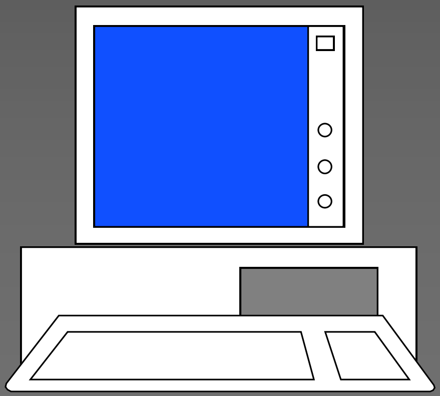
Understanding the Role of Material Properties in Simulations- Part 2

- Hubert Lobo

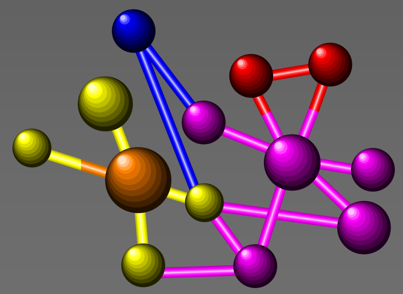
Introduction - Virtual Manufacturing (CAE)

- The computer as a virtual process laboratory
  - – understand the process
  - – create and test scenarios
  - – make improvements at design stage

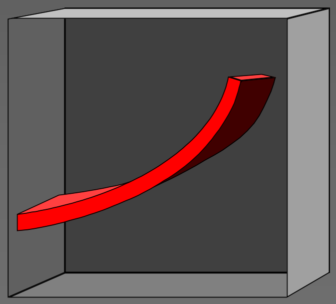


Introduction- Material Properties

- Plastics in simulation
  - Each plastic has a unique property profile
  - The importance of proper representation



=



Scheme of presentation

- Define property requirements
- Identify evaluation parameters
- Follow the injection molding process
- Identify the role of material properties at each stage of the process

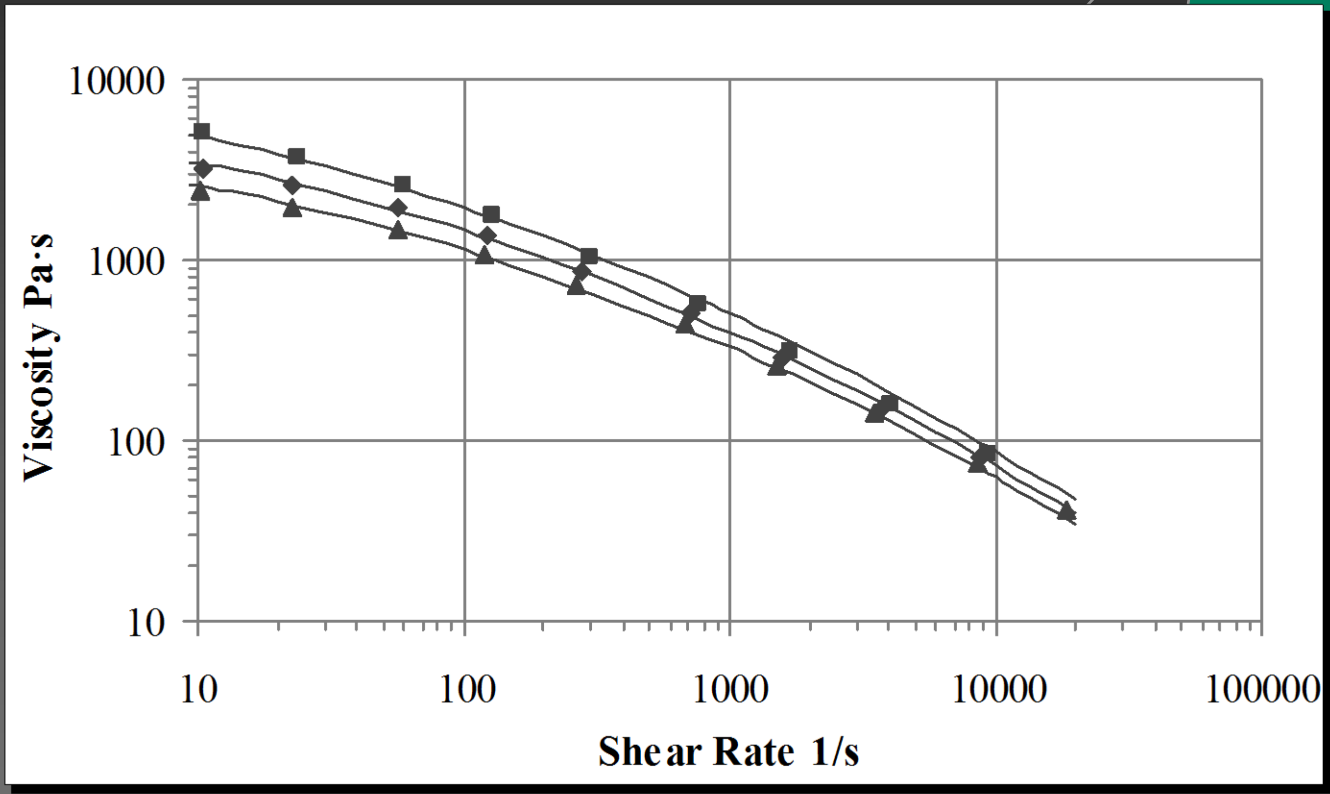
Modes of analysis- mold filling

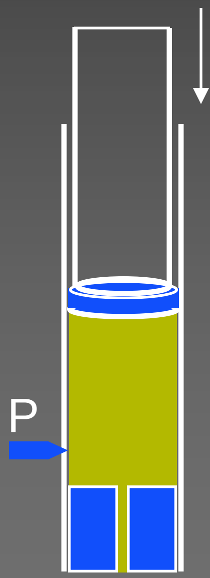
- mold filling
- mold cooling
- post filling simulations
- shrink/warp

