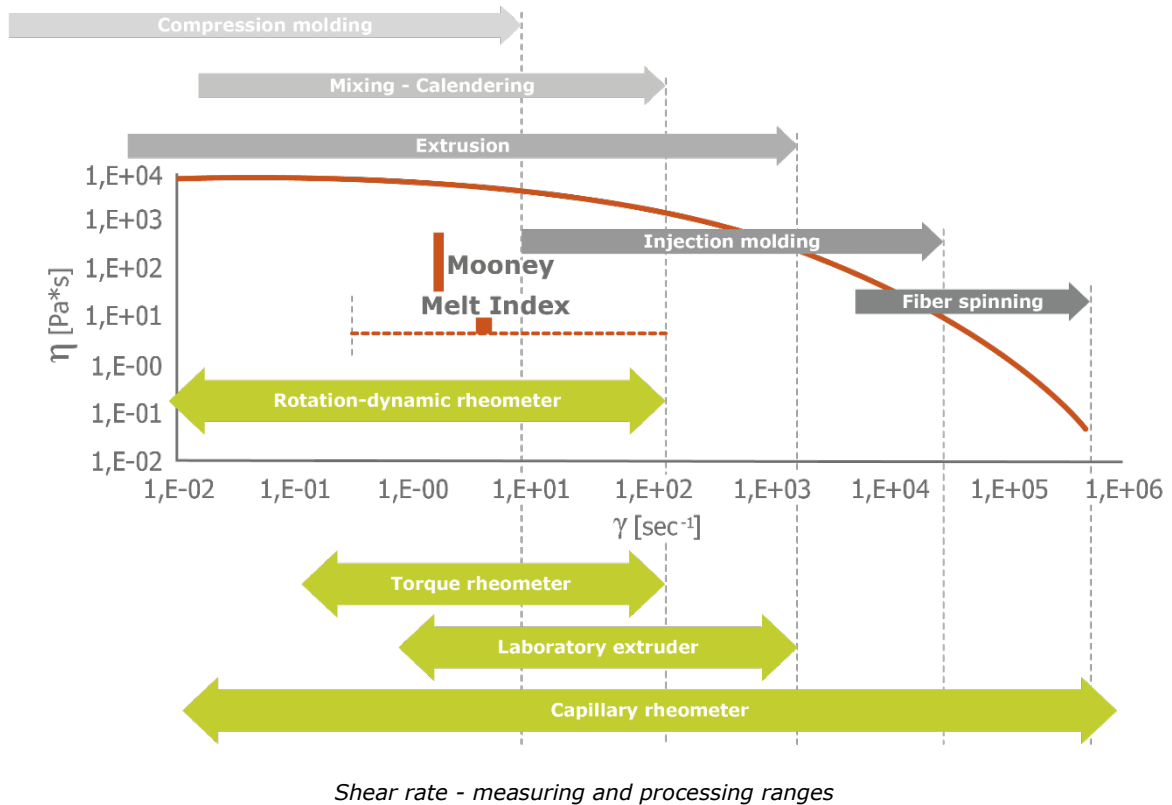


### Determining operating points in extruders and dies

It is vital to know the exact operating point conditions in order to be able to assess the impacts of viscosity differences realistically in the fields of plastics extrusion and injection molding. Furthermore, information about the operating conditions allows you to determine the size of the measurement window for testing. The process-determining factor is the shear rate. The actual shear rate is determined from geometry parameters and the volume flow. An estimation as a guideline for various processes and measuring instruments is shown in the following diagram.

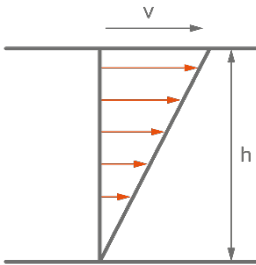


### Simple equations for determining the shear rate

A more detailed analysis than the estimation in the diagram above is provided by a numerical calculation of the shear rate in the respective melt flow-way of the process as a function of geometry and volume flow. In this case, the shear rates in melt flow-ways can either be determined in a complex manner through simulation programs or be approximated quite well using simple models. The latter method offers a simple way to determine the shear rate or shear rate range at which the measurement is performed and which can be used for effective material selection to compare the viscosity of various materials at the respective shear rate or shear rate range of the operating point.

