AF2903 Road Construction and Maintenance

Rheology

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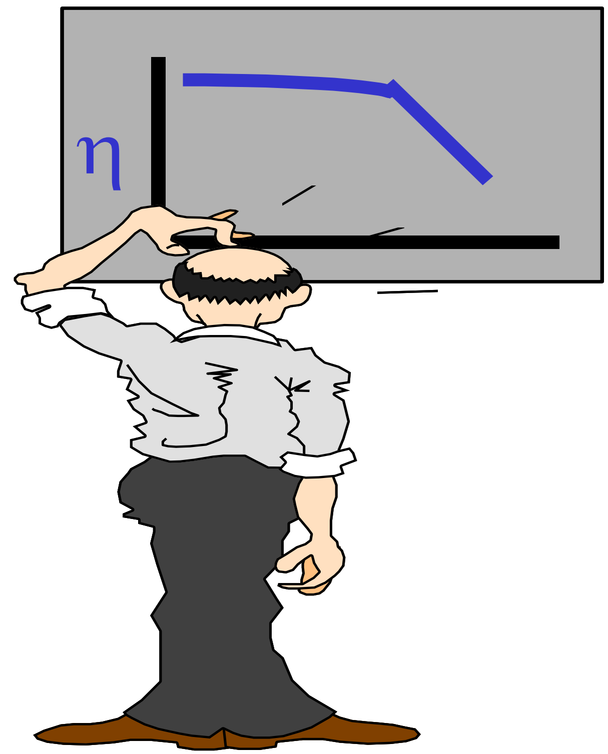
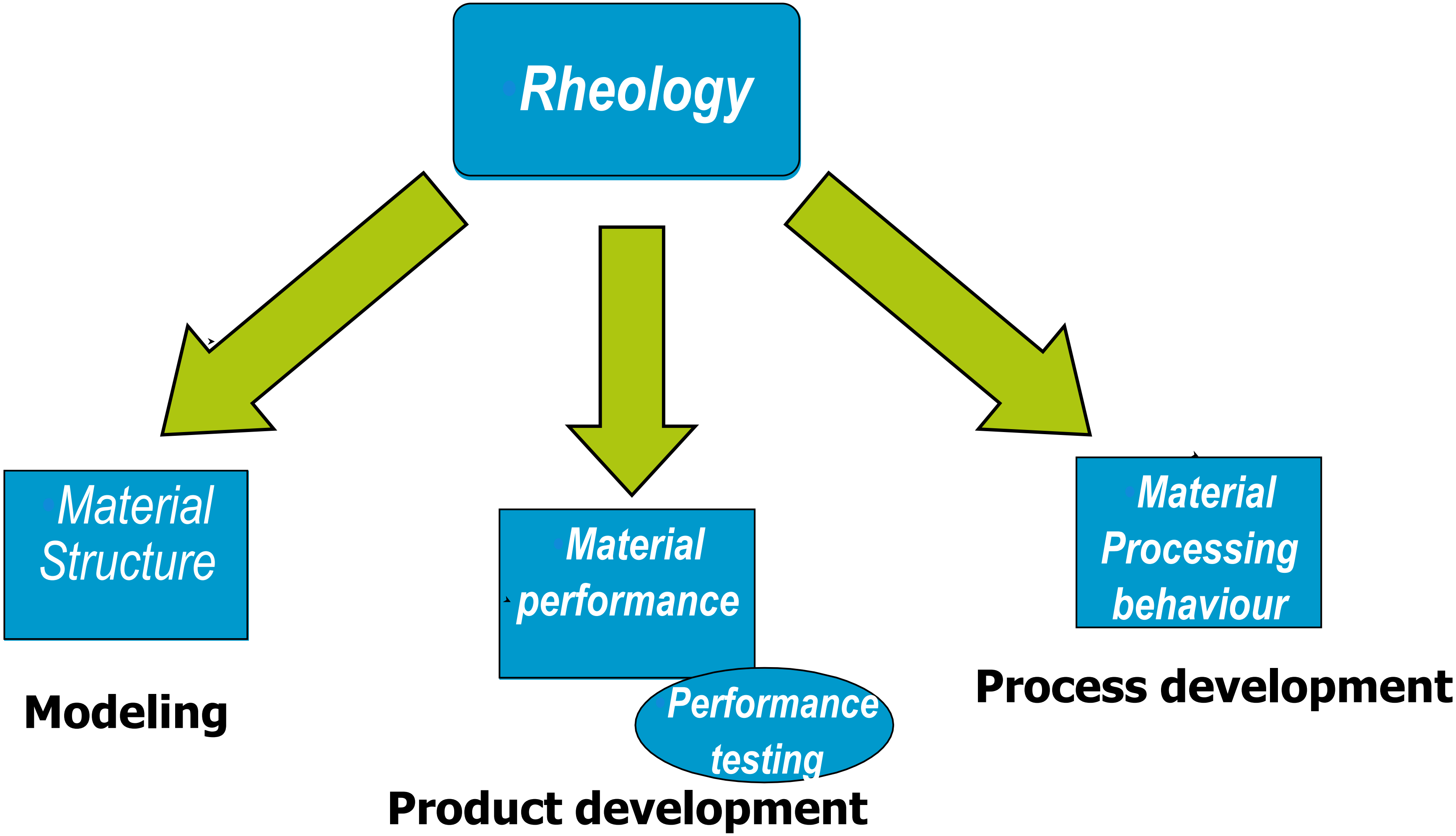
An Introduction to Rheology



Rheology

THE STUDY OF DEFORMATION AND FLOW OF MATTER



The Rheological Techniques

- Flow – pumping, dispensing, spraying etc
- Creep – what happens under gravity – stability
- Oscillation – structure and the effects of time and temperature

What is rheology looking at?

- A response to giving energy
    - Applying a shearing force – pushing
    - Changing temperature – excitation

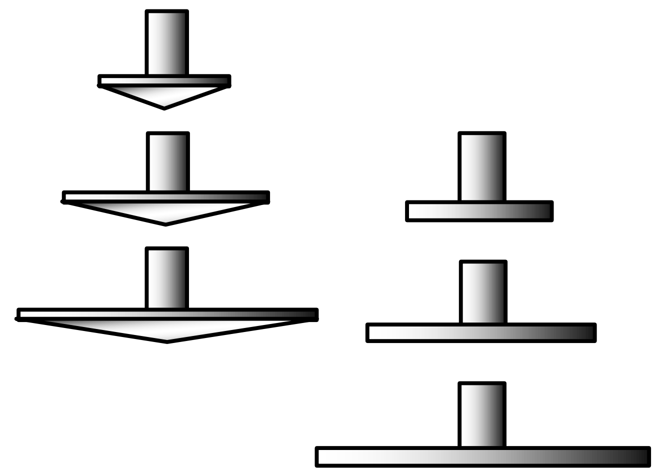
- Is the energy used to do something or is it stored?

What is a Rheometer?

- Basically consists of five main components

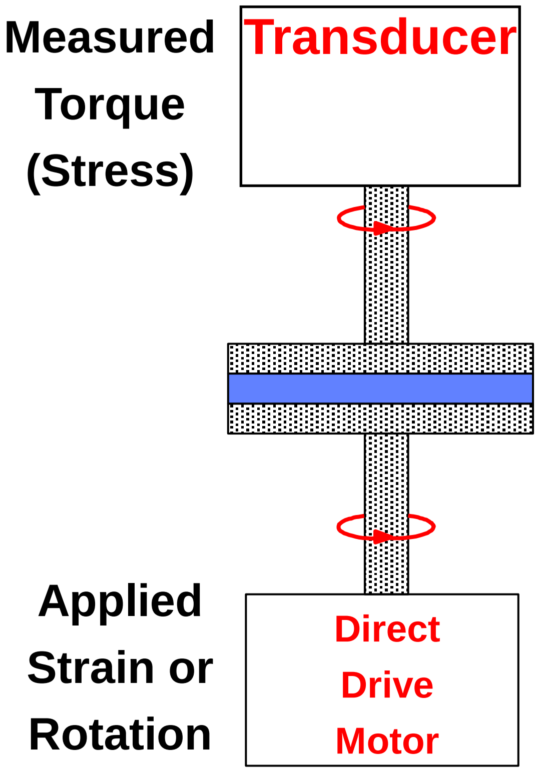
- Air bearing – near frictionless rotation
- Motor – smooth application of torque
- Optical encoder – measures rotation
- Temperature control – accurate and source of energy
- Geometry – what connects the rheometer to the sample

Dynamic Shear Rheometer (DSR)

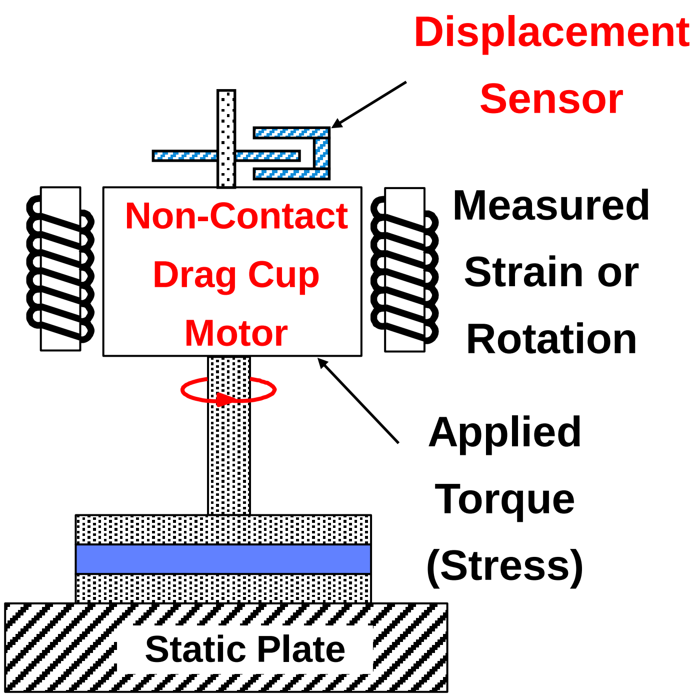


Rotational Rheometers Designs

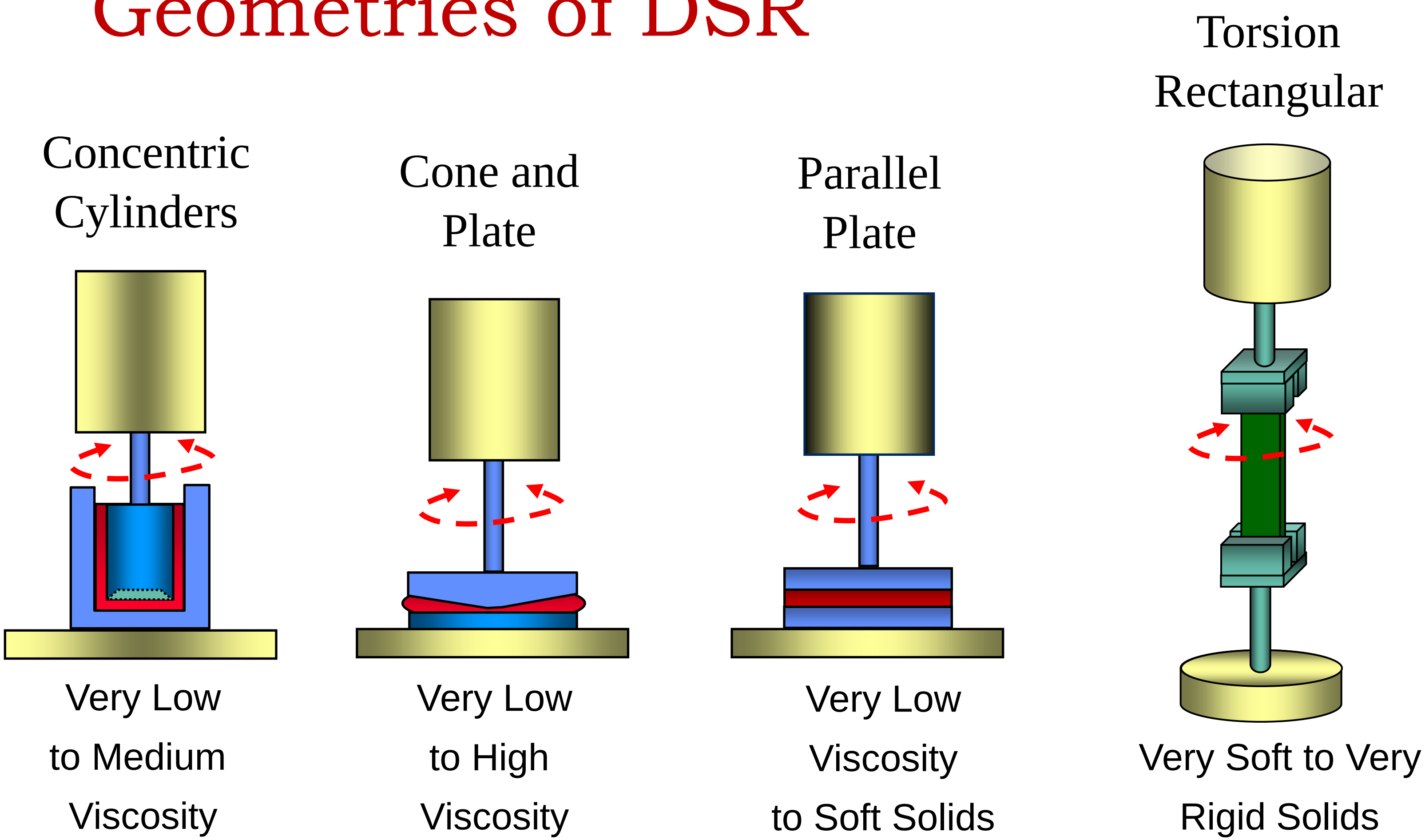
- Controlled Strain
- *SMT – Separate motor & transducer*



