A STUDY COMPARING ELECTRIC, OIL, AND PRESSURIZED WATER HEATING FOR COMPOSITE MOLDING

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ABSTRACT

Electric cartridge heaters have been used for many years to heat composite molds. They are easy to install and operate and thus make a logical choice. Unfortunately, they consume large amounts of electricity to operate, do not offer cooling, and are notorious for inconsistent heating.

Oil heating has been used to heat and cool composite molds for an equally long period primarily as a carry-over from its use in other plant equipment and plant heating. Unfortunately it is very slow to build temperature, consumes large amounts of electricity, and does not fit with the modern “greener” philosophy of manufacturing.

Due to the inherent energy savings, high temperature spectrum, precise temperature control, and fast ramp rates, pressurized water offers numerous advantages over both systems when applied to composite molding.

1. INTRODUCTION

As more OE’s eliminate oil heating from clean room environments and utilities cost increase, the need for a viable option to oil and electric cartridge heating has been created. Water due to its inherent properties makes an excellent choice. With the use of pressurization to increase the temperature spectrum, water can be a direct replacement for oil systems. Due to the inherent energy savings, high temperature spectrum, precise temperature control, and fast ramp rates for both heating and cooling, pressurized water systems have been used for injection molding for over 35 years. There are also numerous Aerospace companies that have recently adopted it as part of their Out-of-Autoclave (OoA) strategies.

1.1 Intent

The intent of the study and consequent desire to publish or present the data, was to help provide molders with better insight into when to use each of the three (3) solutions for the molding of composite parts. Publishing and presenting of the study should also help to educate the Composites sector in technology that is not yet as ubiquitous as electric or oil heating but provides for energy consumption reductions and more consistent part quality.

1.2 Audience

Companies or persons engaged in the manufacture of composite parts.

1.3 Scope

The study is focused on (3) three primary heating methods; electric cartridge, pressurized water, and oil. It does not attempt to compare Ovens against the three methods.

1.4 Background

Much of the motivation for the study was due to customer questions about cycle times, energy consumption, temperature precision, mold temp gradient, and ramp rates they could expect as they moved from oil and electric cartridge heaters to pressurized water systems. As a manufacturer of temperature control units in both water and oil, Single did not typically get involved in mold or mold design or the prediction of ramp rates for. In order to better answer customer questions about these items, the study was commissioned.

The current industry perception is that oil is more precise for mold temperature control than electric cartridge but slower. Cartridges are notorious for large temperature gradients across molds but are relatively fast and easy to install. Pressurized water is relatively unknown to this sector.

2. EXPERIMENTATION

2.1 Test parameters for Oil versus Pressurized water

1. Use equipment with similar flow rates through the mold.
2. Use equipment with similar heating/cooling capacities.
3. Use similar line sizes to the test mold from both test units.

Goal:

1. Determine Temperature Control Unit (TCU) temperature profiles, mold temperature profiles, and energy consumption for both systems.

Test Equipment:

Item	Description
Used Single H0.2	12 kW Heating / 41 kW Cooling
Hours	10 Hours on unit
Power Supply	460 V/60 Hz (3 phase)
Flow	60 liters/minute rated flow
Heating Lines out to mold	10 mm I.D
Line Length	1.5 m
Number of Lines	2
Cooling lines into TCU	10 mm I.D
Line Length	3.5 m
Number of Lines	2

Used Single D0.2	24 kW Heating / 116 kW Cooling
Hours	100 Hours on unit
Power Supply	460 V/60 Hz (3 phase)
Flow	100 liters/minute rated flow
Heating Lines out to mold	18 mm
Line Length	3.5 m
Number of Lines	2
Cooling lines into TCU	15 mm I.D
Line Length	3.5 m
Number of Lines	2
Mold	Webber externally plumbed Nickel, single sided test mold
Mold Weight	35.6 Kg
Measured flow through mold (water)	25 liters
Method	Differential pressure
Measured flow through mold (oil)	28 liters
Method	Differential pressure
Ambient air temperature for test	18.3°C
Temperature probe	Atkins Series 384 Digital
Amp Meter	Fluke 442
Chilled water supply temperature	26.6°C
Flow (water)	(60 l/minute)

Figure 1.

Comments:

1. In order to use units from stock, an oil unit with 2x the heating capacity, 2.8x the cooling capacity, and 1.6x the maximum rated flow as compared to the water unit was used.
2. The oil unit's inside diameters for the heating/cooling inlets were 1.8x larger than the inside diameters for the water unit's heating/cooling inlets, thereby allowing for significant gains in flow rates through the mold.

Experimental Procedure

A nickel shell externally plumbed mold was provided by Weber Manufacturing, Ontario, Canada, for the test. The Weber mold was chosen because of its ability to be heat balanced by controlling the location and number of tubes used to deliver the liquid medium. Temperature readings confirmed that variation across the mold at temperature was within the desired <1°C (with pressurized water). The mold was completely open to the 18°C room temperature and was not insulated. This was believed to represent the worst possible scenario for heat loss.

Figure 2.

The water unit was taken up to a temperature of 100°C and allowed to soak at that temperature for 5 minutes in order to purge air from the system. The unit was then taken back down to 25°C. 5 additional trials were run to determine the variation in operator performance in capturing temperature data. Acceptable R&R's were achieved. The sixth run was used to plot the data.

The oil unit, because they are notoriously hard to rid of air entrapment, was taken to a temperature of 200°C five (5) times before running the actual test.

Mold temperature readings were taken using a surface pyrometer on the molding surface at the center of the mold at one minute intervals. The outgoing and returning fluid temperatures from the mold and kW's were read directly from the controller provided on the unit.

The data was plotted using 2010 Excel and is shown in the following charts.

