Thermally Induced Dimensional Variation in Extrusion

"Thermally Induced Dimensional Variation in Extrusion"

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Outline

- T-melt variation in extrusion
- Consequences of T-melt variations
- Simulation of the cooling process
- Thermally induced wall thickness variation in pipe extrusion
- Reduce melt temperature variation

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Melt Temps in Extrusion

- Result of viscous dissipation and heat transfer
- Conductive heat transfer is slow – polymer thermal conductivity low
- Melt temperatures are inherently non-uniform

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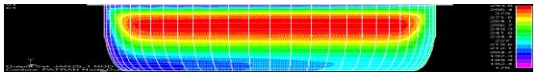
63-mm Extruder at 100 rpm
0.2 MI HDPE (FEA)



Note high melt temperatures in center region – natural ***HOT SPOT***!
Next slide expanded vertical scale

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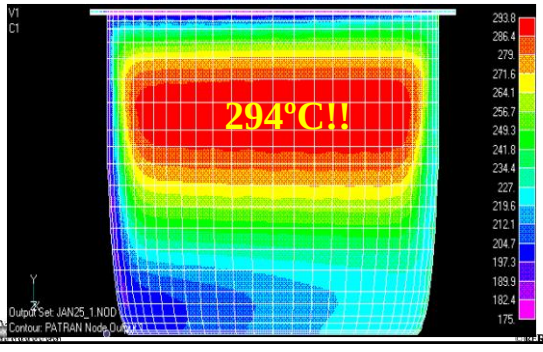
63-mm Extruder at 100 rpm
0.2 MI HDPE (FEA)



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Experiments Univ. Bradford
E. Brown and A. Kelly

- Melt temperature variation measured at end of 2.5" (63.5-mm) extruder
- Fast response T/C mesh was used
- Three different screws tested
  - Rapid compression
  - Tapered (gradual) compression
  - Barrier type screw

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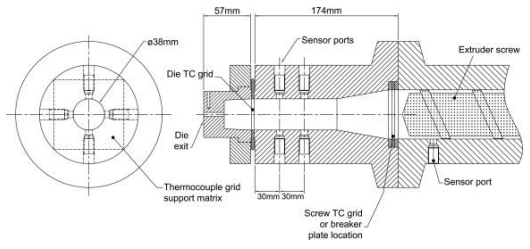
Experimental Setup



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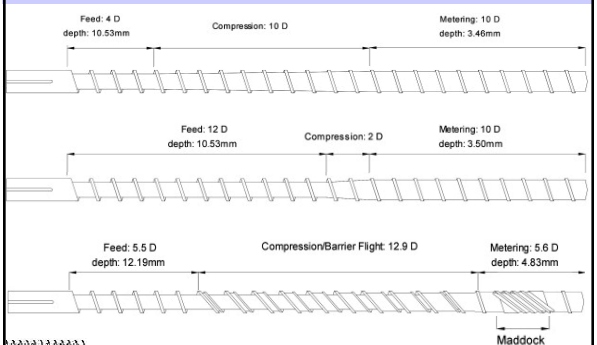
Screw Geometries



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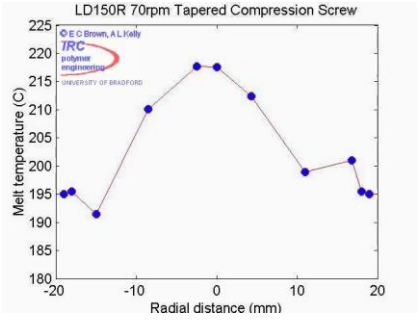
Compression Screw 70 rpm



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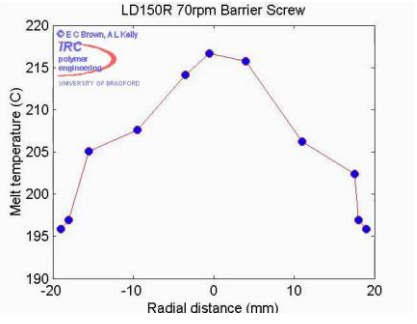
Barrier screw 70 rpm



