Moldflow Summit 2017

Prediction of Cycle Times for Rapid Cycle Molding Applications

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- Historical approach
- New Approach
- Equipment
- Theoretical Heating Curves
- Mold Design
- Conclusion

Historical Approach

$[(Mass_{Mold})(C_{pMold})(Mold\ Temp_{final} - Mold\ Temp_{initial})/t]$

- Many mold heating equipment manufacturers attempt to size equipment for rapid cycling with the above formula.

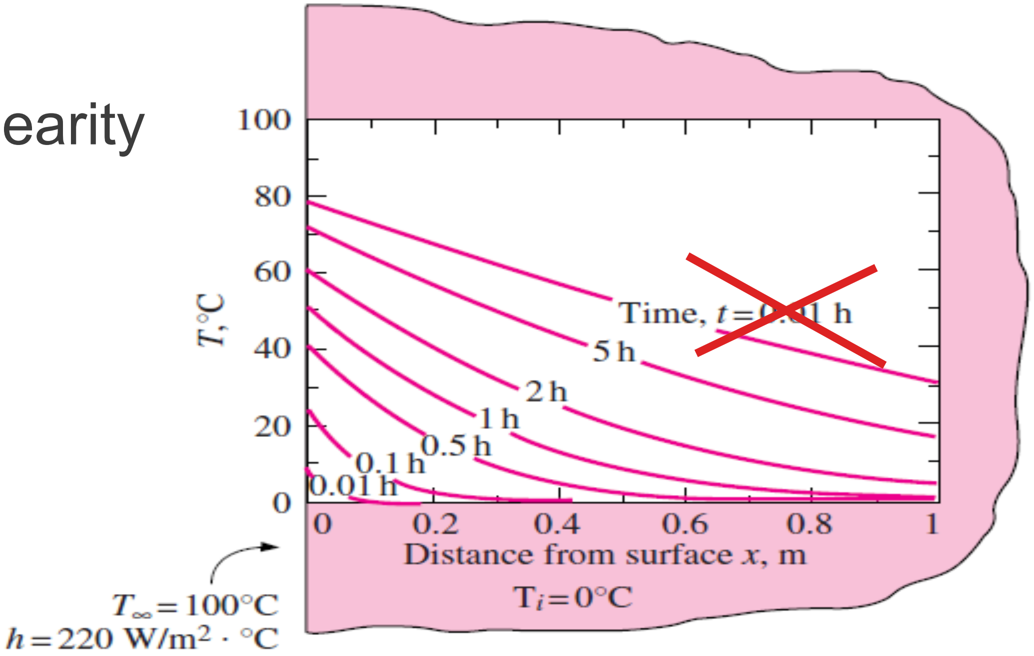
- [(250kg)(.47kJ/kg-C)(200°C-25°C)]/60sec = 342kw
  WOW!

- When does this formula work reasonably well? Systems with heating/cooling rates **<u>less than 2°C/min.</u>**

- How does this apply to forced convection heating of molds? **It doesn’t!**
- How does this apply to rapid cycling molds? **It doesn’t!**
- What happens when it is used for these applications? **Nothing good! Failed customer trials.**
- Why? **The formula doesn’t capture the non-linear nature of heat transfer.**
- Is there a better formula? **Yes, sort of!**