- Controlled Stress
- *CMT – Combined motor & transducer*



Geometries of DSR



Water → to → Steel

How does a rheometer work?

- **Fundamentally a controlled stress rotational rheometer will**
  - Apply a Torque (Force)
  - Measure an angular displacement
  - Calculate a rate of displacement (speed/velocity)

- **If measured shear rate<requested shear rate, increase torque**
- **If measured shear rate>requested shear rate, decrease torque**

- **Feedback loop iterative process**

- **For controlled strain instruments, this process is the same just the variables are the other way round**
  - Apply velocity
  - Measure torque

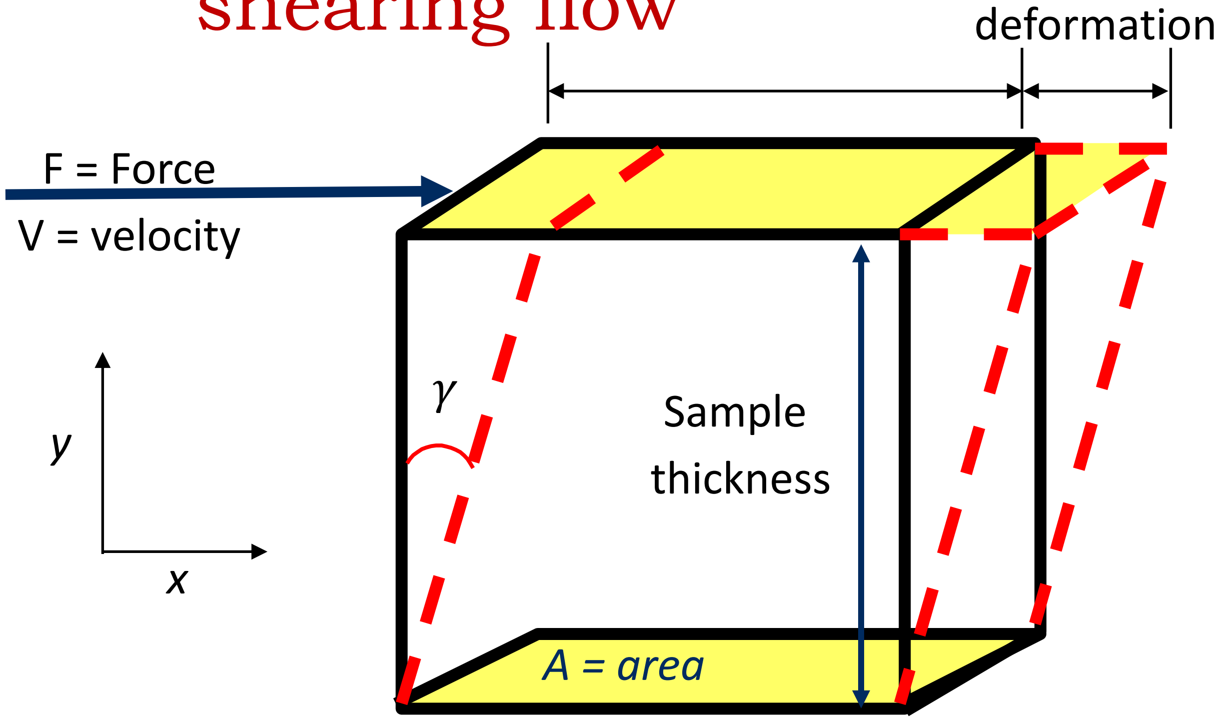
FLOW

- Process ability in handling and application

Viscosity

- Definition: resistance to flow
- The units of viscosity are . . . . .
  - SI unit is the Pascal.Second (Pa.s)
  - cgs unit is the poise
    - 10 Poise =1 Pa.s
    - 1 cP (centipoise) = 1 m Pa.s (milli-pascal-second)

Terminology - Simple shear and shearing flow



Shear Stress: $\sigma = F/A$

Strain: $\gamma = dx/y_o$

Shear Rate: $\dot{\gamma} = d\gamma/dt = V/y$

Viscosity $\eta = \frac{\sigma}{\dot{\gamma}}$

Modulus $G = \frac{\sigma}{\gamma}$

Cone Angles and Diameters

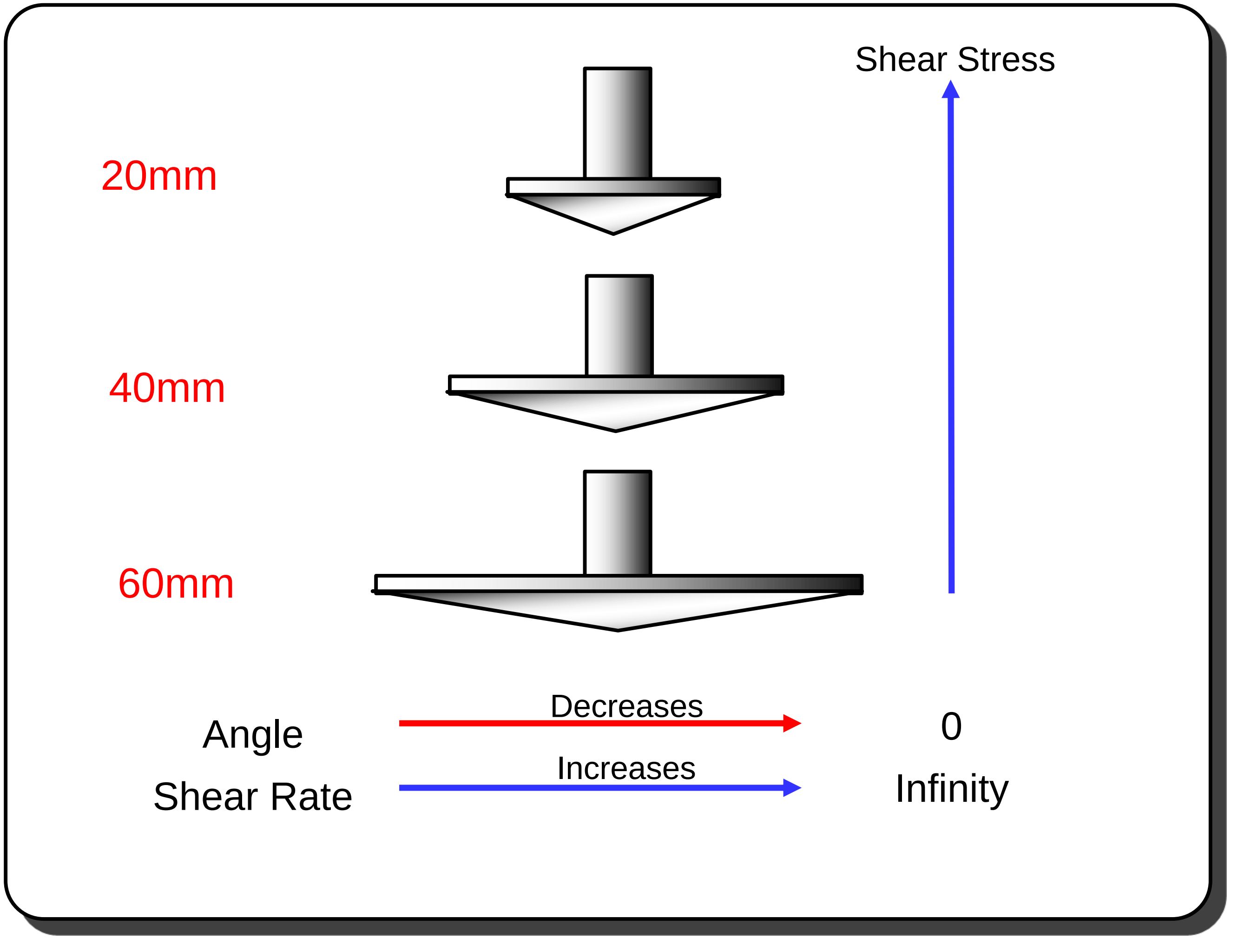
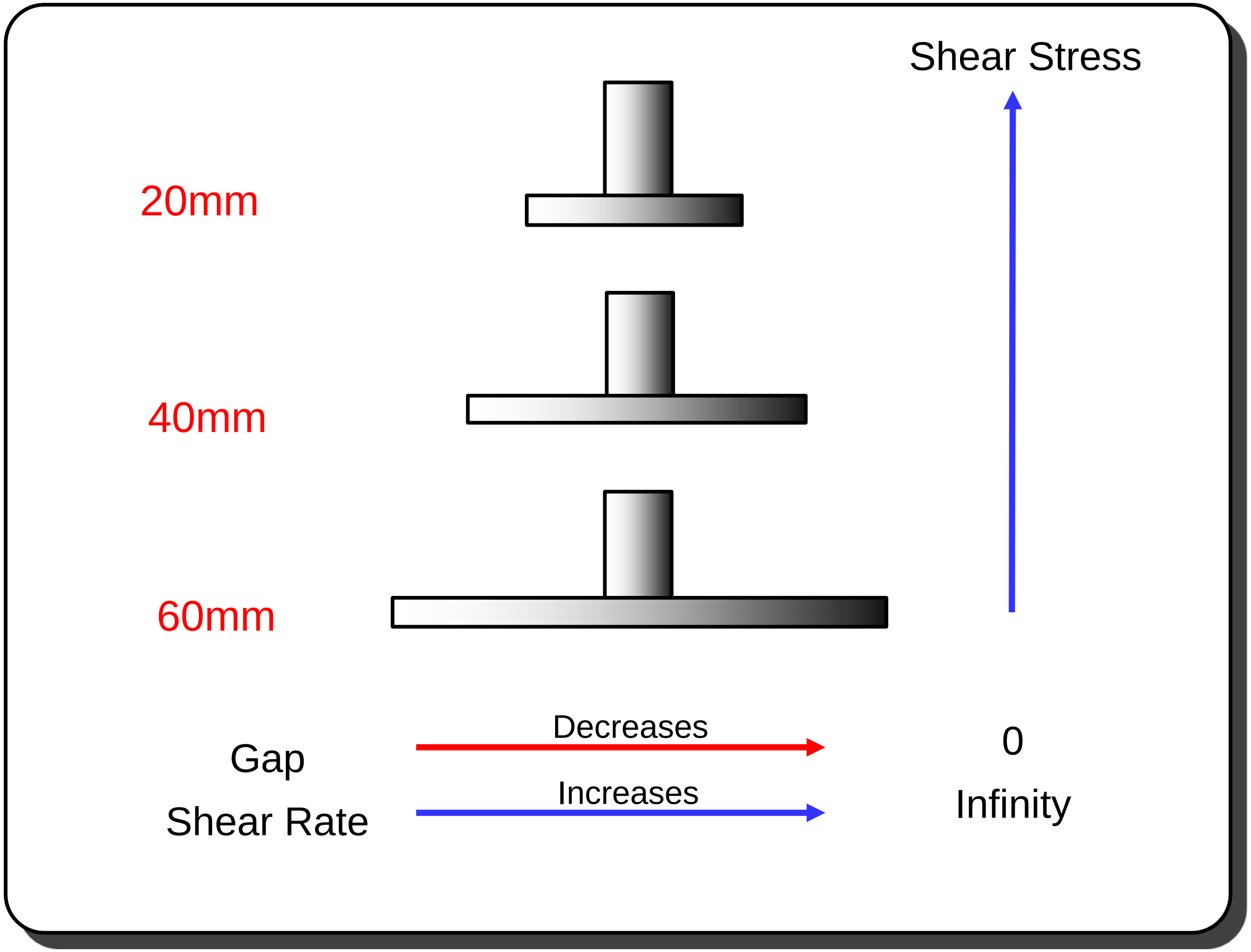