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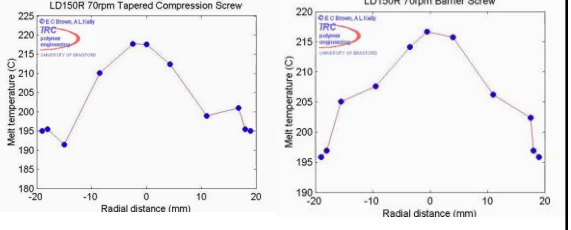
Compression vs. Barrier



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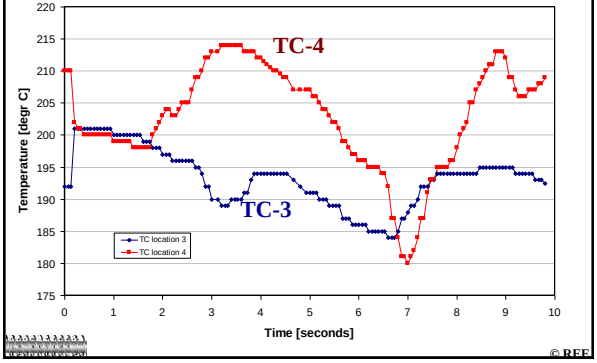
Temperature vs time

compression screw



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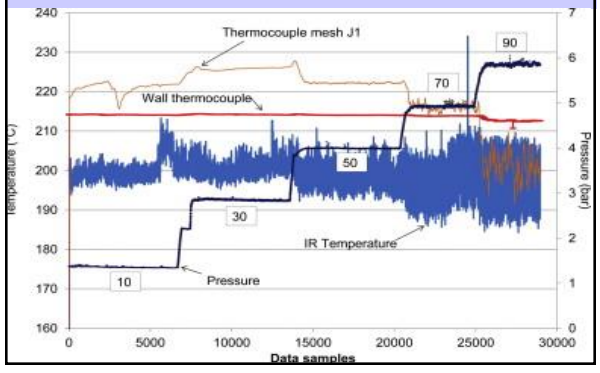
Temperature vs. Time



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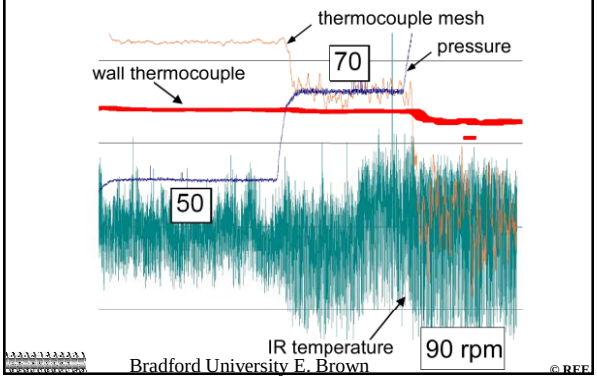
IR vs TC Temperatures



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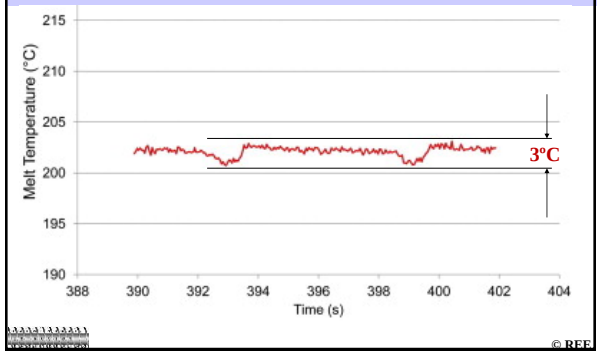
IR Temp-Time 10 rpm



