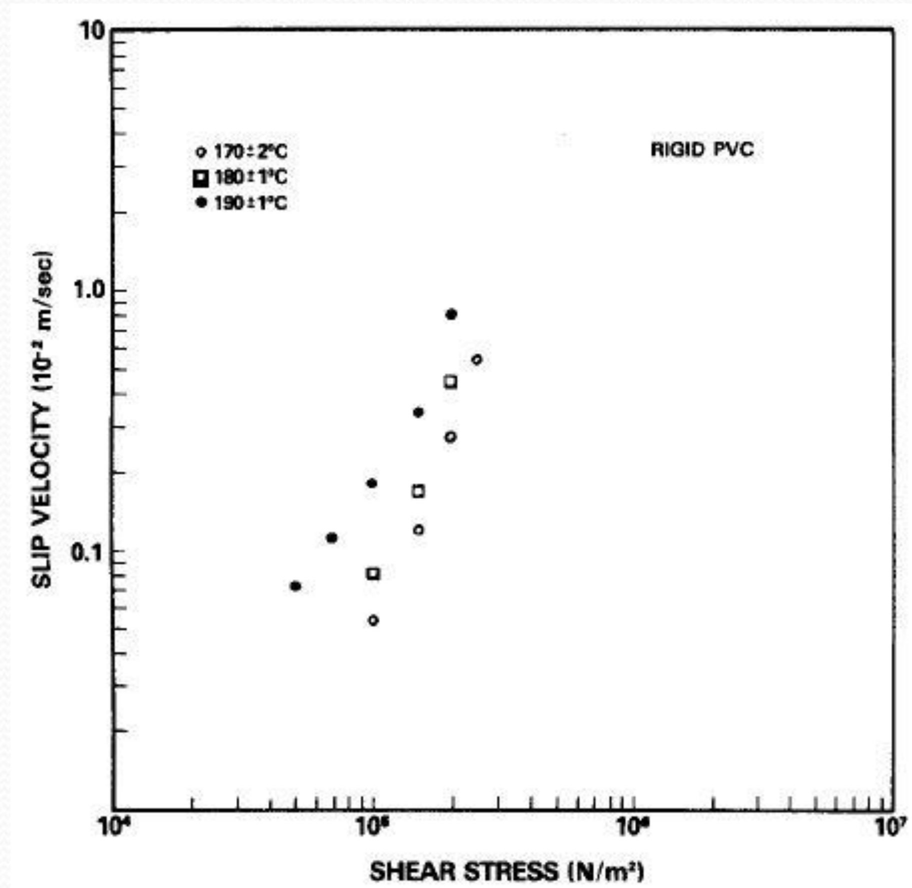
Consistency *K*(*T*) variation



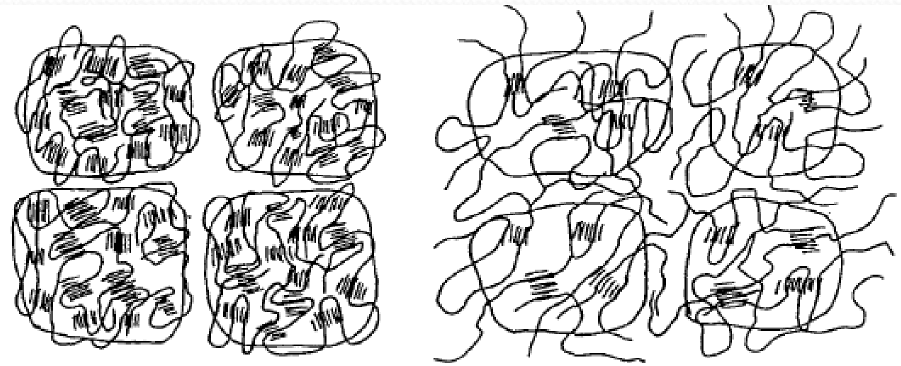


Power-Law exponent $n(T)$ and Wall Slip Velocity U_s variation





MODEL OF PVC FUSION
according to J. W. Summers
e.g. J. Vinyl Add. Techn., 3, 130-139 (1997)