Plate Gaps and Diameters



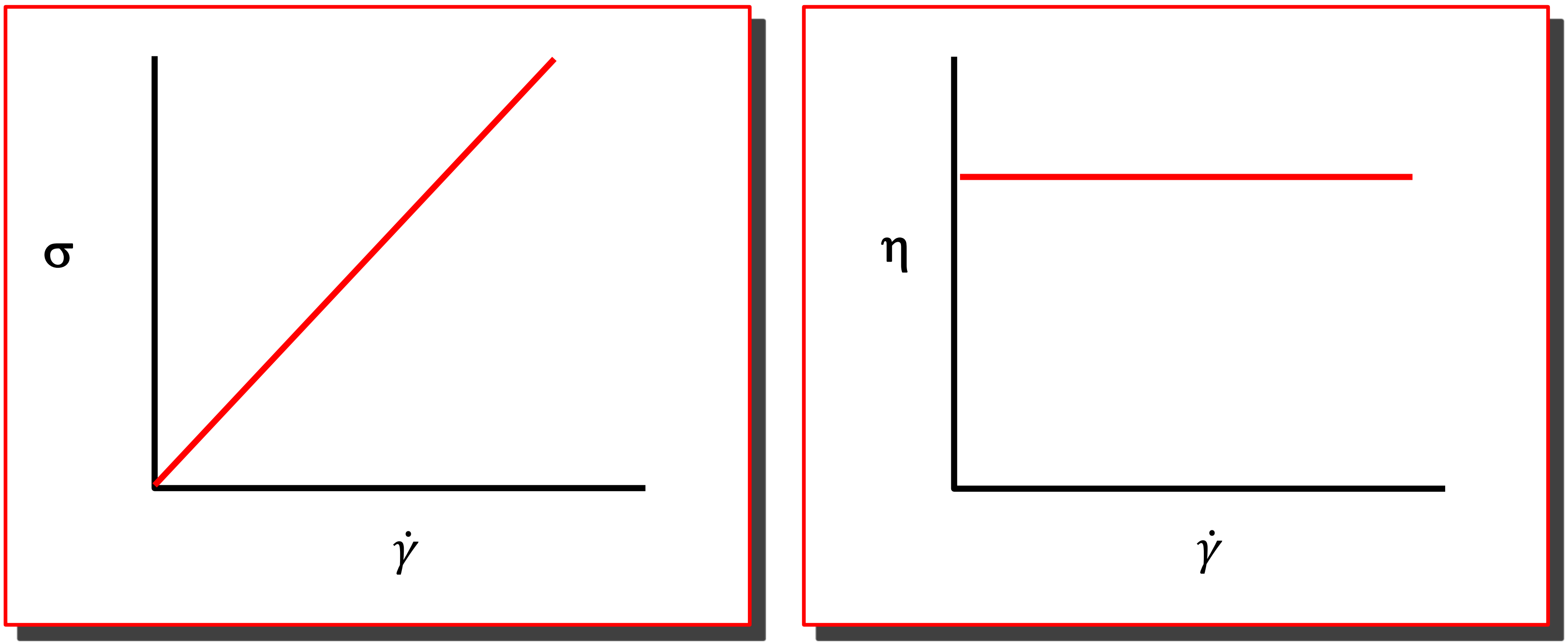
Typical Viscosities (Pa.s)

- Various materials and their viscosities

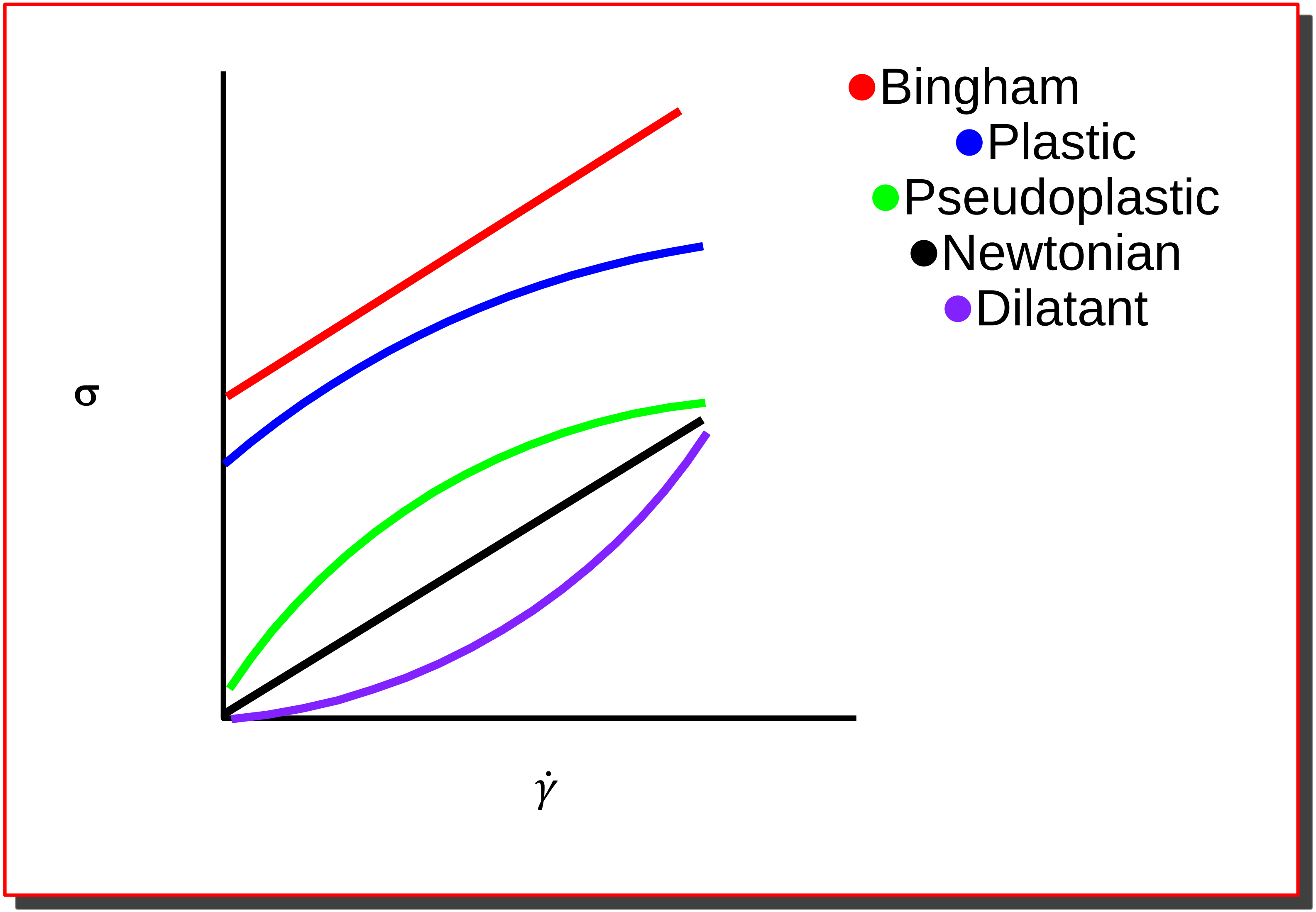
BITUMEN	100 000 000
POLYMER MELT	1 000
GOLDEN SYRUP	100
LIQUID HONEY	10
GLYCEROL	1
OLIVE OIL	0.01
WATER	0.001
AIR	0.00001

What Is A Flow Curve?

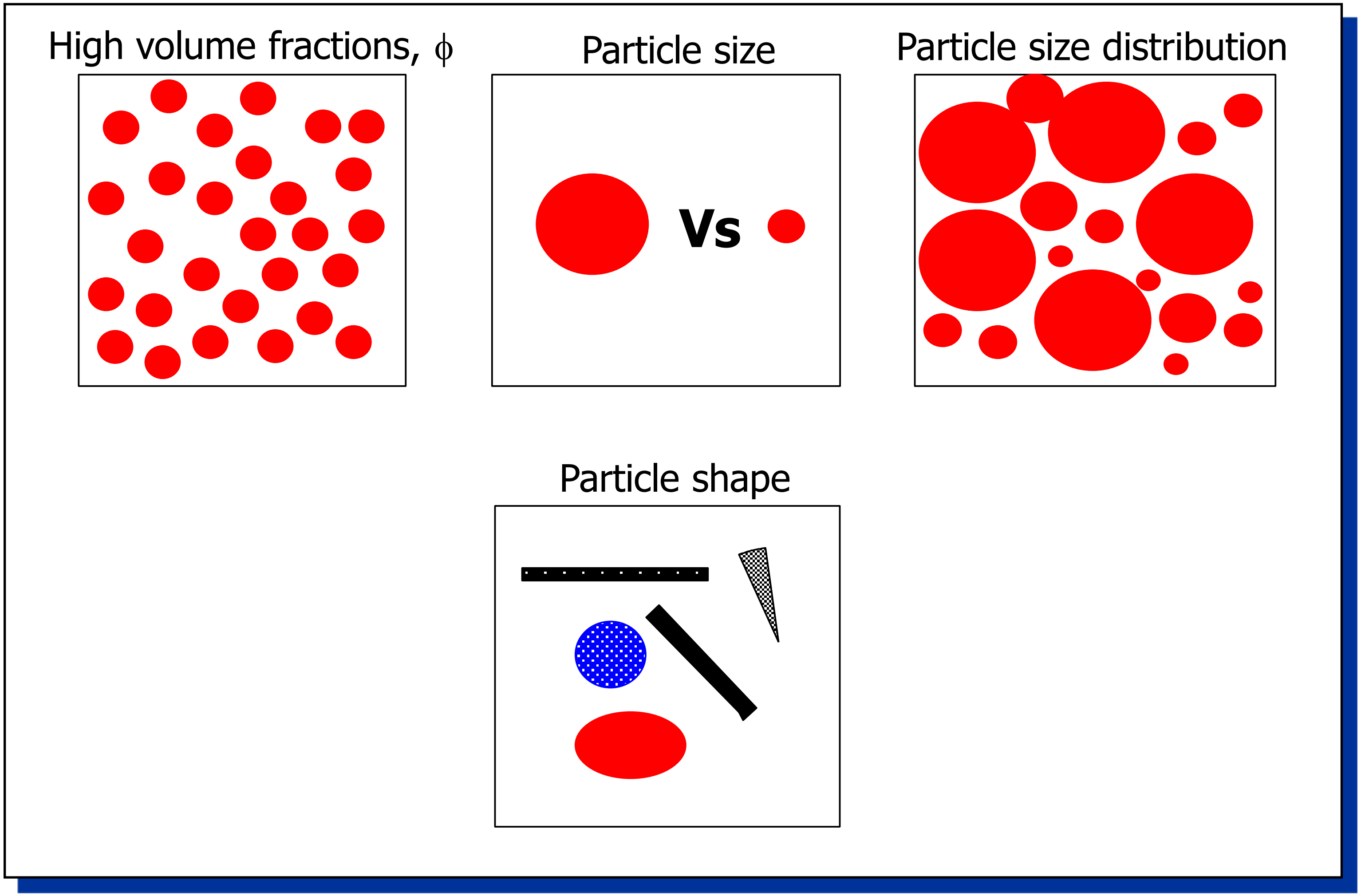
... a graph of shear stress versus shear rate