Data requirements- mold filling

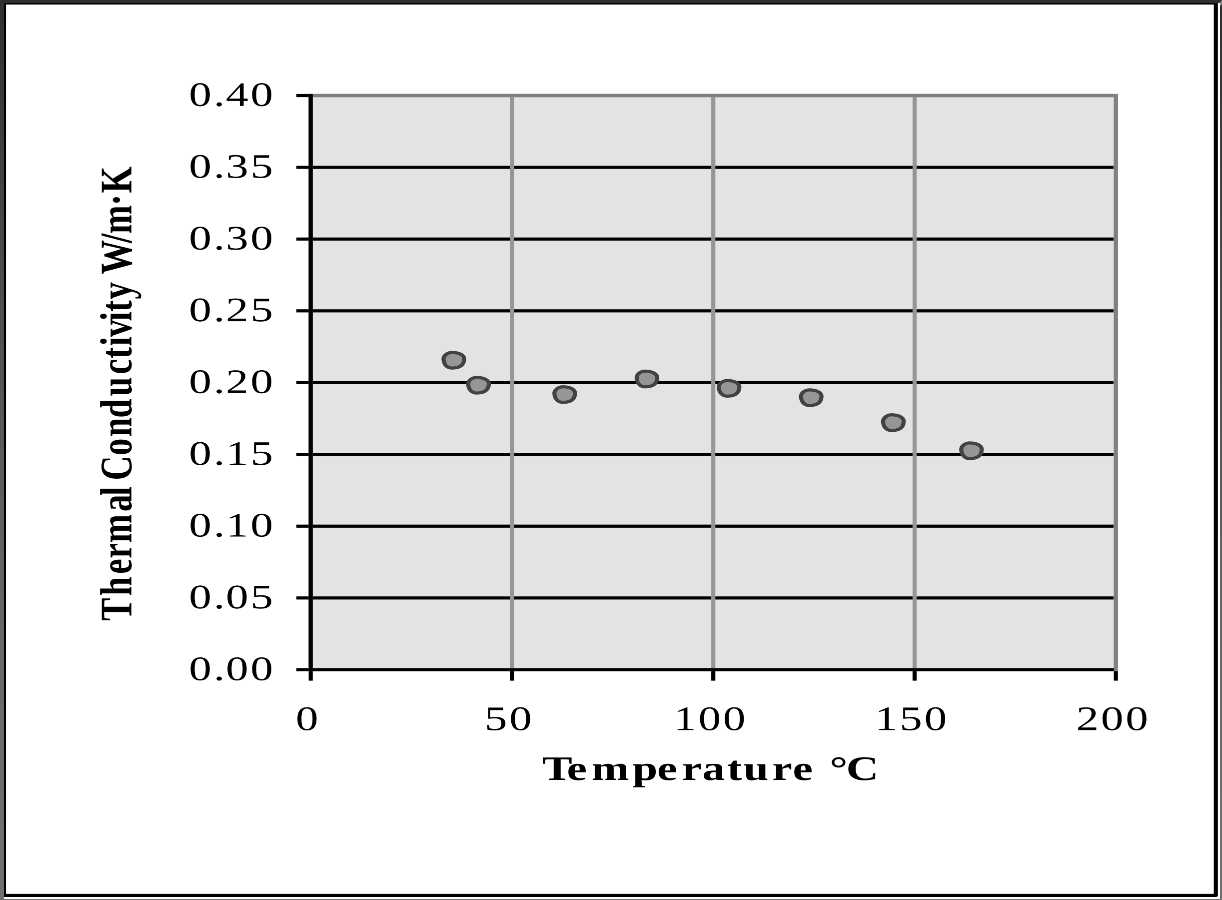
- viscosity v/s shear rate, temperature
- thermal conductivity v/s temperature
- specific heat v/s temperature
- melt density
- no flow temperature ^{M}
- eject temperature ^{M}
- transition temperature ^{C}