These simple models are:

**Two-plates model** for a gap with a moving plate:

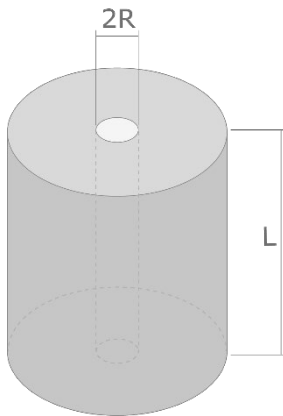


$$\dot{\gamma}_{ap} = \frac{v}{h}$$

where v      speed of the plate  
h              gap height

Pipe flow for round and slit geometry

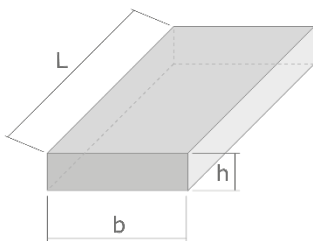
**Round hole die:** Apparent shear rate: GAMap [s<sup>-1</sup>]



$$\dot{\gamma}_{ap} = \frac{4 \cdot \dot{V}}{\pi \cdot R^3}$$

where  $\dot{V}$       volume flow generated by piston  
R              radius of the capillaries

**Slit die:** Apparent shear rate: GAMap [s<sup>-1</sup>]



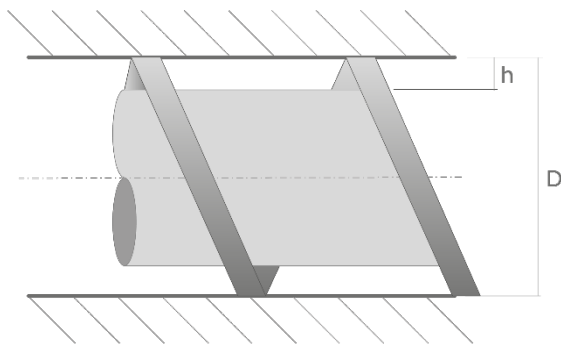
$$\dot{\gamma}_{ap} = \frac{6 \cdot \dot{V}}{b \cdot h^2}$$

Where  $\dot{V}$       volume flow generated by piston  
b              slit width  
h              slit height

## Application examples

### Determining the shear rate in the extruder screw:

The two-plates model can be used to estimate the shear rate in the screw section of an extruder. The speed of the moving plate  $v$  results from the screw diameter and the extruder speed as



$$v = \pi * D * n / 60$$

where  $D$  = screw diameter [mm]

$n$  = extruder speed in [rpm]

And the shear rate results from

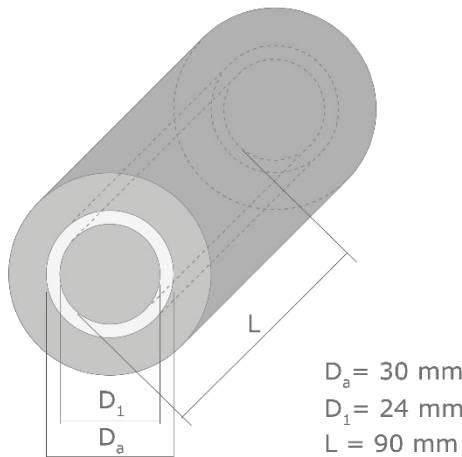
$$\dot{\gamma}_{ap} = \frac{\pi * D * n}{60 * h}$$

Example: For a 90mm extruder, the apparent shear rate results from a thread depth of 4.5mm in the zone close to the head and at a speed of 60rpm:

$$\dot{\gamma}_{ap} = \frac{\pi * 90 * 60}{60 * 4,5} = 62,8 \text{ 1/s}$$

## Determining the shear rate in a pipe die

The respective pipe die has the following geometry:



The line speed of the haul-off is 25m/min.