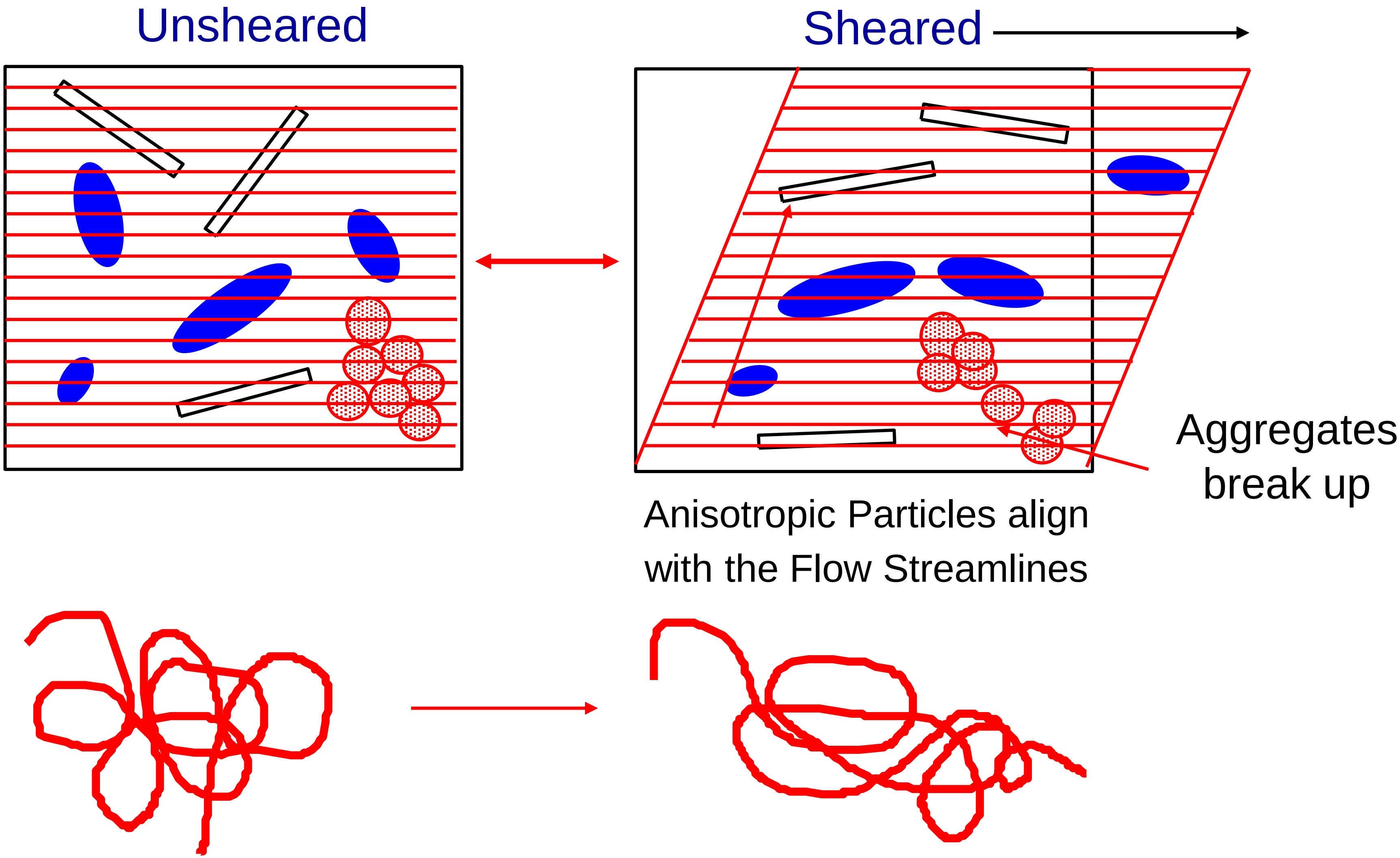
Newtonian - simplest case


Bingham
Plastic
Pseudoplastic
Newtonian
Dilatant
σ
$\dot{\gamma}$

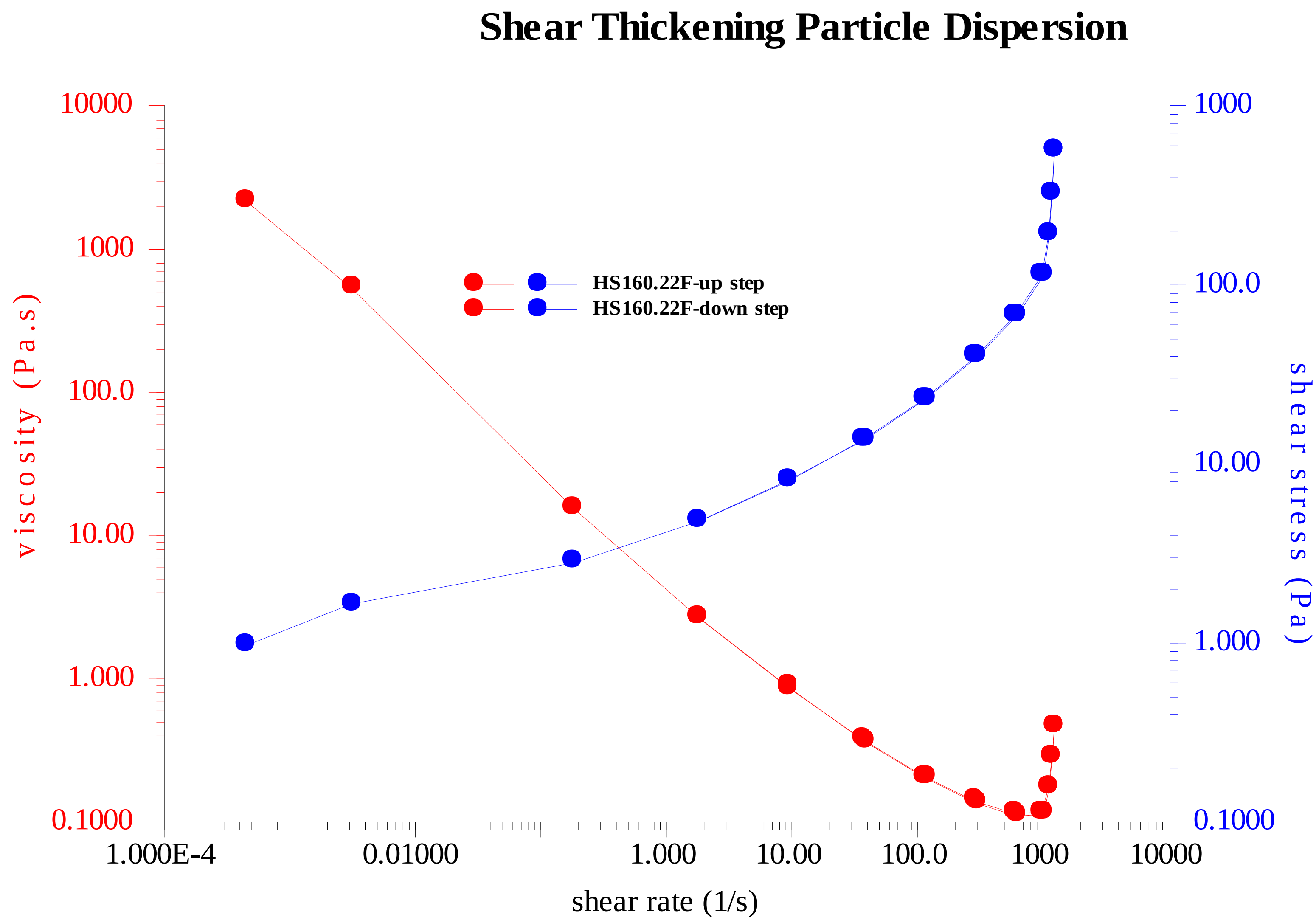
Factors Influencing Rheology



Shear thinning - why does it occur?