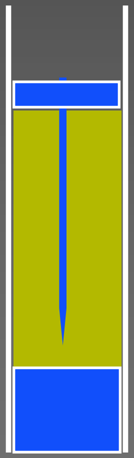
Viscosity


10000
1000
100
10
Viscosity Pa·s
10
100
1000
10000
100000
Shear Rate 1/s

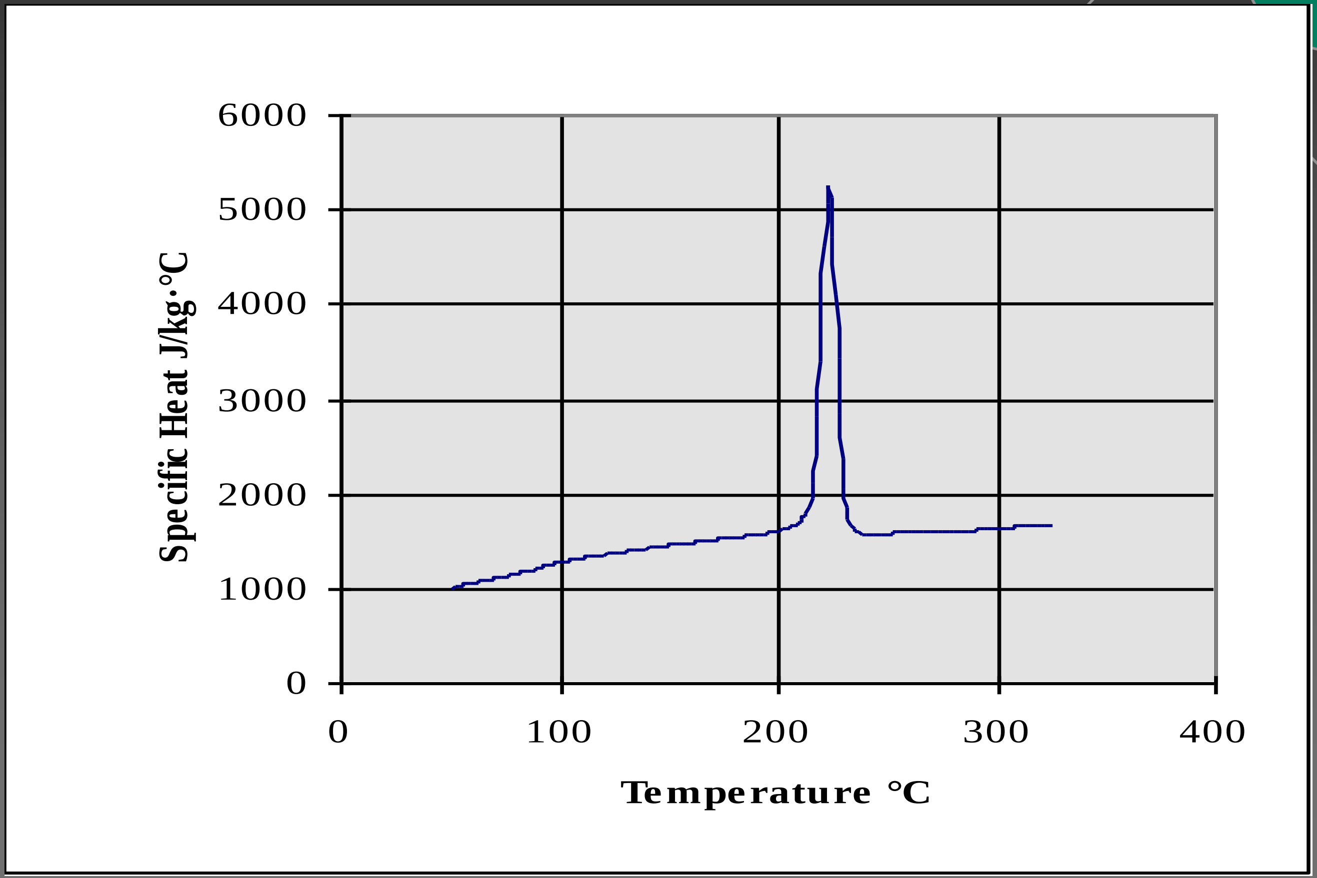

P

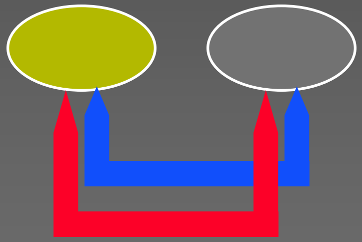
Thermal Conductivity





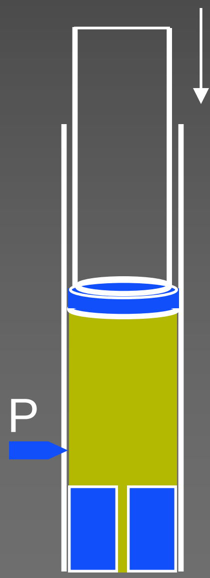
Specific Heat





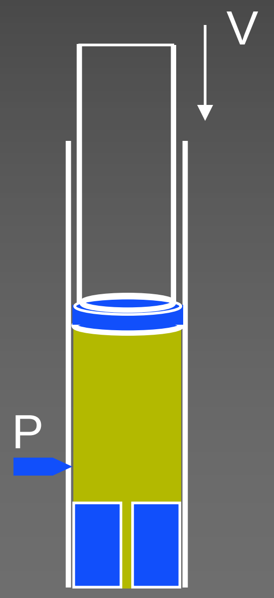
Melt Density

- High-pressure flow rate measurements
- Instrument-capillary rheometer



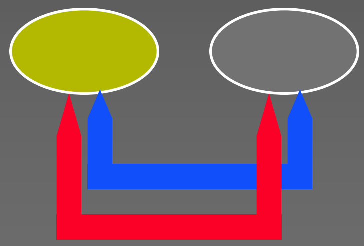
No Flow Temperature

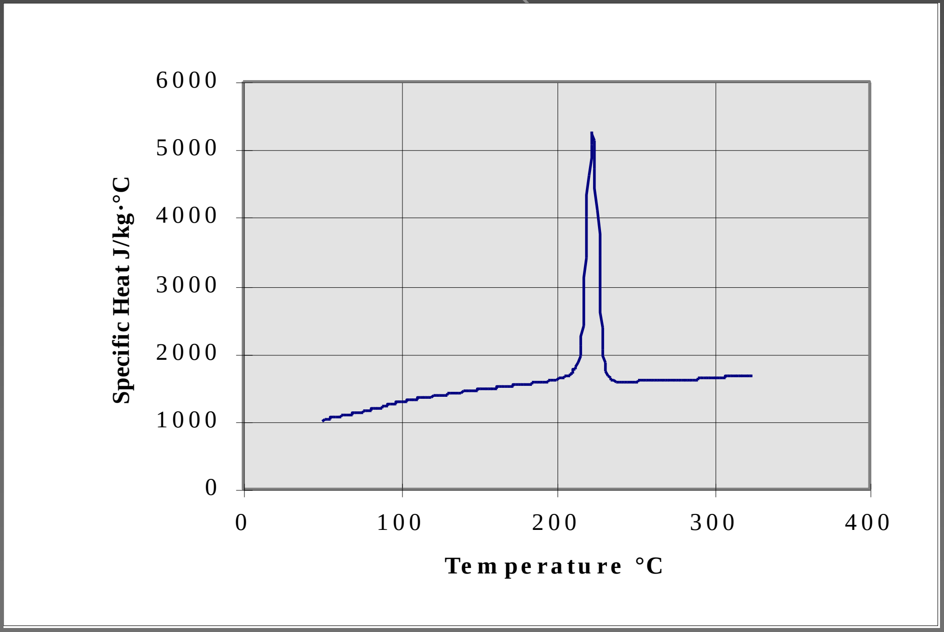
- Moldflow requirement:
- Temperature at which flow ceases under a particular applied load. (133 Bar)
- Instrument-capillary rheometer



DSC Transitions

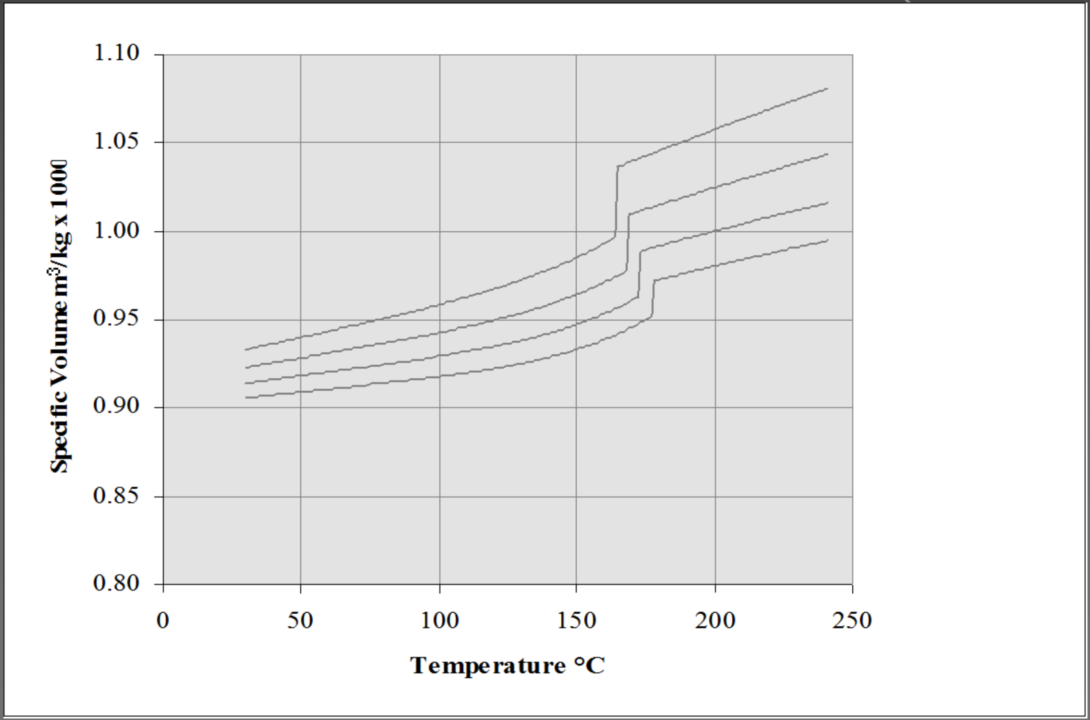
- Eject Temperature
- Transition Temperature





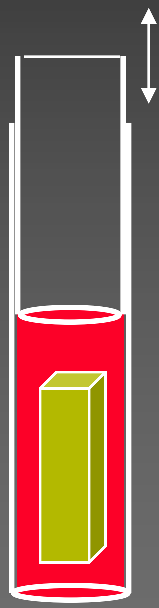
Additional Data - post filling

- pvT



pvT

- A: High pressure dilatometry
- B: Piston-cylinder method
  - Temperature ranges
    - » Process to ambient
  - Pressure Range
    - » 0-200 MPa



