

# INVESTIGATION OF INJECTION MOLDING PERFORMANCE USING INDUCTION BARREL HEATING

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## Abstract

This paper investigates the relative energy consumption of induction barrel heating and band-heaters during injection molding with a range of advanced plastic resins. The impact of induction barrel heating on the stability of process variables such as part weight and dimensional variability are also investigated.

## Background and Objective

With increasing cost pressure and emphasis on energy efficiency the plastics industry must find new ways to increase yields and save energy. Using more responsive and efficient means to heat the barrel during injection molding and extrusion presents an opportunity. Conventional barrel heating methods are relatively sluggish and inefficient. Induction barrel heating using a layer of thermal insulation interposed between the induction coils and the barrel appears to be significantly more responsive and efficient, with recent tests in lab environments providing encouraging results<sup>(1)</sup>.

The objective of this study is to add to the knowledge base by investigating the incremental value of induction barrel heating on a production-level process molding commercial-grade parts using advanced resins.

## Overview of Tests Performed

A rigorous process study was conducted that compared both the traditional band-heater method used on injection molding barrels to induction barrel heating using a nXheat<sup>TM</sup> system from Xaloy. This test study includes selection and setup of a molding machine and mold, installation of the induction barrel heating equipment and interconnection to the machine control system.

A process screening experiment was conducted comparing several resin grades being molded in two molds. The machine was run in a production mode to achieve consistent cycle time. The same experiment was conducted using both induction barrel heating and standard band-heaters. Data acquisition (DAQ) equipment was installed external of the machine to monitor barrel temperatures and power data. A digital weight scale and an optical coordinate measurement machine were used to measure part weight and dimensions.

## Detailed Test Procedure

An Injection molding machine was selected that would represent a common industry size press. A Husky G-Line series machine with a 550-ton clamp capability provided an ideal test platform. This machine has the option of several size barrel capacities and a 50 mm / 482 gram shot size barrel was selected for this study.

During testing with band-heaters a conventional barrel cover (Figure 1) with interior fiberglass insulation was used to minimize heat losses. If operated without an insulated cover band-heaters would be expected to be even less efficient. During testing with induction the nXheat<sup>TM</sup> system, comprising Litz cable coil windings and interposed thermal insulation, was installed in all four barrel zones in place of the band-heaters (Figure 2).

Two different molds were selected for evaluation. The first mold, a helmet test mold producing a semi spherical part, was used for its thick wall section and resultant higher part weight, thus yielding shorter melt residence time. The mold was center sprue gated and the part weight was calculated at ~75% of barrel capacity. This test was used to evaluate the energy consumption of the two barrel heating methods.

Power consumption by the barrel heating devices and the machine's hydraulic pump motor was monitored by two methods to ensure accuracy (current transducer measurements using the DAQ and a 3-phase power meter).

The second mold used for the study was a PC notebook base frame. This was selected for its thin wall, higher injection fill requirements and longer melt residence time. This mold has multiple gates through a three-plate cold runner system. This test was used to evaluate the impact of the two barrel heating methods on short-term (<1 hour) part-to-part consistency, as reflected by part weight variability and dimensional variability. Future testing is planned to investigate the effect of induction barrel heating on longer-term process stability.

For weight measurement we used a Sartorius GMBH Gottingen scale type U 5000 D, which measures to 0.01grams (repeatability of ~0.03 grams on a 120 gram part). To measure part dimensions we used a Micro-Vu optical coordinate measurement machine (repeatability of ~0.05 mm on a 275 mm dimension).

The selected barrel was modified to accept additional thermocouples. The control thermocouples used for each zone were at a depth of 28.6 mm (1.125"). Three additional deeper thermocouples were added for monitoring purposes. These were placed at a depth of 44.5 mm (1.750") to provide faster measurement response closer to the screw and melt. Although the shallow depth thermocouples were used for controlling, both shallow and deep thermocouples were monitored for data.