Actual heating curves of cast iron block with forced convection

- Reduced time **increases** non-linearity of heat transfer



(c) Convection at the surface

McGraw-Hill, 4th edition

New Approach

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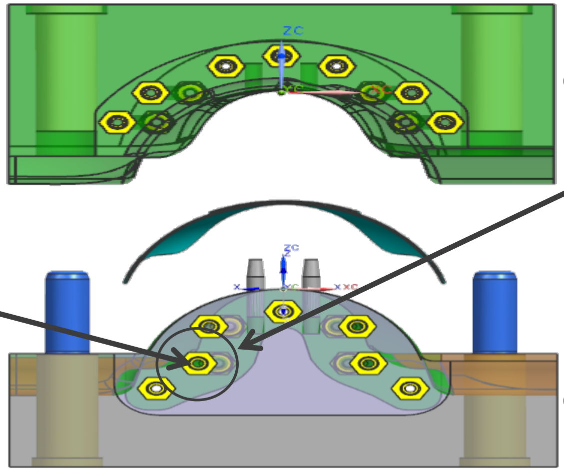
$$T(@x,t) = (\mathrm{erfc}[x/2\{(\alpha)(t)\}^{1/2}] - \exp[(h)(x)/k + (h)^2(\alpha)(t)/k^2][\mathrm{erfc}[x/2\{(\alpha)(t)\}^{1/2} + h\{(\alpha)(t)\}^{1/2}/k])*(T_{Fluid}-T_i))+T_i$$

- What is the formula determining?

Temperature of the mold at a known (circular) distance away from the heat source at a known time.



Drawing courtesy of Promolding

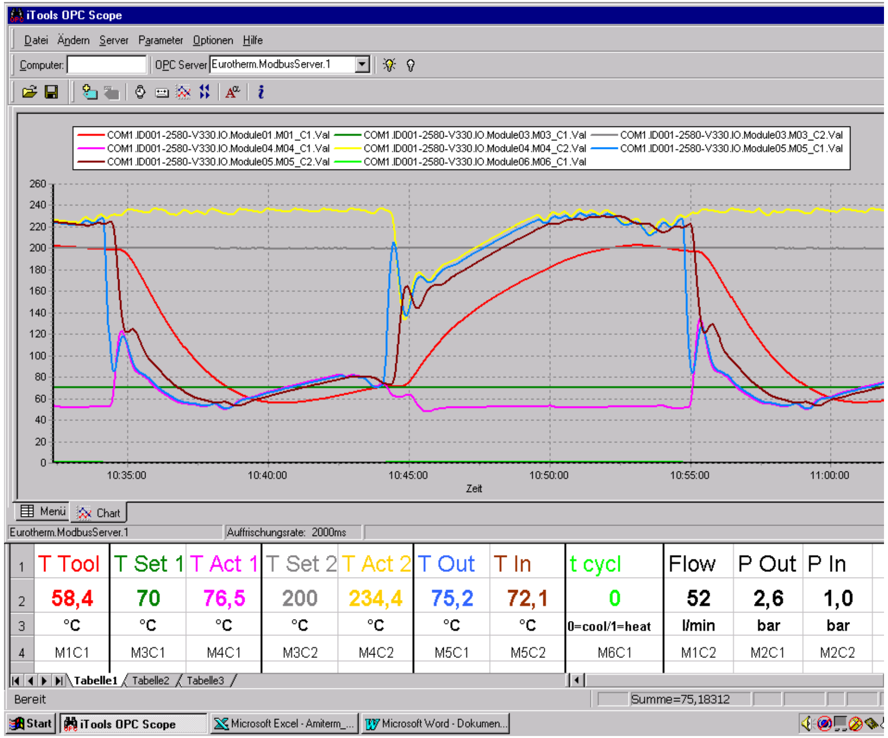
Limitations

- We are only determining the contribution of (1) fluid passage to the total temperature rise of the mold.
- Passages at different depths are not usually considered.

