MPC
Materials Processing Consultants LLC

# Twin Screw Extruder and Continuous Mixer Rate Limitations

Anthony C. Neubauer
SPE Fellow; Dow Fellow (retired)

Materials Processing Consultants LLC

# Why Extruders?

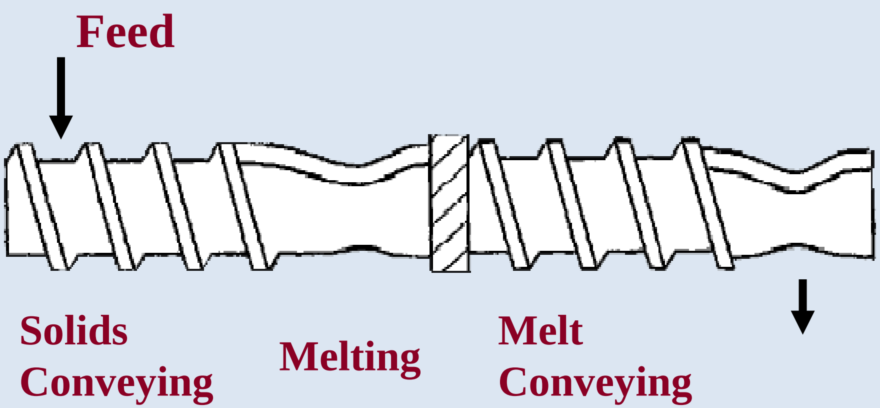
- Ideal for processing viscous fluids; e.g., polymers
  - Melting
  - Pressure Generation
  - Blending and Compounding
  - Devolatilization
  - Reactive Extrusion

Morphology Conversion (Melting, Pressure Generation)

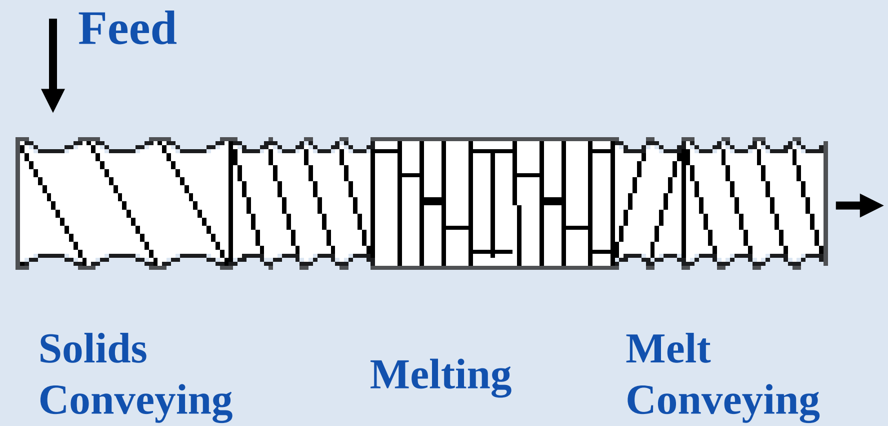
e.g., blown film
blow molding
injection molding
sheet
tubing / pipe
granular → pellets

# Equipment Description

## Continuous Mixer




## Twin Screw Extruder




**In essence, a series of forward acting and reverse acting screw 'pumps' with & without throttling systems.**

# Assumptions

- **Resin Feed System not Limiting**
- **Starved Fed, i.e., not Flood Fed**
- **Downstream Processing Systems not Limiting**
  - **Melt Filtration**
  - **Die Pressure**
  - **Etc.**

# Rate Limiting Systems

- **Power (Torque)**
- **Feed Neck; i.e., <u>no longer Starved Fed</u>**
  - **Feed Throat Fluidization**
  - **Solids Conveying**
  - **Screw Channel Fluidization**
  - **Melt Conveying**
  - **Melting Section**
- **Other**
  - **Compounding and Blending**
  - **Reactive Extrusion**
  - **Devolatilization**