Additional Data - Moldflow shrink/warp

- Shrinkage/Warpage coefficients

Shrinkage coefficients

- Injection molding of grid-marked tags
- Different thicknesses
- Several process conditions
- Bidirectional measurement of shrinkage
- Correlate using Moldflow

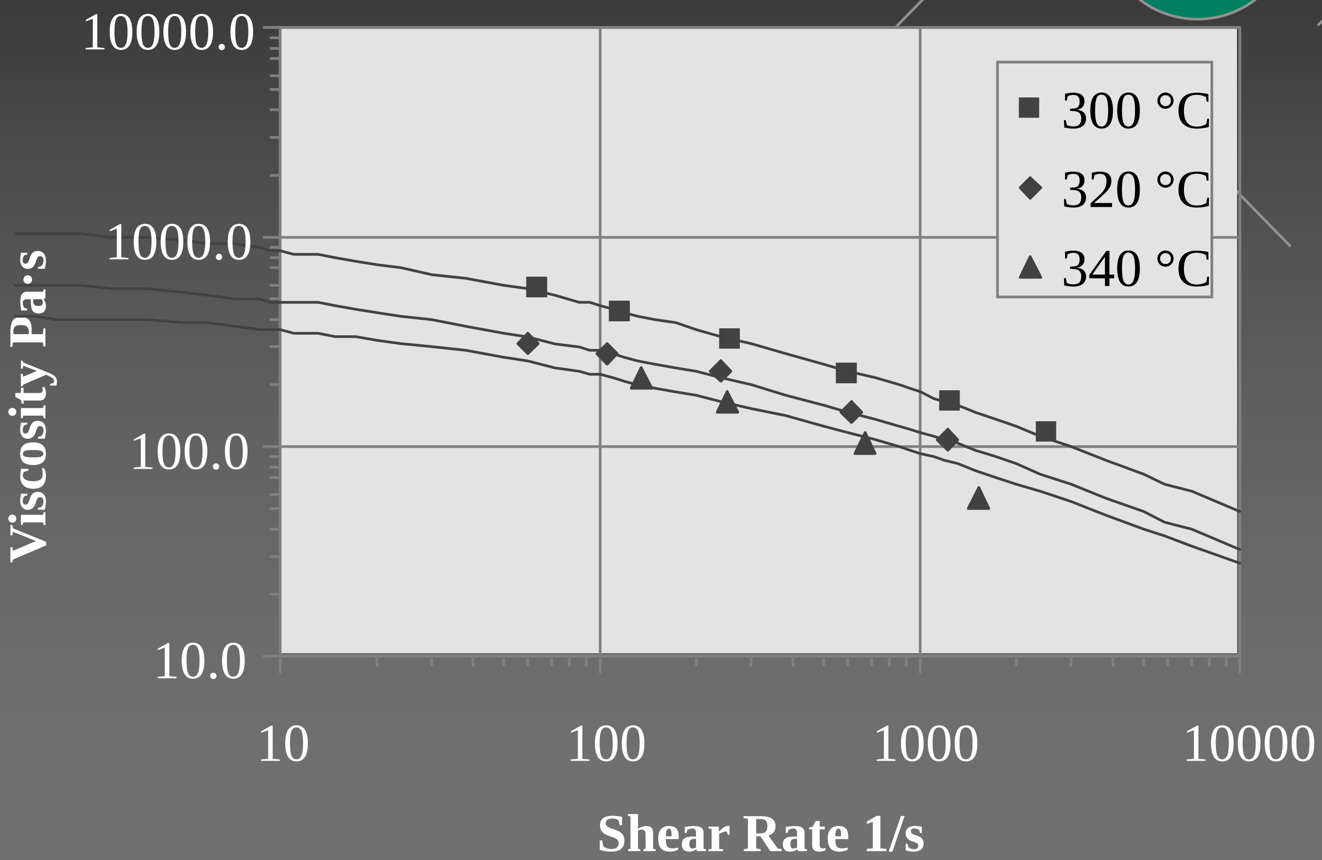
Evaluation Parameters

- material property based parameters
- evaluate effects seen in the process
- understand and interpret simulation results
- compare materials
- develop criteria for selection based on desired processability

Properties of Evaluation Parameters

- Easily calculated
- Estimates of actual parameters
- Must be considered along with other relevant parameters

Viscosity



10000.0
1000.0
100.0
10.0
Viscosity Pa·s
300 °C
320 °C
340 °C
10
100
1000
10000
Shear Rate 1/s

Evaluation Parameters-Viscosity

- Nature of the 2nd order matrix
  - Temperatures
    - » Tmelt
    - » Tmelt+20
    - » Tmelt-20
  - Shear rates
    - » 100
    - » 1000
    - » 10000

T	γ	η
Tmelt-20	1000	$\eta 1$
Tmelt	100	$\eta 2$
Tmelt	1000	$\eta 3$
Tmelt	10000	$\eta 4$
Tmelt+20	100	$\eta 5$
Tmelt+20	1000	$\eta 6$

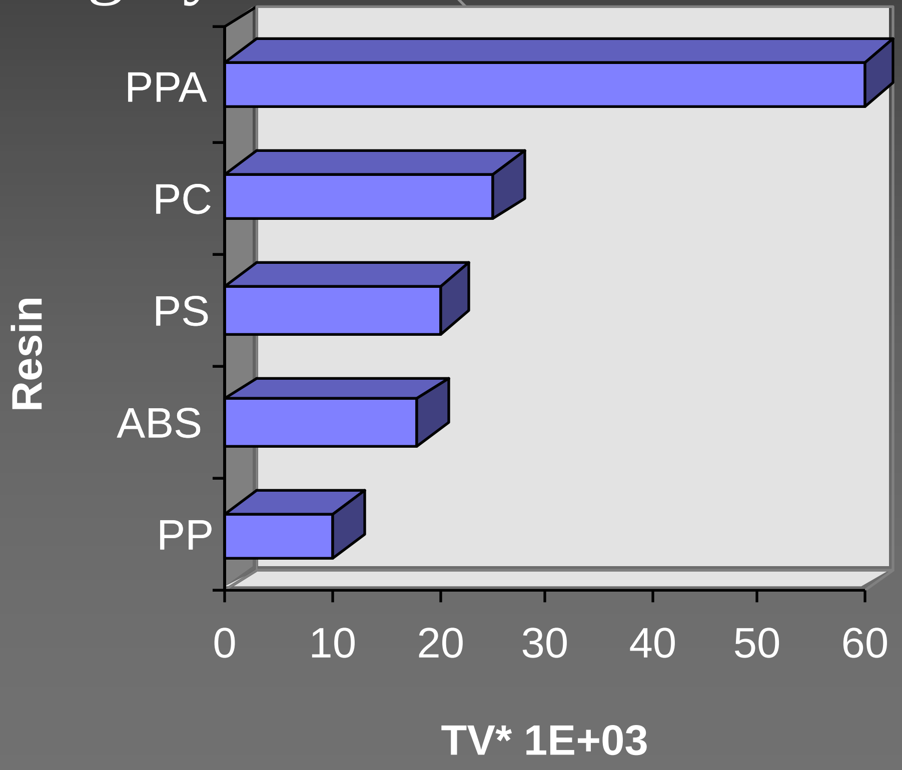
Evaluation Parameters -Viscosity

- Temperature sensitivity of viscosity
  - $TVL = (\ln \eta 1 - \ln \eta 3) / 20$
  - $TVH = (\ln \eta 3 - \ln \eta 6) / 20$