Equipment

Pressurized Water or Oil Mold Heaters

Actual Heating Curves



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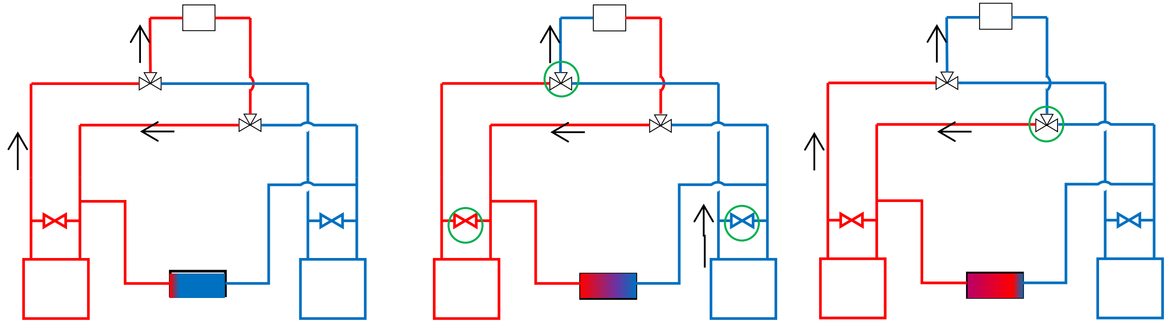
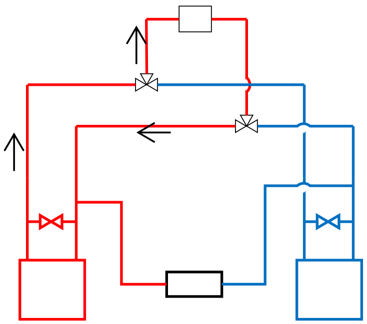
Limitations of equipment

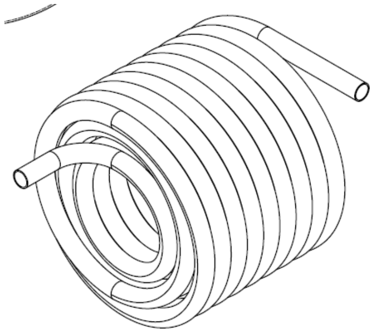
- Theoretical math requires constant supply temperature.
- Actual system can only provide constant supply temperature for up to 30 seconds.
- How to overcome? **Parking/storing return fluid for re-use.**

Energy Battery

- Energy Battery
  2-4 liters







How does this effect temperature rise at mold surface?

Greatly improves it by raising the average fluid temperature.