Shear-thickening of Silica Dispersion



Factors affecting viscosity

Shear Rate

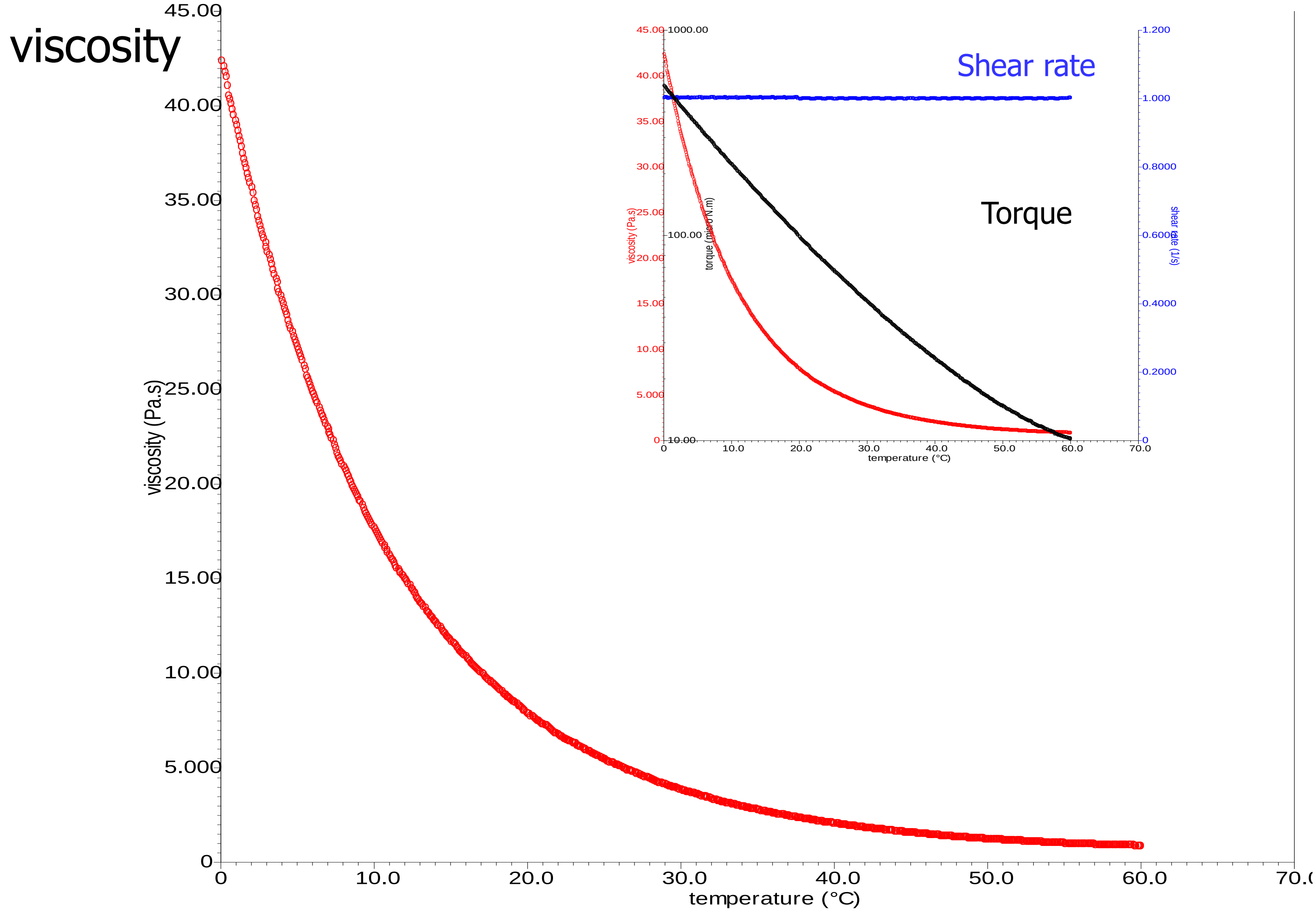
Time of Shearing

Temperature

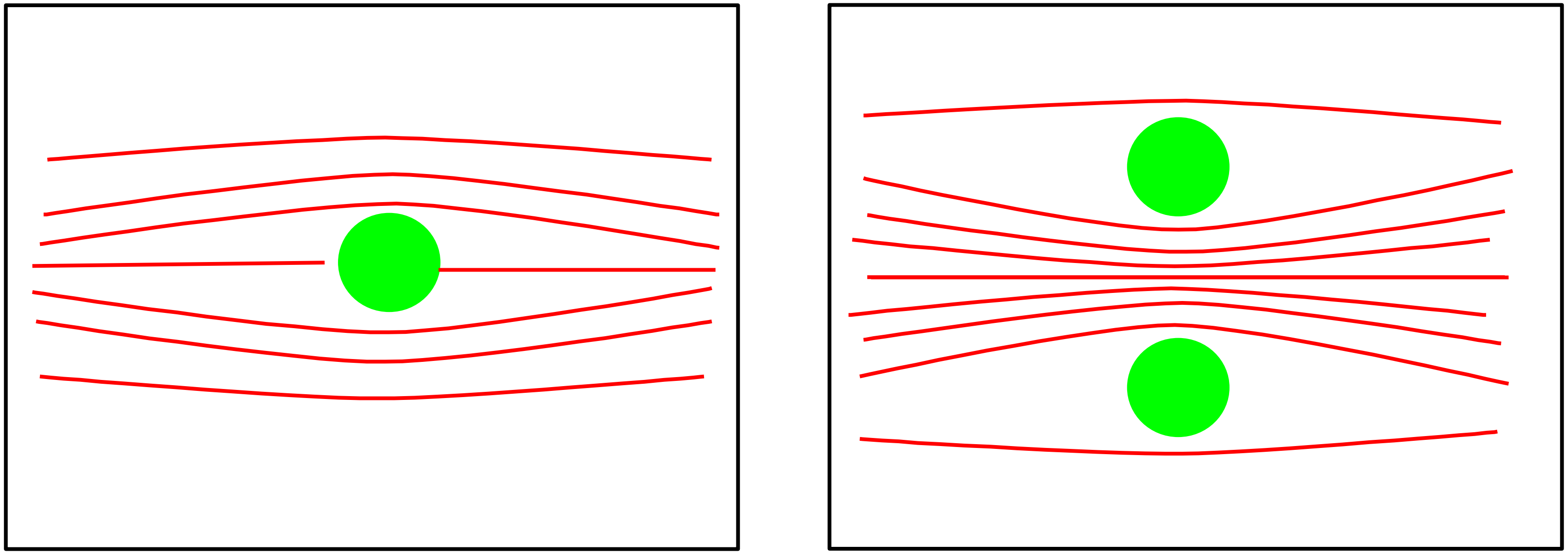
Concentration

Pressure

Effect of Temperature



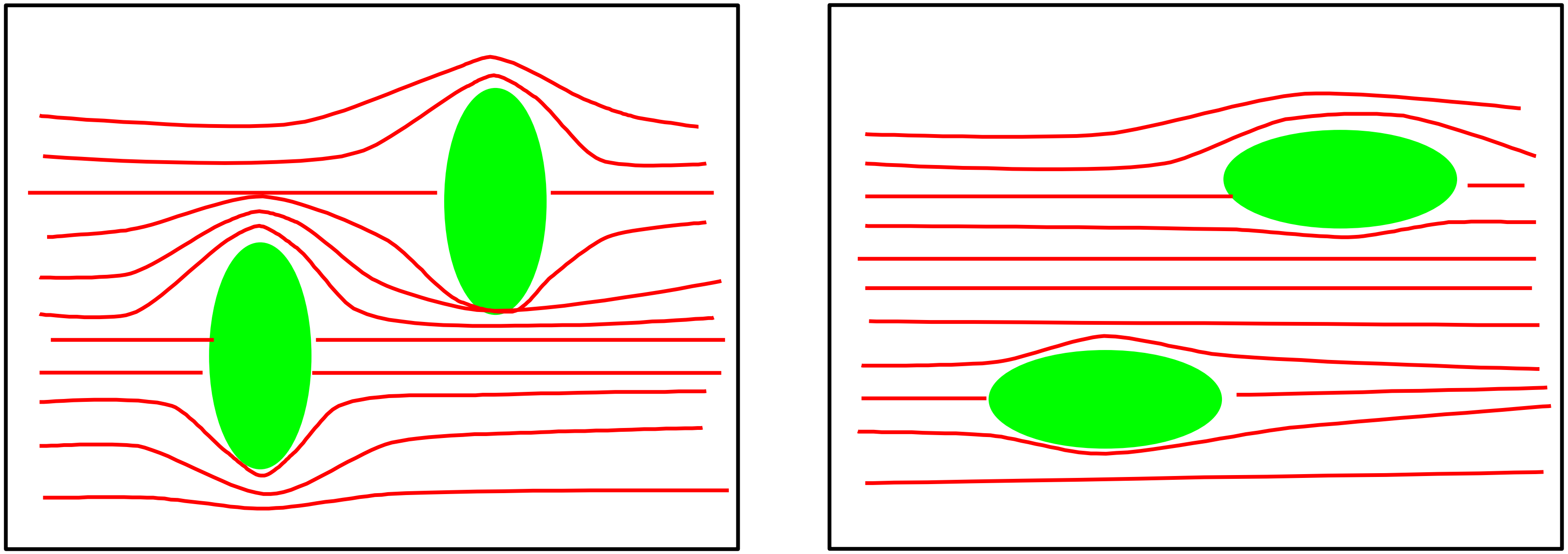
Effect of Concentration or Pressure



Flow restricted as more particles added, i.e. increase concentration

The limiting value of the reduced viscosity as the concentration approaches zero....

Effect of Shape and Alignment

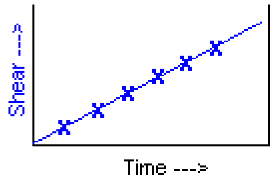


Aligned show less concentrated flow lines

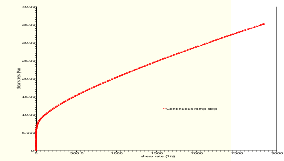
Flow Measurements

Test type

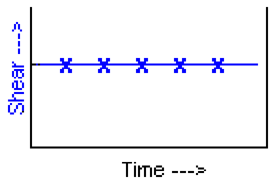
The following test types are available:



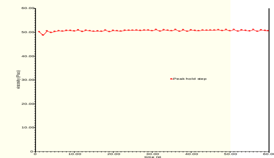
Continuous
Continually ramps the shear and samples at defined intervals.



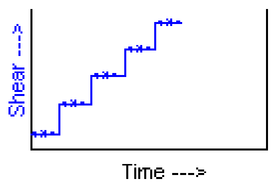
Typical plot shear stress vs. shear rate



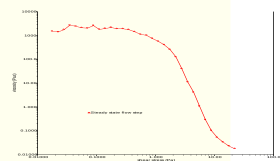
Peak hold
Holds the shear constant and samples at defined intervals.



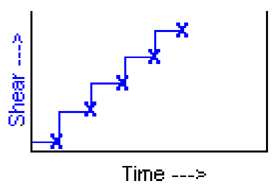
Typical plot viscosity vs. time



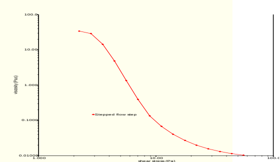
Steady state flow
Applies successive shear values.
Data sampled under equilibrium conditions.



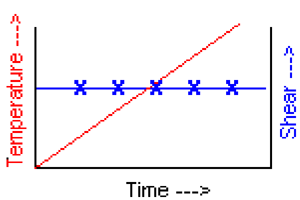
Typical plot viscosity vs. shear stress/rate



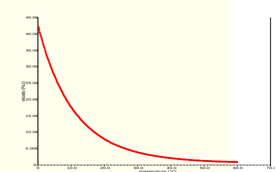
Stepped flow
Applies successive shear values.
Data sampled over last x seconds.



Typical plot viscosity vs. shear stress/rate

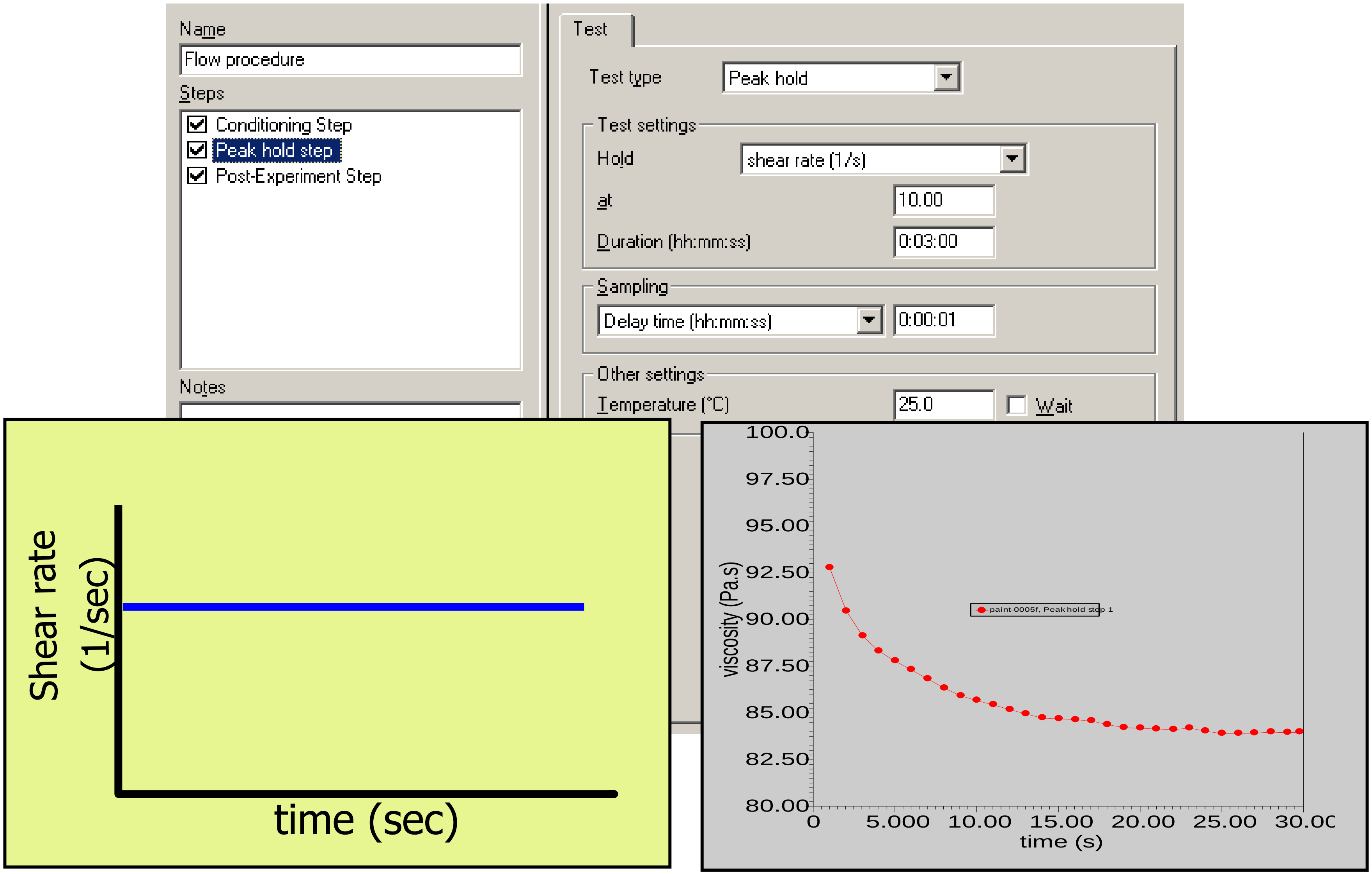


Temperature ramp
Holds the shear constant whilst ramping the temperature.
Samples at defined intervals.