T	γ	η
Tmelt-20	1000	$\eta 1$
Tmelt	100	$\eta 2$
Tmelt	1000	$\eta 3$
Tmelt	10000	$\eta 4$
Tmelt+20	100	$\eta 5$
Tmelt+20	1000	$\eta 6$

Evaluation Parameters -Viscosity

- Rules
  - if TV is large, material is highly sensitive
  - TVL > TVH
  - Semi-crystalline
    - » TVL == TVH
  - Amorphous
    - » TVL >> TVH



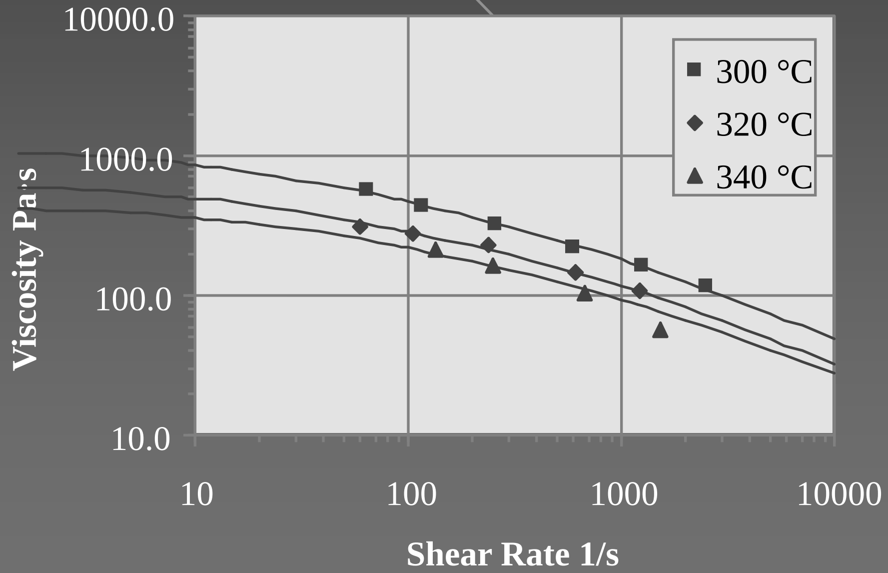
Evaluation Parameters -Viscosity

- Shear sensitivity of viscosity
  - Defining a limited power-law index.
    - » SHB= (ln η3 - ln η4) / 2.303

T	γ	η
Tmelt-20	1000	η1
Tmelt	100	η2
Tmelt	1000	η3
Tmelt	10000	η4
Tmelt+20	100	η5
Tmelt+20	1000	η6

Evaluation Parameters -Viscosity

- Rules
  - 0<SHB < 1
  - Large SHB = shear sensitive
  - Important exception:
    - » broad newtonian (eg. PC)



Evaluation Parameters- Thermal

- Thermal mass
  - TMASS=(rho*Cp)
  - units = $J/m^3.K$
  - True measure of heat capacity
- Rules
  - Large TMASS = cools slowly
  - Large TMASS = more heat to remove

Steel
TMASS=3.6e6
Cp=460

Plastic
TMASS=1.9e6
Cp=1700

Evaluation Parameters- Thermal

- Thermal diffusivity
  - $\alpha = (k / TMASS)$
  - units = m^2/s
  - Measure of heat transfer rate
- Rules
  - Large α = cools quickly