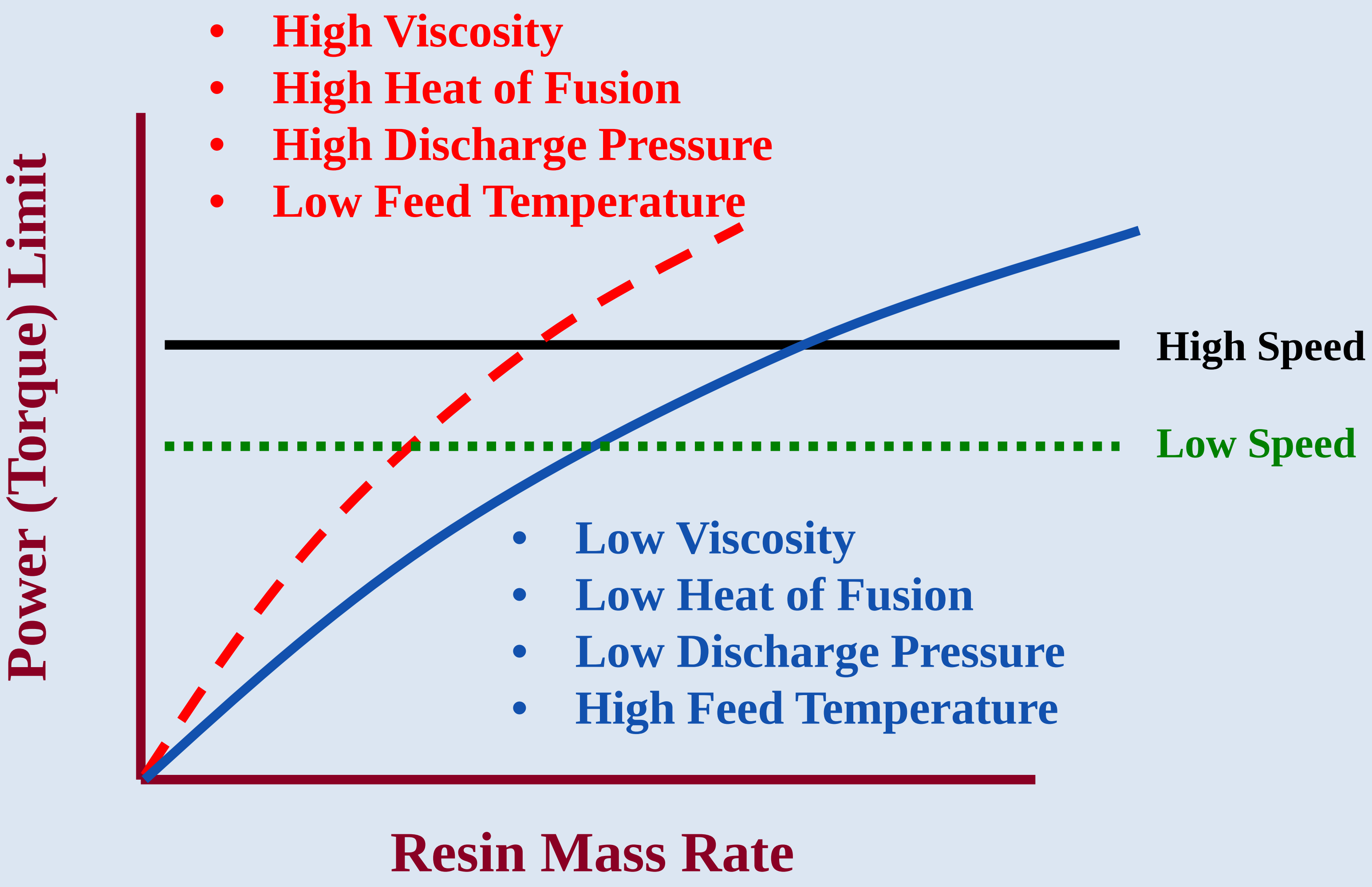
# Power (Torque) Limitation

$$Rate_{\max} = \frac{\text{Maximum Allowable Power}}{\text{Specific Energy Input (SEI)}}$$