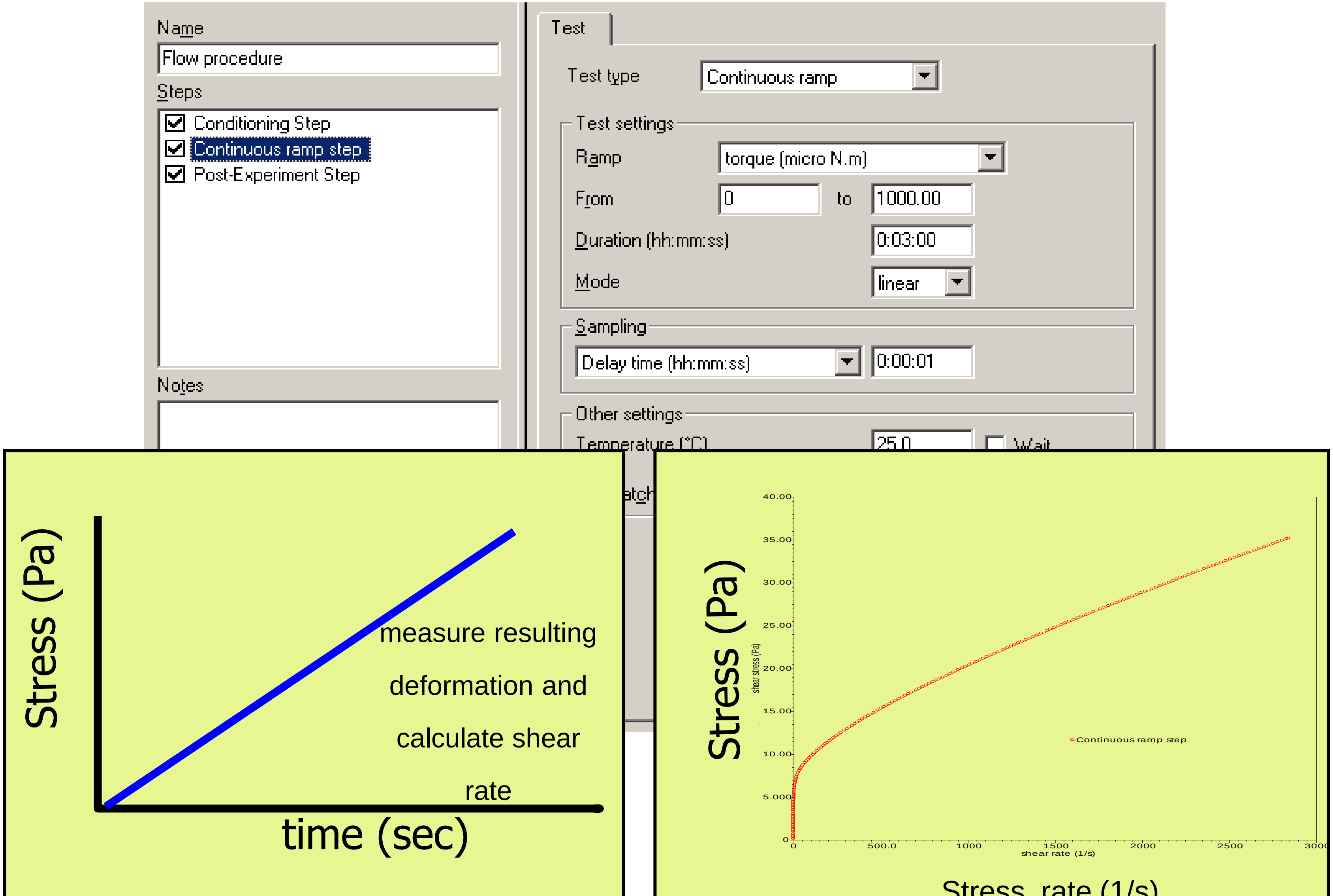


Typical plot shear stress vs. shear rate

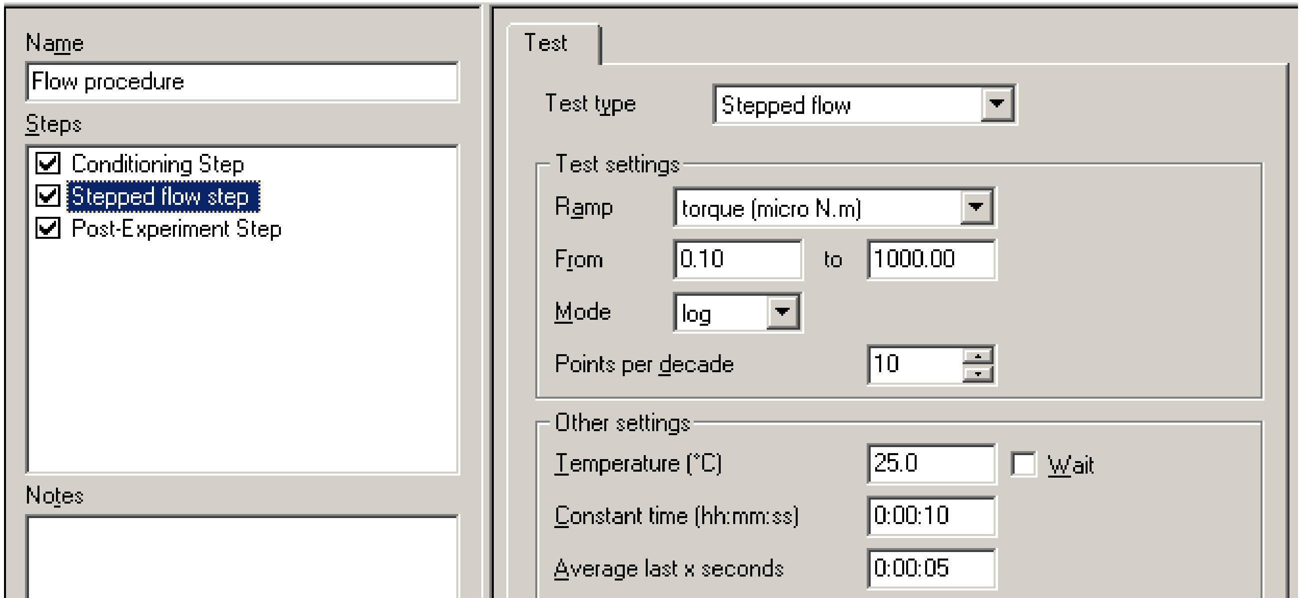
Peak Hold – a “Brookfield” test

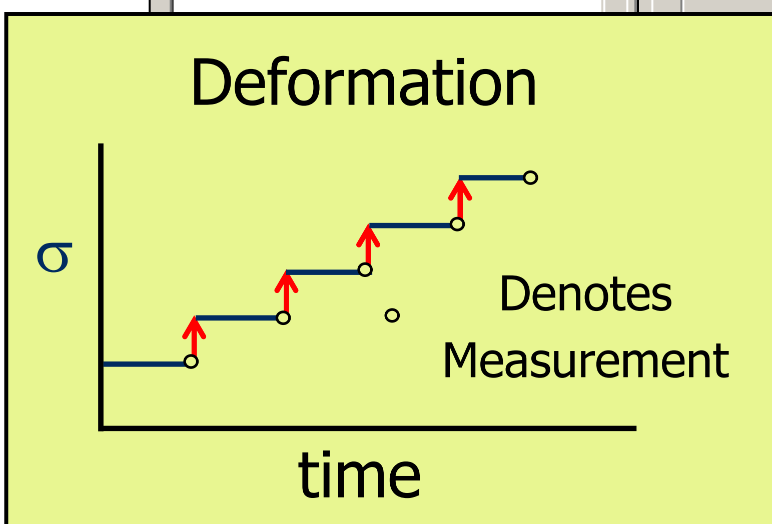


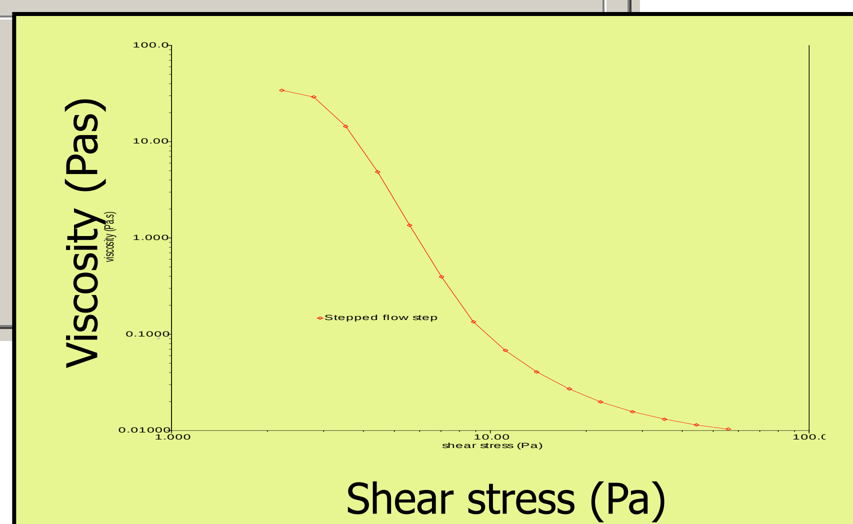
Continuous Flow Template



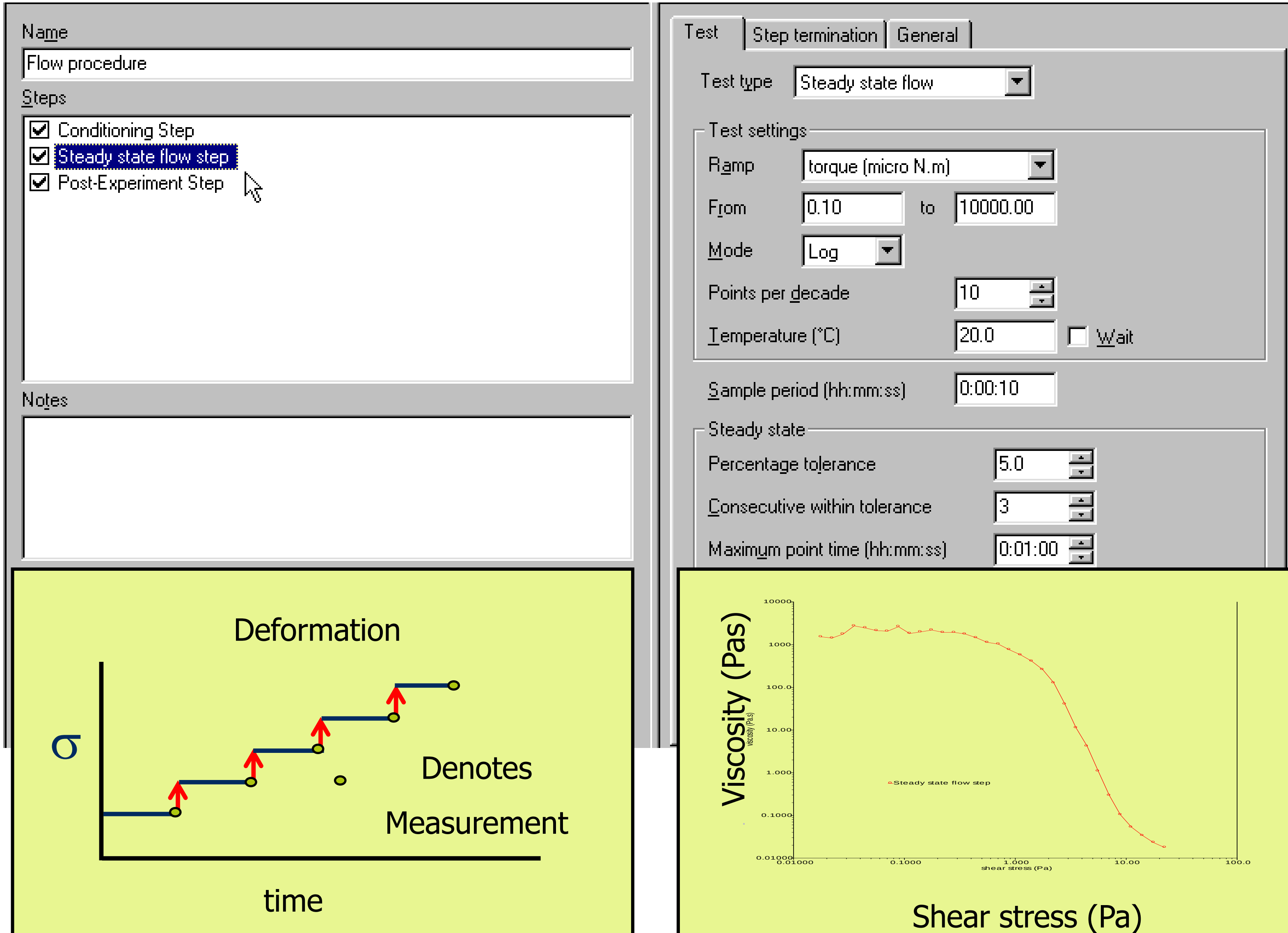
Stepped Flow Template







Steady State Flow Template



Introduction to Viscoelasticity

Viscoelasticity Defined

Range of Material Behaviour

Solid Like ------------------------------- Liquid Like

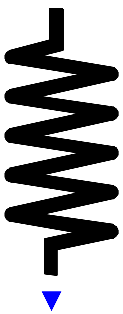
Ideal Solid ----- Most Materials ----- *Ideal Fluid*