PP/Talc
α = 8.7e-8
k = 0.21

PP
α = 7.7e-8
k = 0.17

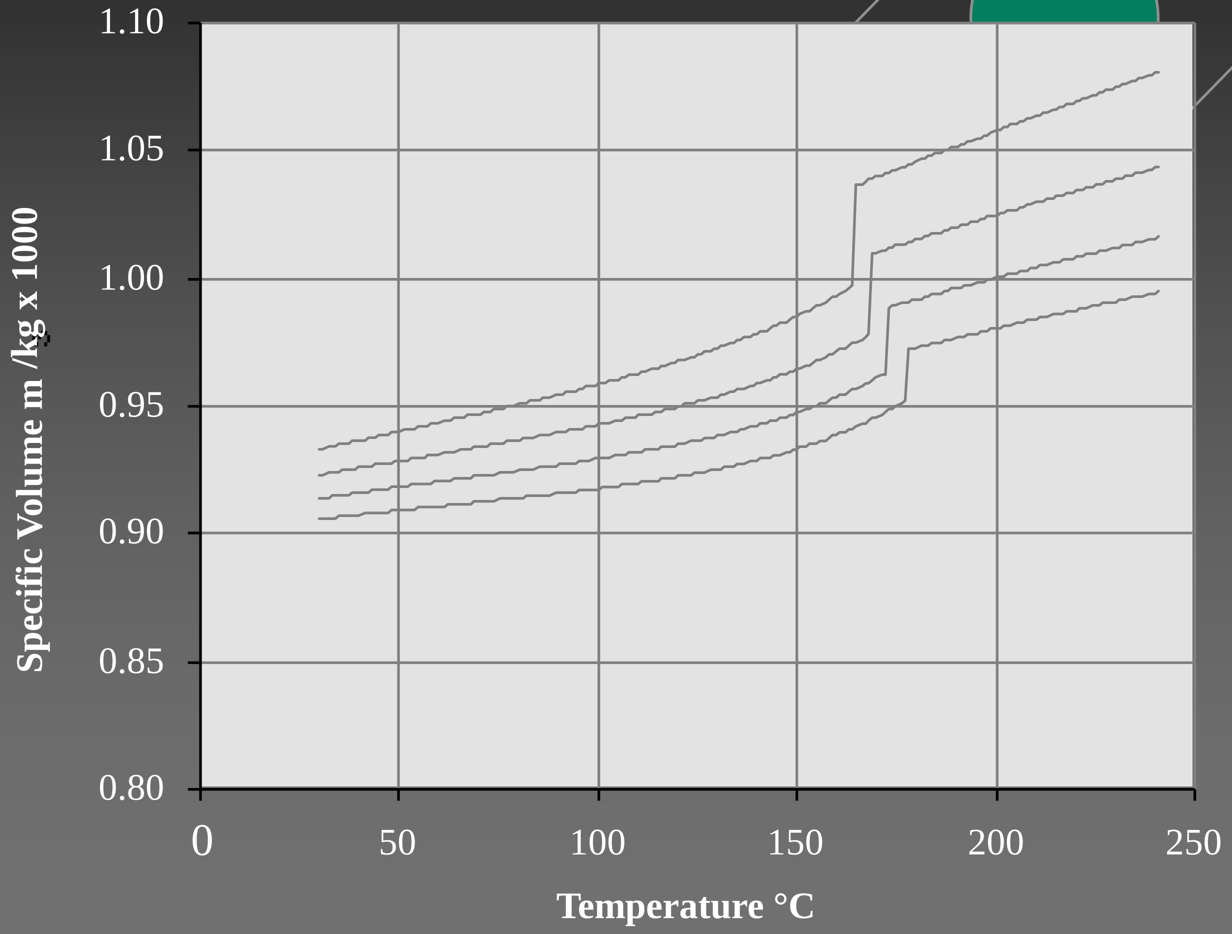
Evaluation Parameters- Thermal

- No-flow temperature
  – NOFLO
  – maps closely with crystallization temp
  – 20-30C higher than Tg (amorphous materials)

Evaluation Parameters- Thermal

- Eject Temperature
  - – EJECT
- Rules
  - – High (EJECT - TMOLD) = lower cycle time

Evaluation Parameters- PVT



Evaluation Parameters-PVT

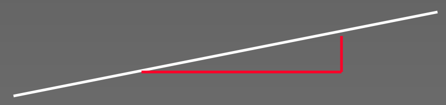
- Nature of the PVT matrix
  - Temperatures
    - » TS1 - TS7
    - » TB1-TB2
    - » TM1-TM4
  - Pressures
    - » 0 MPa
    - » 160 MPa

T	P	V
TS1	0	VS1
TS2	0	VS2
TS3	0	VS3
TS4	0	VS4
TS5	160	VS5
TS6	160	VS6
TS7	160	VS7
TB1	0	VB1
TB2	160	VB2
TM1	0	VM1
TM2	0	VM2
TM3	160	VM3
TM4	160	VM4

Evaluation Parameters- PVT

- Volumetric expansion coefficient (VEC)
  - VEC=dV/dT
  - VECS=(VS1-VS2) / (TS1-TS2)
  - VECM=(VM1-VM2) / (TM1-TM2)

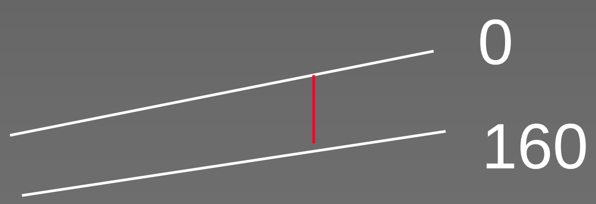
T	*P*	*V*
TS1	0	VS1
TS2	0	VS2
TS3	0	VS3
TS4	0	VS4
TS5	160	VS5
TS6	160	VS6
TS7	160	VS7
TB1	0	VB1
TB2	160	VB2
TM1	0	VM1
TM2	0	VM2
TM3	160	VM3
TM4	160	VM4



0 MPa

Evaluation Parameters- PVT

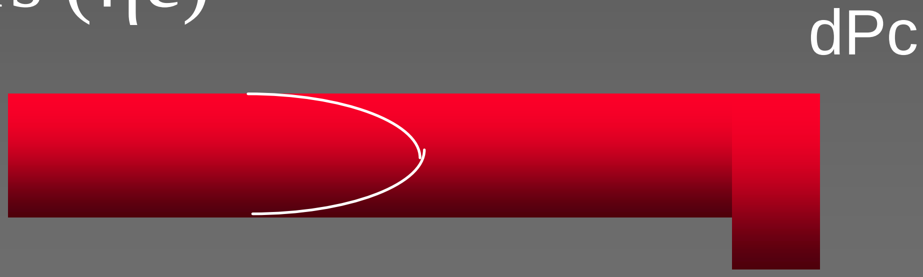
- Compressibility (COM)
  - COM = dV/dP
  - COMS = (VS1-VS5) / 160
  - COMM = (VM1-VM3) / 160



T	*P*	*V*
TS1	0	VS1
TS2	0	VS2
TS3	0	VS3
TS4	0	VS4
TS5	160	VS5
TS6	160	VS6
TS7	160	VS7
TB1	0	VB1
TB2	160	VB2
TM1	0	VM1
TM2	0	VM2
TM3	160	VM3
TM4	160	VM4

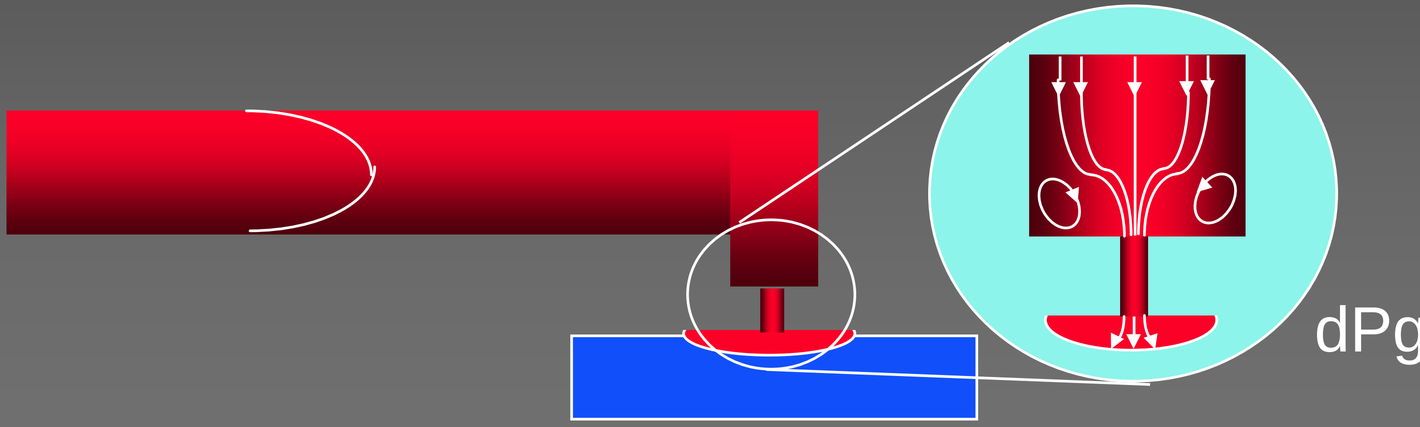
In the runner..

