Temperature Control Methods for Out-of-Autoclave Composite Molding

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Agenda

- The Oven – beyond Pizza making
- Common Out-of-Autoclave (OoA) heating methods
- Current tooling concepts
- Conduction only (Electric cartridge, Embedded resistive)
- Convection (Oven, Oil, Pressurized Water)
- IR/Induction
- Future
- Conclusion
The Oven

As companies develop more Out-of-Autoclave (OoA) applications, ovens have become a popular solution for mold heating.

Why?
- They offer acceptable product quality
- Similar temperature ranges to Autoclaves
- Well understood process for manufacturing personnel

Are there faster less energy intensive ways to heat and cool OoA molds?
Common OoA Methods

- Electric cartridge heaters
- Resistive heating (embedded copper, carbon nanotubes, ceramics, etc.)
- Ovens
- Oil
- Steam
- Water
- Radiation/Induction
Current Tooling Concepts

OoA tools come in many forms

- Heated platen systems utilizing fluids or electric cartridge heaters to heat tools
- Carbon fiber, Ceramic, or copper heaters embedded in composite or ceramic tools
- Traditional steel and aluminum tools with jacketing
- Oven heated tools
Current Tooling Concepts

- Nickel tools with external plumbing
  - www.webermfg.ca

- Immersion tools with skins immersed between heat transfer fluids
  - www.quickstep.com.au
Electric Cartridge Heaters

Advantages
🌟 Heat only the tool
🌟 Easy to install
🌟 Fast heating rates
🌟 Good for high temperature applications (700°F)

Disadvantages
🌟 Due to conduction only heating (or minimal convection), and slight air gap at install, they require large kW draws to operate
🌟 Performance degrades rapidly as oxides form between the tool and cartridge

Is there a better way?
Electric Cartridge Heaters

- Offers no cooling option
- Very non-uniform heating profiles are common (20-40°F across tool)

Is there a better way?
Embedded Resistive Heating

Advantages

❖ Should offer energy consumption reductions as they are located close to the part
❖ Good for high temperature applications assuming composite tool resin can hold up
❖ Only heating the product not the whole tool therefore fast ramp rates should be possible

Is there a better way?

www.horizoncomposites.com
Embedded Resistive Heating

Disadvantages

- Heating profiles similar to electric cartridge heaters due to conduction only heat mode
- Offers no cooling option
- Will high localized temperatures degrade composite tool resins over time due to radiant heat component

Is there a better way?
Ovens

Advantages

❖ Can offer efficiency gains of convection heating due to movement of air
❖ Can offer limited cooling

Disadvantages

❖ Air’s density of .8 kg/m³, thermal conductivity of .035 W/m*K, and specific heat of only 1.018 kJ/kg*K at 180°C, does not allow it to transport or transfer much energy
❖ Heats slowly
❖ Large amperage draws (300 amps +) in order to heat oven volume and tool

Is there a better way?
The oven itself has to be re-heated after tool change out
- Sensitive to tool placement and air flow through the tool
- Limited precision on temperature control (+/- 5-10°F)
- Not stable if part has thick and thin sections due to low specific heat of air (1.018 kJ/kg*K air, water 4.302 kJ/kg*K)
- Typically large structures that are not conducive to cellular manufacturing arrangements

Is there a better way?
Oil Heat

Advantages
- Offers efficiency gains of convection heating
- Has higher density, specific heat, and thermal conductivity than air
- Can heat and cool the tool in same channels
- High temperature range (with Single Temp Control units 660°F)

Disadvantages
- More viscous than water, steam, or air
- Viscosity is very temperature dependent. Very slow to warm up and purge in colder facilities
- Can be loud while operating due to modulation valves

Is there a better way?
Oil Heat

- Can burn operators if a line breaks
- Have to run nitrogen over oil to minimize oxidation of oil
- Oil should be replaced every 3-5 years. $75/gal typical
- Many Aerospace OE’s will not allow use for composite part processing of thermosets
- Not green for disposal. Many of the oils are Benzene based. A known carcinogen
- Messy during change over or the “inevitable leaking line”
- Stinky … when running