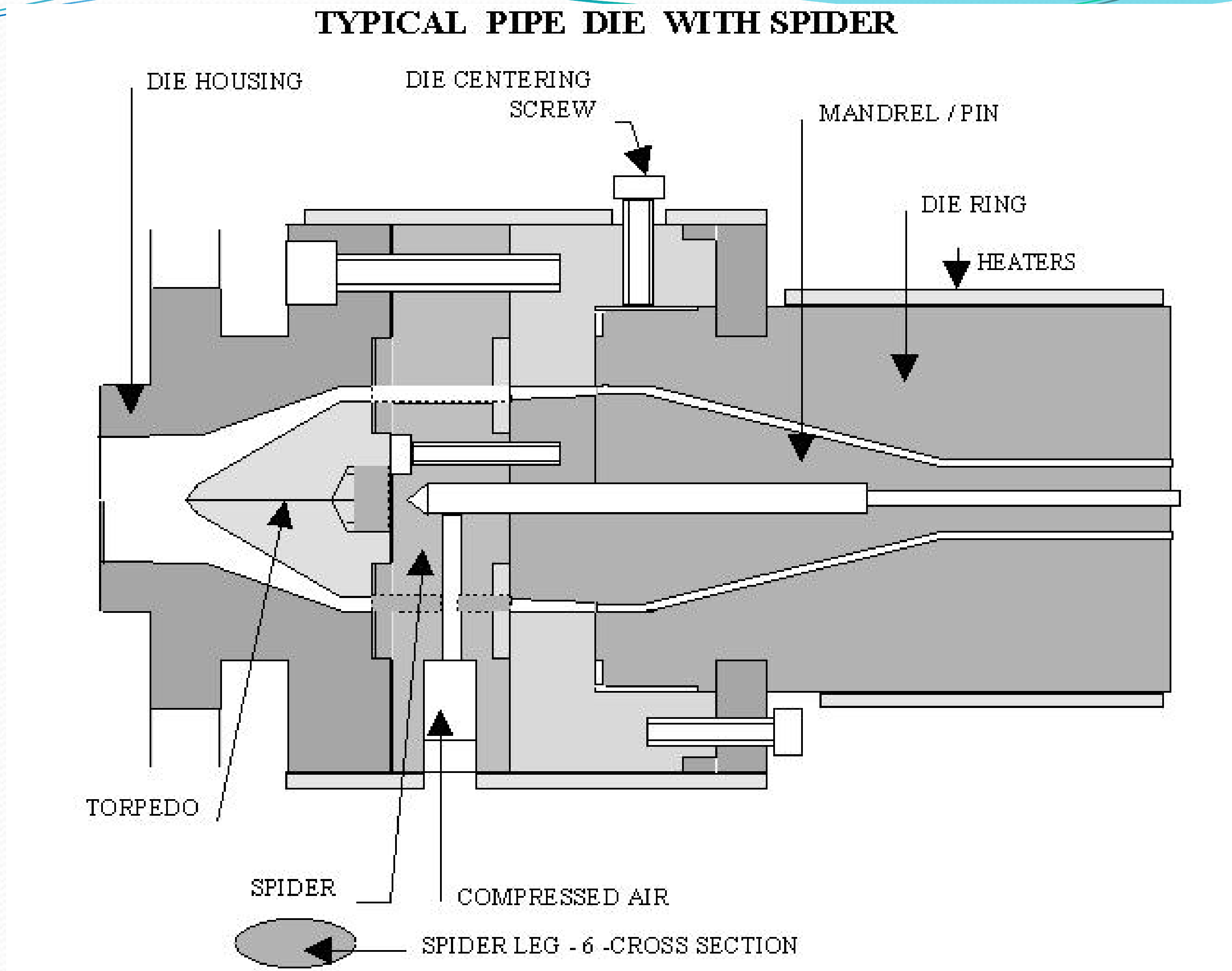


a) Unfused PVC primary particles.

b) Partially melted PVC primary particles.

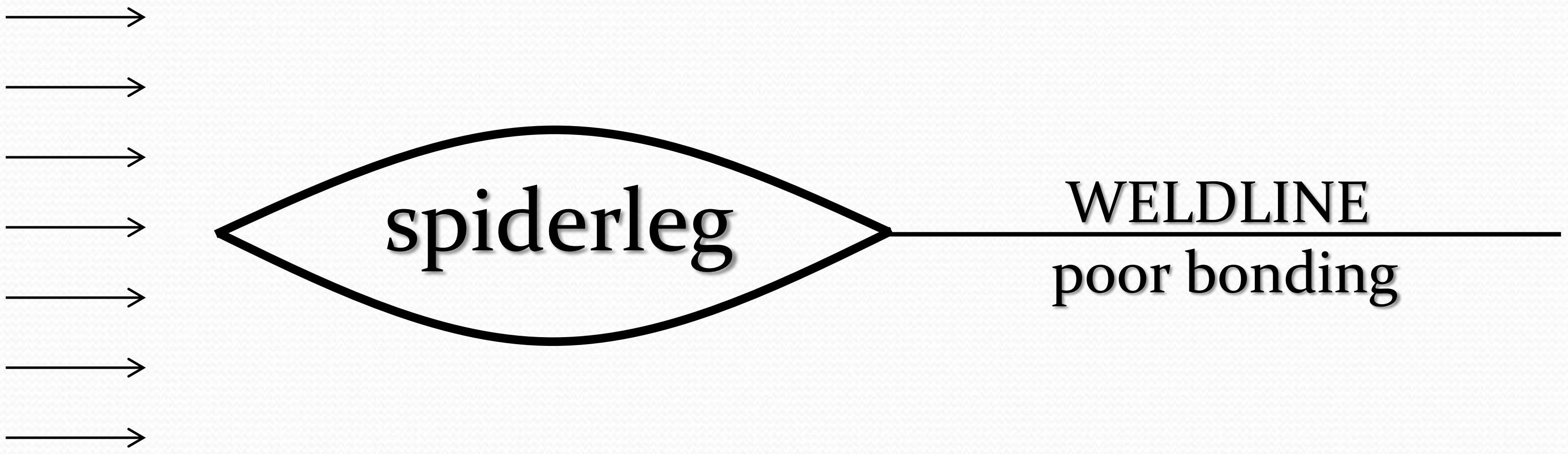
c) Partially melted then recrystallized high molecular weight PVC, showing strong three dimensional structure.