- very hot resin (TVH)
- high shear rate (SHB)
- viscous heating (TMASS, TVH)
- flow around corners (ηe)



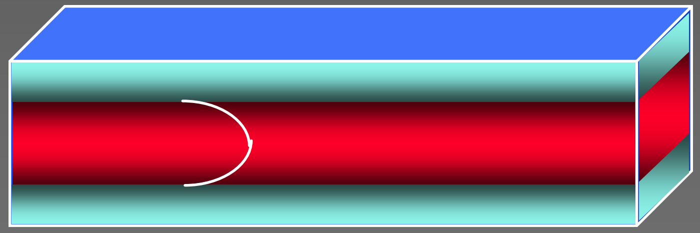
At the gate

- extensional flow (ηe)
- very high shear rates (SHB)
- viscous heating (TMASS, TVH)



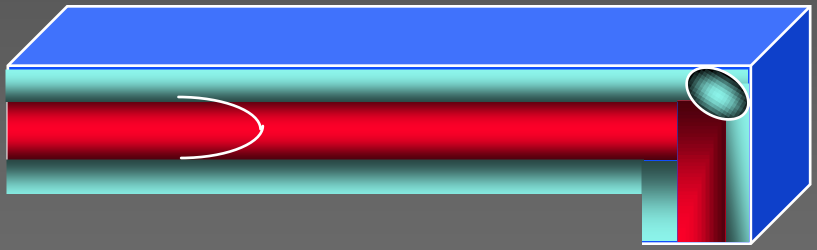
Within the part

- Frozen layer formation
  - α
  - NOFLO
  - CRY



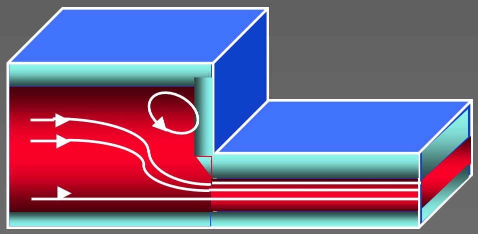
Within the part

- Flow around corners
  - – additional pressure loss (ηe)



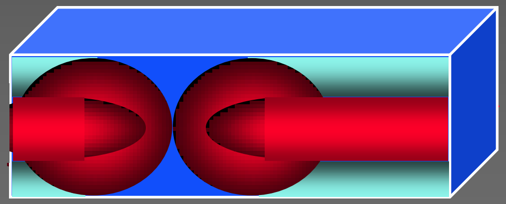
Within the part

- Thick and thin sections
  - – additional pressure loss (ηe)



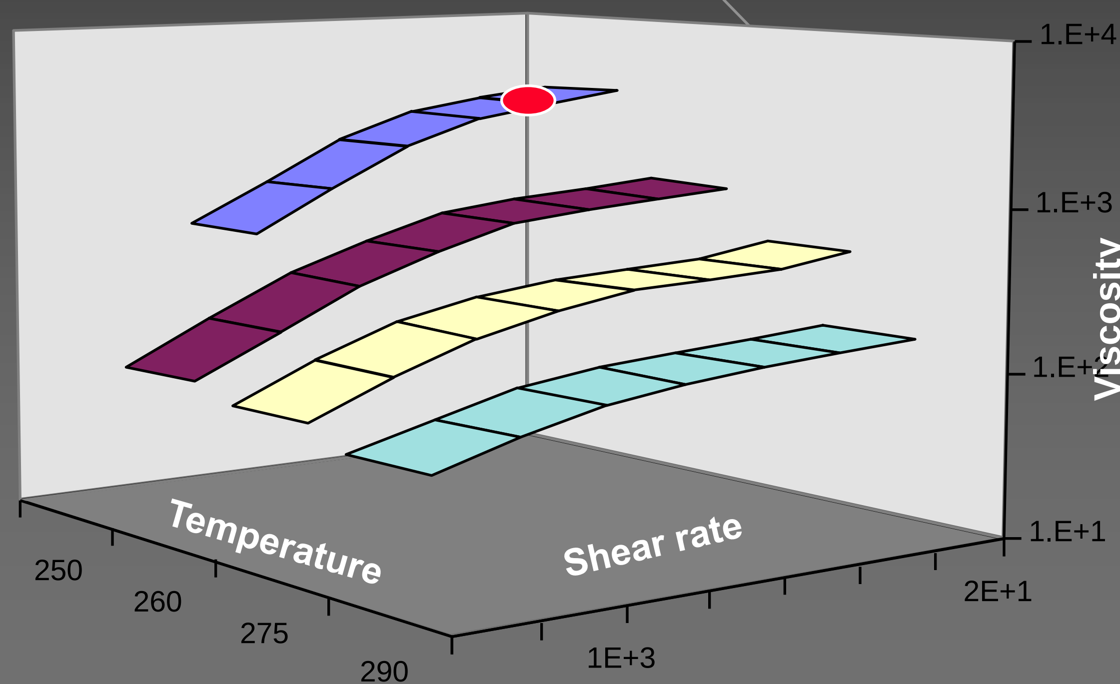
Weld lines...