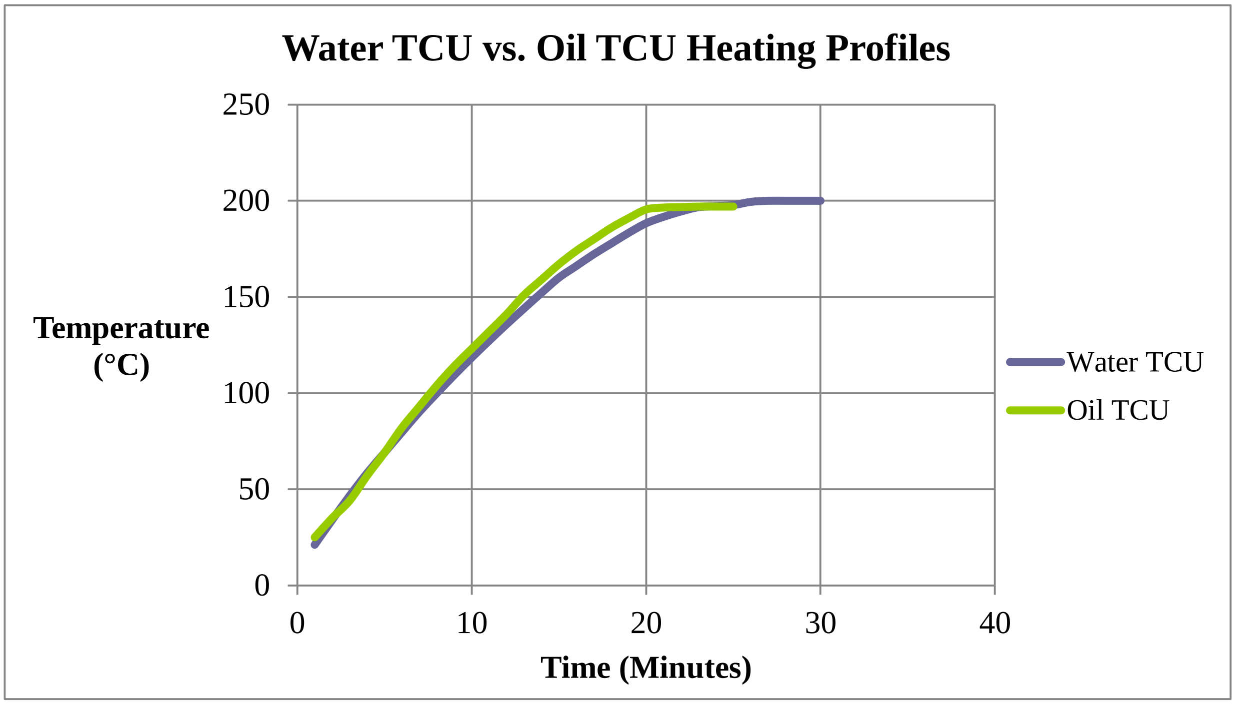


Figure 3.

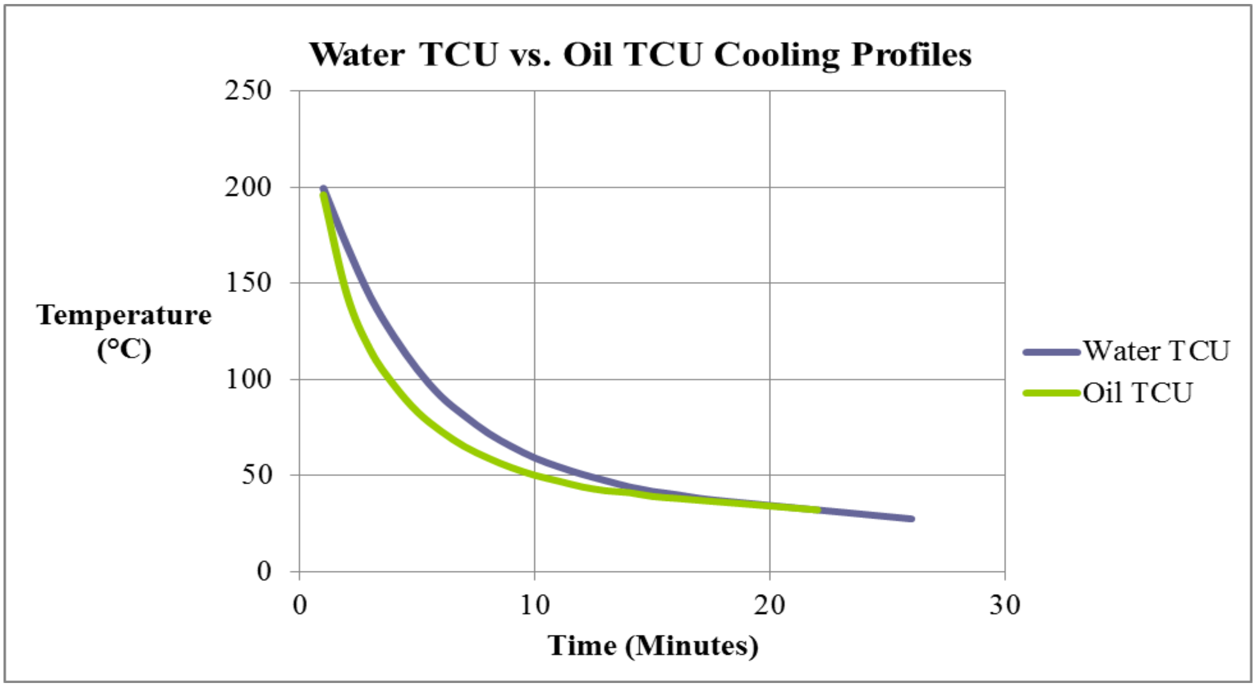


Figure 4.