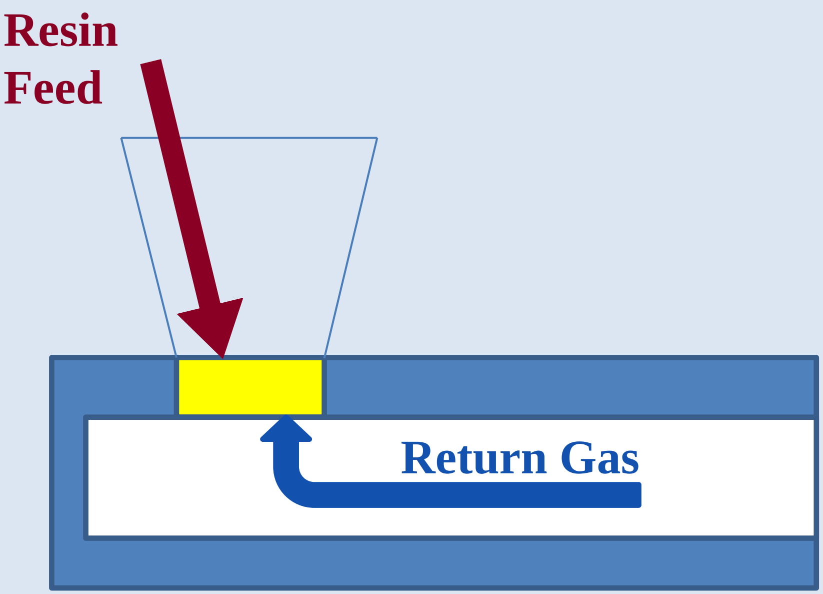
**SEI is a function of:**

- **Polymer Type**
  - **Viscosity; MW and MWD**
  - **Heat of Fusion**
- **Screw / Rotor Geometry**
- **Operating Conditions**
  - **Speed, Feed Rate, Feed Temperature**
  - **Discharge Pressure**
  - **Slot / Gate / Throttle Valve Position (if applicable)**

# Power (Torque) Limitation



# Feed Throat Fluidization




**Return Gas is the result of the Δ between solid and melt bulk densities; e.g.,**

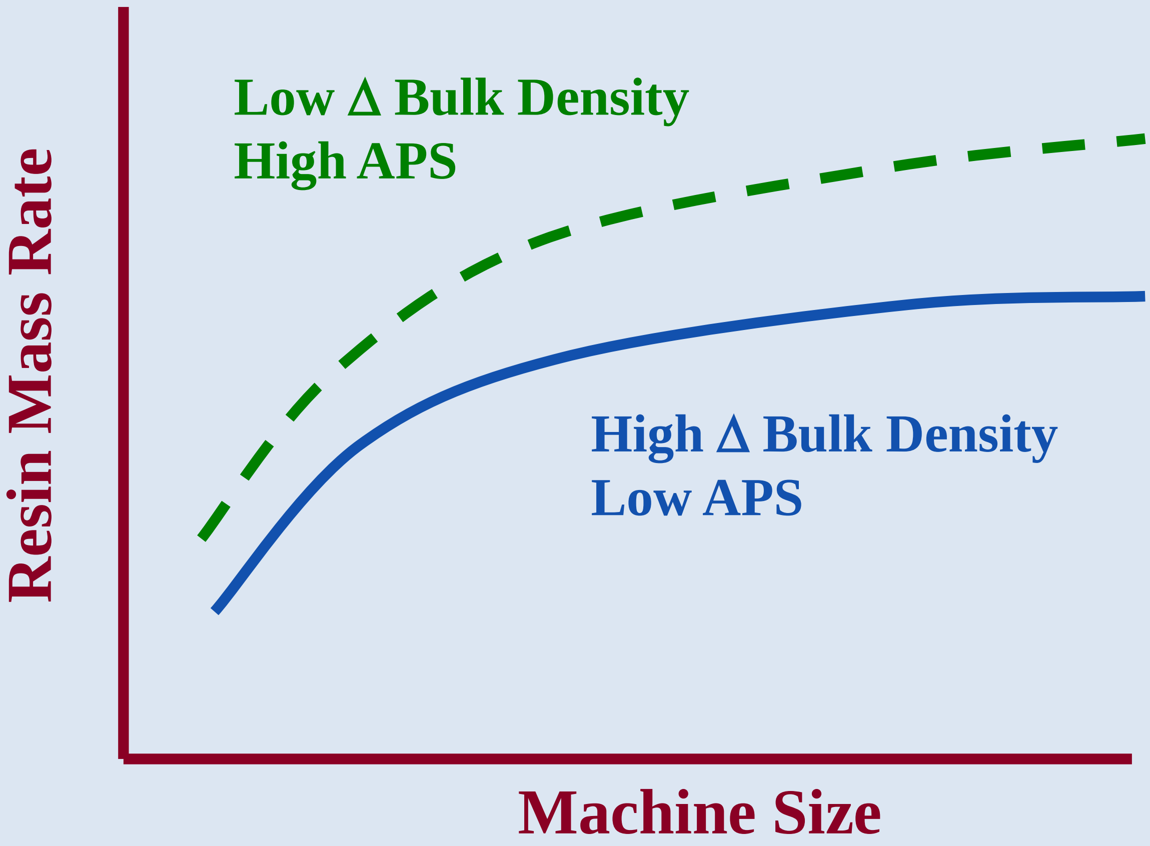
| | Bulk Density, $kg/m^3$ | Volumetric Rate, $m^3/hr$ |
|---|---|---|
| Solid | 400 | 4.0 |
| Melt | 800 | 2.0 |
| | Δ = | 2.0 |