Purely Elastic ---- *Visco*elastic --- *Purely Viscous*

Viscoelasticity: Having both viscous and elastic properties

Response for Classical Extremes

Spring

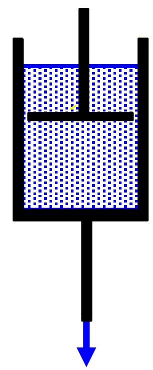


Purely Elastic Response

Hookean Solid

$\sigma = E\varepsilon$ or $\tau = G\gamma$

Dashpot



Purely Viscous Response

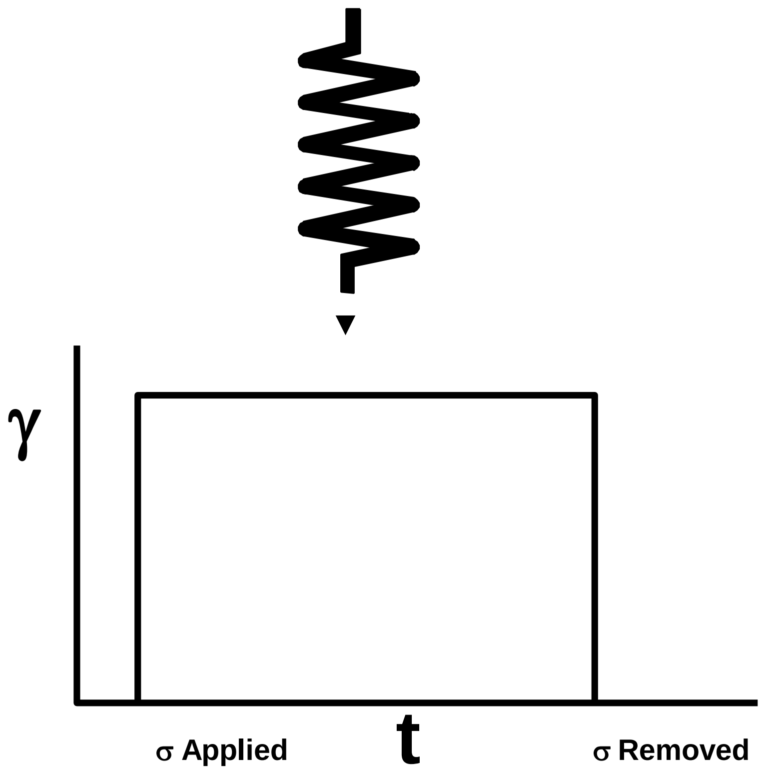
Newtonian Liquid

$= \eta\dot{\gamma}$

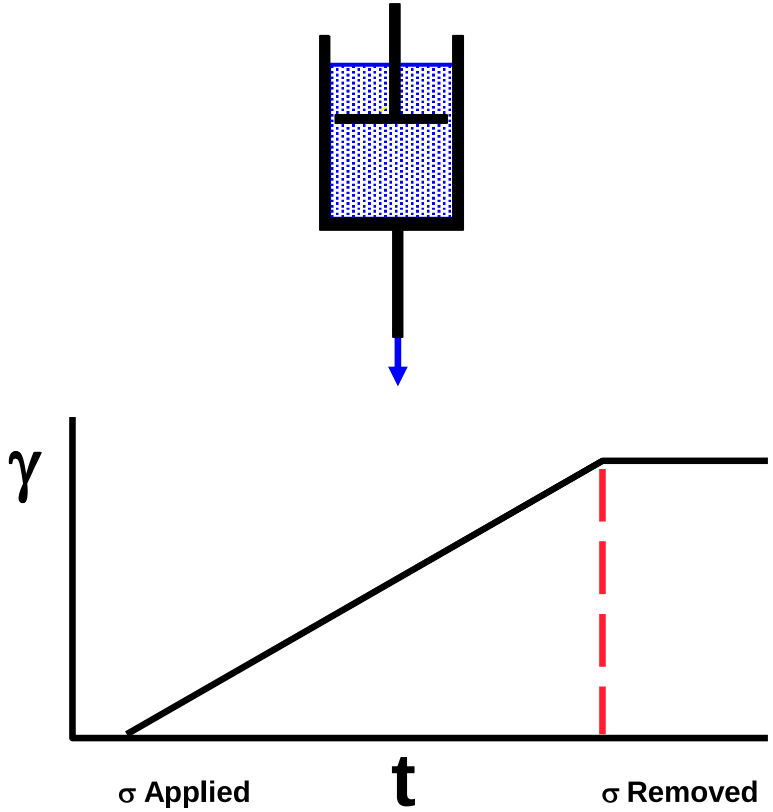
In the case of the classical extremes, all that matters is the values of stress, strain, strain rate. The response is independent of the loading.