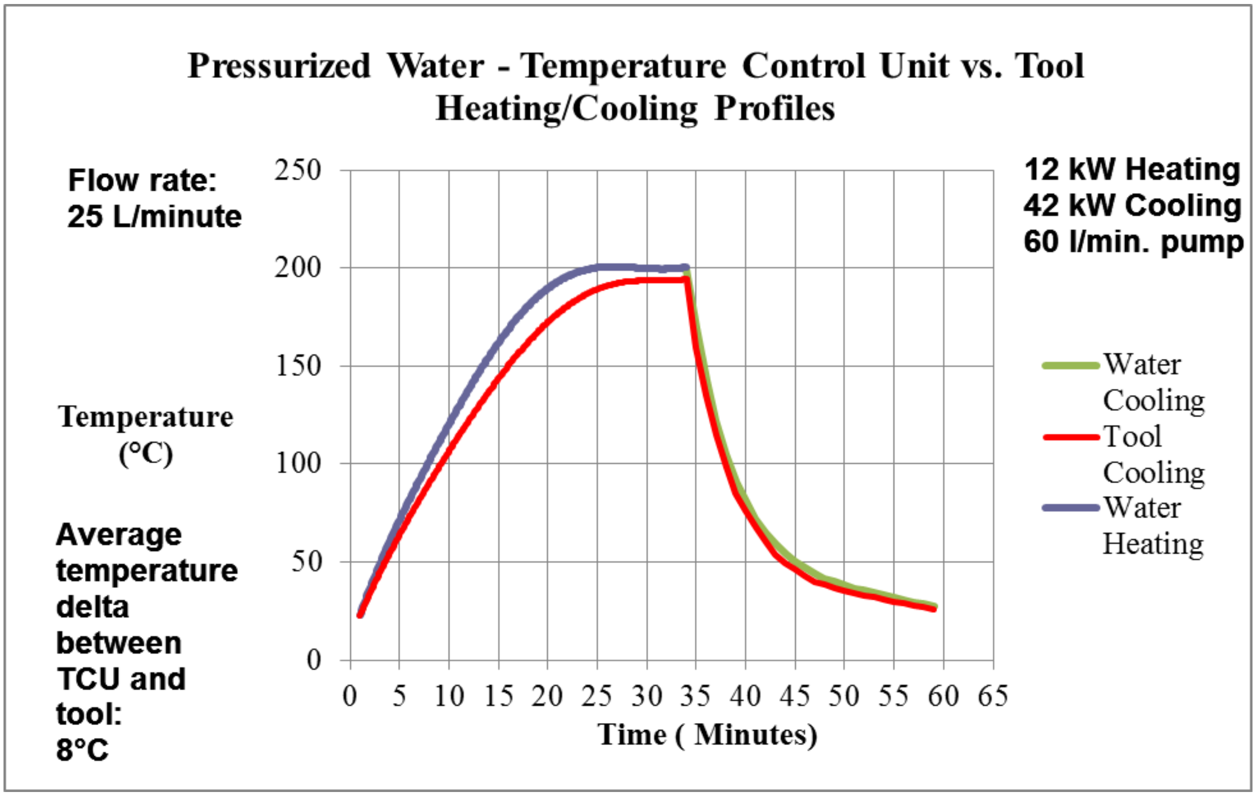


Figure 5.

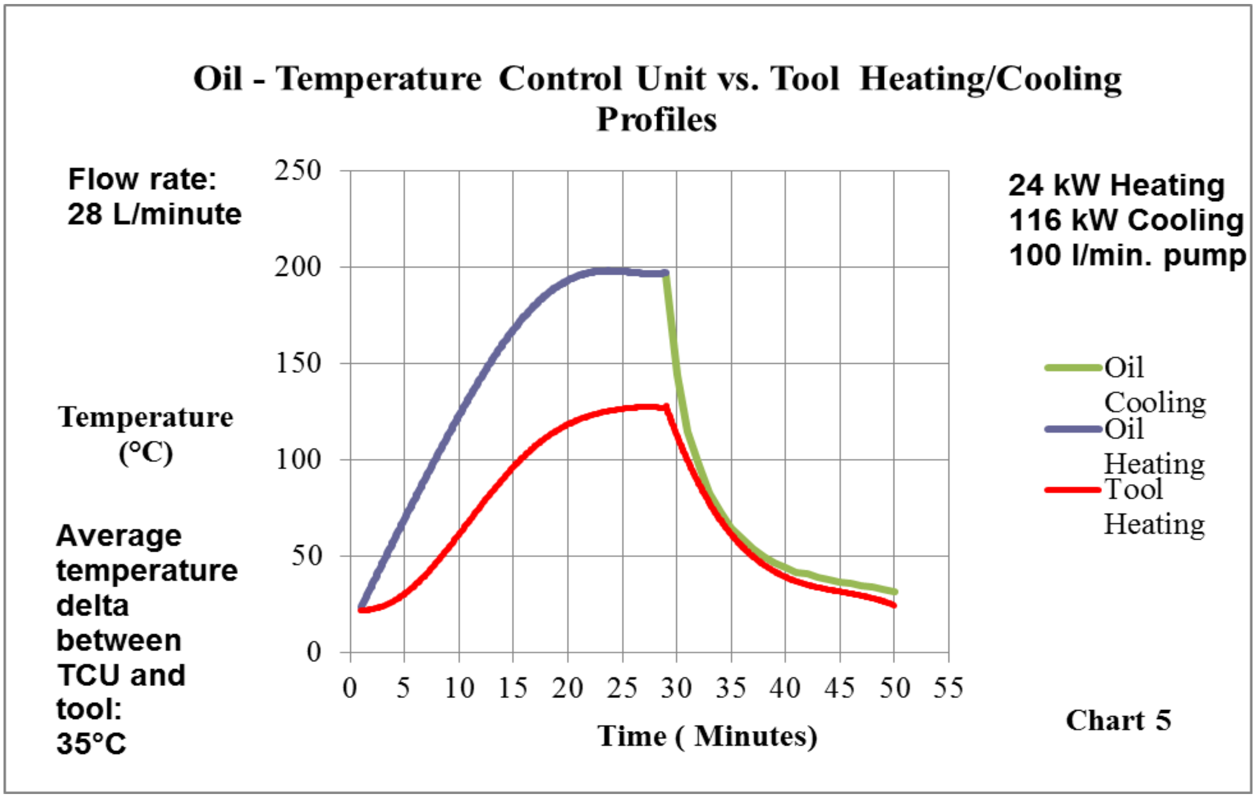


Figure 6.