**Basis: 1,600 kg/h Resin Feed Rate**

| | Velocity, m/s |
|---|---|
| Resin | 0.17 |
| Gas | 0.09 |

**Basis: 90 mm Ø Port**

# Feed Throat Fluidization



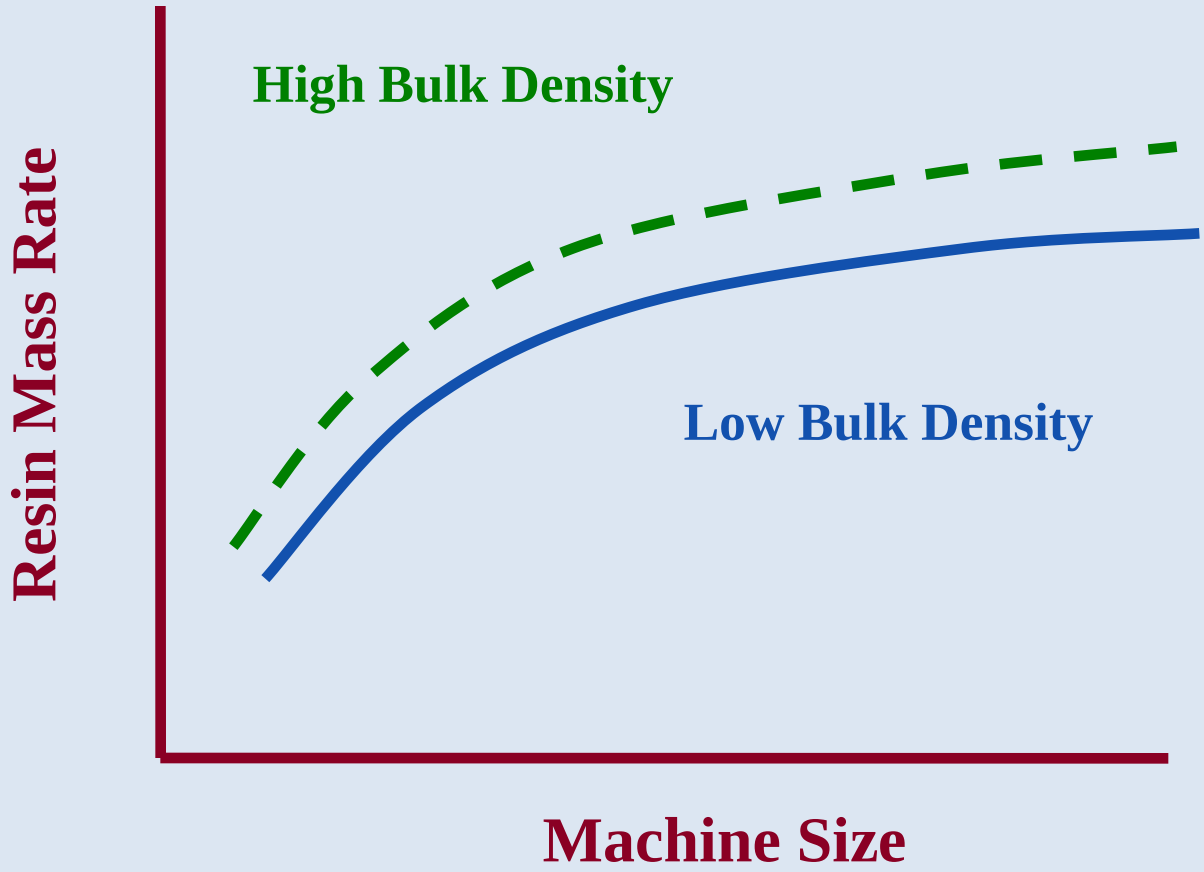

**Scale-Up**

rate $\propto D^3$

area $\propto D^2$

APS = Average Particle Size

# Solids Conveying



# Screw Channel Fluidization

$$\text{Ratio} = \frac{\text{Superficial Gas Velocity}}{\text{Minimum Fluidization Velocity}}$$