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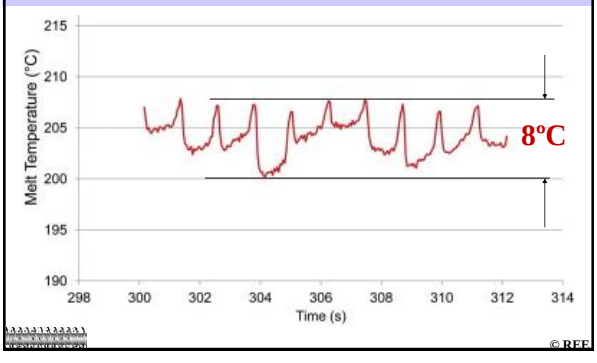
IR Temp-Time 50 rpm



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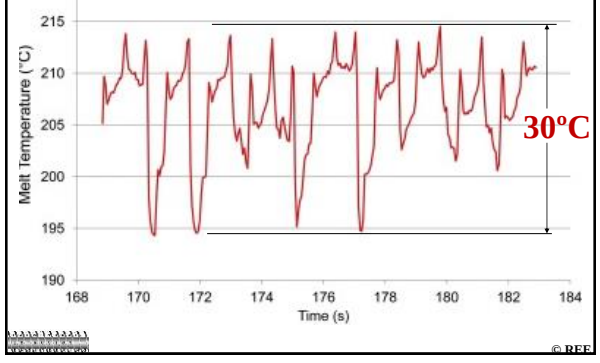
IR Temp-Time 90 rpm



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Findings

- Wall TC shows little variation
- TC mesh shows large variation **(10-40°C)**
- Barrier screw better than non-barrier
- Infrared temperatures show even larger **(20-80°C)** and faster variation
- IR temperatures show periodicity related to screw speed

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Melt temperature variation

- Short term melt temperature variation occurs in ***all*** extruders
- Can be measured with IR probes - not with immersion probes!
- Can create a variety of problems, e.g. ID waviness in extruded pipe
- Thermal mixing is ***CRITICAL!***

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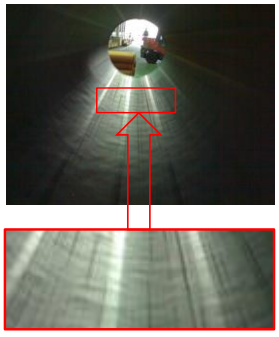
Pipe ID Waviness

- Common problem
- Caused by melt temperature variation
- Example is shown on the right



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Causes of wall thickness variation in pipe-1 *Overeijnder*

- Variations in elastic stresses by folding of the melt in channels of TSE
- Incorrect die design
- Incorrect screw and barrel temperatures
- In coextrusion viscosity differences between layers

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Causes of wall thickness variation in pipe-2 *Overeijnder*

- Unmelt at discharge end of the extruder
- Friction at calibration sleeve greater than melt strength
- Improper alignment head and calibrator
- Slipping of puller cleats
- Foamed pipe cell sizes too large (> 0.15 mm)

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Wall Thickness Variation

- Amplitude typically varies from 0.1 to 3% of the wall thickness
- Frequency varies with cause
- In thermally induced thickness variation, frequency corresponds to melt temperature variation

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chillWARE® by SMS plus

- Simulates cooling by FEA/FDM
- Material data base
- 2D/3D temperature field
- Residual stress analysis
- Optimization of cooling process
- Optimization US wall thickness

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chillWARE® Modules

- Pipe (2D)
- Cable (2D)
- Coex pipe (2D)
- Rod (2D)
- Sheet (3D)
- Profile (3D)

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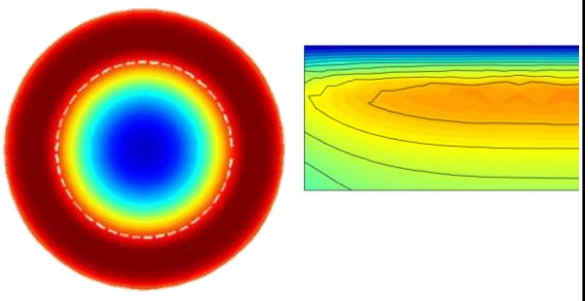
chillWARE® Results



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Can answer questions like

- How long a cooling line needed?
- How to reduce operational cost?
- How to reduce residual stress, shrinkage, sagging, etc.?
- Temperatures along length of line?
- What is optimum layout?
- How long for crystallization?

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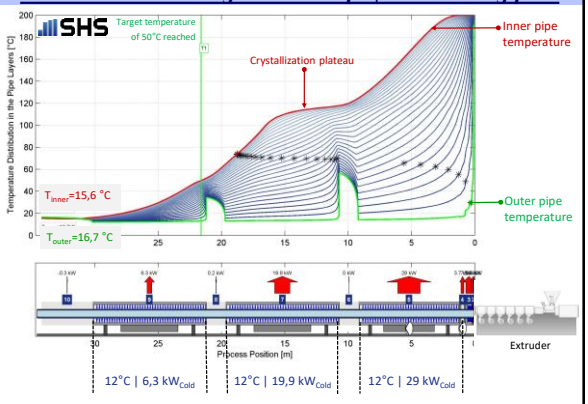
chillWARE® - Cooling Sim. PE-Pipe | 12°C cooling fluid



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Pipe Extrusion

- OD is fixed by calibrator
- Outer surface cools & solidifies first
- Inner layers cool more slowly and shrink toward outer diameter
- With non-uniform melt temps this results in wall thickness variation

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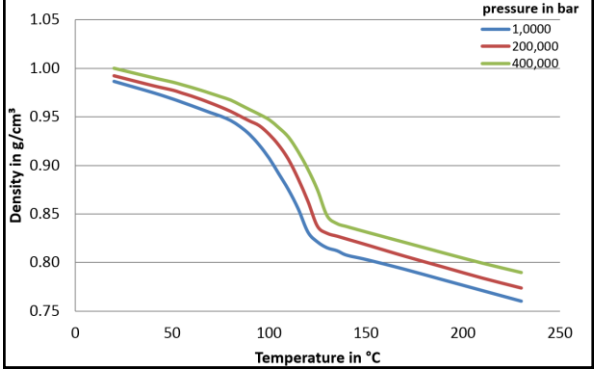
Density vs Temperature



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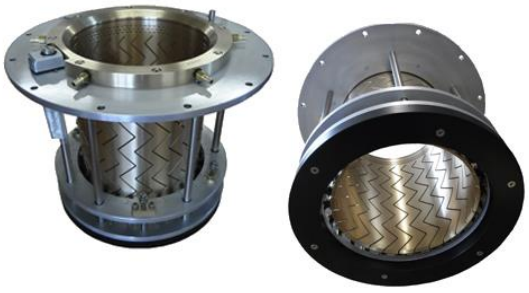
Adjustable Calibration



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Process Data

Parameter	Unit	Value
Material	-	PE 100
Final Outer Diameter	mm	250
Final Wall Thickness	mm	24
Mass Throughput	kg/h	350
Melt Temperature Case 1	°C	218
Melt Temperature Case 2	°C	188
Processing Velocity	m/min	0.35
Outer Diameter of Calibration	mm	256.6
Wall Thickness @ Extrusion Die	mm	31.04

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Cooling Section

- Vacuum calibration length 600 mm
- Two vacuum spray cooling tanks length 9,000 mm each
- Two spray cooling tanks with a length of 9,000 mm each

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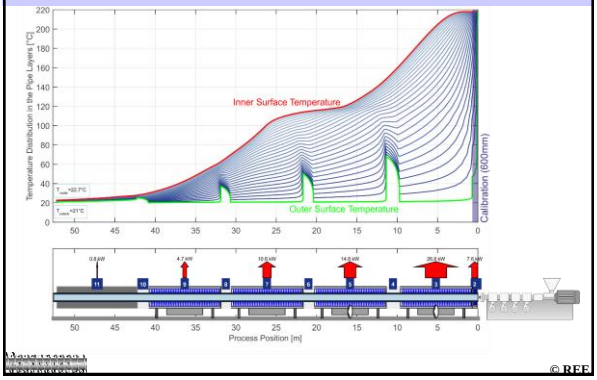
chillWARE results



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reference production process

- 7.6 kW thermal power is dissipated in vacuum calibration unit
- Outer surface temperature 47.4°C, inner temperature still at 218°C
- Average cross sectional temperature is 194°C

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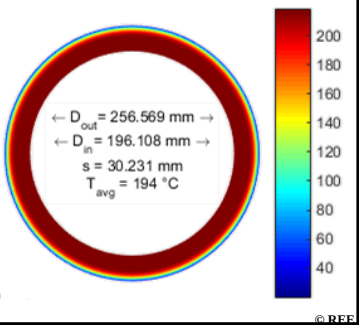
Temperatures at T_m 218°C

Temperature distribution at end of calibration



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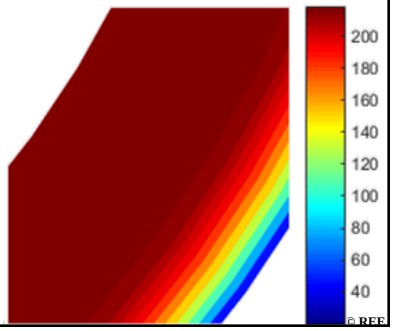
Temperatures Detail

Note that only ~20% of pipe has solidified!



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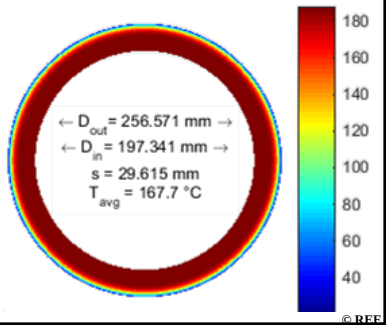
Temperatures at T_m 188ºC

Temperature distribution at end of calibration



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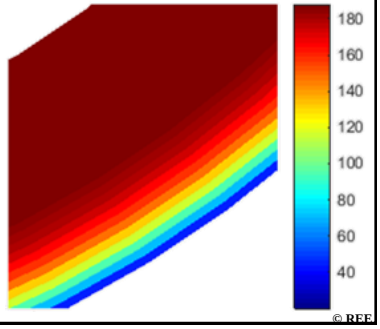
Temperatures Detail

With melt temperature of 188ºC



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Dynamic Variation

- Melt temperature varies at frequency of f = 0.833 Hz (50 rpm)
- At 0.35 m/min wave length: 0.007 m
- Diameter variation expressed as:

$$D_a(t) = 0.5 \cdot ((D_{a,\mathrm{mod}} - D_{a,ref}) \cdot \sin(2\pi \cdot f \cdot t) + D_{a,\mathrm{mod}} + D_{a,ref})$$

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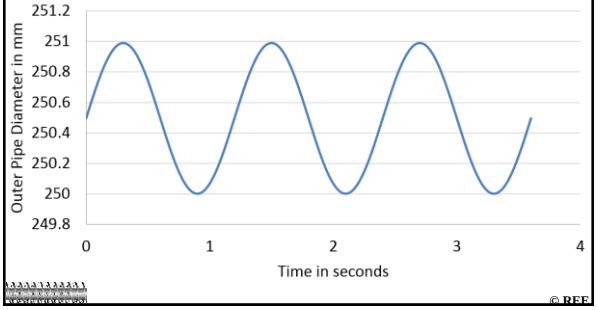
OD Variation with time



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Simulation Results

- Outer diameter increased by 0.4%
- Wall thickness increased by **2.25%**
- Non-uniform melt temperatures can cause significant dimensional variation in extrusion

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Reduce T-melt Variation

- Use IR T-melt measurement!
- Improve thermal mixing by
  - Dynamic distributive mixers
  - Static mixers
  - Axial mixing is most important!
- Large inventory dies ineffective

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Thank You!

- Organizers for the opportunity to present this information
- Attendees for your attention
- Any questions?

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