Spring and Dashpot Models

Elastic Deformation

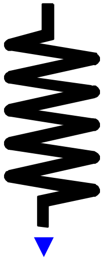


Viscous Flow



Viscoelasticity

Spring



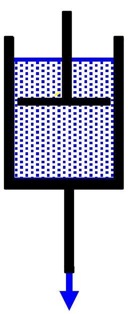
Purely Elastic Response

Hookean Solid

$\sigma = E\varepsilon$ or $\tau = G\gamma$

+

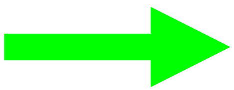
Dashpot



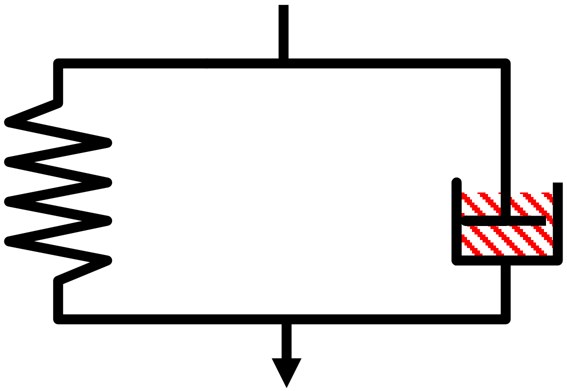
Purely Viscous Response

Newtonian Liquid

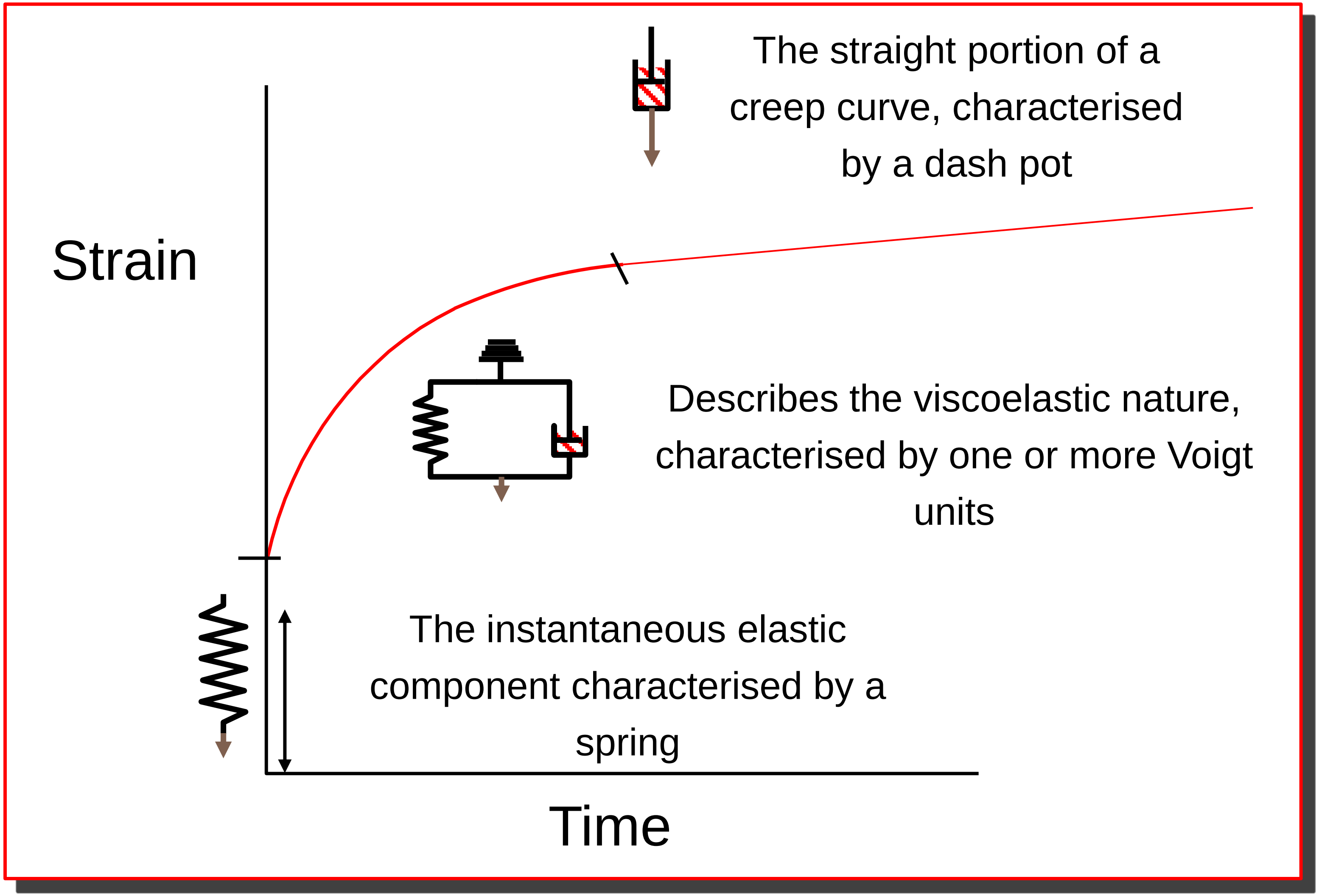
$\sigma = \eta\gamma$



Visco Elastic

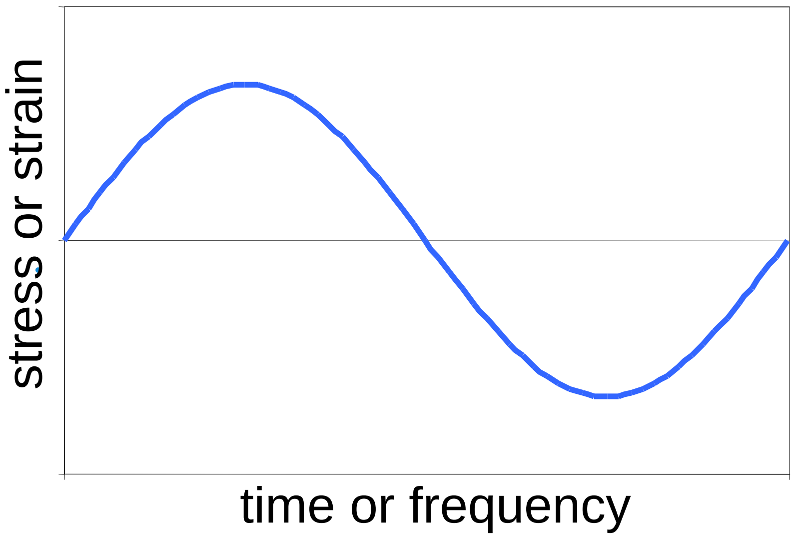


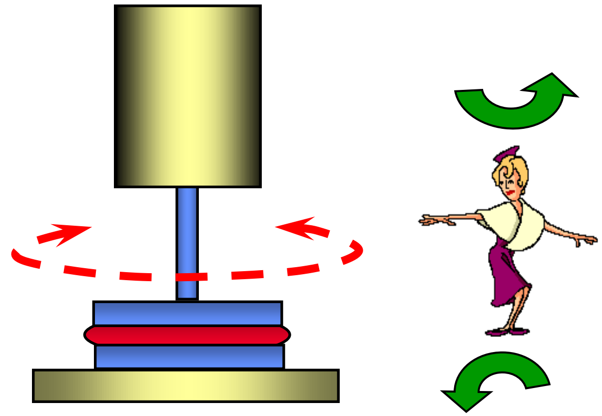
Parts of a creep curve



Introduction to Dynamic Measurements

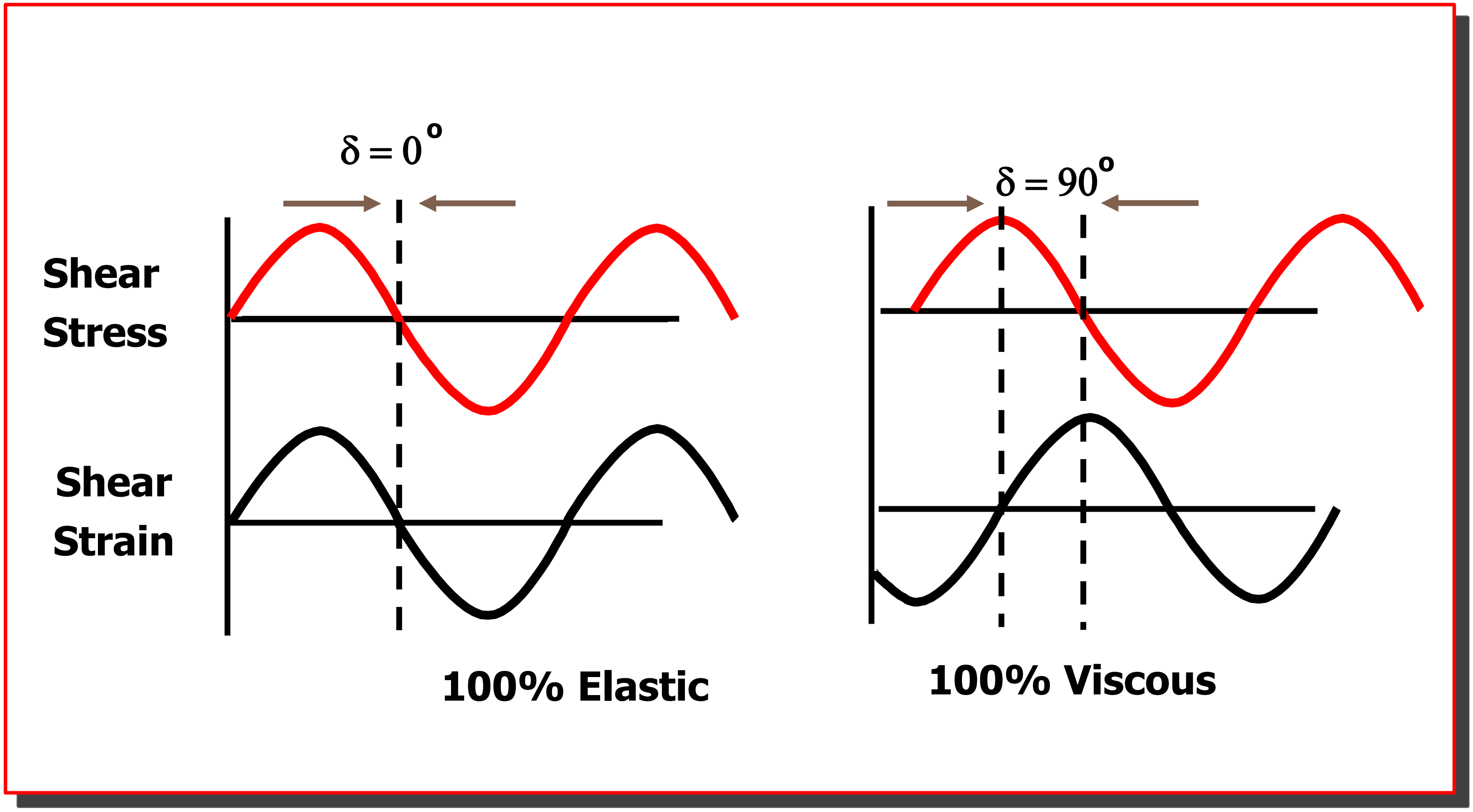
What is Oscillation?





- Deformation applied Sinusoidally
- User defined Stress or Strain amplitude, frequency & temperature
- Control either
  - Amplitude – test how robust a material is
  - Frequency –responses to the rate at which energy is given
  - Temperature – cures and transitions
  - Nothing – watch structure form

Oscillation



Viscoelastic Parameters

G* - Complex Modulus: Measure of materials overall resistance to deformation.

$$G^* = Stress^*/Strain$$
$$G^* = G' + iG''$$

G' - Elastic (Storage) Modulus: Measure of elasticity of material. The ability of the material to store energy.

$$G' = (stress^*/strain)\cos\delta$$

G" - Viscous (Loss) Modulus: The ability of the material to dissipate energy. Energy lost as heat.

$$G'' = (stress^*/strain)\sin\delta$$

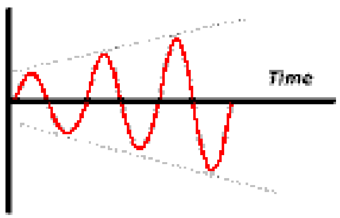
Tan Delta: Measure of material damping - such as vibration or sound damping.

$$\tan\delta = G''/G'$$

Modes of Operation

Oscillation procedure type

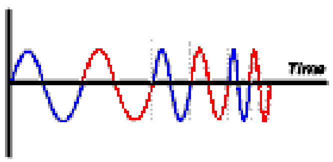
The following test types are available:



Strain / Stress Sweep

Applies a fixed frequency and increments the amplitude of the strain or stress.

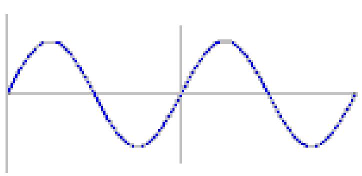
identification of the linear viscoelastic region (LVR)



Freq. Sweep

Applies a fixed amplitude and changes the frequency.

"rheological fingerprint"



Temperature ramp

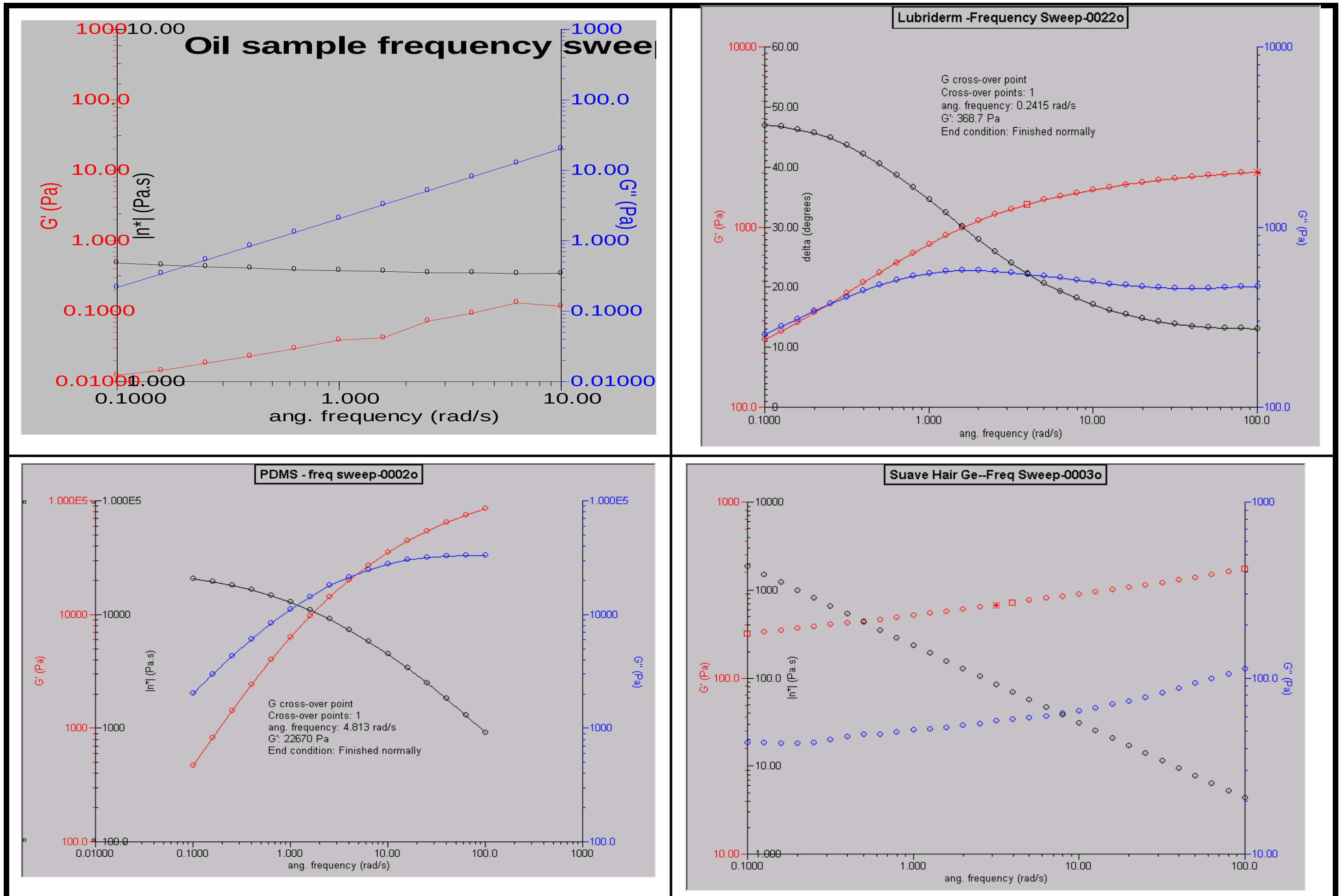
Applies a fixed frequency with a set amplitude. Monitors viscoelastic properties as a function of time / temperature.

Time / Temperature sweep

As per ramp , but applies a sequence of discrete temperature steps rather than a smooth ramp.

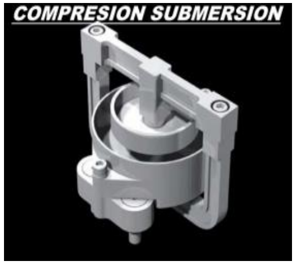
Process conditions, cure and physical transitions

Frequency Sweep Results



- It may look very different depend on samples

Dynamic Mechanical Analysis (DMA)



Modes of Operation:

1- MULTI-FREQUENCY

The multi-frequency mode can assess viscoelastic properties as a function of frequency, while oscillation amplitude is held constant. These tests can be run at single or multiple frequencies, in time sweep, temperature ramp, or temperature step/hold experiments.

2 - MULTI-STRESS/STRAIN

In this mode, frequency and temperature are held constant, and the viscoelastic properties are monitored as strain or stress is varied. This mode is primarily used to identify the Linear Viscoelastic Range (LVR).

3 - CREEP/STRESS RELAXATION

With creep, the stress is held constant and deformation is monitored as a function of time. In stress relaxation, the strain is held constant and the stress is monitored vs. time.

4 - CONTROLLED FORCE/STRAIN RATE

In this mode, the temperature is held constant while stress or strain is ramped at a constant rate. It is used to generate stress / strain plots to obtain Young's Modulus. Alternatively, stress can be held constant with a temperature ramp while strain is monitored.

5 - ISOSTRAIN

In isostrain mode, available on the Q800, strain is held constant during a temperature ramp. Isostrain can be used to assess shrinkage force in films and fibers