**Less than 5:**

**No fluidization in the screw channels.**

**Greater than 8:**

**Sufficient fluidization within the screw channel to result in rate limitation.**

# Fluidization Solutions

- Increase cross-sectional area - free volume
  - rectangular feed throats
  - modify screw cross-section profile
- Increase screw / rotor speed
- Increase effective particle size and bulk density
  - co-feed large particles
  - use cohesive additive
- Design TSE / CM with up or down stream vents
- Install force feeder (crammer / stuffer)

# Melt Conveying

## Governing Equation:

$$\dot{Q}_{net} = \dot{Q}_{drag} - \dot{Q}_{pressure}$$
$$= \alpha * N - \frac{\beta * P}{\mu}$$

## Melt conveying increases when:

Free volume increases

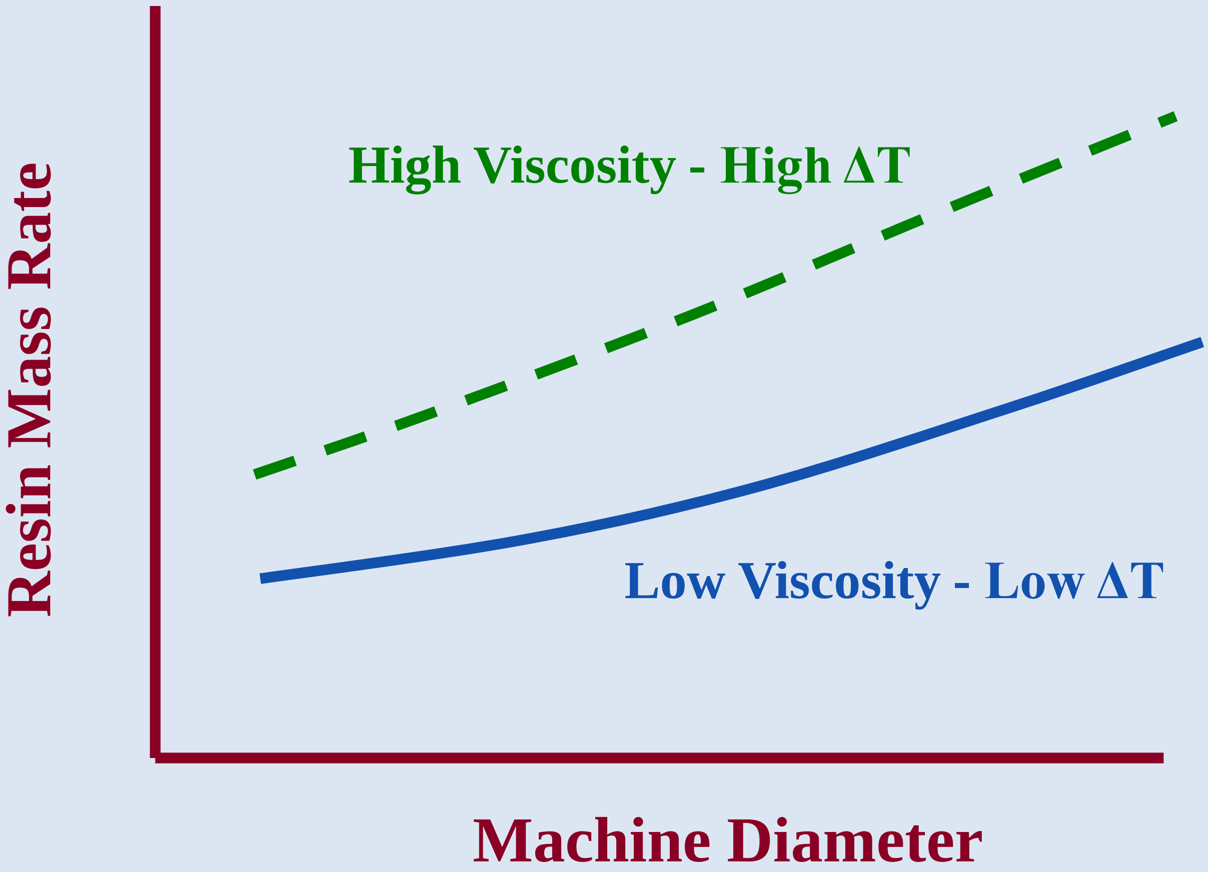
Speed increases

Discharge pressure decreases

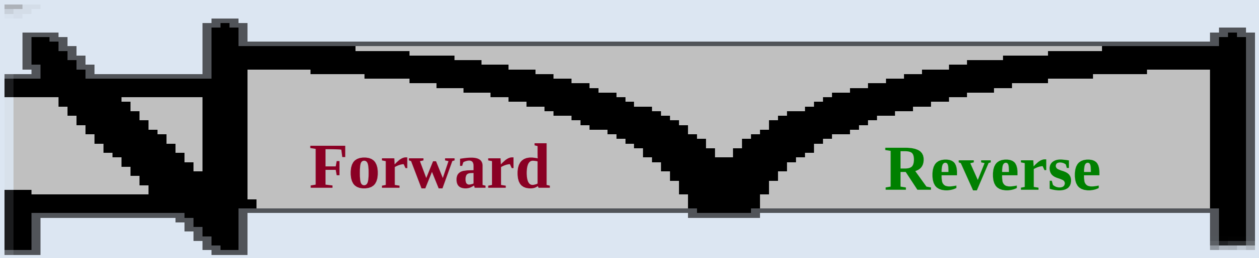
Viscosity increases

$\alpha$, $\beta$ = geometric constants

# Melting Section
# Continuous Mixer



# Why?




$$\dot{Q}_{net} = \left(\dot{Q}_D - \dot{Q}_P\right) - \left(\dot{Q}_D - \dot{Q}_P\right)$$

α, N = constant

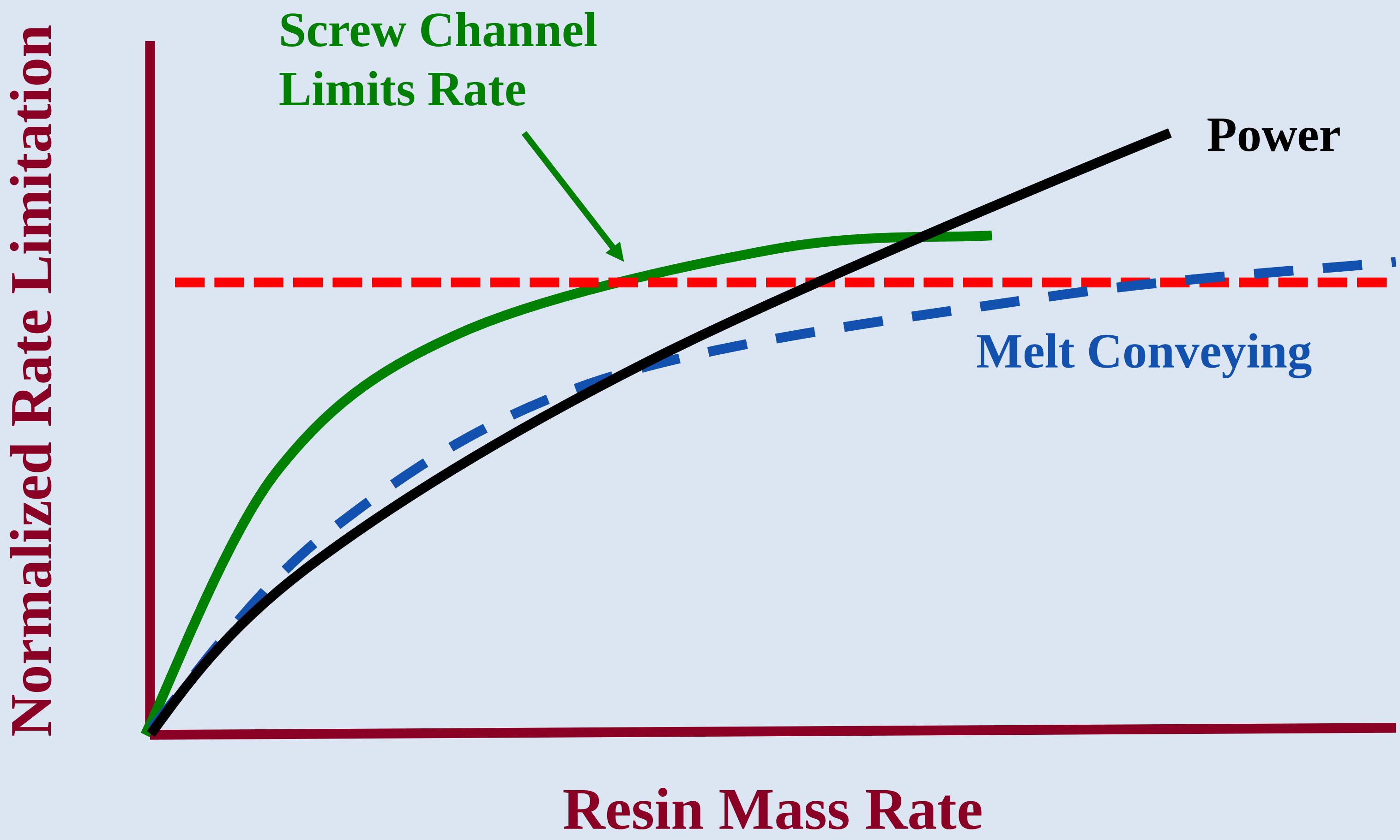
$$= \frac{\beta * P * (\mu_F - \mu_R)}{\mu_F * \mu_R}$$