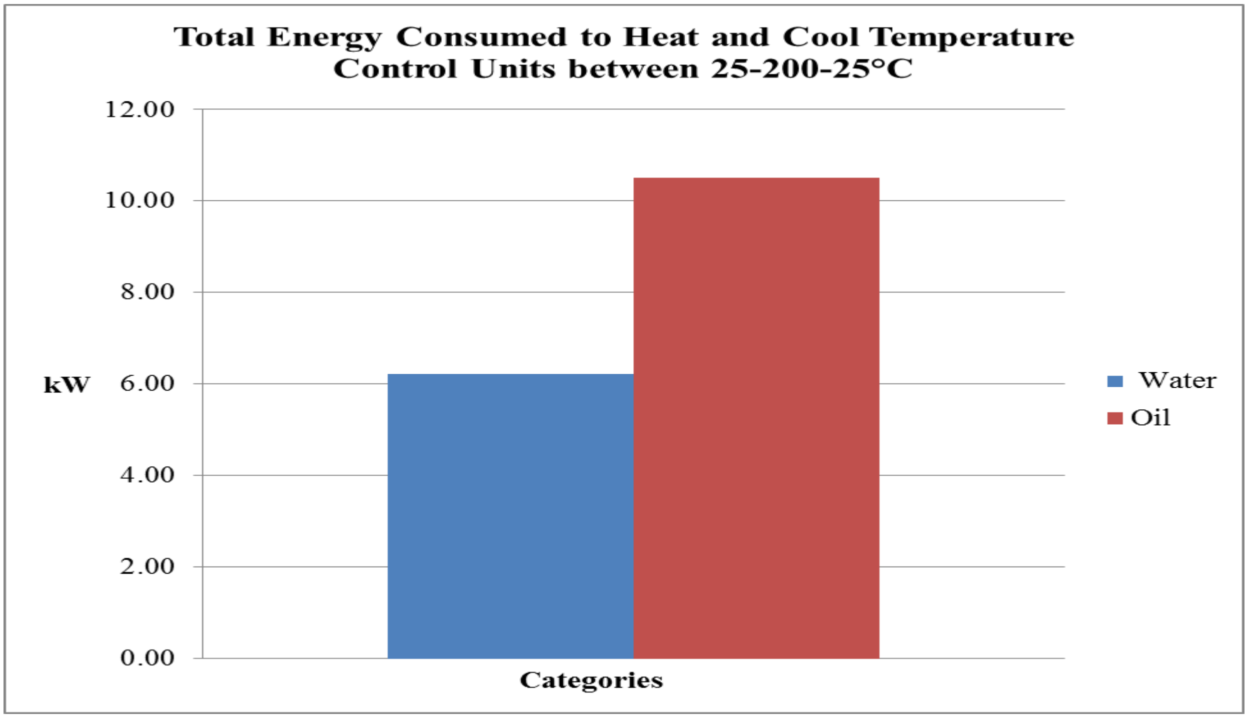

Total Energy Consumed to Heat and Cool Temperature Control Units between 25-200-25°C
12.00
10.00
8.00
kW
6.00
4.00
2.00
0.00
Categories
Water
Oil

Figure 7.

2.2 Test parameters for Electric Cartridge heaters versus Pressurized water

1. Use the same mold for both cartridge heaters and pressurized water.
2. Use the same size holes in the mold for both cartridge heaters and pressurized water.
3. Use equipment with similar heating capacities.

Goals:

1. Determine mold temperature profiles and energy consumption for both systems.

Test Equipment:

Item	**Description**
Used Single H0.2	6 kW Heating / 41 kW Cooling
Hours	100 Hours on unit
Power Supply	460 V/60 Hz (3 phase)
Flow	60 liters/minute rated flow
Heating Lines out to mold	8 mm I.D
Line Length	1.5 m
Number of Lines	2
Cooling lines into TCU	8 mm I.D
Line Length	1.5 m
Number of Lines	4
Mold	Two sided test mold
Mold Weight	18 Kg
Calculated flow through mold (water)	10 liters
Method	Single Temp Heat Transfer Spreadsheet
Ambient air temperature for test	21°C
Temperature probe	Atkins Series 384 Digital
Amp Meter	Fluke 442
4x 750 Watt 5/16" x 5" cartridge heaters	240V

Figure 8.