The volume flow is determined by the cross-section of the extruded material and the speed:

$$\dot{V} = \frac{\pi}{4}(D_a^2 - D_i^2) \cdot v = \frac{\pi}{4}(30^2 - 24^2) \cdot 50 \cdot \frac{1000}{60} [\text{mm}^3/\text{s}] =$$

212057,5 mm<sup>3</sup>/s

The geometry can be considered as a slit by cutting it open. The resulting shear rate is this:

$$\dot{\gamma} = \frac{6 \cdot \dot{V}}{b \cdot h^2} = \frac{6 \cdot 212057,5}{24 \cdot \pi \cdot 3^2} [1/\text{s}] = 1875 [1/\text{s}]$$

This information can then be used to analyze any material differences in the shear rate range around the operating point.

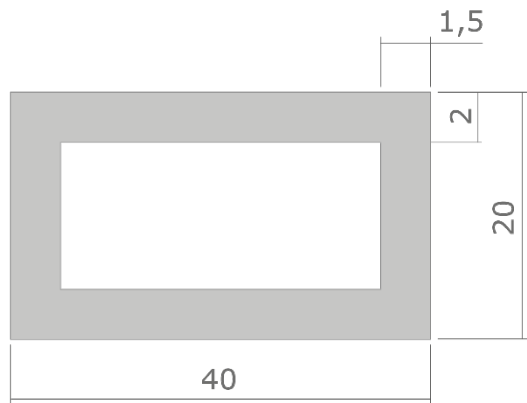
If the length of a parallel melt flow-way in a die or die segment is known, a rough estimate of the extrusion pressure can also be made with the aid of the viscosity measurement using the following equation:

$$\tau_{ap} = \eta \cdot \dot{\gamma} = \frac{p \cdot h}{2 \cdot L} \quad \text{transformed, the equation for the pressure is then:}$$

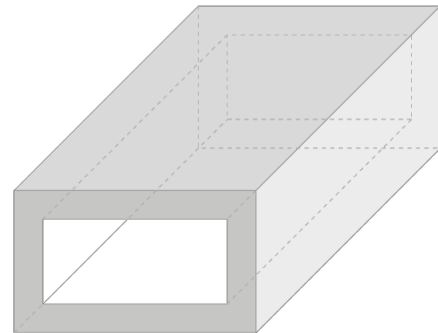
$p = \frac{\eta \cdot 12 \cdot L \cdot \dot{V}}{b \cdot h^3}$  with a viscosity of 182Pas at a shear rate of 18751/s and a length of 90mm, the pressure is

$$p = \frac{182 \cdot 12 \cdot 90 \cdot 212057,5}{(24 \cdot \pi) \cdot 3^3} = 205 \text{ bar}$$

## Calculating the shear rate in a profile die



Extrusion die



Extrusion profile

The line speed  $v$  of the haul-off is 15m/min

The die is initially divided into slit segments. For each segment, the volume flow is calculated as  $V = v * H_i * B_i$  for segment  $i=1$  or 2.

Segment 1:

$$\dot{V} = v * H_1 * B_1 = \frac{15000}{60} * 1,5 * 20 \text{ mm}^3/\text{s} = 7500 \text{ mm}^3/\text{s}$$

$$\dot{\gamma} = \frac{6 * \dot{V}}{B * H^2} = \frac{6 * 7500}{20 * 1,5^2} \left[ \frac{1}{\text{s}} \right] = 1000 \left[ \frac{1}{\text{s}} \right]$$

Segment 2:

$$\dot{V} = v * H_1 * B_1 = \frac{15000}{60} * 2 * 40 \text{ mm}^3/\text{s} = 20000 \text{ mm}^3/\text{s}$$