d) Partially melted then recrystallized low molecular weight PVC, showing weak three dimensional structure.



from www.pitfallsinmolding.com

WELDLINES



LINES OF REDUCED MECHANICAL PROPERTIES

Minimize WELDLINE problems:

1. Melt homogeneity
2. Higher temperature (limited for PVC, degradation)
3. Higher pressure (longer die, constriction)
4. Special spiderleg design

WELDLINES behind the spiderlegs are regions of reduced mechanical properties

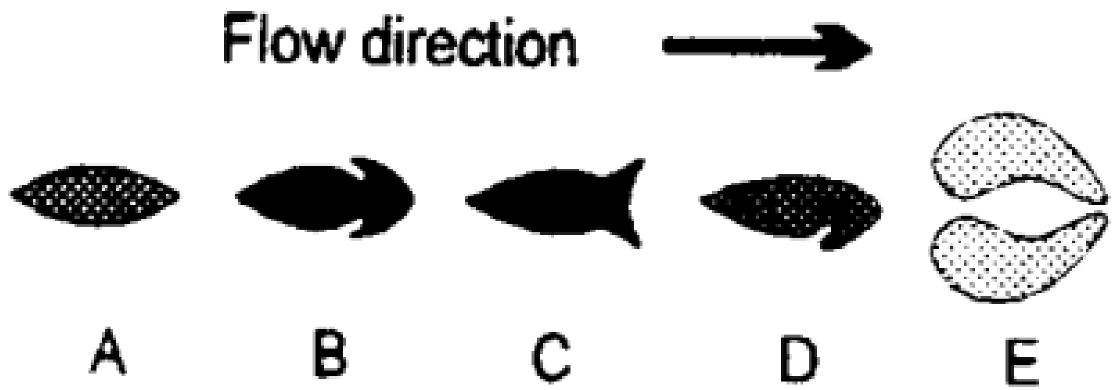


Fig. 2. Conventionally shaped spider A and new shapes of spiders B - E.

Y. Huang and P. Prentice, Pol. Eng. Sci., 38, 1506 (1998)

PROPRIETARY SPIDERLEG DESIGN

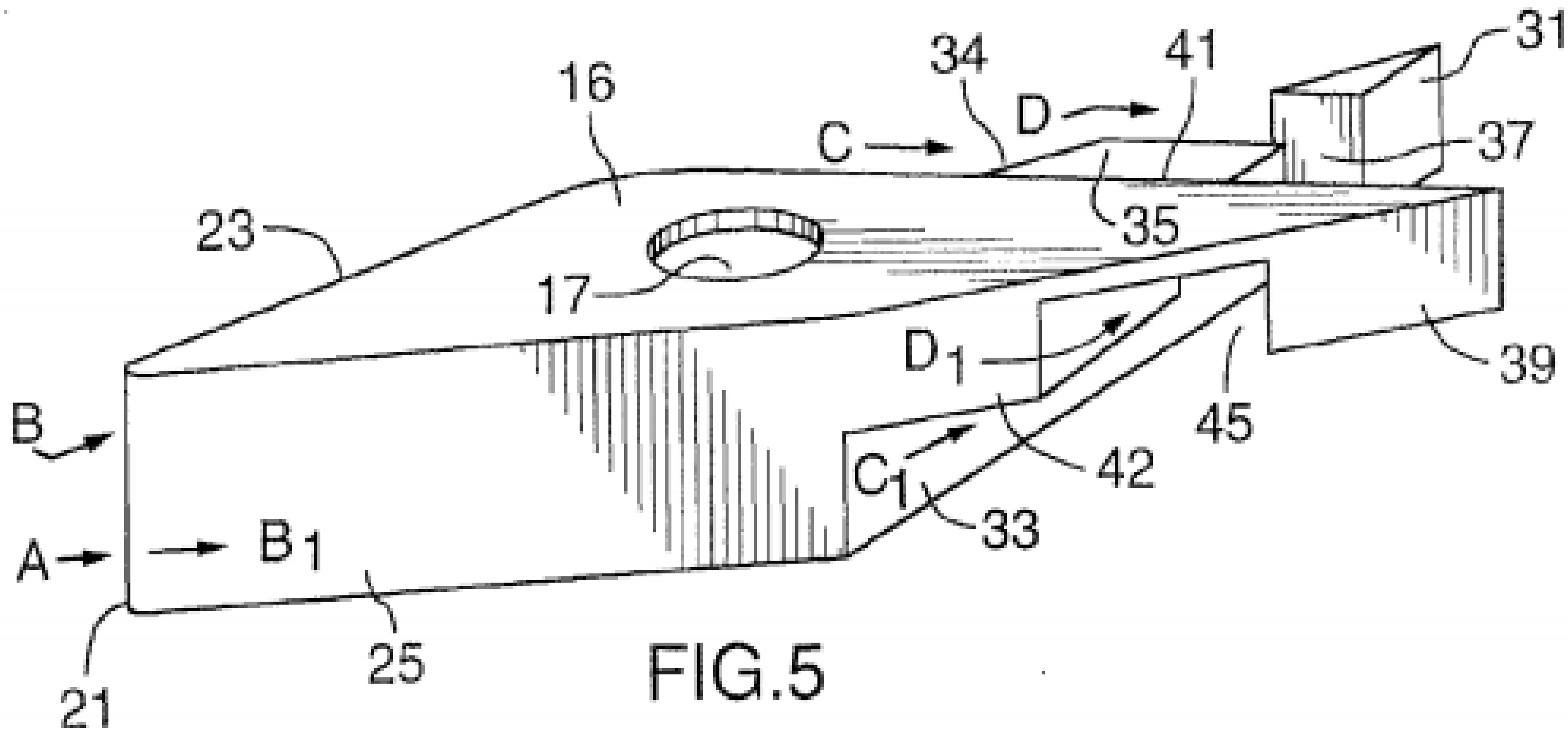
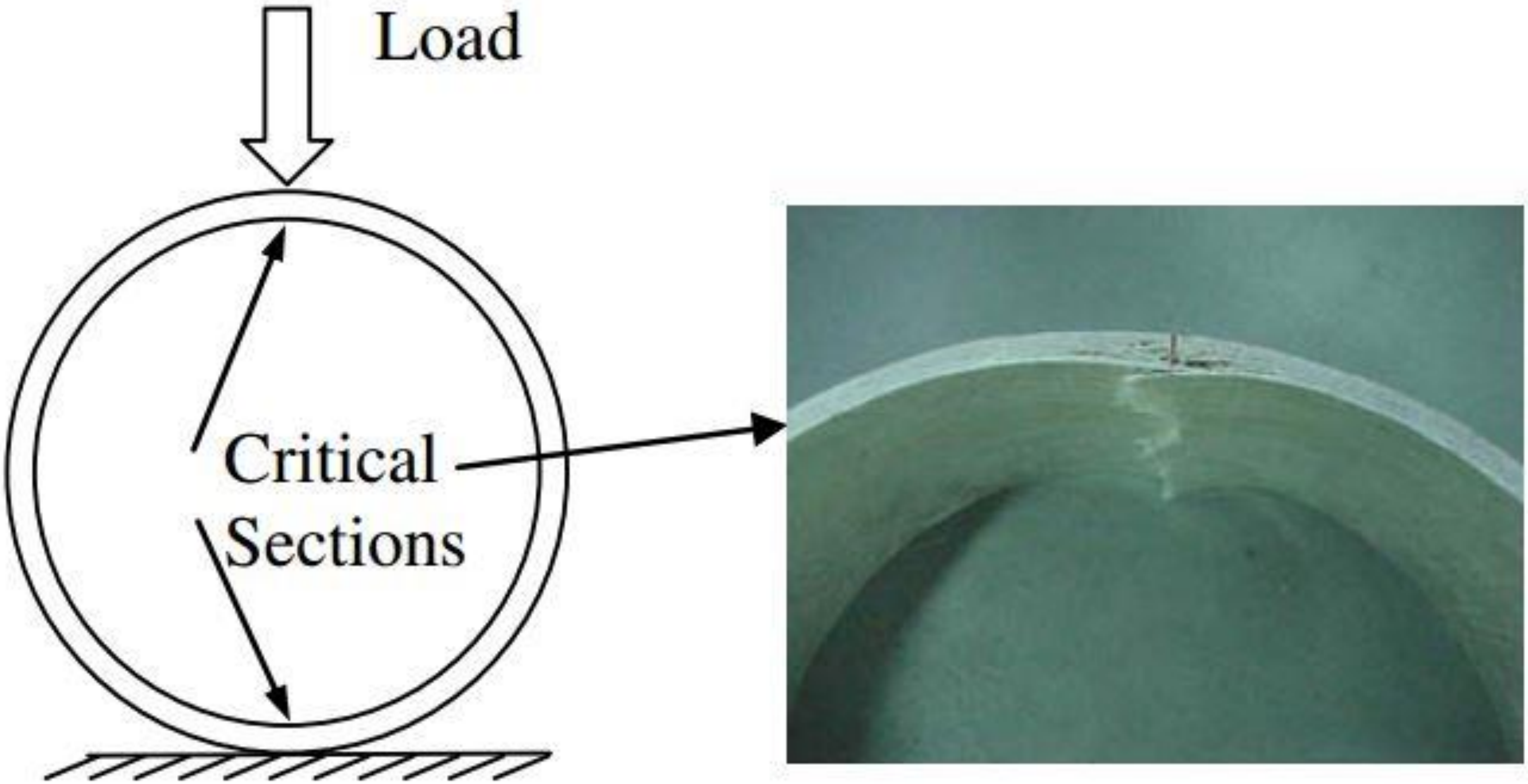


FIG.5

M.A.L. Lupke and S.A. Lupke, EP2311623 (2011)

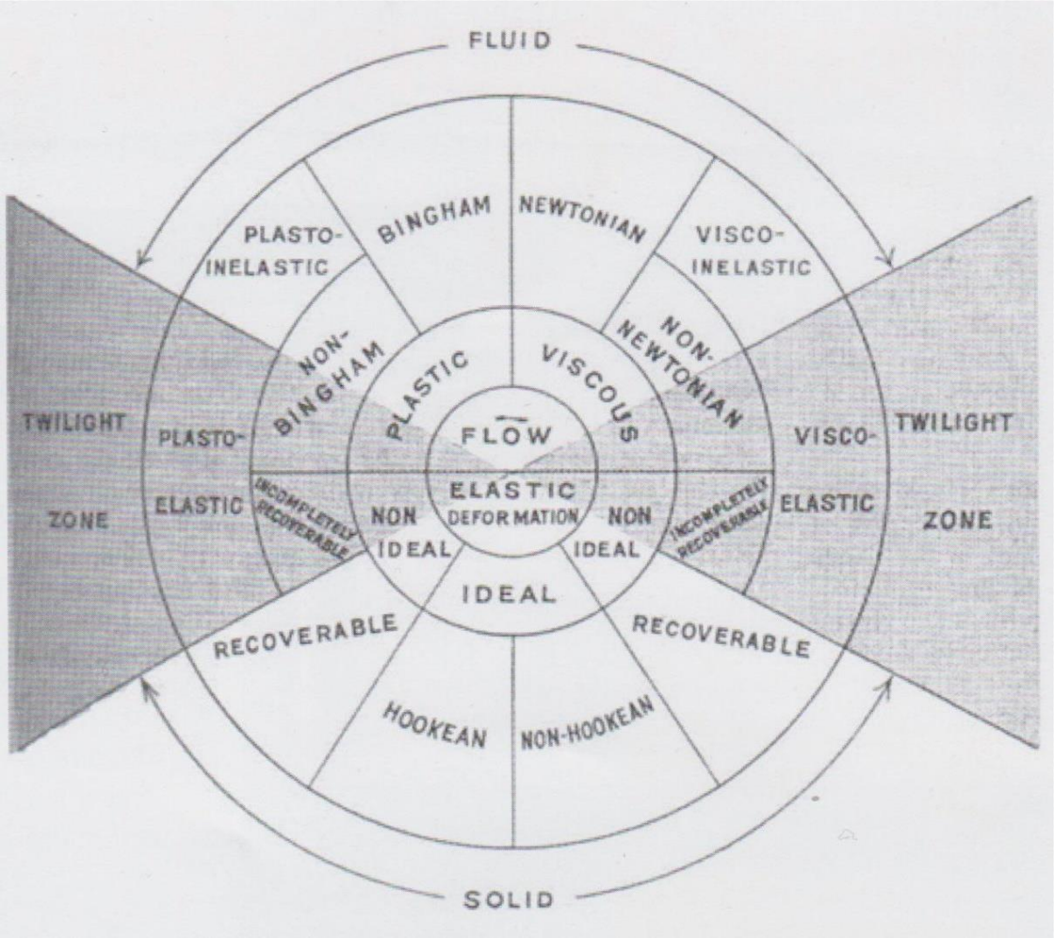
Customer wants:

- High output (meters/min)
- Minimum weight (kg/meter)
- Add more $CaCO_3$ filler (OMYA recommends up to 30 phr)
- Pipe must pass the parallel plate test



Picture from: R.M. Guedes, Comp. Struct., <u>88</u>, 188 (2008).