Is there a better way?
Steam Heat

Advantages

🌟 Offers efficiency gains of convection heating
🌟 Has higher specific heat and thermal conductivity than air or oil
🌟 Can heat and cool the tool in the same channels
🌟 Has much lower density and viscosity than oil but has higher specific heat and thermal conductivity rates
🌟 Fast ramp rates on heat up

Is there a better way?

www.recousaheaters.com
Steam Heat

Disadvantages

☀ Can burn operator if a line breaks
☀ Requires water de-mineralization to achieve maximum performance and equipment life
☀ Large amperage required to heat through phase change
☀ Hard to keep in suspension in tools with non-linear passages
☀ Requires engineer on site due to pressure vessel designation
☀ Limited precision on temperature control (+/-5°F)

Is there a better way?
Pressurized Water

Advantages

- Offers efficiency gains of convection heating
- Consume 65+% less energy than oil systems
- Has higher density, specific heat, and thermal conductivity than oil or steam
- Can heat and cool the tool in the same circuit
- High temperature range (440 °F)
- Fast ramp rates on heat up and cool down
- Can replace oil or steam systems while reducing plant floor space requirements by 50%
- Precise temperature control (+/-2 °F) across the tool

Is there a better way?
Pressurized Water

- With use of quick disconnects allows for modular plant equipment designs/layouts
- Safe at line break. Low temp water vapor due to decompression
- Low kW heaters (3-15 kW typical) due to fluid cooling of heaters and efficient energy transfer to medium
- Long heater life
- Stable if part has thick and thin sections due to high specific heat of water (4.302 kJ/kg*K)
- Can use steam or oil as the heat source while utilizing the precise nature of pressurized water to control the mold temperature

Is there a better way?
Pressurized Water

Disadvantages

- Requires water de-mineralization to achieve maximum performance and equipment life

*Is there a better way?*
IR / Induction

Advantages
- Good for flat or formed parts
- High temperatures
- Fast ramp rates
- Only heats the part

Disadvantages
- Not so good for 3-d parts
- Large kW draw
- Non-uniform heating profiles are common

Is there a better way?
Future at SINGLE

- Water enhancers to increase thermal transfer rates
- Develop in-house tooling group to research larger conformal tooling designs
- Higher temperature applications
Conclusion

There are many ways to heat/cool a large variety of OoA tools. Each offers a unique solution to an OoA tool heating problem.

The following table is an attempt to summarize the characteristics of each method:
## Conclusion

<table>
<thead>
<tr>
<th>Heating Method</th>
<th>Temperature Range</th>
<th>Cooling</th>
<th>Tool Temperature Gradient</th>
<th>Ramp Rates</th>
<th>Energy consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric Cartridge</td>
<td>700°F+</td>
<td></td>
<td>20°F+</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>Embedded Resistive</td>
<td></td>
<td></td>
<td>20°F+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ovens</td>
<td>500°F+</td>
<td>limited</td>
<td>7-10°F+</td>
<td>low</td>
<td>high</td>
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<tr>
<td>Oil</td>
<td>660°F</td>
<td>Yes</td>
<td>4°F+</td>
<td>medium</td>
<td>medium</td>
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<tr>
<td>Steam</td>
<td>300°F+</td>
<td>Yes</td>
<td>5°F+</td>
<td>high</td>
<td>medium</td>
</tr>
<tr>
<td>Pressurized Water</td>
<td>440°F</td>
<td>Yes</td>
<td>2°F+</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>IR/Induction</td>
<td>700°F+</td>
<td></td>
<td>20°F+</td>
<td>high</td>
<td>high</td>
</tr>
</tbody>
</table>

**Questions?**
Cartridge heater vs pressurized water study:


File:
PMC Test Electric heat vs water
Oil versus pressurized water study:

File:
Single Temperature Controls Study Oil vs water for Out-of-Autoclave Tools
Pressurized water versus steam study: