I FLUIDI

Affinché un fluido scorra è necessario fornirgli energia ininterrottamente.
La resistenza di un fluido alla variazione irreversibile di posizione dei suoi elementi di volume si chiama *VISCOSITA'*.

LEGGE del fluido ideale (newtoniano)

$$\tau = \eta \dot{\gamma}$$

dove: τ = sforzo di taglio

η = viscosità

$\dot{\gamma}$= gradiente di velocità

Curve di flusso e di viscosita'

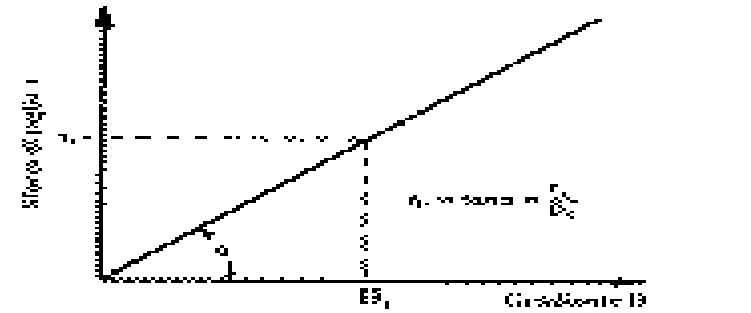


Fig. 3 Curva di flusso di un liquido newtoniano

TABLE 2.3.1 / The Viscosity of Some Familiar Materials at Room Temperature

Liquid	*Approximate Viscosity (Pa·s)*
Glass	10^{40}
Molten glass (500°C)	10^{12}
Asphalt	10^{8}
Molten polymers	10^{3}
Heavy syrup	10^{2}
Honey	10^{1}
Glycerin	10^{0}
Olive oil	10^{-1}
Light oil	10^{-2}
Water	10^{-3}
Air	10^{-5}

Adapted from Barnes et al. (1989).

Si dice curva di flusso un grafico dello sforzo di taglio in funzione del gradiente di velocità.

Nella curva di viscosità viene invece diagrammata η in funzione del gradiente di velocità

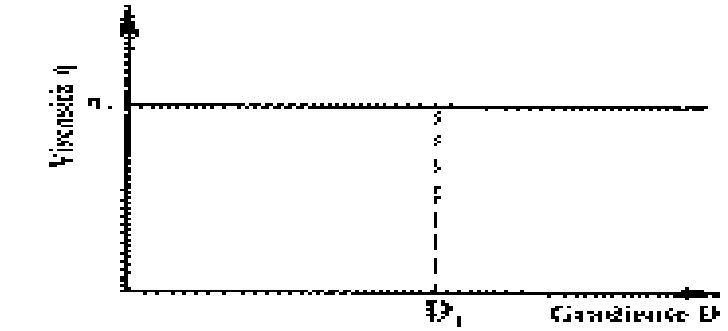
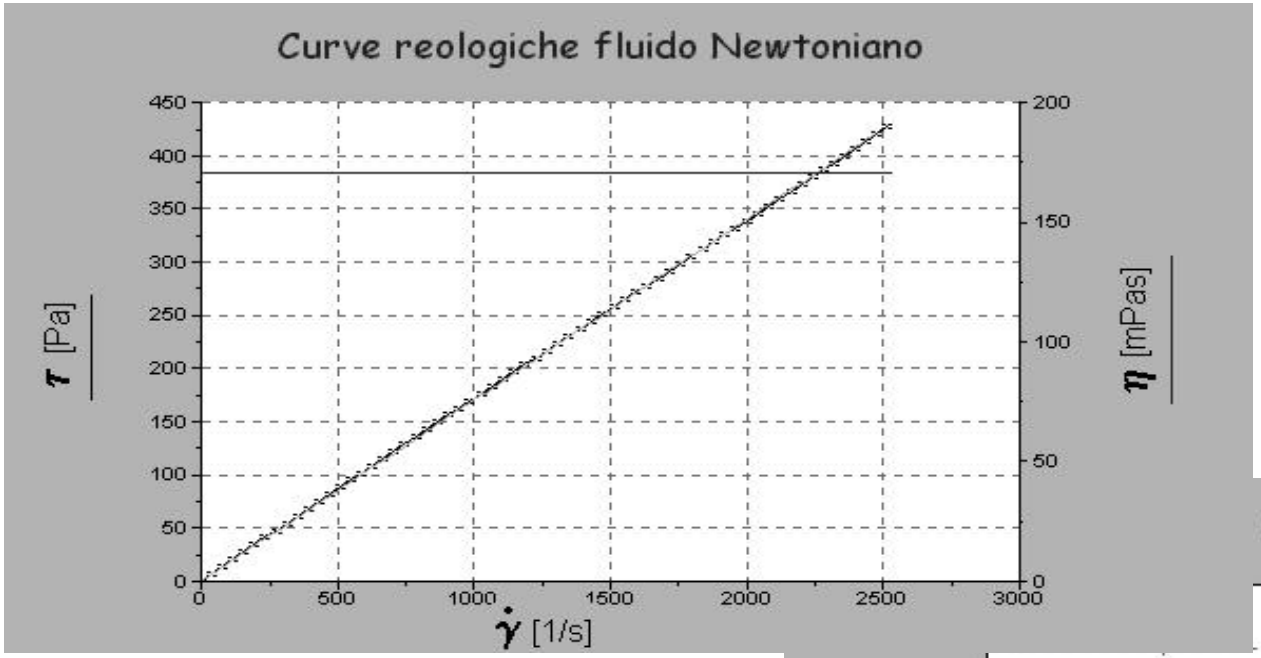
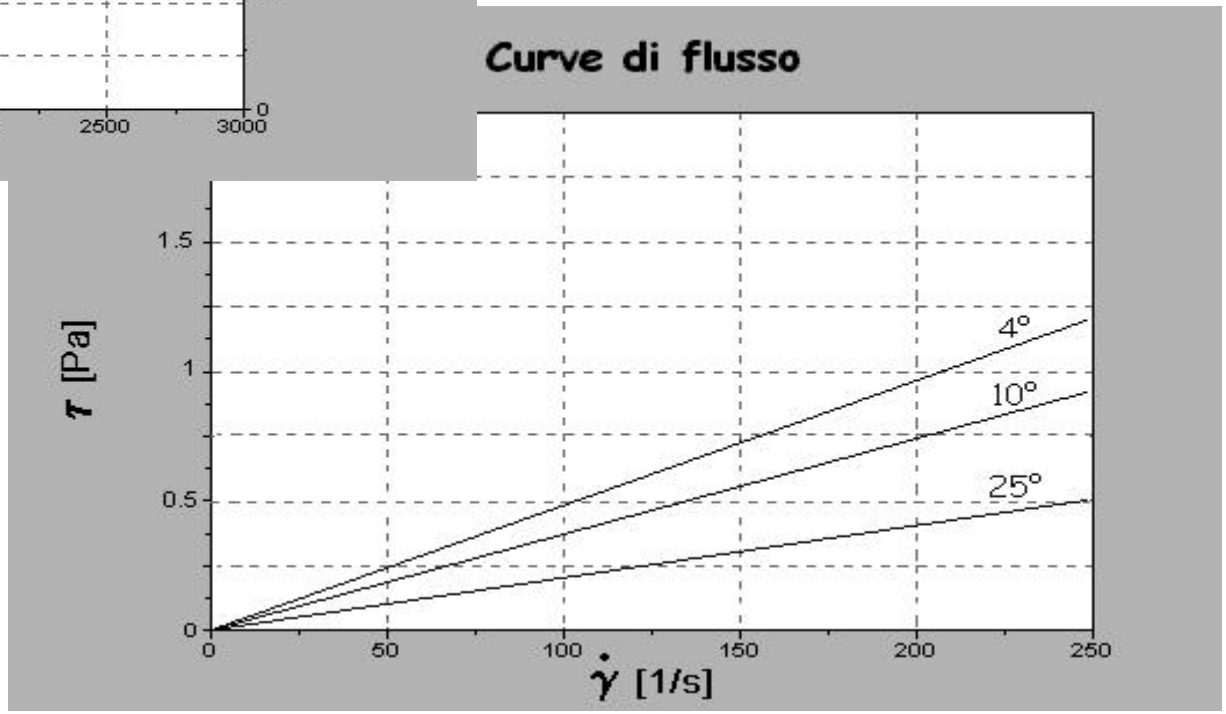


Fig. 4 curva di viscosità di un liquido newtoniano

Sostanze: curve di flusso e di viscosita'





Sostanza: Latte intero UHT
Temperatura: 4, 10, 25 °C

Viscosita'

TABLE 2.3.2 / Shear Rates Typical of Some Familiar Materials and Processes

Process	*Typical Range of Shear Rates (s^{-1})*	*Application*
Sedimentation of fine powders in a suspending liquid	$10^{-6} - 10^{-4}$	Medicines, paints
Leveling due to surface tension	$10^{-2} - 10^{-1}$	Paints, printing inks
Draining under gravity	$10^{-1} - 10^{1}$	Painting and coating; emptying tanks
Screw extruders	$10^{0} - 10^{2}$	Polymer melts, dough
Chewing and swallowing	$10^{1} - 10^{2}$	Foods
Dip coating	$10^{1} - 10^{2}$	Paints, confectionery
Mixing and stirring	$10^{1} - 10^{3}$	Manufacturing liquids
Pipe flow	$10^{0} - 10^{3}$	Pumping, blood flow
Spraying and brushing	$10^{3} - 10^{4}$	Spray-drying, painting, fuel atomization
Rubbing	$10^{4} - 10^{5}$	Application of creams and lotions to the skin
Injection mold gate	$10^{4} - 10^{5}$	Polymer melts
Milling pigments in fluid bases	$10^{3} - 10^{5}$	Paints, printing inks
Blade coating	$10^{5} - 10^{6}$	Paper
Lubrication	$10^{3} - 10^{7}$	Gasoline engines

Adapted from Barnes et al. (1989).

Variabili che influenzano la viscosita'

Struttura chimica

la viscosità dipende principalmente dalla natura chimica del fluido (acqua, petrolio, miele, ecc.)

Temperatura

la viscosità varia fortemente con la temperatura

Pressione

un aumento di pressione aumenta in generale la resistenza allo scorrimento viscoso (ad altissime pressioni)

Gradiente

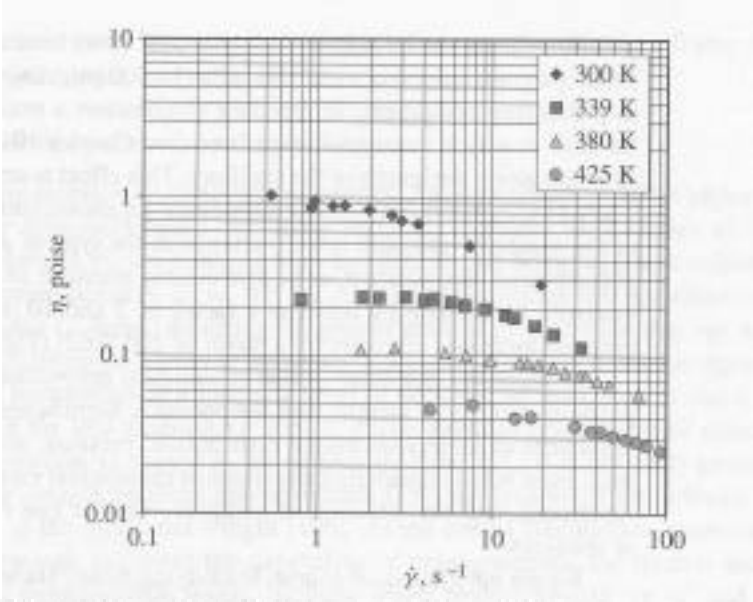
influenza la viscosità nei fluidi non newtoniani

Tempo

per alcune sostanze la viscosità dipende dalla "storia reologica" precedente, cioè dal tempo trascorso in condizioni di sollecitazione prima della misura

Effetti di temperatura e pressione

η e' una funzione forte della temperatura



Viscosity versus shear rate at four different temperatures for a polybutadiene melt. $M_w = 145$ kg/mol, $M_w/M_n = 1.1$

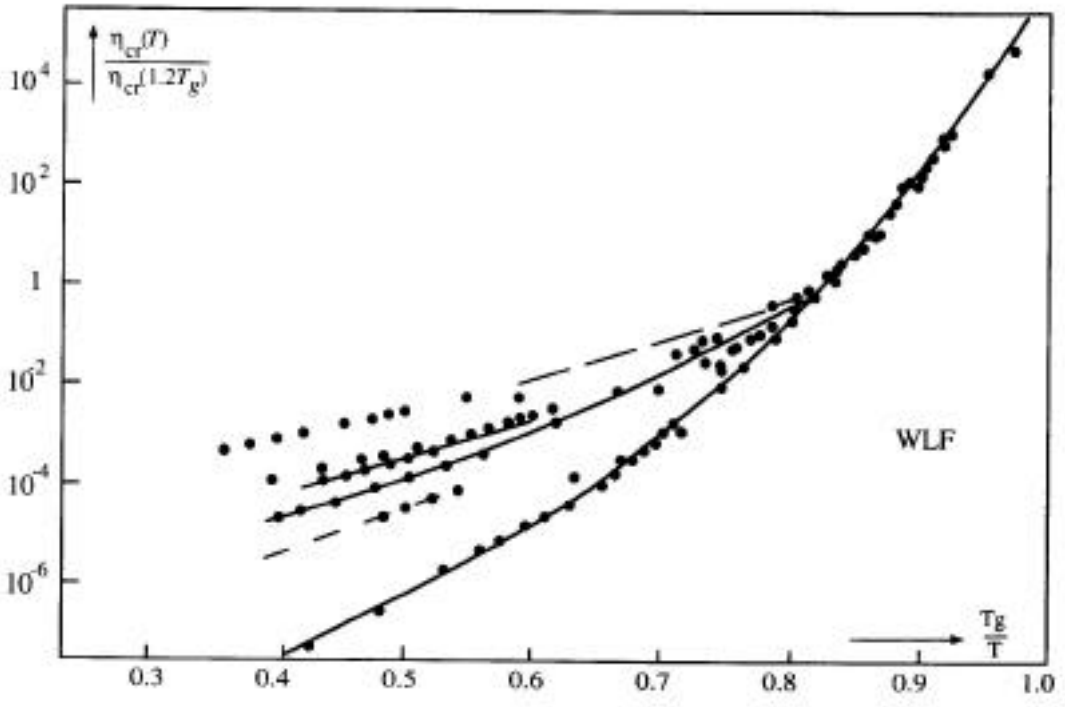


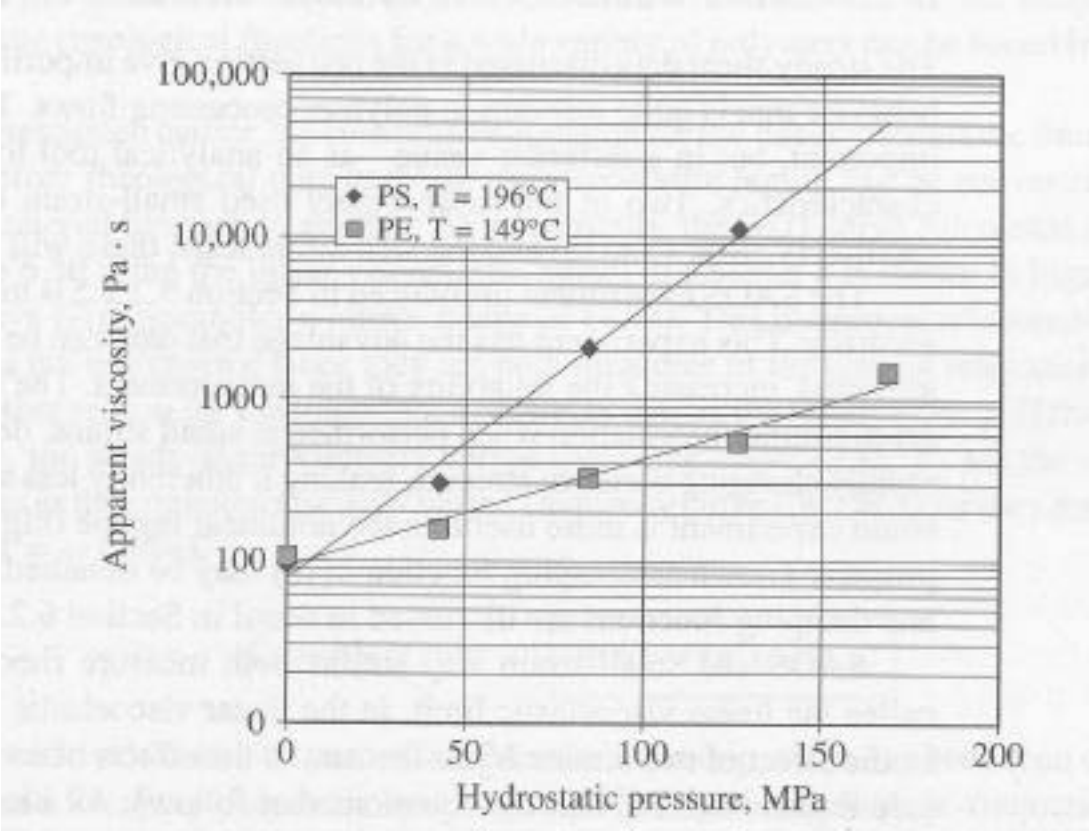
Figure 11.6.1. η_{cr} is zero shear viscosity at break point in Figure 11.4.2. Note the transition to exponential T dependence far from $T_g[T_g/T \cong 0.85]$. Adopted from Van Krevelen (1990).

Per molti liquidi, inclusi i polimeri , alle alte T $\eta = \eta_\infty \exp\left[\frac{E_\eta}{RT}\right]$

Nello stato sottoraffreddato tipicamente per $T < T_g+100$ $\log \frac{\eta T_r \rho_r}{\eta_r T \rho} = \frac{-C_1(T - T_r)}{C_2 + T - T_r} = \log a_T$

Effetti di temperatura e pressione

η aumenta con P a causa della aumentata forza frizionale tra molecole



Si ha $\eta_0 = K e^{aP}$

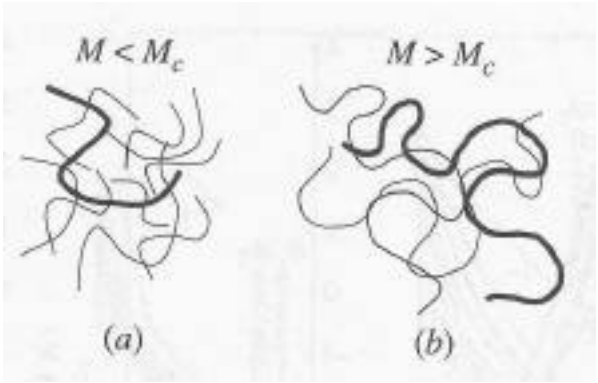
Figure 6.29 Apparent viscosity of polystyrene and branched polyethylene as a function of pressure; replotted from Maxwell and Jung [172]. Use of the term "apparent viscosity" reflects that the Rabinowitsch correction has not been applied; see Chapter 10. *Source:* Reprinted from *Modern Plastics*, March, 1957, pp. 174–182, 276, a publication of the McGraw-Hill Companies, Inc.

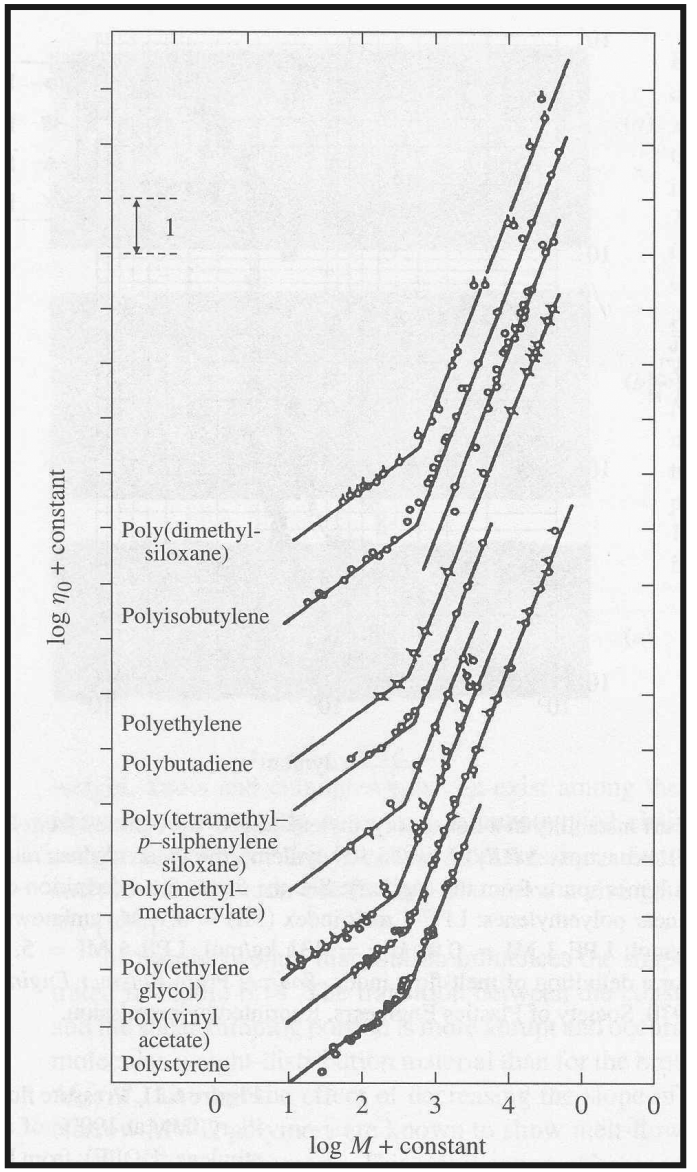
Effetti peso molecolare

Oltre la composizione chimica le proprieta' piu' significative che influenzano la reologia sono, nei polimeri, il ***peso molecolare*** e la ***distribuzione di pesi molecolari***

η, effetti del peso molecolare

Esistenza di due regimi →
evidenza della presenza di entanglements



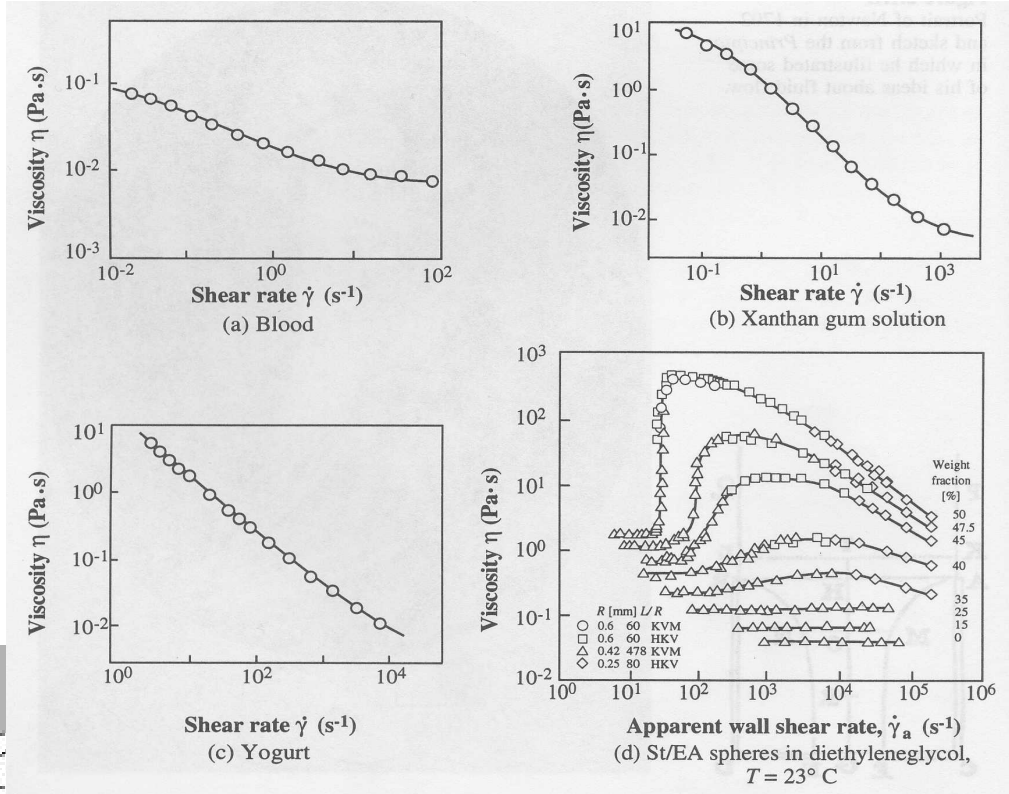


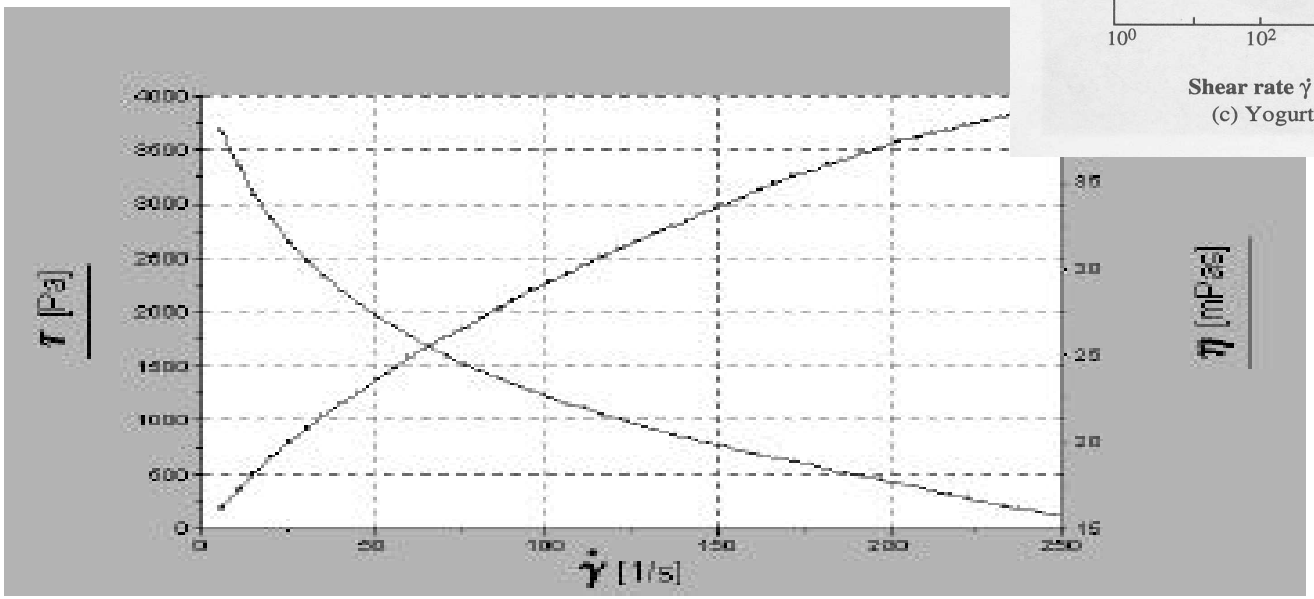
Effetti del gradiente di velocita': non newtonianita'

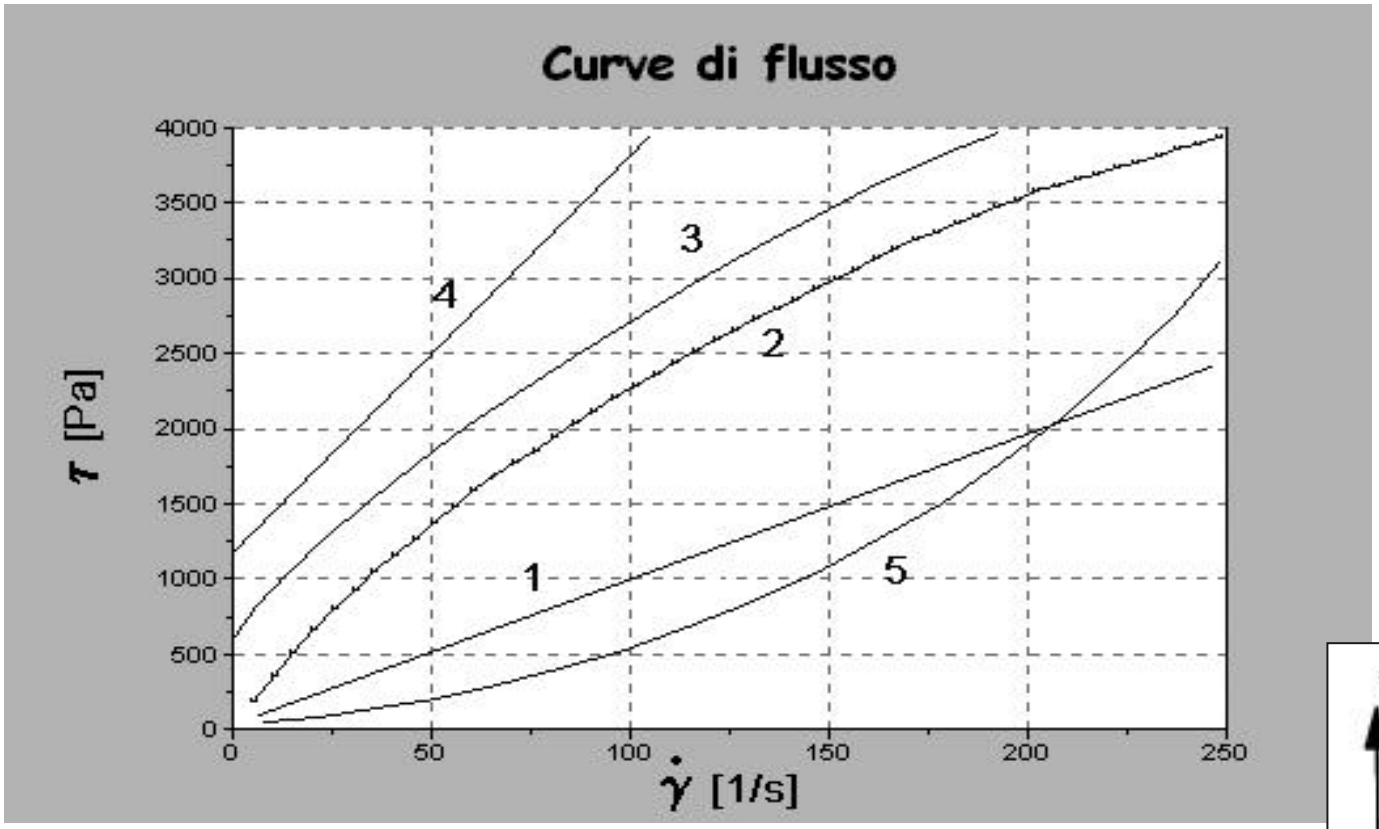
La viscosita' di stato stazionario η e'
una delle funzioni materiali piu' usate

Una viscosita' non costante vs la velocita'
deformazione
presenza di non-newtonianita'

$$\eta = \eta(\dot{\gamma})$$

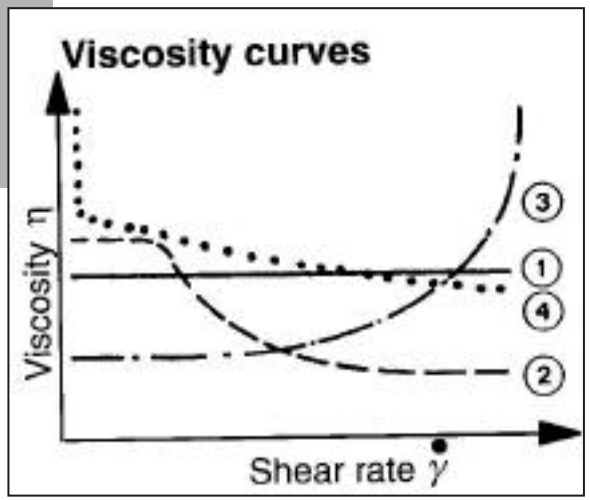






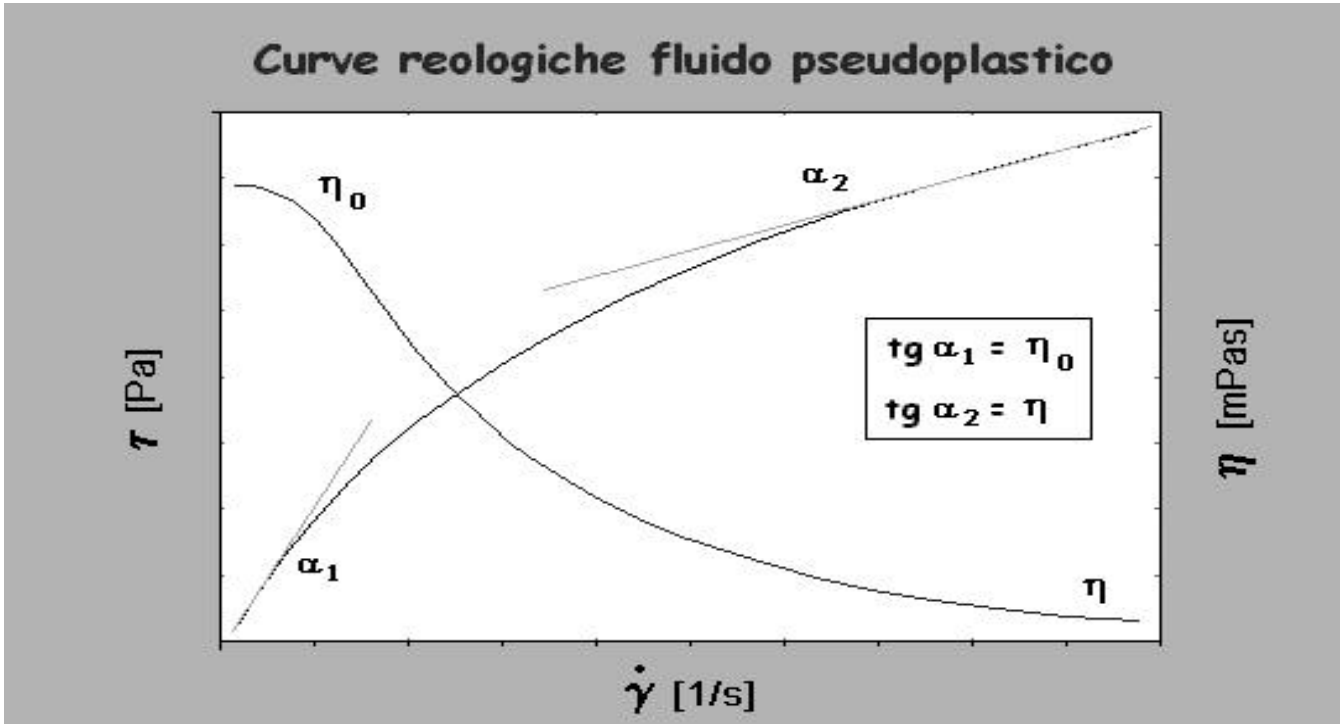
1 Newtoniano
2 Pseudoplastico
3 Plastico
4 Bingham
5 Dilatante

① Newtonian liquid
② Pseudoplastic liquid
③ Dilatant liquid
④ Pseudoplastic liquid with yield point = plastic liquid



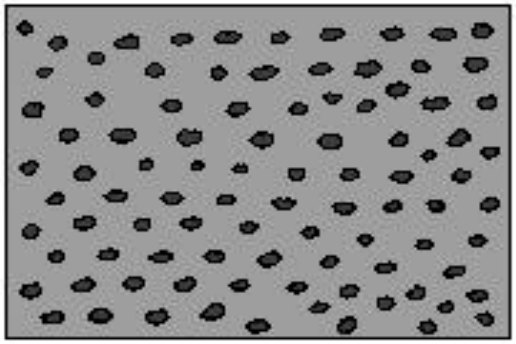
•Pseudoplastici

Fluidi che diminuiscono la loro viscosità al crescere del gradiente

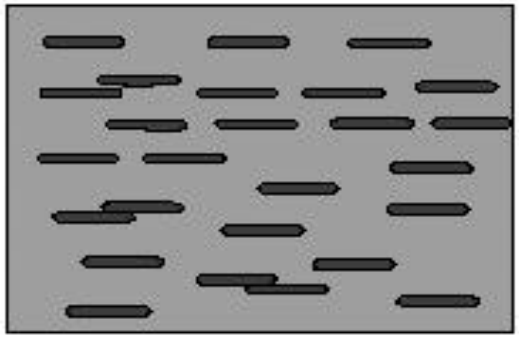


soluzioni concentrate di polimeri
sospensioni di particelle concentrate
emulsioni concentrate

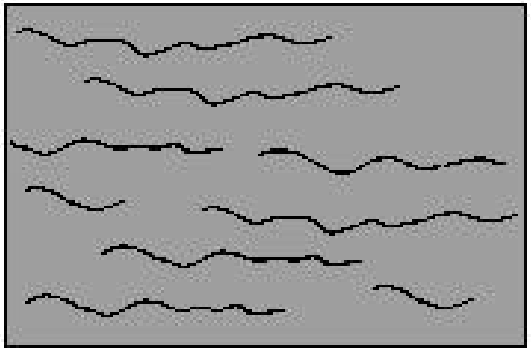
Disaggregazione



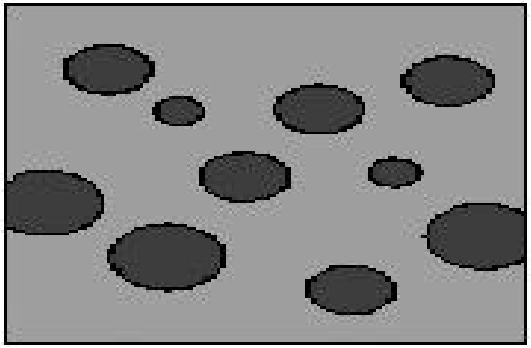
Orientamento al flusso



Stiramento

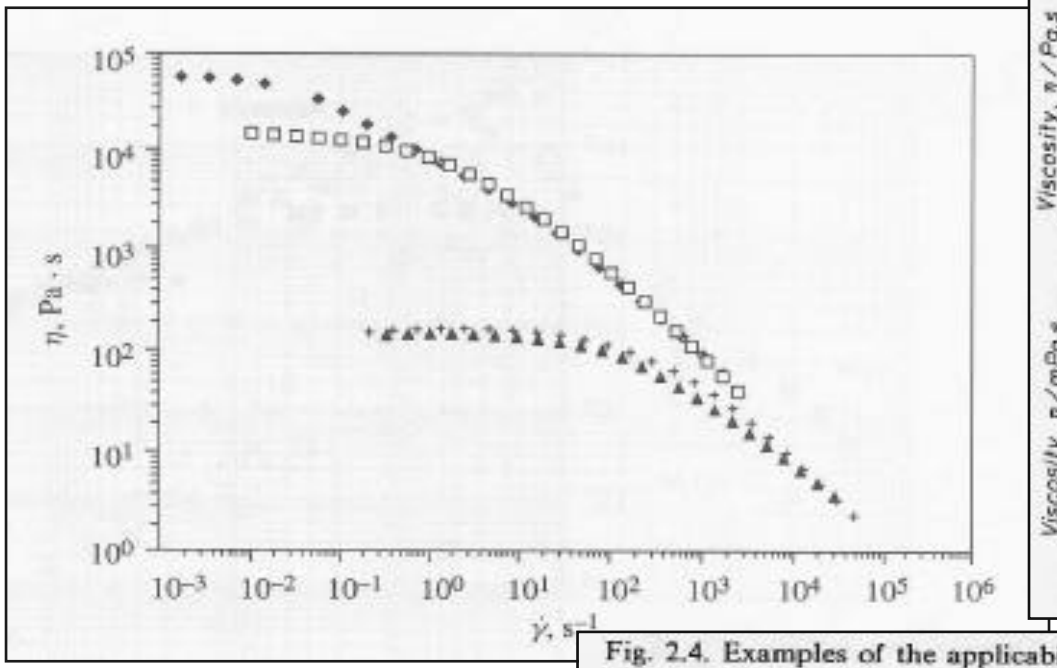


Deformazione



Shear thinning

Figure 6.3 Shear viscosity η as a function of shear rate $\dot{\gamma}$ for linear and branched polydimethylsiloxanes. +, M_w=131 kg/mol, M_w/M_n=1.9, linear; △, M_w=156 kg/mol, M_w/M_n=2.8, branched; □, M_w=418 kg/mol, M_w/M_n=3.2, linear; ◇, M_w=428 kg/mol, M_w/M_n=2.9, branched; from Piau et al. [207]. *Source:* Reprinted from *Journal of Non-Newtonian Fluid Mechanics*, **30**, J. M. Piau, N. El Kissi, and B. Tremblay, "Low Reynolds number flow visualization of linear and branched silicones upstream of orifice dies," 197–232, Copyright © 1988, with permission from Elsevier Science.



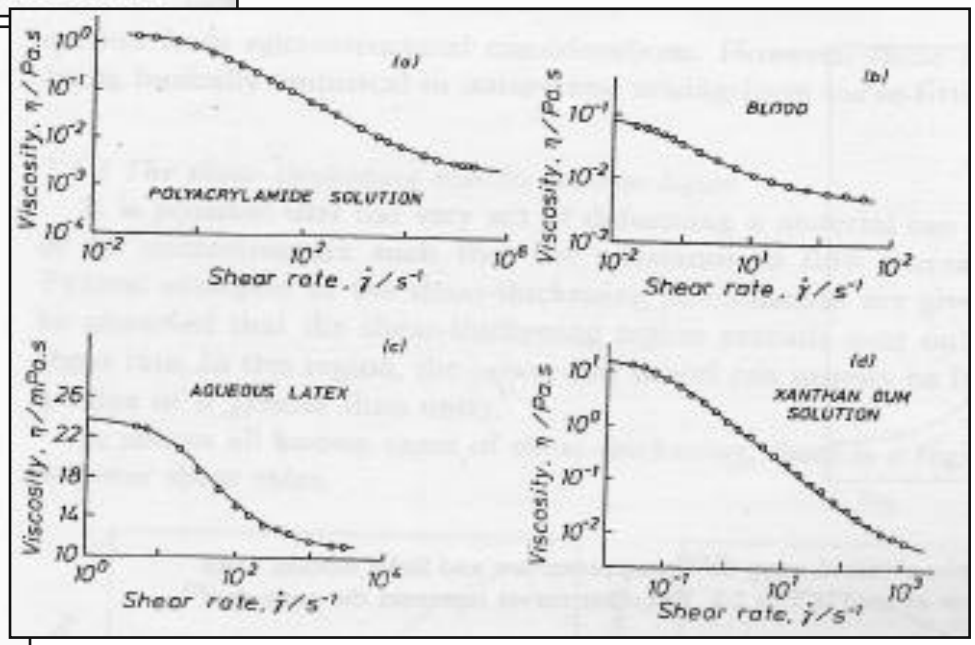
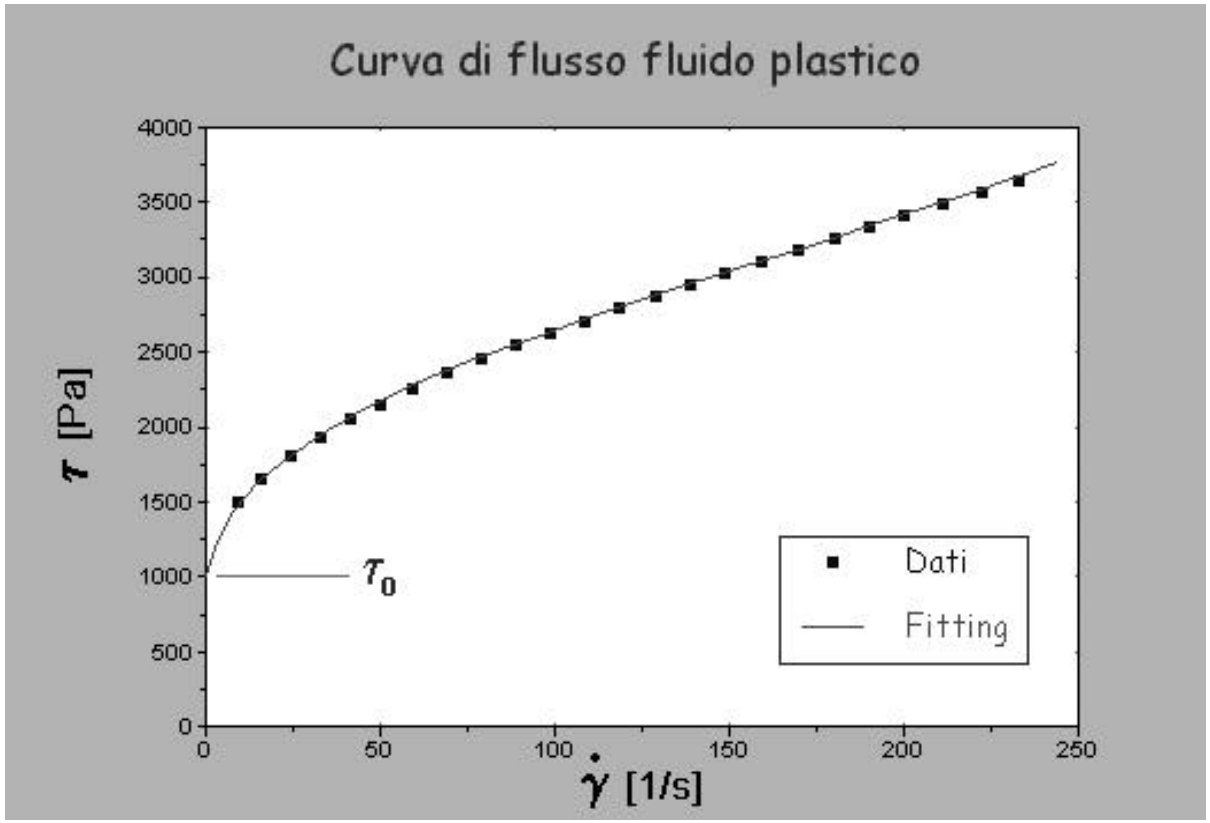
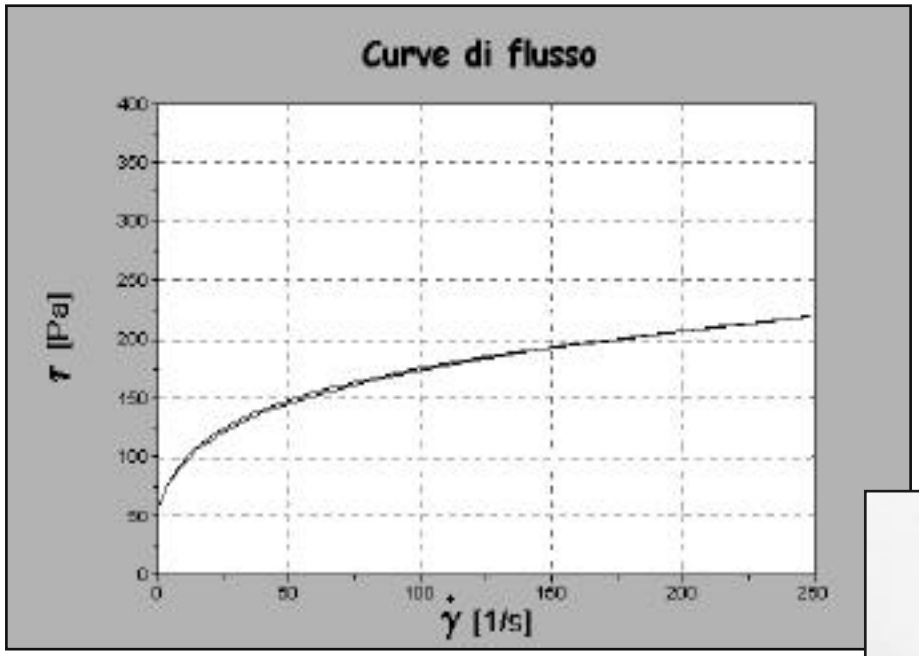


Fig. 2.4. Examples of the applicability of the Cross equation (eqn. (2.2a)): (a) 0.4% aqueous solution of polyacrylamide. Data from Boger (1977(b)). The solid line represents the Cross equation with $\eta_0 = 1.82$ Pa.s, $\eta_\infty = 2.6$ mPa.s, $K = 1.5$ s, and $m = 0.60$; (b) Blood (normal human, $Hb = 37\%$). Data from Mills et al. (1980). The solid line represents the Cross equation with $\eta_0 = 125$ mPa.s, $\eta_\infty = 5$ mPa.s, $K = 52.5$ s and $m = 0.715$; (c) Aqueous dispersion of polymer latex spheres. Data from Quemada (1978). The solid line represents the Cross equation with $\eta_0 = 24$ mPa.s, $\eta_\infty = 11$ mPa.s, $K = 0.018$ s and $m = 1.0$; (d) 0.35% aqueous solution of Xanthan gum. Data from Whitcomb and Macosko (1978). The solid line represents the Cross equation with $\eta_0 = 15$ Pa.s, $\eta_\infty = 5$ mPa.s, $K = 10$ s, $m = 0.80$.

•**Plastici** Fluidi pseudoplastici che presentano una soglia di scorrimento

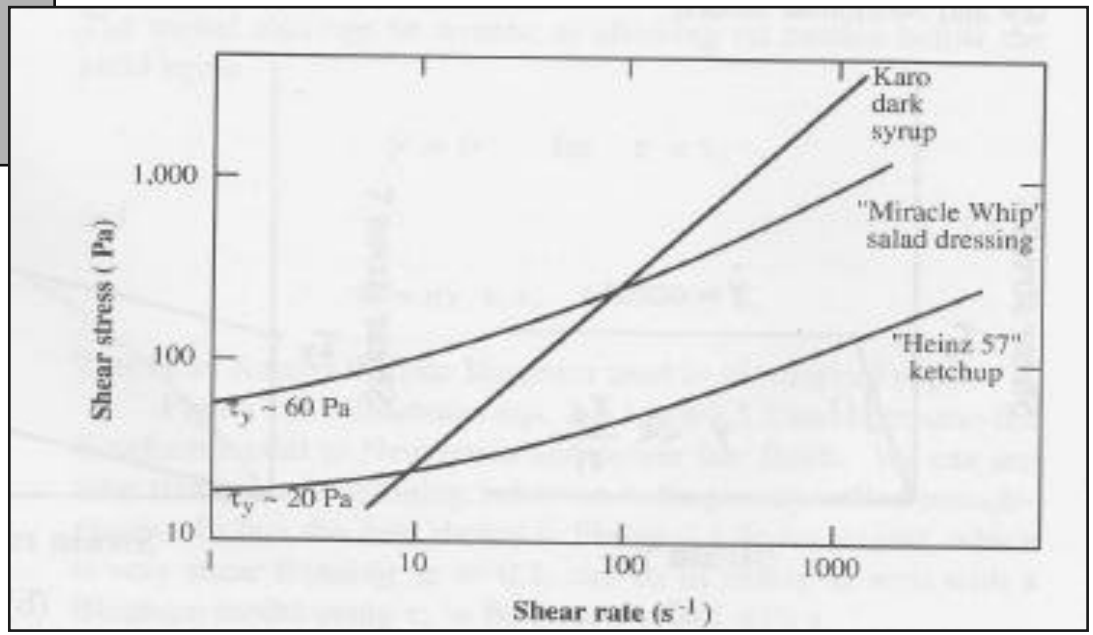


Sistemi dispersi e sistemi polimerici a concentrazione superiore ad un valore critico che a riposo sono formati da particelle
aggregate fra di loro in una struttura reticolare tridimensionale.
Per mettere in moto il fluido è necessario rompere
tali legami e quindi esercitare uno sforzo detto
limite di scorrimento

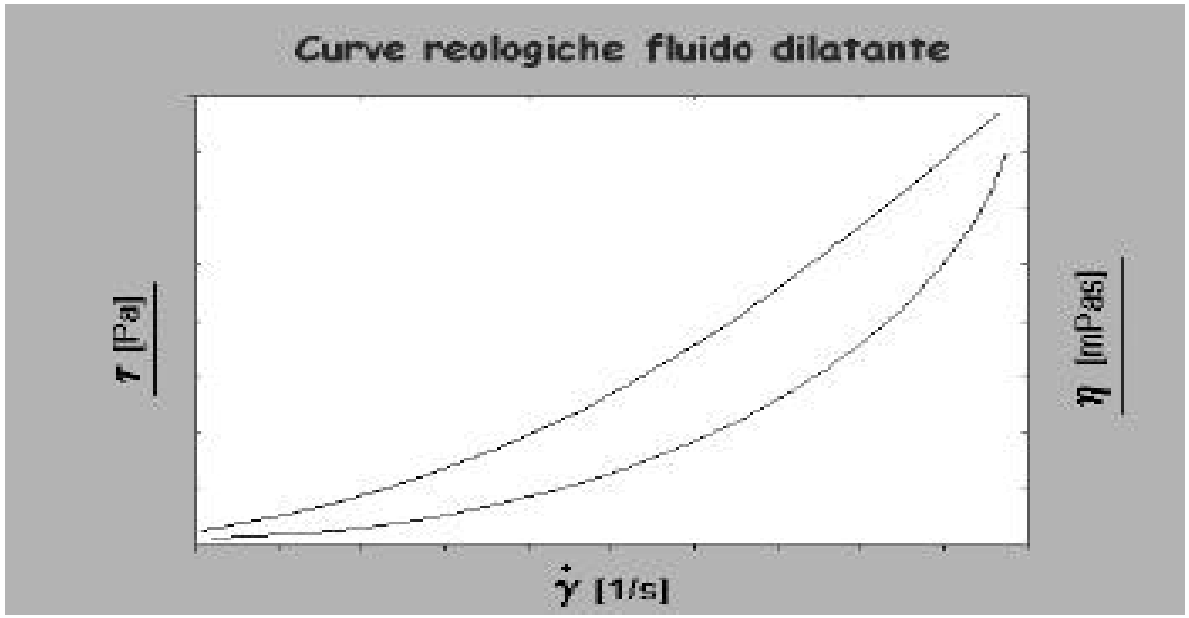


Sostanza: Ketchup
Temperatura: 20 °C

Figure 2.5.2.
Flow data for several food products (courtesy of Graco Co.). The Newtonian syrup has a higher viscosity at high shear rate, while the viscoplastic salad dressing and the ketchup show a yield stress and much higher viscosity at low rates.



•**Dilatanti** Fluidi che aumentano la loro viscosità al crescere del gradiente



Sospensioni di particelle solide molto piccole e altamente concentrate in un fluido.
Il volume occupato dalle particelle è molto più grande del volume occupato dal fluido che riempie completamente gli interstizi.

Shear thickening

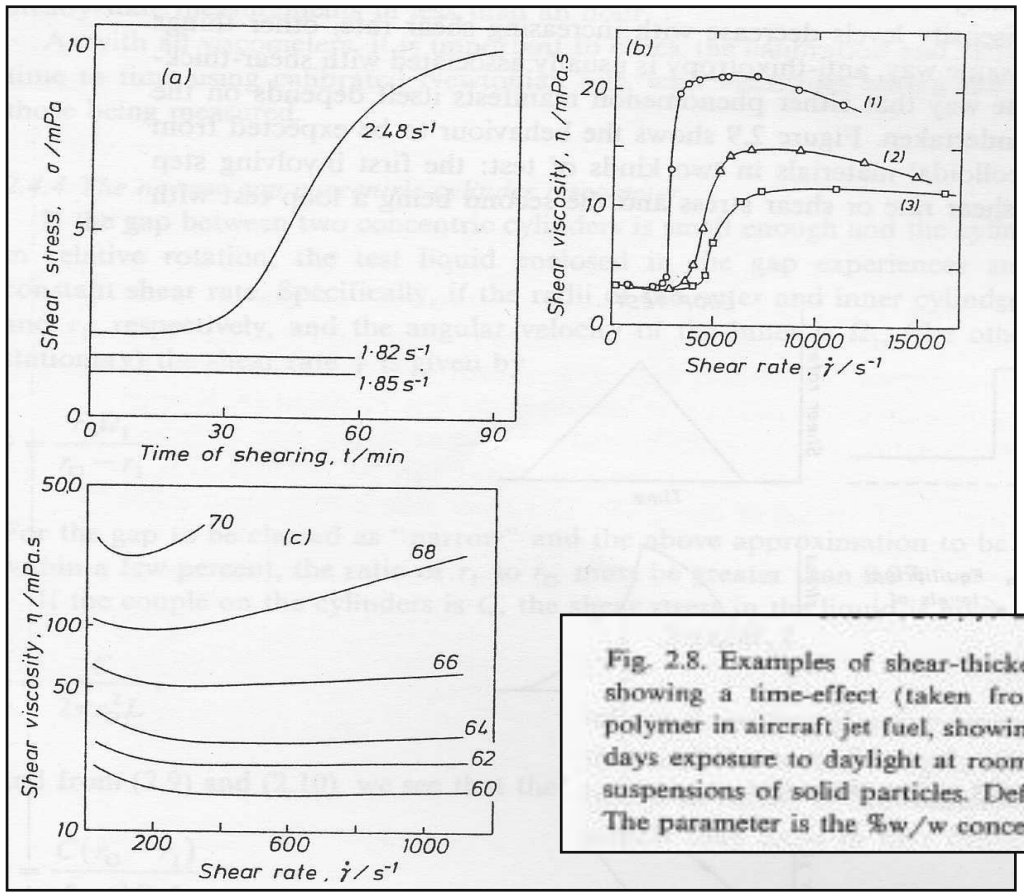


Fig. 2.8. Examples of shear-thickening behaviour: (a) Surfactant solution. CTA-sal. solution at 25 °C showing a time-effect (taken from Gravsholt 1979); (b) Polymer solution. Solution of anti-misting polymer in aircraft jet fuel, showing the effect of photodegradation during (*1*) 1 day, (*2*) 15 days, (*3*) 50 days exposure to daylight at room temperature (taken from Matthys and Sabersky 1987); (c) Aqueous suspensions of solid particles. Deflocculated clay slurries showing the effect of concentration of solids. The parameter is the %w/w concentration (taken from Beazley 1980).

Equazioni per il flusso e la viscosita'

flowcurve - models	($\tau = f(\dot\gamma)$)
Newton	$\tau = \eta\dot\gamma$
Bingham	$\tau = \eta_p\dot\gamma + \tau_0$
Ostwald-de-Waele	$\tau = K\dot\gamma^n$
Herschel-Bulkley	$\tau = K\dot\gamma^n + \tau_0$
Casson	$\tau = \sqrt{(\tau_0^n + (\eta_p\dot\gamma)^n)}$
Cross	$\tau = \dot\gamma(\eta_\infty + (\eta_0 - \eta_\infty)/(1+(\dot\gamma/\dot\gamma_b)^n))$
Carreau	$\tau = \dot\gamma(\eta_\infty + (\eta_0 - \eta_\infty)/(1+(\dot\gamma/\dot\gamma_b)^2)^{n/2})$

Viscosity - models	($\eta = f(\dot\gamma)$)
Newton	η=constant
Bingham	$\eta = \tau_0/\dot\gamma + \eta_p$
Ostwald-de-Waele	$\eta = K\dot\gamma^{n-1}$
Herschel-Bulkley	$\eta = \tau_0/\dot\gamma + K\dot\gamma^{n-1}$
Casson	$\eta = \sqrt{((\tau_0/\dot\gamma)^n + \eta_p^n)}$
Cross	$\eta = \eta_\infty + (\eta_0 - \eta_\infty)/(1+(\dot\gamma/\dot\gamma_b)^n)$
Carreau	$\eta = \eta_\infty + (\eta_0 - \eta_\infty)/(1+(\dot\gamma/\dot\gamma_b)^2)^{n/2}$

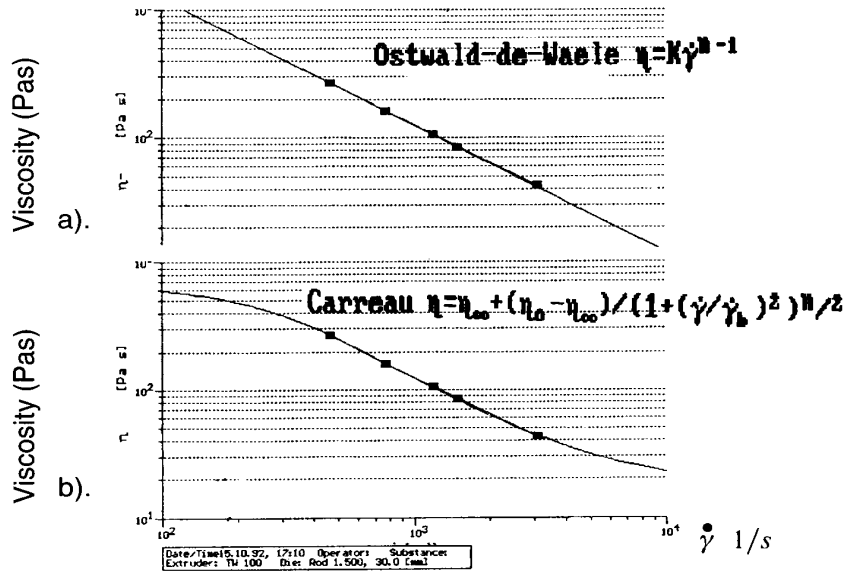


Fig. 132 Comparing extrapolated Ostwald-de-Waele and Carreau regression curves on the same viscosity data points.

Material	K_2(Pa · s^n)	n	Shear rate range (s^{-1})
Ball-point pen ink	10	0.85	10^0–10^3
Fabric conditioner	10	0.6	10^0–10^2
Polymer melt	10000	0.6	10^2–10^4
Molten chocolate	50	0.5	10^{-1}–10
Synovial fluid	0.5	0.4	10^{-1}–10^2
Toothpaste	300	0.3	10^0–10^3
Skin cream	250	0.1	10^0–10^2
Lubricating grease	1000	0.1	10^{-1}–10^2

Power law : $\tau = K_2 \dot\gamma^n$

n=1, newtoniano

n<1, pseudoplastico

n>1, dilatante

Fluidi che presentano caratteristiche reologiche tempo-dipendenti.

La viscosita' puo' aumentare o diminuire in funzione del tempo di deformazione.

•**Tissotropia**: decremento della viscosita' per shear stress seguto da un graduale recupero della struttura alla rimozione dello stress
•Andamento con graduale incremento della viscosita' sotto stress , seguito da graduale recupero e' detto **antitissotropia** o tissotropia negativa.

Indagini reologiche attuabili

• **C**urva viscosità vs tempo a gradiente costante per osservare la distruzione della struttura all' interno del materiale
• **C**urve viscosità vs tempo dopo differenti tempi di attesa per vedere o determinare la rigenerazione del campione
• **C**urva di flusso in andata e in ritorno a temperatura costante per valutare la cosiddetta "Area di isteresi"
• **M**isure dinamiche (oscillatorio)

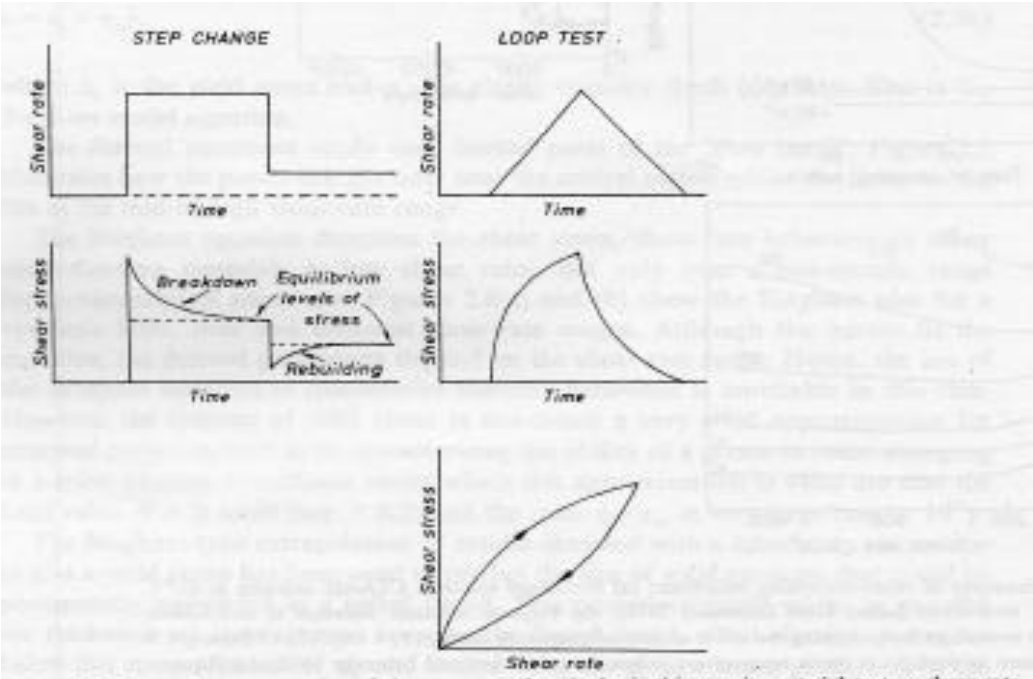
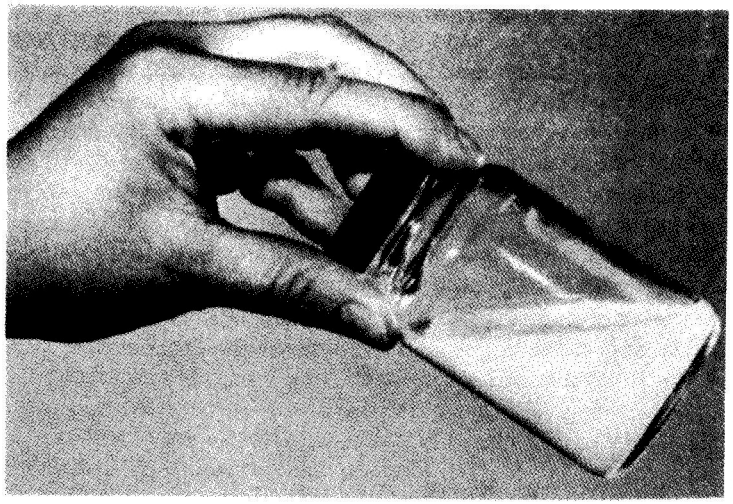


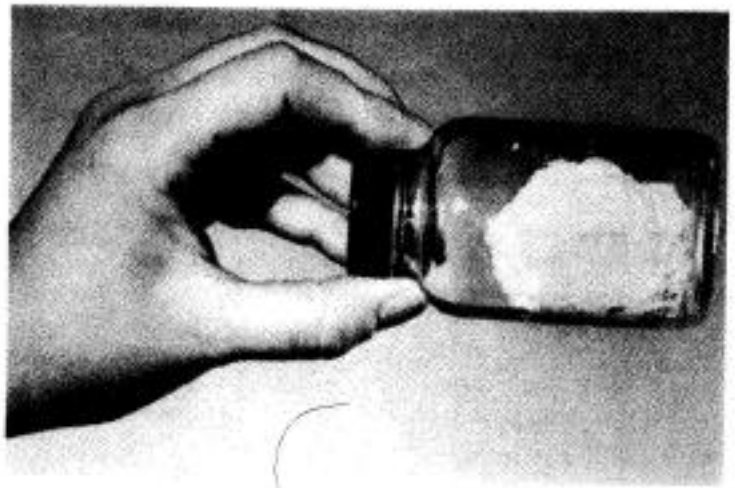
Fig. 2.9. Schematic representation of the response of an inelastic thixotropic material to two shear-rate histories.

Esempio di antitissotropia

The liquid is an alkaline perbunan latex

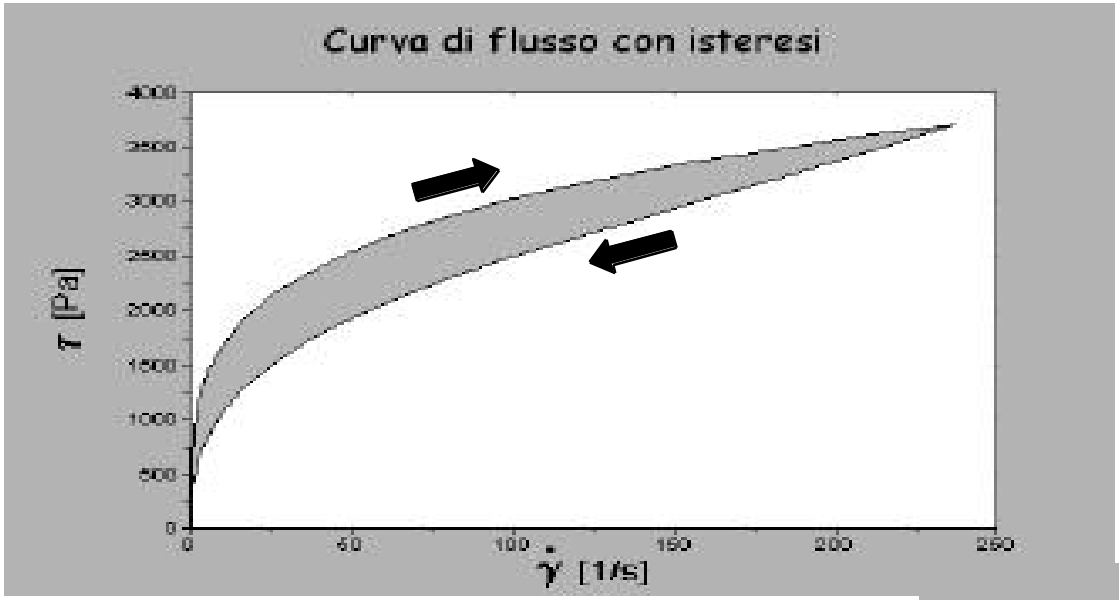


a) AFTER PROLONGED REST



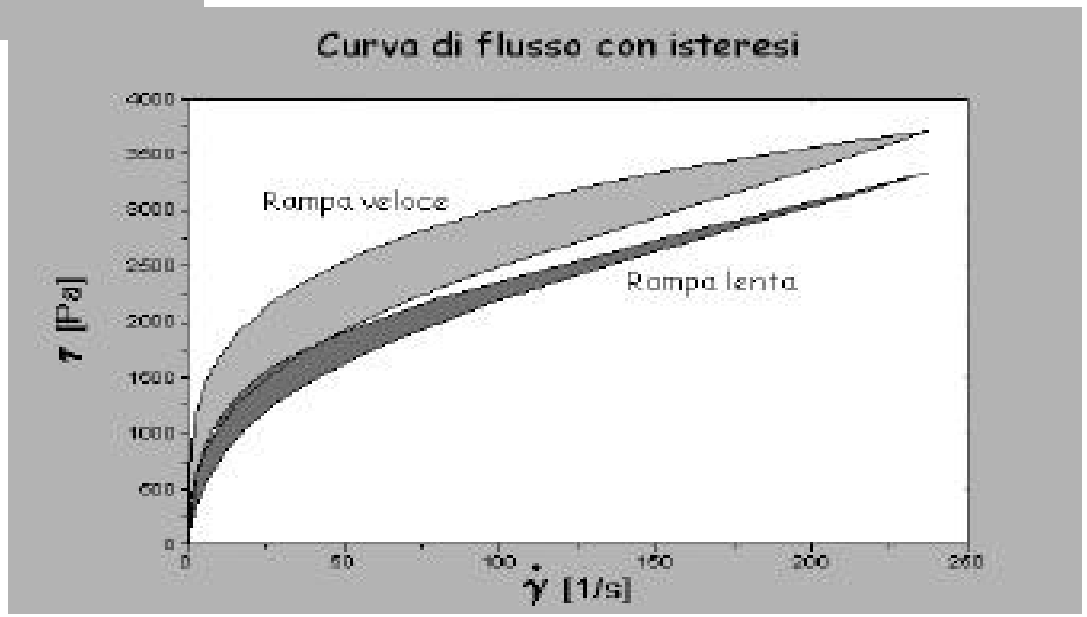
b) IMMEDIATELY AFTER VIGOROUS SHAKING

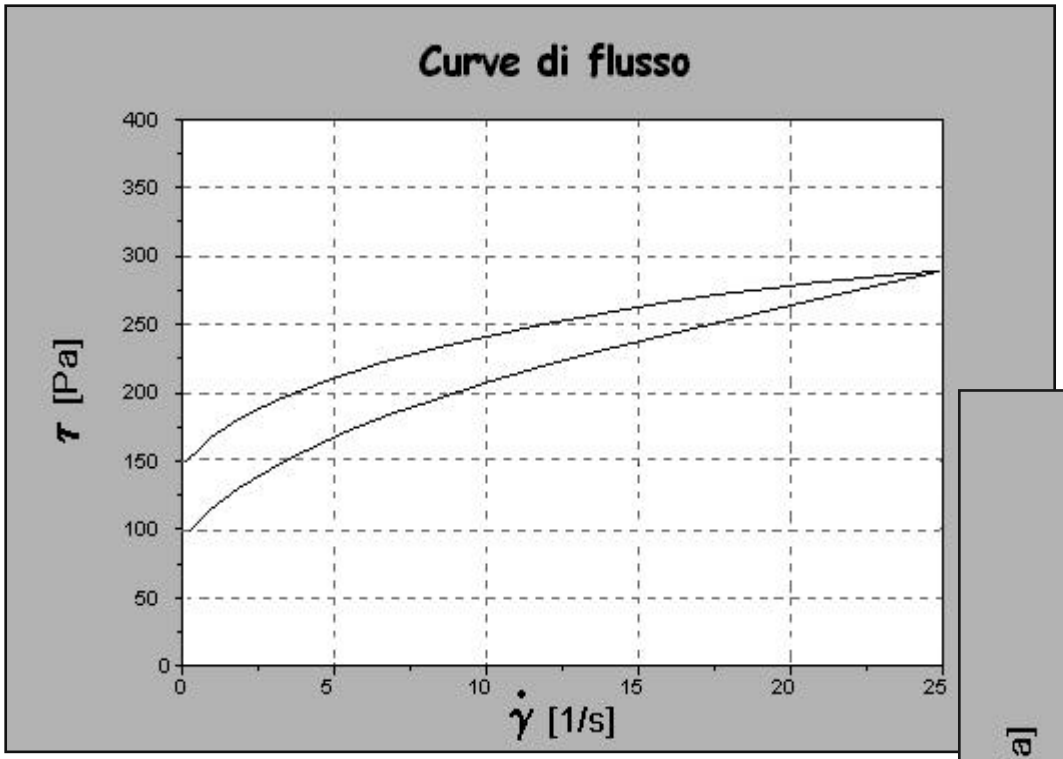
NOTA: Il fenomeno della tissotropia usualmente si associa allo shear thinning, l'antitissotropia al comportamento di shear thickening



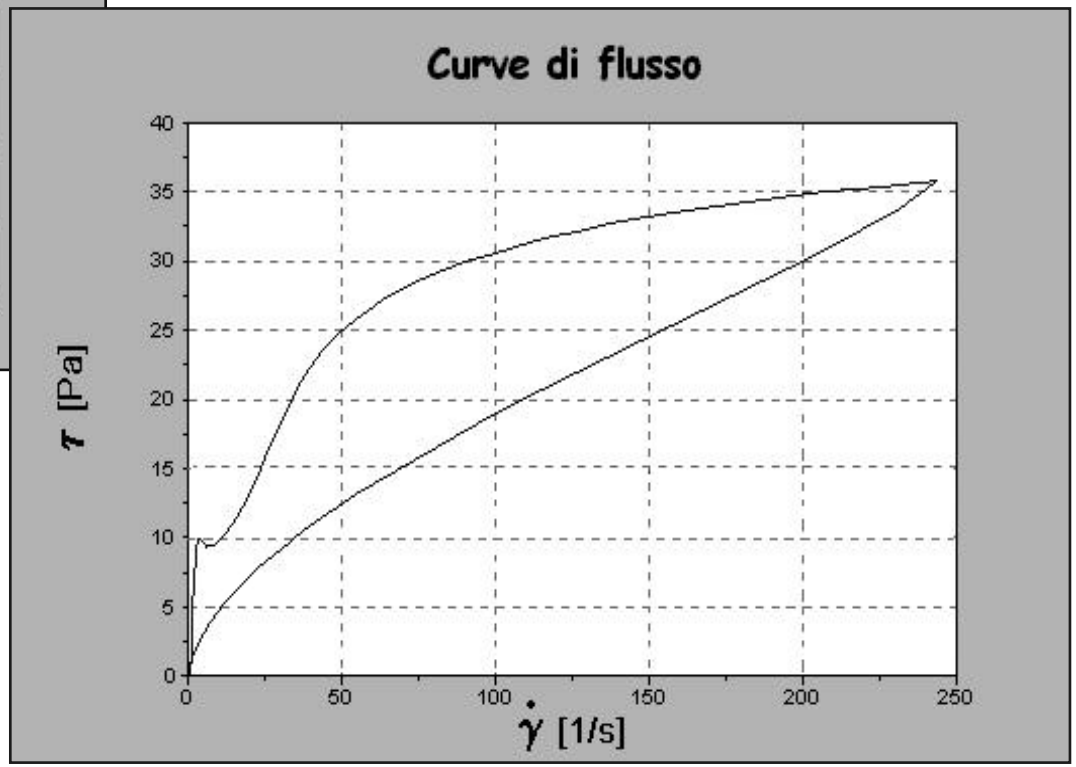
L’area di isteresi fornisce una indicazione delle proprietà tissotropiche del materiale, non e' sufficiente per la sua caratterizzazione

Rampa veloce
• il materiale non ha il tempo di recuperare
• il materiale è sottoposto a forze di stress meno a lungo
Rampa lenta
• il materiale ha il tempo di recuperare
• il materiale è sottoposto a stress in modo più completo





Sostanza: Yoghurt
Temperatura: 20 °C



Sostanza: Maionese
Temperatura: 20 °C