FLUID AND SOLID RHEOLOGY MUST BE CONSIDERED



L. BILMES "A Rheological Chart" Nature, 150, 432-433 (1942)

o**Einstein-Batchelor** (equation):

viscosity $\eta_c = \eta_p (1 + 2.5\phi + 6.25\phi^2)$

satisfactory approximation even at high loadings (ϕ volume fraction)

o**Krieger-Dougherty** model for fitting:

$$\eta/\eta_p = (\phi - \phi/\phi_m)^{\kappa\phi_m}$$

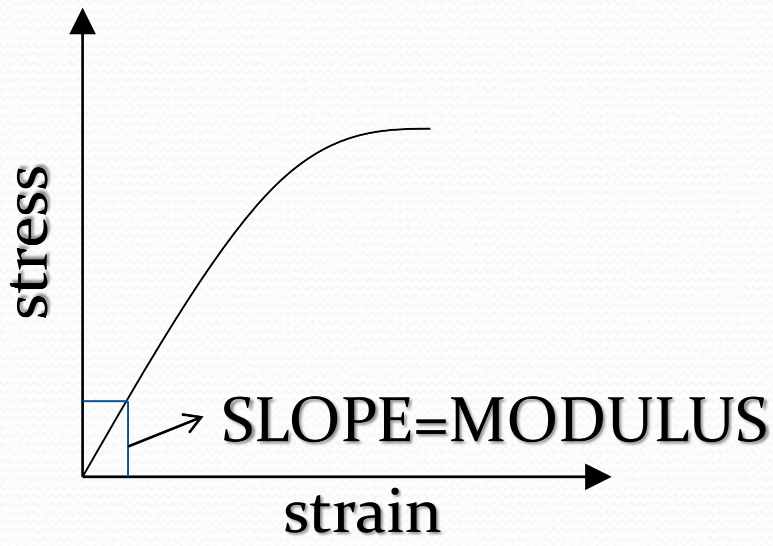
where ϕ_m : volume fraction at maximum packing

TENSILE TESTING

- **Einstein-Guth-Gold (Modulus):**

$$E_c = E_p(1 + 2.5\phi + 14.1\phi^2)$$

- **Failure strain:** $\varepsilon_c = \varepsilon_p(1 - 1.105\phi^{1/3})$



-As PVC is melting the microcrystallites fuse together forming some kind of a partially gelled mass. The degree of gelation (or fusion) is higher at higher temperatures. But, at high temperatures degradation will occur.

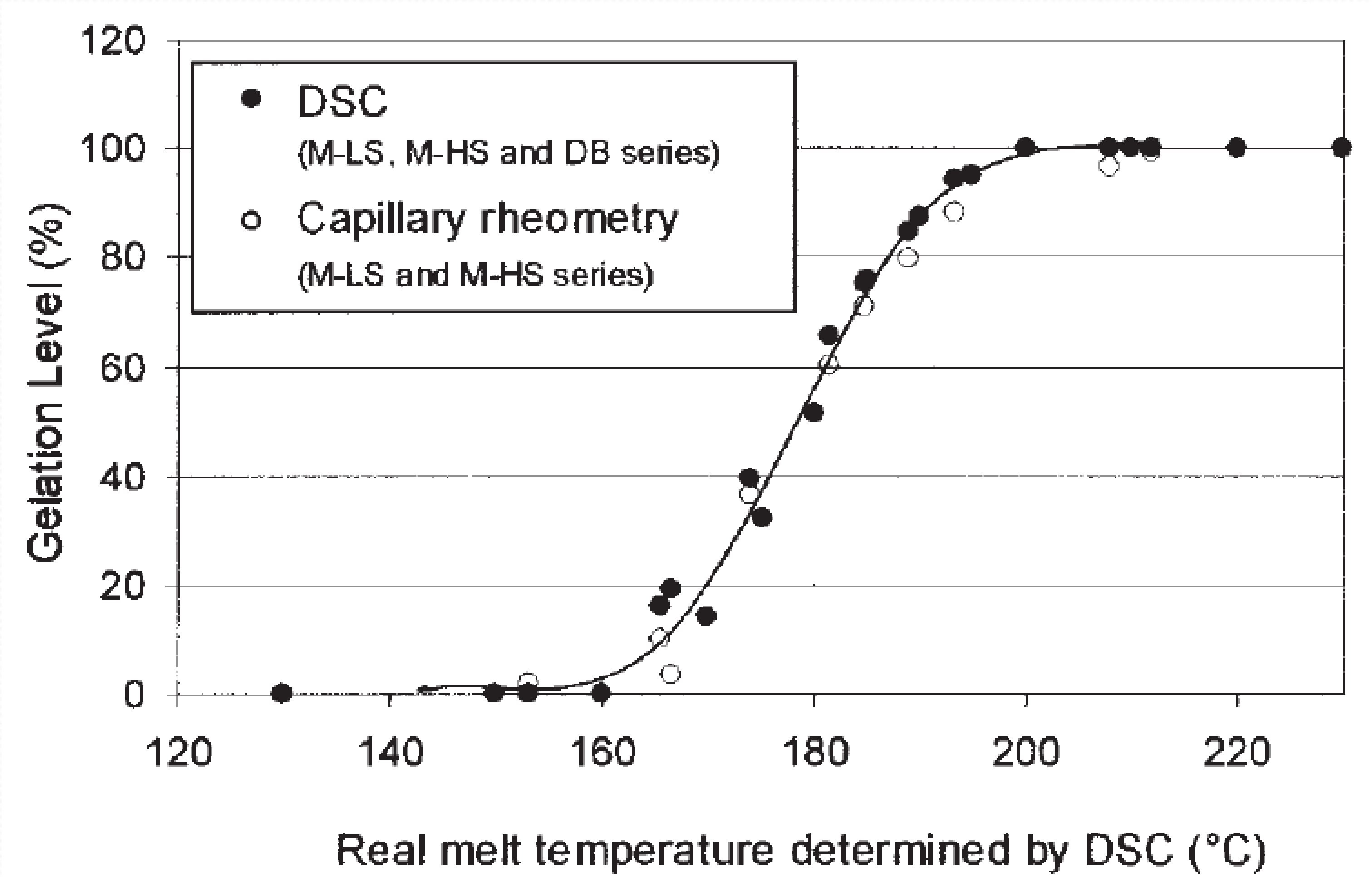
- TEMPERATURE WINDOW: 185^{o}C-205^{o}C.