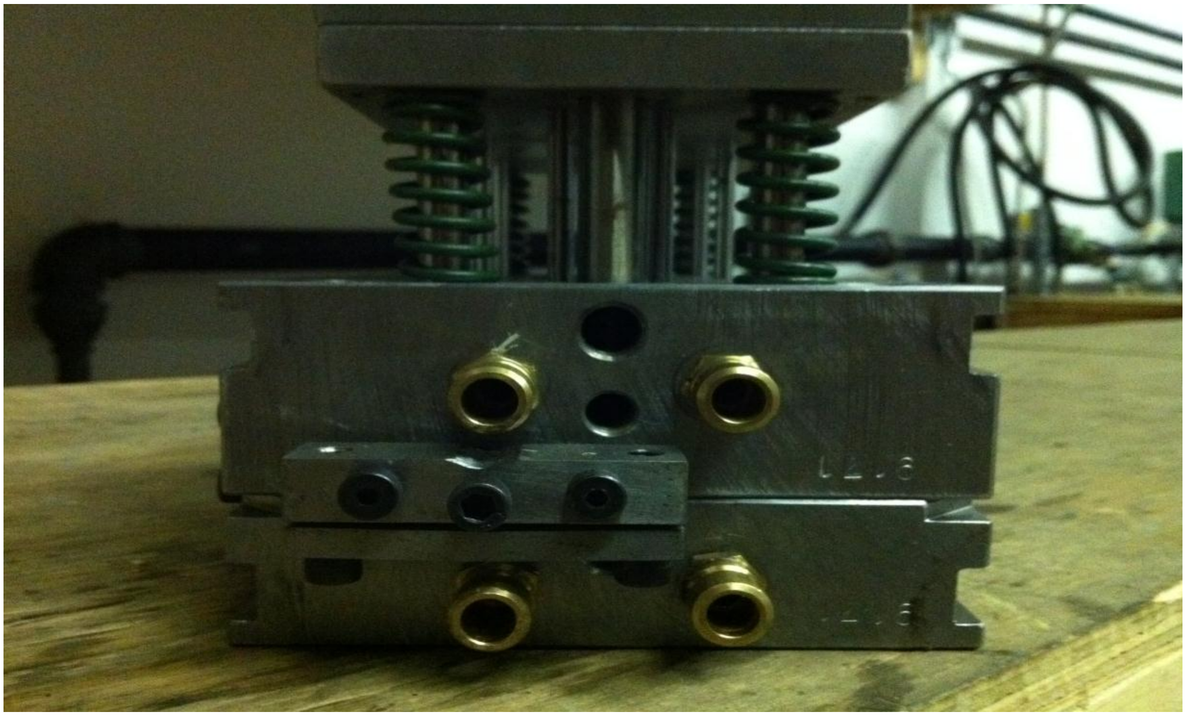
Comments:

1. The mold temperatures for the electric cartridge tests were controlled by comparison of input received from a thermocouple placed in the mold to a temperature set point on the unit’s controller.

2. The mold temperatures for the water tests were **NOT** controlled by comparison of input received from a thermocouple placed in the mold to a temperature set point on the unit's controller. The controller on the unit was set to the set point and allowed to monitor the temperature via the incoming water temperature from the mold.
3. In order to allow the same mold to be used for both methods, the mold was not optimized for the water unit. Limited flow due to the small mold passages would only a flow of 9 liters/minute, thus not allowing for much energy to be transferred to the mold.
4. The unit, due to availability, was also the smallest model and thus had substantially less available heating capacity than the cartridge heaters. The unit at 6kW had 1/5 the heating capacity as compared to the electric cartridge heaters.

Experimental Procedure

Holes were drilled 19mm below both parts centered on a 50mm width on both the stationary and moving halves of the mold. The diameter of these holes was properly sized for a 130mm cartridge heater placed directly below the entire part. These same holes were also used as water channels with the heater cartridges removed. The water was required to turn multiple 90° turns and exited the same end as it entered. Not typically a preferred mold design but allowed for water and cartridge placement directly under the part. A thermocouple was centered between the two plaques and on the centerline of the 130mm length on both mold halves for mold temperature monitoring and for control with the electric heat.



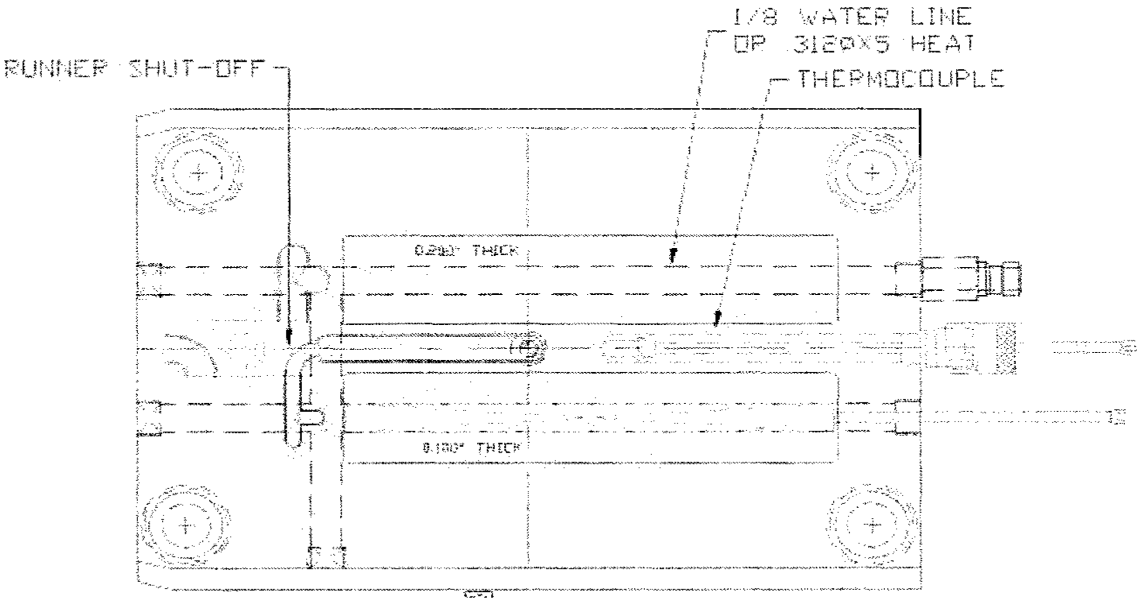


Figure 9.

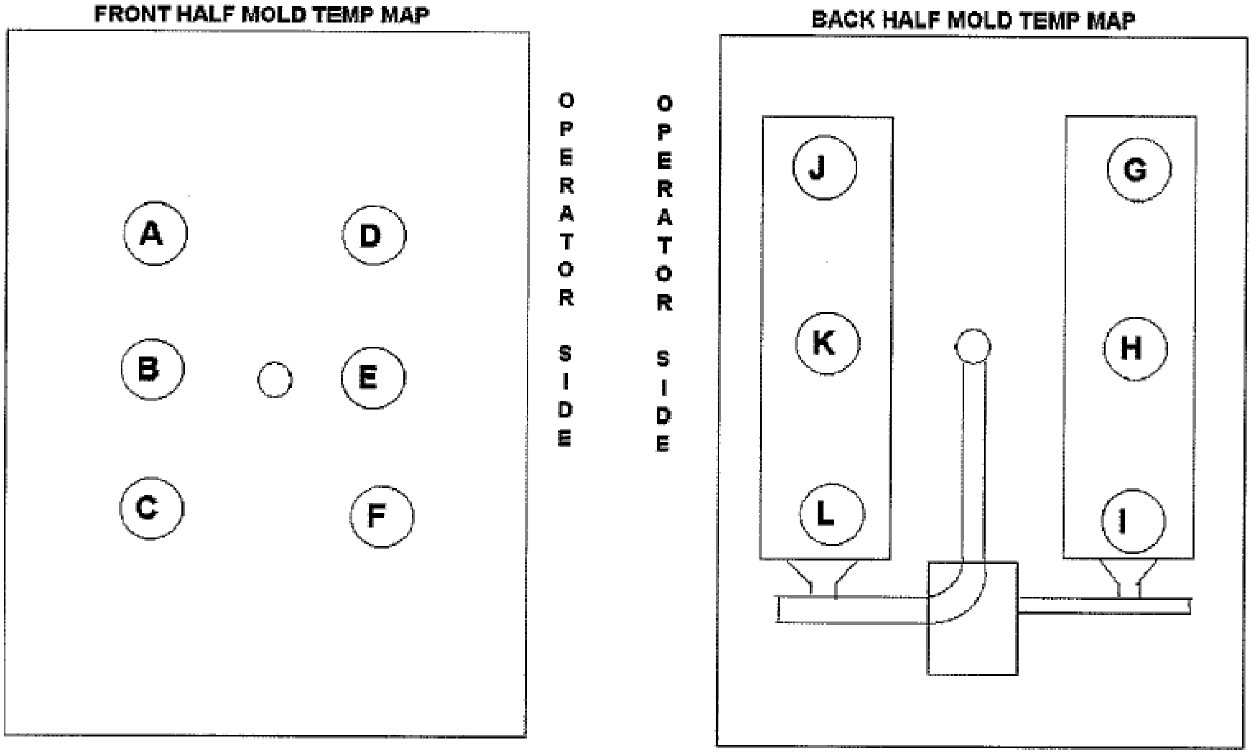


Figure 10.

The material used for all trials was polyetheretherketone (PEEK). The mold temperature controller was set to 193°C and the temperature reading from the thermocouple was allowed to stabilize with the mold closed. Mold temperature readings were taken using a surface pyrometer on the molding surfaces near the gate, in the part center, and opposite the gate after heat soak after (1) one and (2) two hours of production. After the 2-hour runs for each part were completed, the heater cartridges were removed and the mold was set-up using the pressurized water temperature control unit. The same molding process established for the electric heat was used for the pressurized water. Mold temperature readings were taken just as was performed for the electric heat trials.

The consistency of the thermocouple reading was also noted during the molding trials. After the mold reached steady state during the initial heat soak period, the mold was opened to prepare for the trial. During the electrically heated trials, any changes to the steady state condition yielded large temperature swings in the thermocouple reading. The thermocouple reading changed by as much as +/- 13°C in these trials. The thermocouple reading dropped significantly at this time, but did recover to reach steady state at the set point within 10 minutes. The thermocouple temperature of the water heated molds varied by only +/- 5°C and was not greatly influenced by changes in the steady state operating condition.

The mold surface temperature was taken at 12 places in the beginning, middle, and end of each (2) two hour run with a surface pyrometer.

Heat Type	Part	Time	Temperature - °C											
Electric	2.54 mm Thick	Soak Temp.	163.3	173.3	129.4	158.3	175.6	130.6	157.2	169.4	149.4	160.6	172.8	150.0
		1 Hour	154.4	165.0	142.2	150.6	165.0	147.2	157.2	173.3	158.3	158.3	171.7	156.1
		2 Hours	156.1	168.9	142.8	155.6	168.3	142.8	155.6	172.2	160.6	156.1	168.9	157.8
	5.08 mm Thick	Soak Temp.	158.3	169.4	135.6	155.0	170.0	141.1	154.4	174.4	145.0	159.4	177.2	147.2
		1 Hour	153.3	165.0	141.1	156.1	171.1	143.3	156.7	173.9	158.9	164.4	178.9	161.7
		2 Hours	155.0	166.7	141.1	158.3	176.1	145.0	155.0	171.1	157.8	163.9	177.2	159.4
Water	2.54 mm Thick	Soak Temp.	172.8	175.0	172.2	174.4	176.1	174.4	173.3	174.4	172.8	174.4	175.6	175.6
		1 Hour	171.7	176.7	172.2	173.9	175.6	172.2	173.3	176.7	174.4	175.0	176.1	176.7
		2 Hours	172.2	177.2	171.7	172.8	177.2	173.3	172.8	177.8	175.0	175.6	176.7	176.1
	5.08 mm Thick	Soak Temp.	170.0	172.2	172.2	175.0	175.0	174.4	172.2	172.2	171.7	173.9	175.0	174.4
		1 Hour	172.8	176.1	172.8	175.0	178.3	173.3	171.7	175.6	173.9	176.7	177.8	177.8
		2 Hours	172.8	176.1	172.8	174.4	178.9	173.9	172.2	175.0	174.4	174.4	176.1	175.6
		Location	A	B	C	D	E	F	G	H	I	J	K	L

Figure 11.

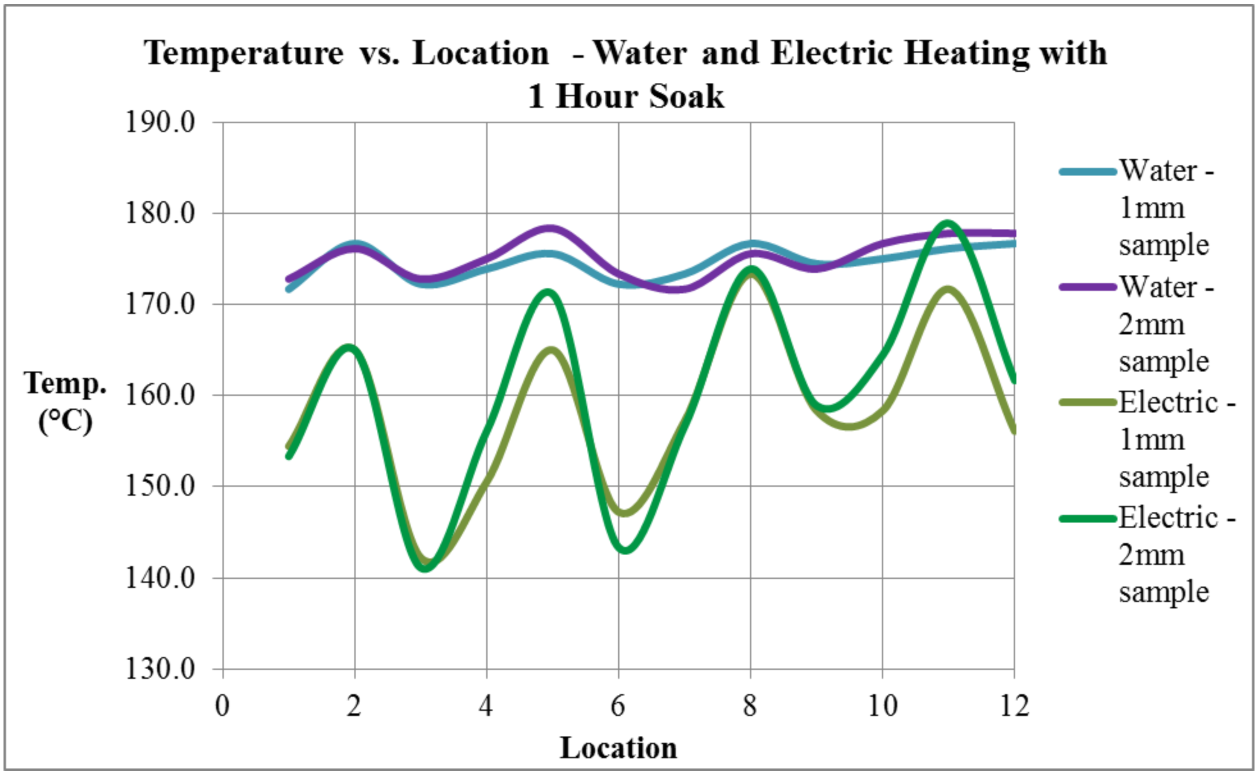


Figure 12.

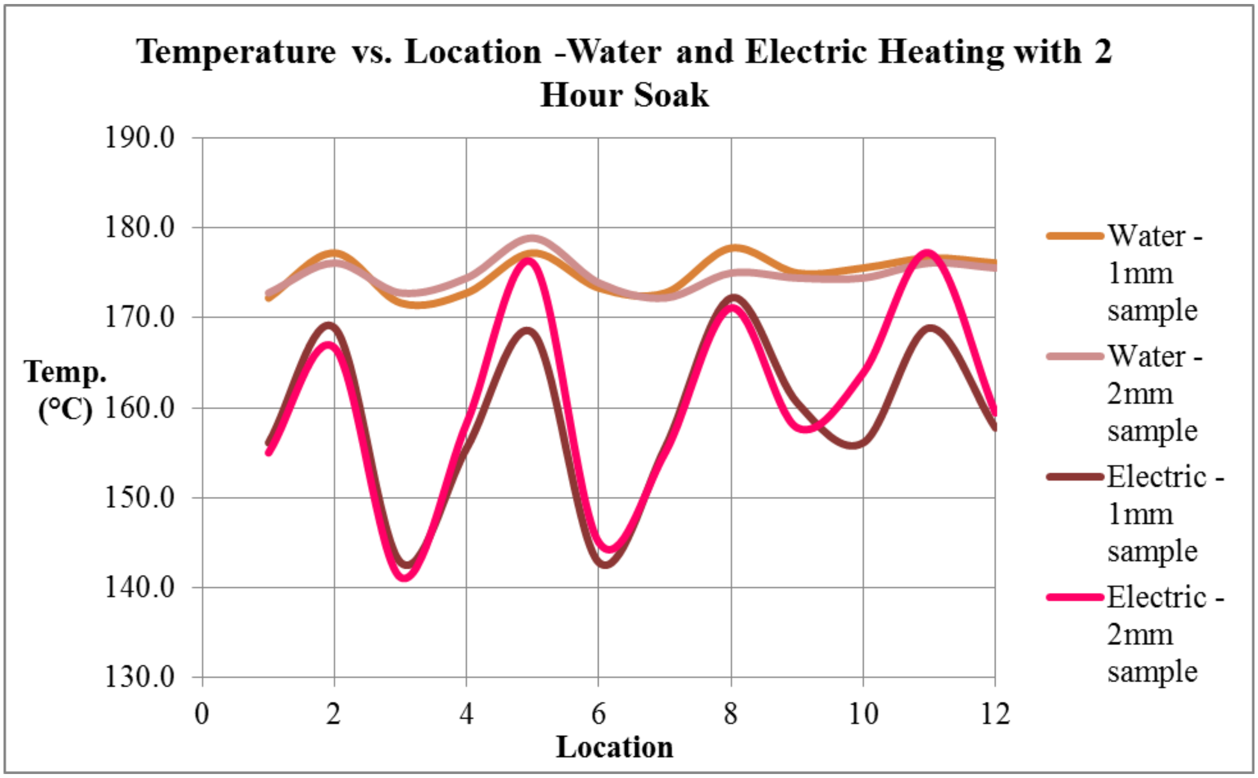


Figure 13.

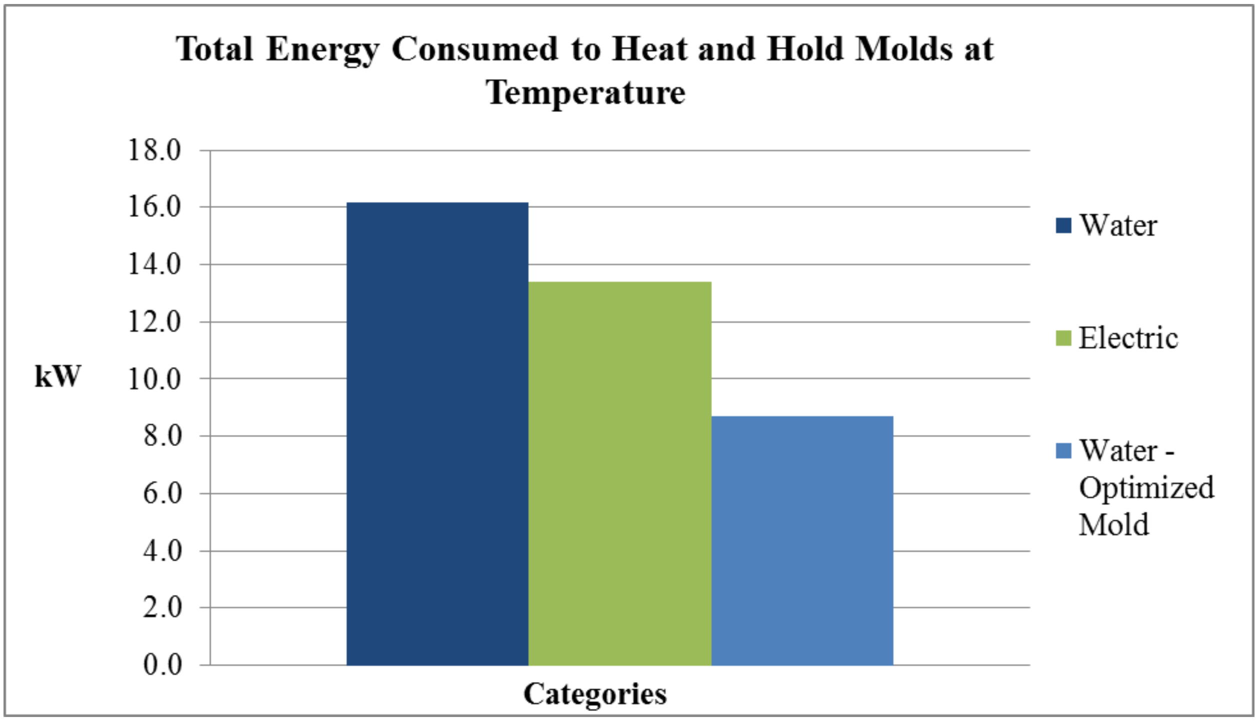


Figure 14.

A review of the temperature readings indicates that the water heated runs were more consistent over the 2 hours. The average differential in temperature of the same location over the 2 hours in the water heated runs was 1.94°C, while the average differential in temperature of the same location over the 2 hours in the electrically heated runs was 6.7°C.

A more concerning point is the difference in temperature over the length of a part. The average temperature differential over the length of one part at the same moment in time is 21.0°C for the electrically heated trials. The average for the water heated trials was only 2.7°C. This large temperature differential over the length of one part in the electrically heated mold could create crystallinity changes within a part. This would create shrinkage differences throughout the part/ resulting in a high degree of molded in stress. This stress could cause part warpage, creep, and physical property differences within the same part. In order to confirm an acceptable level of crystallinity the parts were analyzed with differential scanning calorimetry (DSC) to determine the % crystallinity in the parts.

The DSC results confirm the concerns raised by the mold temperature readings during the molding trials and the part dimensional results. The water heated mold produced parts that had consistent and acceptable DSC results throughout the length the part; however, the parts produced from the electrically heated mold had differing crystallinity percentages throughout any single part.

3. RESULTS

3.1 Oil versus Pressurized water

The tool used showed a larger flow rate for the oil unit. This is as would be expected with a rated flow of 100 liters/hour as compared to 60 for the water unit. Temperature differentials for incoming and outgoing fluid for the oil unit averaged 3.75°C. The water unit average 2°C. Both numbers are within the range of typical values for tools flowing at optimum rates. Based upon this, it is unlikely that either system's efficiency in heat transfer would benefit from additional flow.

Not charted in the study is that fact that the oil unit averaged a 2.75°C differential across the tool face while the water was unit under 1°C.

3.2 Electric Cartridge heaters versus Pressurized water

The design of the electric heating system can be improved with multiple control zones and faster thermocouple response times. Unfortunately, this would raise energy consumption and equipment costs. By enlarging the tool passages by 40%, the pressurized water system would raise the temperature closer to the set point, reduce the variation across the tool, and consume less energy.

Although not tested for in this test, the cooling cycle can be the longer cycle for molding. The water unit offers cooling through the same channels as the heating fluid and can be quickly cycled. The electric cartridge heaters offer no cooling. Cooling systems do exist to compliment electric heating systems but require an additional chiller and channels to be added to the mold. Experience with our customers has shown that the cooling cycle is of major concern and is the longer cycle by a factor of five (5) for thermoplastic composite molding applications.

4. CONCLUSIONS

4.1 Oil versus Pressurized water

Even with 2x the heating capacity (24kW vs. 12kW), 2.8x the cooling capacity (116 kW vs. 41kW), and 1.6x higher rated flow (100 Liters/min. vs. 60 Liters/min.), the oil unit was unable to reduce heating and cooling times of the mold as compared to the water unit. The oil unit also consumed 69% more electricity. The most concerning limitation for the oil unit is the large temperature difference between the TCU and the mold.

4.2 Electric Cartridge heaters versus Pressurized water

Although the tool was not optimized for the water unit, the unit appears to perform better in every category as compared to electric cartridge heaters.