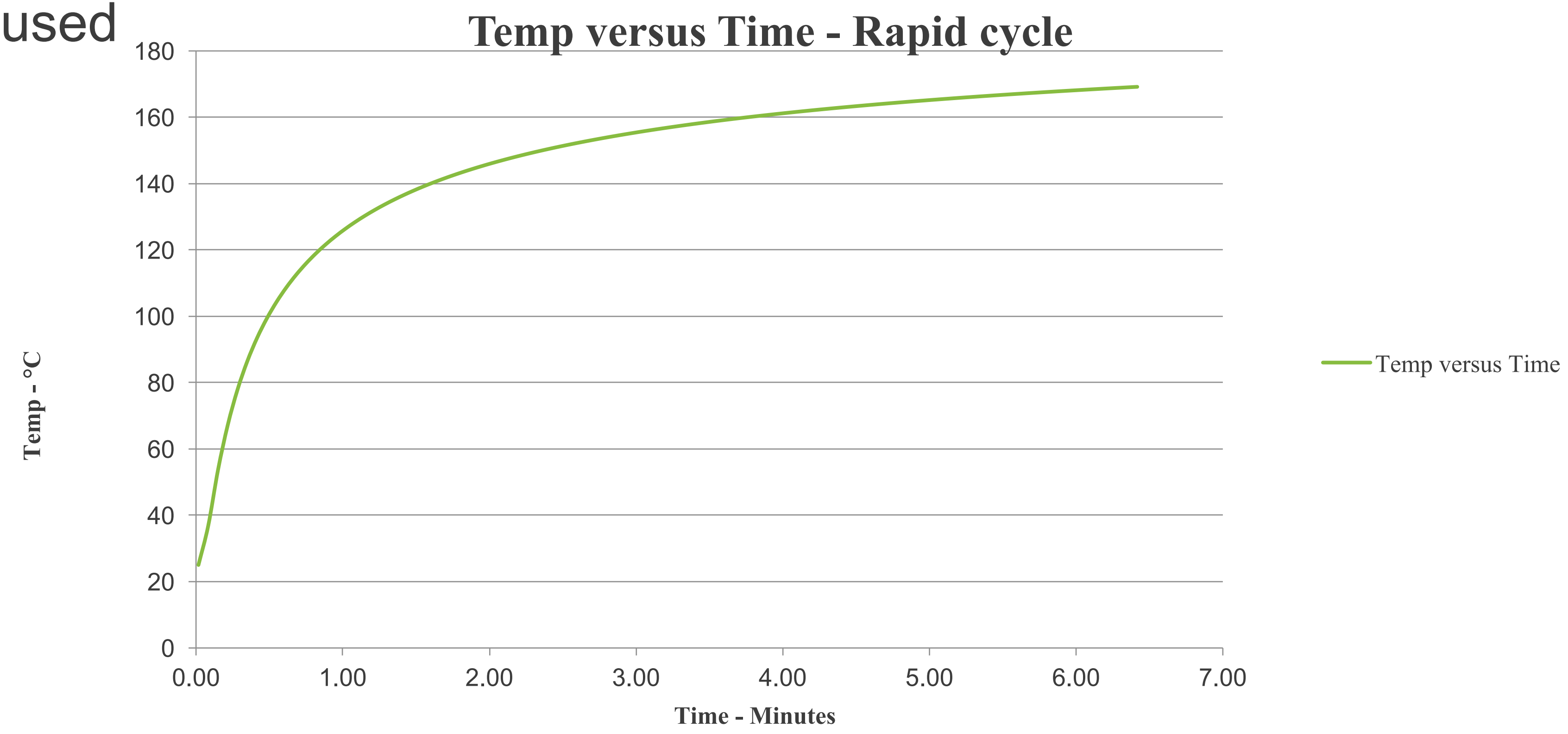
Theoretical Heating Curves

Rate Predictions

Tool		
Cp_{tool} = specific heat at temperature	0.460	kJ/kg-C
k_{tool} = thermal conductivity at temperature	27.0	W/m*C
$\alpha = k_{tool} / (\rho_{tool})(Cp_{tool})$	0.000008	m^2/sec
Heating		
	Rapid Cycle Calcs	
FLOW RATE THROUGH TOOL	45.0	Liters/min.
T_i = Tool starting temperature	25	°C
T_{Fluid} = Fluid temperature	200	°C (Constant tank temp)
UNIT + TANK FLUID VOLUME	4	l
Time to empty tank = (System volume)/Pump flow	9	sec
TOTAL FLUID VOLUME	7	l
x = total distance in tool from heat source	0.013	m
t = Time to heat tool	15	sec
$T(@f,t) = (erfc[(x)/(2)\{(\alpha)(t)\}^{1/2}] - exp[(h)(x)/(k) + (h)^2(\alpha)(t)/k^2][erfc[(x)/(2)\{(\alpha)(t)\}^{1/2} + (h)\{(\alpha)(t)\}^{1/2}/k])*(T_{Fluid}-Ti))+T_i$	72.91	°C
Rate	191.631	°C/min.

Curves

Energy battery used



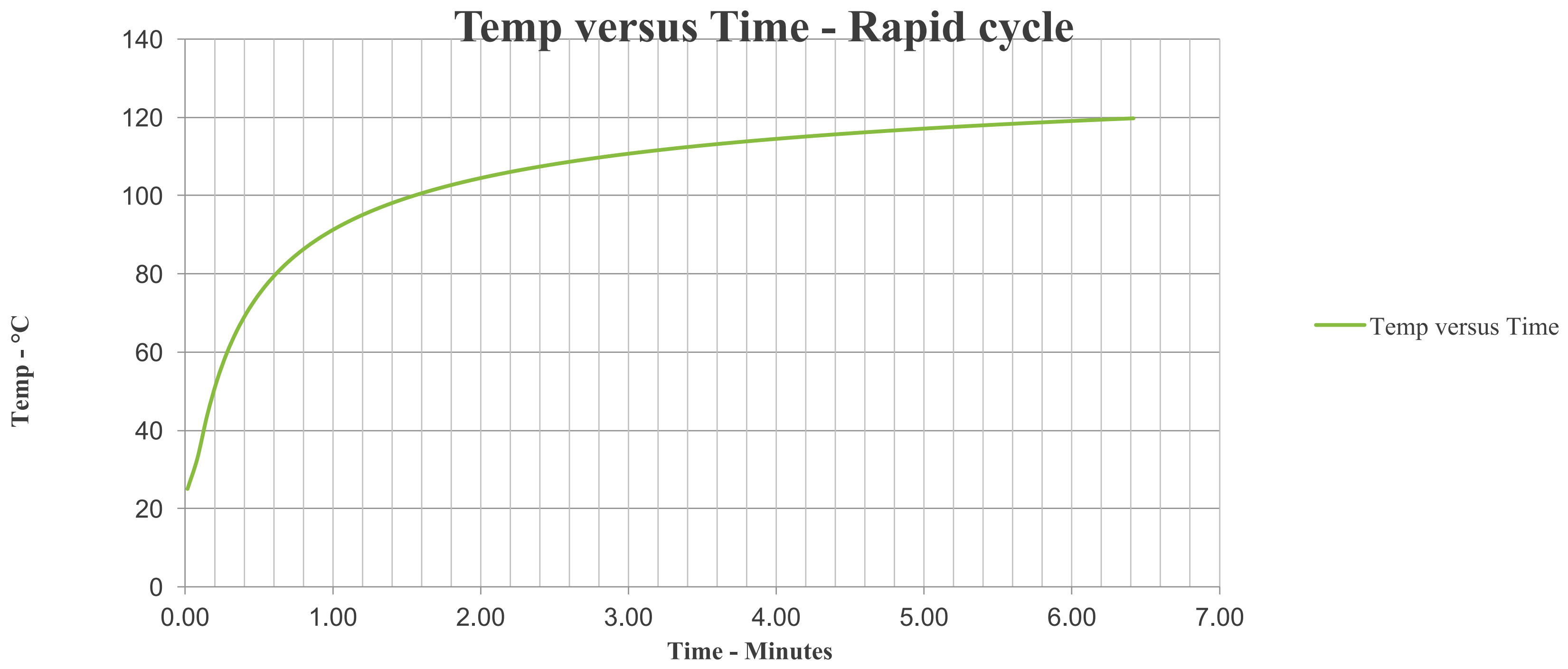
Rate Predictions

No Energy Battery

Tool		
Cp_{tool} = specific heat at temperature	0.460	kJ/kg-C
k_{tool} = thermal conductivity at temperature	27.0	W/m*C
$\alpha = k_{tool} / (\rho_{tool})(Cp_{tool})$	0.000008	m^2/sec
Heating		
	Rapid Cycle Calcs	
FLOW RATE THROUGH TOOL	45.0	Liters/min.
T_i = Tool starting temperature	25	°C
T_{Fluid}= Fluid temperature	140	°C (Constant tank temp)
UNIT + TANK FLUID VOLUME	4	l
Time to empty tank = (System volume)/Pump flow	9	sec
TOTAL FLUID VOLUME	7	l
x = total distance in tool from heat source	0.013	m
t = Time to heat tool	15	sec
$T(@f,t) = (erfc[(x)/(2)\{(\alpha)(t)\}^{1/2}] - exp[(h)(x)/(k) + (h)^2(\alpha)(t)/k^2][erfc[(x)/(2)\{(\alpha)(t)\}^{1/2} + (h)\{(\alpha)(t)\}^{1/2}/k])*(T_{Fluid}-Ti))+T_i$	56.48	°C
Rate	125.929	°C/min.

Curves

No energy battery



Mold Design

Is it important?

The most important part of rapid cycling that is not under the control of the mold heater manufacturer.

Why?

From earlier formula we see that the depth to the heat source from the part surface is compounded by erfc function.

Mold Design

What do mold makers like?

16mm diameter or larger straight gun drilled passages at 25mm down from the part surface and 60mm apart.

Why?

If the drill “walks” they have plenty of material above to ensure no break out, larger drills walk less, and more material reduces the chances of mold cracks developing in those areas.

Mold Design

What does rapid cycling require?

8mm diameter conformal passages at 8mm down from the part surface and 12mm apart.

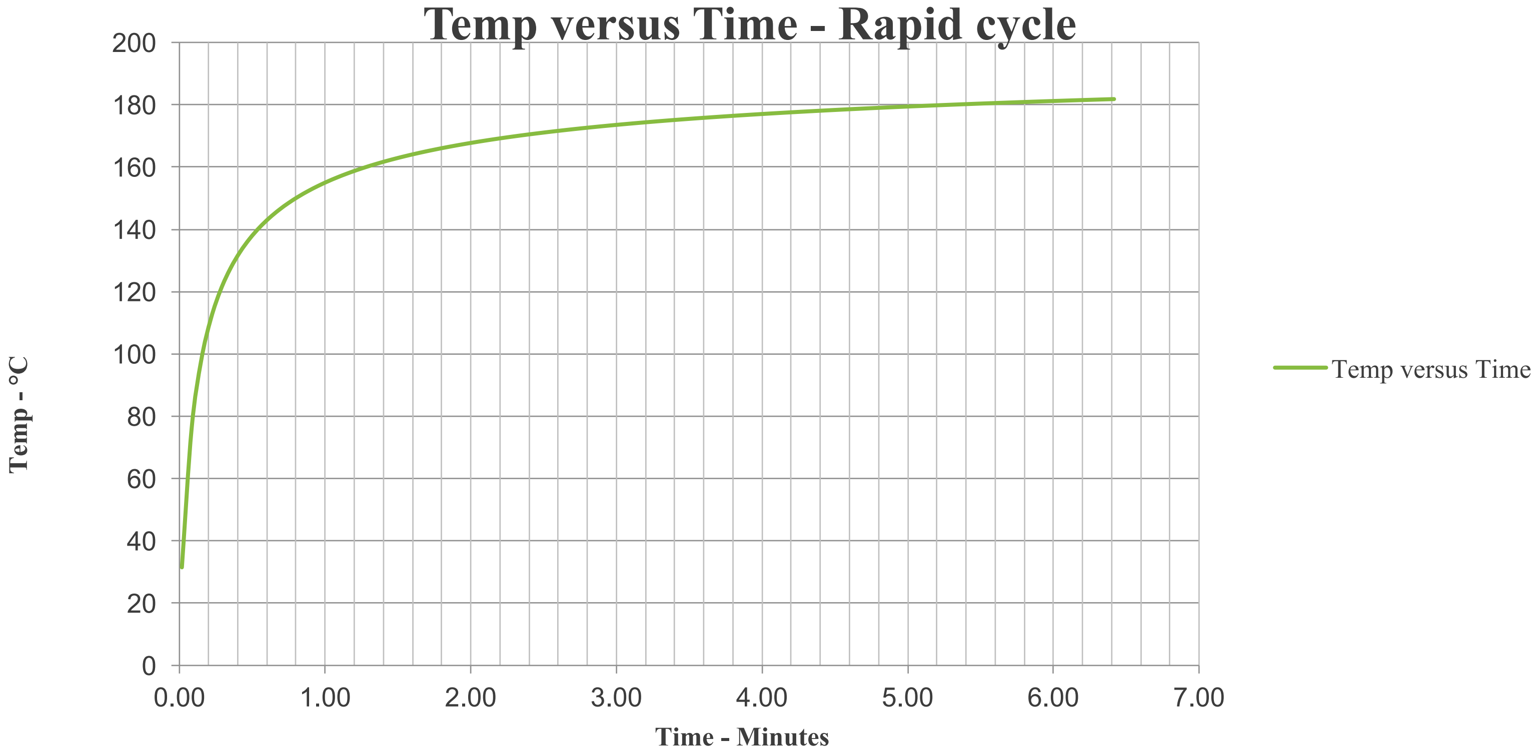
Why?

From earlier formula it can be seen that reducing the depth from heat source to part surface has a non-linear effect on heating rate (ie: it's a lot faster!)

Energy Battery with depth from part surface reduced by 50%

Tool		
Cp_{tool} = specific heat at temperature	0.460	kJ/kg-C
k_{tool} = thermal conductivity at temperature	27.0	W/m*C
$\alpha = k_{tool} / (\rho_{tool})(Cp_{tool})$	0.000008	m^2/sec
Heating		
	Rapid Cycle Calcs	
FLOW RATE THROUGH TOOL	45.0	Liters/min.
T_i = Tool starting temperature	25	°C
T_{Fluid}= Fluid temperature	200	°C (Constant tank temp)
UNIT + TANK FLUID VOLUME	4	l
Time to empty tank = (System volume)/Pump flow	9	sec
TOTAL FLUID VOLUME	7	l
x = total distance in tool from heat source	0.006	m
t = Time to heat tool	15	sec
$T(@f,t) = (erfc[(x)/(2)\{(\alpha)(t)\}^{1/2}] - exp[(h)(x)/(k) + (h)^2(\alpha)(t)/k^2][erfc[(x)/(2)\{(\alpha)(t)\}^{1/2} + (h)\{(\alpha)(t)\}^{1/2}/k])*(T_{Fluid}-Ti))+T_i$	116.44	°C
Rate	365.760	°C/min.

Energy Battery with depth from part surface reduced by 50%



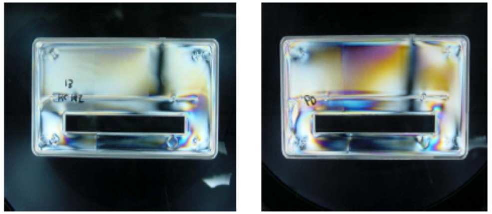
Conclusion

Rapid cycling can eliminate many defects during molding amorphous polymer parts. Sinks, weld lines, blemishes, exposed fiber, birefringence, etc.

Heat and Cool – Reduced Molded-in-Stress

Material: Lexan LS2 Resin (Solvent: CCL_4)

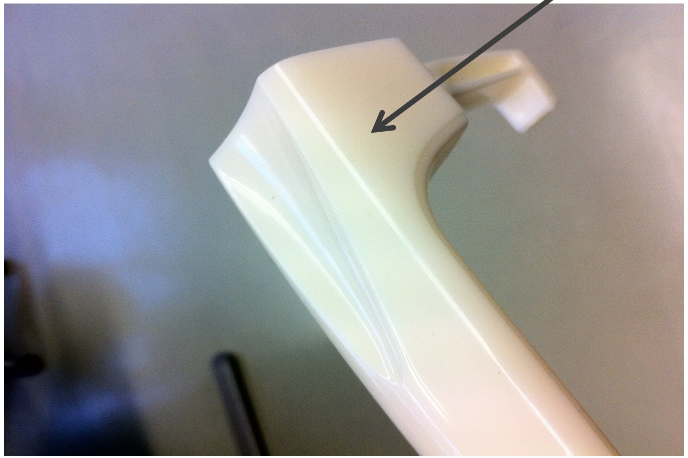
	Mold Temp (deg C)	As Molded	Annealed 2 hrs (120C)
Heat and Cool	70-140C	No crack	No crack
Conventional	60C	Crack	No crack
Conventional	90C	Crack	No crack



Application
- Lens
- Automotive Lighting

Annealing not required after molding with Heat and Cool

Thick walled part without sink.



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Conclusion

What currently limits its use in more applications?

The current philosophy used for mold design; which **increases cycle time.** Ok for European customers not so good for US!

Having better tools to predict cycle times will greatly increase the chance of success for more rapid cycle projects.

Thank you!

Q+A‘s