-$CaCO_3$ influences viscosity, temperature (more viscous dissipation) and fusion.

Three methods for determination of degree of gelation:

- DSC
- Entrance pressure in a "zero" length capillary
- Torque rheometry

GELATION LEVEL DETERMINATION



L-A Fillot et al. J. Vinyl Add. Techn., 98-107 (2006)

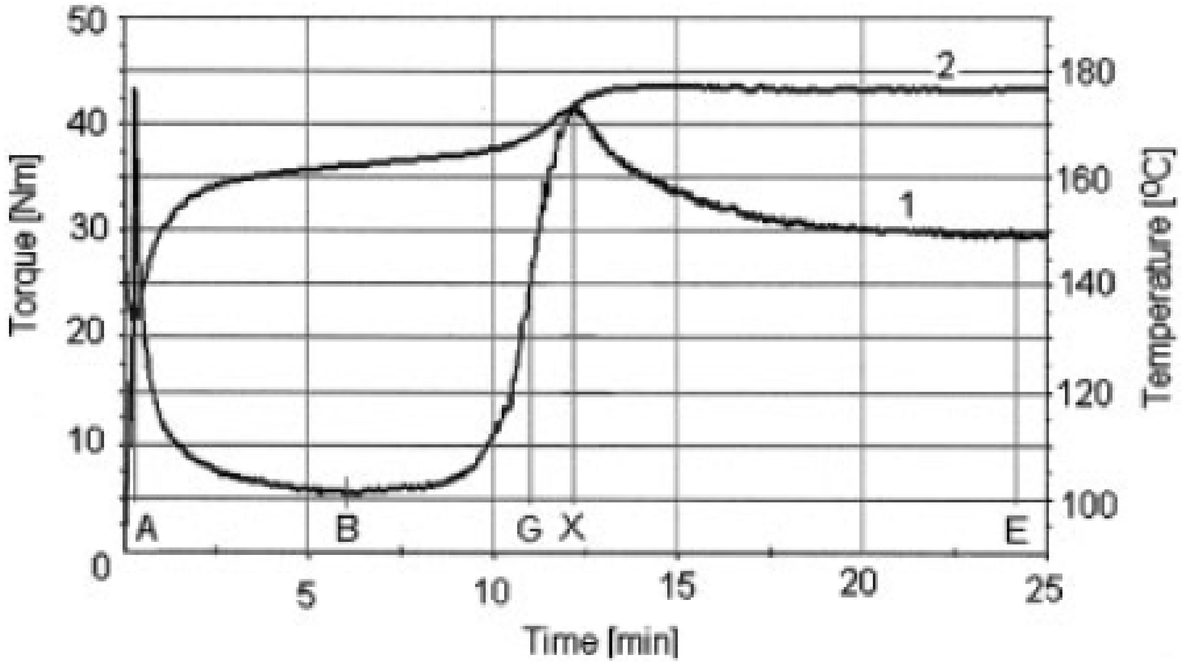


Figure 1 Typical torque rheometer process curve of rigid PVC: 1: torque at (A) the point of loading; (B) the minimum point; (G) the point of inflection; (X) the maximum point; (E) the end of the test (most often at the point of equilibrium); 2: temperature.