| Viscosity | ΔT | Δμ | $Q_{net}$ |
|---|---|---|---|
| High | High | High | +++ |
| Low | Low | Low | + |

# Melting Section
# Twin Screw Extruder

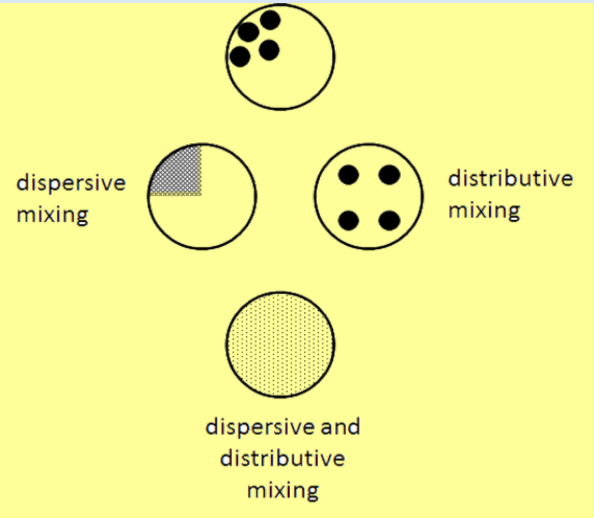
- **Difficult to generalize**
  - **Principles similar**
- **'Infinite' number of combinations**
- **Refer to manufacturers “Processing Guidelines”**
  - **Basic operating characteristics**

# Combined Results



# Rate Limiting Systems - Other

- Blending and Compounding
  - Distributive mixing
  - Dispersive mixing
- Reactive Extrusion
  - Injection & mixing of reactants
  - Activation energy, kinetics, etc.
  - Residence time
- Devolatilization
  - Diffusion, surface renewal, etc.
  - Mixing; e.g., stripping agent
  - Vent gas flow velocity




Vacuum ports

vapor-liquid separation

Souders-Brown eq.

$$V = k\sqrt{\frac{\rho_l - \rho_v}{\rho_v}}$$

where k = 0.064 m/s

# References


- Neubauer, A.C., Leach, E.A., "Twin Screw Extruder and Continuous Mixer Rate Limitations“, *SPE ANTEC Technical Papers*, **49**, 327 (2003)
- Souders, M., Brown, G.G., “Design of Fractionating Columns, Entrainment and Capacity”, *Industrial and Engineering Chemistry*, **26,** 98 (1934)
- Todd, D.B., “Polymer Devolatilization”, *32nd SPE ANTEC Technical Papers*, 472 (1974)
- Biesenberger, J.A. (ed.), **Devolatilization of Polymers: Fundamentals, Equipment, Application**, Hanser (1983)

Questions ??