- melt front temperature
  - α
- available pressure



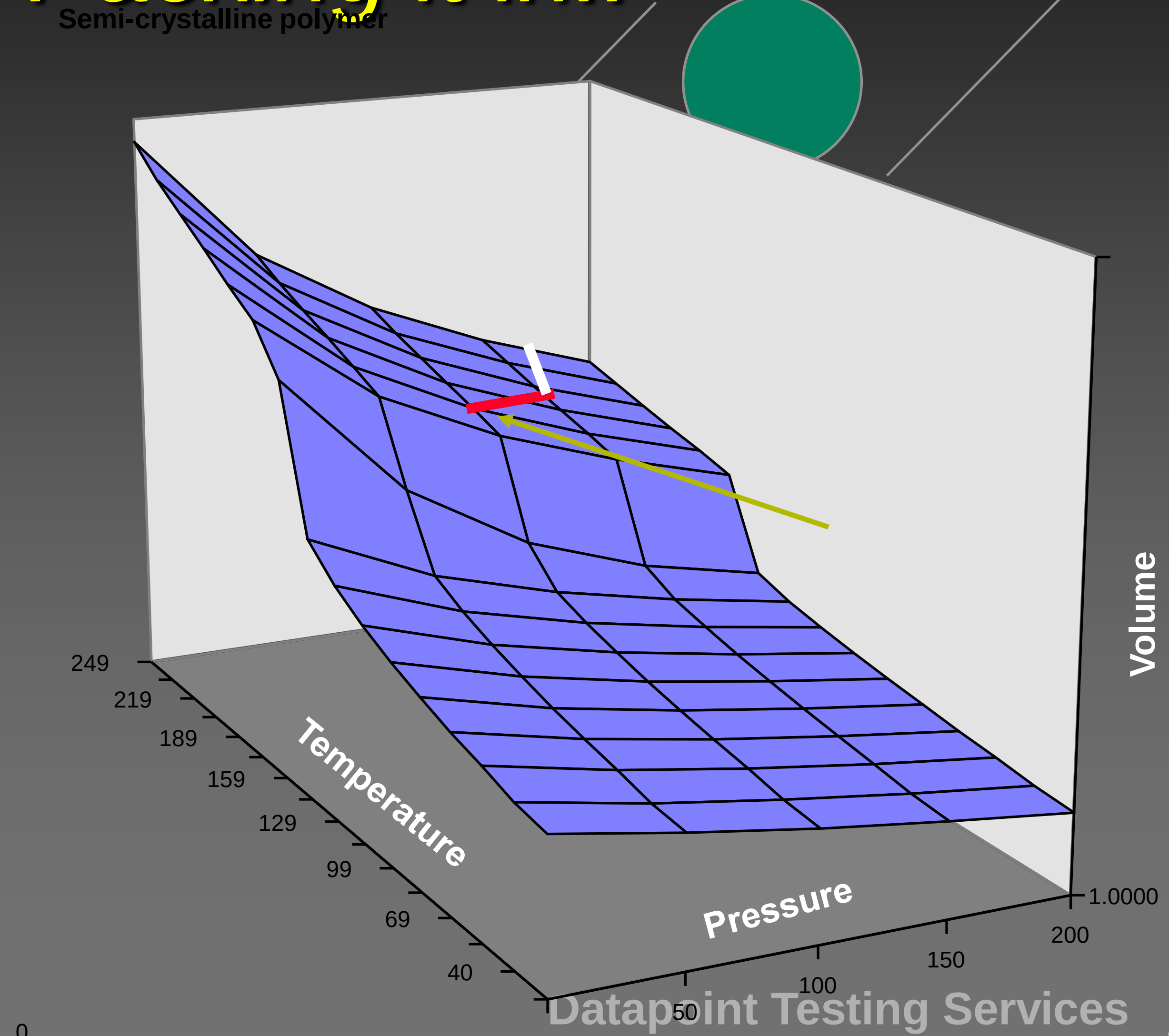
End of fill

- low shear rates (TVL)
- low temperature



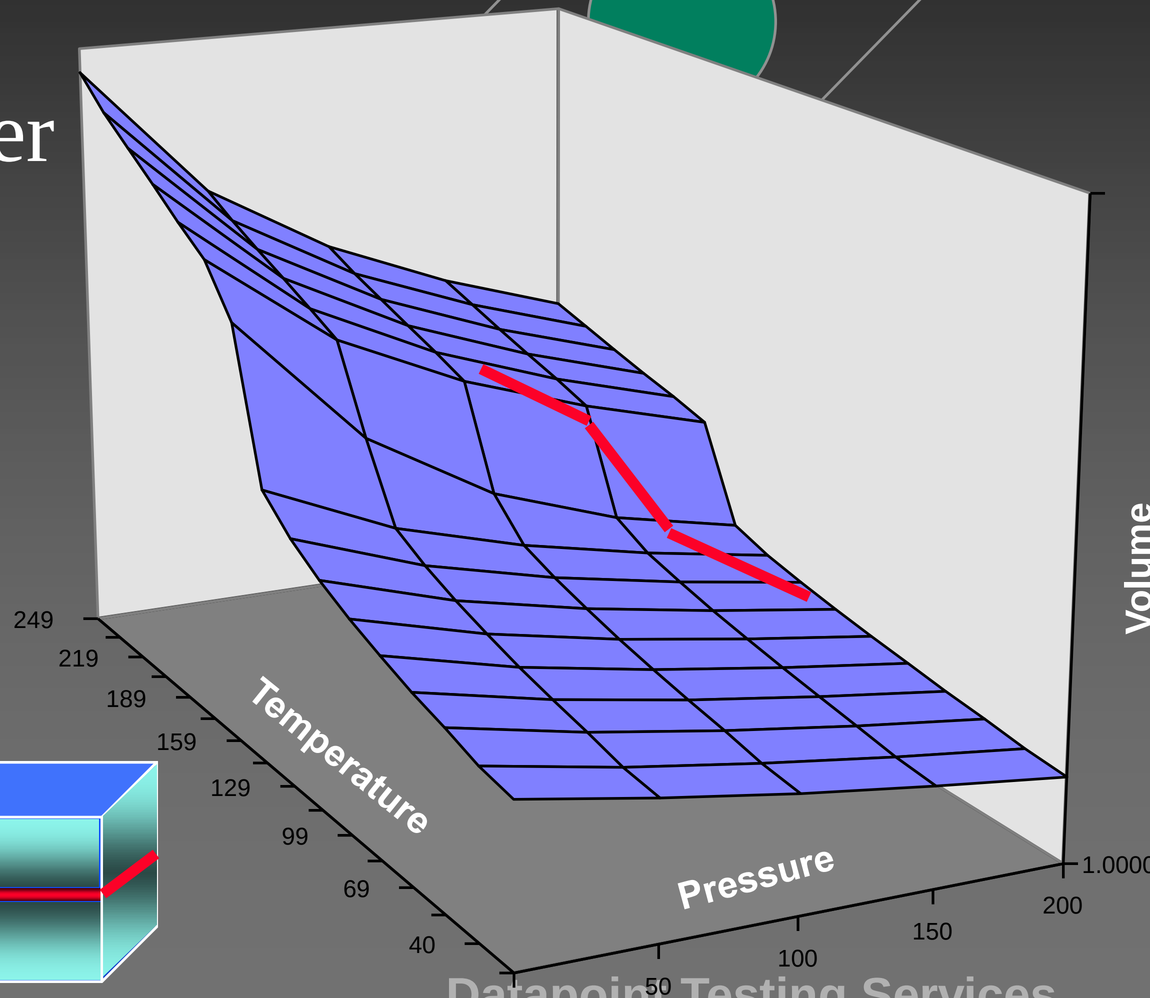
Packing it in..

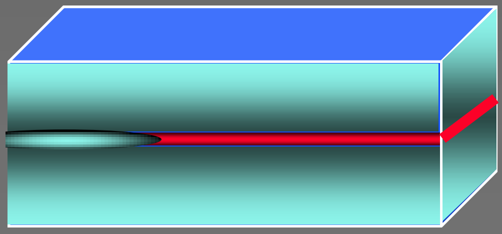
– Factors:
  - » COMM
  - » TVL



Cooling off

- cooling polymer
  - α
  - CRY, VEC
- freeze off
  - NOFLO
  - TVL-TVH





Conclusion

- Evaluation parameters are:
  - tools to examine simulation results
  - aid in understanding resin behavior in the mold
  - aid in selection of resin based on desired processability
  - easy to calculate and use every day

Questions, call us; 1-888-DATA-4-CAE

Future considerations

- extensional flow situations
- accumulation of residual stresses
- stress relaxation
- warpage

Effect of viscosity

- shear thinning behavior reduces pressure penalty +
- high temperature sensitivity of viscosity -
- high pressure raises viscosity -
- high shear rate induces viscous heating +

Effect of thermal conductivity

- high solid conductivity reduces cycle time +
- high conductivity tightens process window -

Effect of PVT

- shows how plastic will solidify
- shows shrinkage level