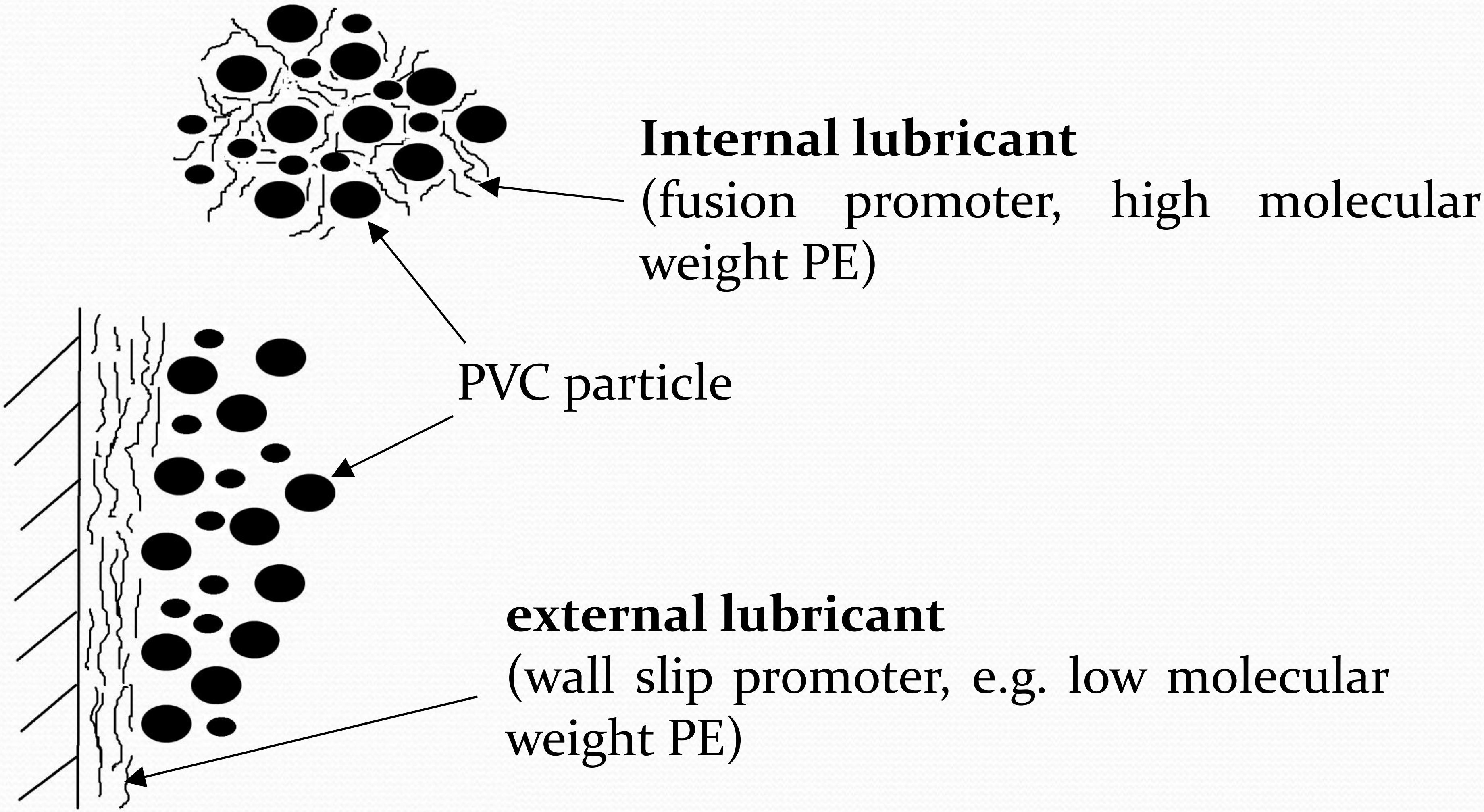
J. Tomaszewska et al., J. Appl. Pol. Sci., 106, 3158 (2007)

The importance of viscous dissipation (heating)

$$\Delta(T) \sim K(T)\dot{\gamma}^{n+1}$$

PVC must NOT BE UNDERFUSED
NOT BE OVERFUSED

Target ~ 195^{o}C



- Very strong rheology modification

Heracleitus (6th century BC)

“ΠΑΝΤΑ ΡΕΙ”
“EVERYTHING FLOWS”

J. R. Dorgan (SOR Montreal 2013)
(Colorado School of Mines)

“EVERYTHING SLIPS”

Translation “ΠΑΝΤΑ ΟΛΙΣΘΑΝΕΙ”

The verb ΟΛΙΣΘΑΝΕΙ appears in Cratylus dialogue by Plato (student of Heracleitus)

THANK YOU
Q & A

www.polydynamics.com