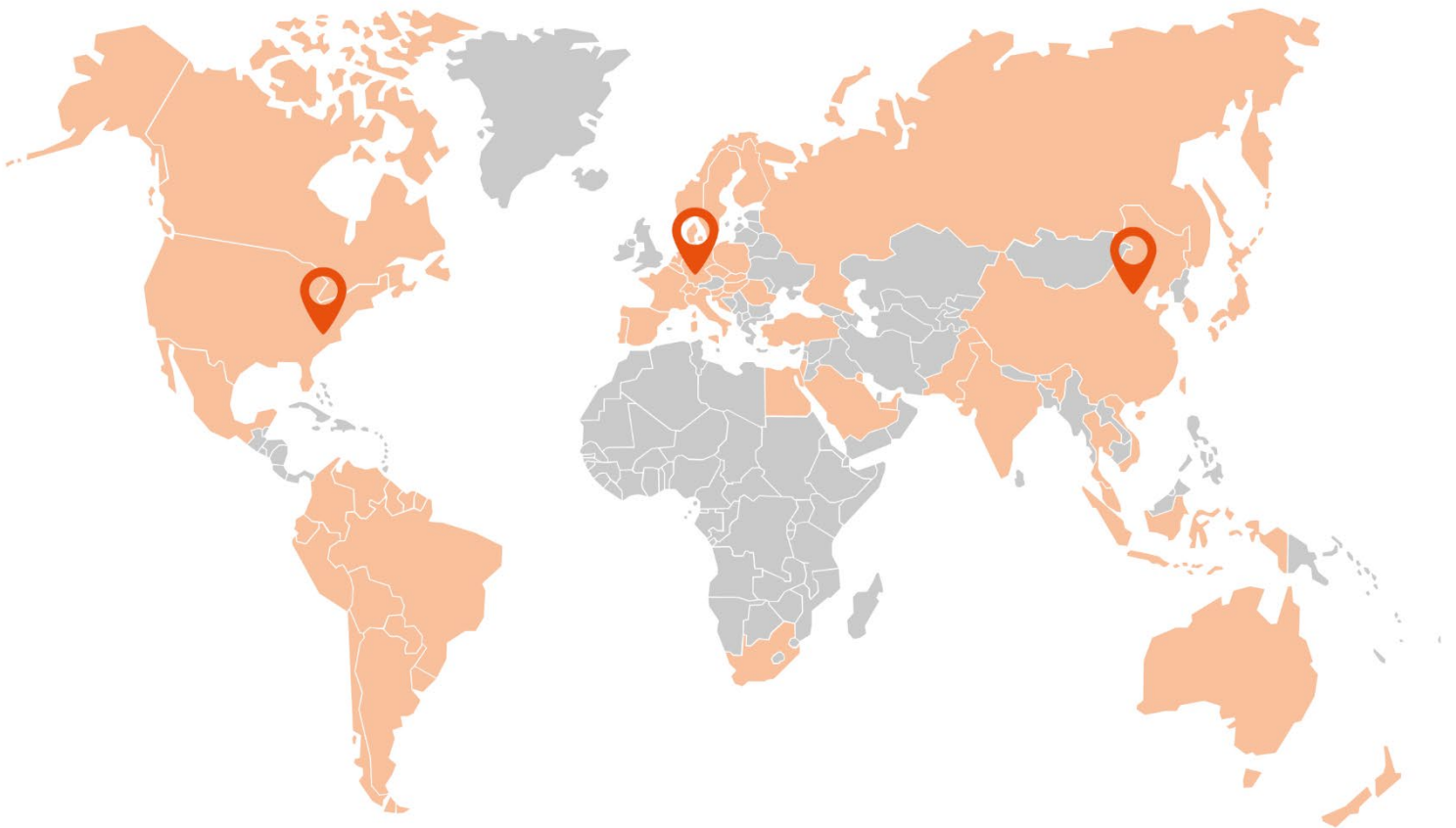
$$\dot{\gamma} = \frac{6 * \dot{V}}{B * H^2} = \frac{6 * 20000}{40 * 2^2} \left[ \frac{1}{\text{s}} \right] = 750 \left[ \frac{1}{\text{s}} \right]$$

## Summary

As shown by the calculations, even a simple examination allows an effective estimation of the operating point with the following advantages:

- Determination of the relevant shear rate range for the measurement
- Evaluation of different materials very close to the operating point with regard to the viscosity level and the resulting pressure development in the die
- Estimation of the pressure loss in the die with simple geometries

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