Processing was conducted using standard processing parameters recommended from resin data sheets.

### **Energy Consumption Test Results**

The electrical energy consumed by the barrel heating means (conventional band-heaters and induction barrel heating) per unit of processed resin is charted in Figure 3, the absolute energy savings (with induction) in Figure 4, and the percent reduction in Figure 5. The absolute reduction in energy consumption varies significantly with the resin processed, from a low savings of about 180

joules/gram savings with Valox\* resin, to a high savings of about 500 joules/gram with Ultem\* resin. The percent reduction is more consistent (varying from 49% with Lexan\* resin to 59% with Ultem\* resin), with an average of 55% that agrees well with prior documented results<sup>(1)</sup>.

Figure 6 shows that the change in the amount of electrical energy consumed by the injection unit's hydraulic pump motor was statistically insignificant, suggesting that the barrel heating means did not affect the efficacy of material conveying, melting and mixing.

Figure 7 shows that with conventional band-heaters the ratio of the total energy consumed by the injection unit to that consumed by the band-heaters varied from about 5 to 9 (with Ultem\* resin), with an average of 6.7. (Note: Total energy consumption = hydraulic pump motor energy consumption + band-heater energy consumption.) The average reduction in barrel heating energy consumption of 55%, up to maximum of 59% with Ultem\* resin, then translates to an average reduction in total injection unit energy consumption of about 8% (i.e.  $55/6.7 = 8.2$ ), up to a maximum of about 12% with Ultem\* resin (i.e.  $59/5 = 11.8$ ).

On an electric injection molding machine the ratio of the injection unit's total energy consumption to the band-heater's energy consumption is frequently half of that on a hydraulic machine. Induction barrel heating might then be expected to reduce the total energy consumption on electric machines by about 15%, up to perhaps as high as 25% with Ultem\* resin. Future testing is planned to confirm this.

Basic heat transfer theory suggests, and prior documented testing<sup>(1)</sup> confirms, that the efficiency of band-heaters drops as increasing barrel and band-heater surface temperatures lead to higher radiation and natural convection heat losses from exposed surfaces. Generally speaking, increasing melt temperatures is then expected to increase energy savings from induction barrel heating, and Figure 8 confirms a loose relationship.

A tighter predictive model requires that the temperature gradient across the barrel wall also be taken into account. Conductive heat transfer theory dictates that for band-heaters to increase the heat input

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to the process the temperature gradient across the barrel wall must be increased. For a given melt temperature band-heaters must then run hotter, and be less efficient, if the process demand for heat increases. The following equation expresses the overall process heat balance;

$$Q_P = Q_M + Q_{L,A} + Q_{L,M} = Q_B + Q_V$$

$$Q_M = M \times C_p \times \Delta T_R$$

$$E_M = C_p \times \Delta T_R$$

$$\Delta T_R = T_M - T_F$$

where;

- $Q_P$  = total process heat demand (joules/sec)
- $Q_M$  = heat absorbed by the resin (joules/sec)
- $Q_{L,A}$  = heat losses to ambient (joules/sec, due to radiation and natural convection)
- $Q_{L,M}$  = heat losses to the machine structure (joules/sec, due to conduction)
- $Q_B$  = heat added by the barrel heating means (joules/sec)
- $Q_V$  = heat generated by viscous heating (joules/sec, due to the screw's action on the melt-stream)
- $M$  = resin mass throughput (grams/sec)
- $C_p$  = resin specific heat (joules/gram-°C)
- $\Delta T_R$  = resin temperature rise (°C)
- $E_M$  = "melt-stream energy" (joules/gram)
- $T_M$  = resin melt temperature (°C)
- $T_F$  = resin dried feed temperature (°C)

The above relationships show that an increase in resin temperature rise (by either reducing the feed temperature or raising the melt temperature) and an increase in resin specific heat will both increase the demand for heat, ultimately reducing the efficiency of band-heaters, leading to a predictable increase in the savings provided by induction barrel heating. The approximate melt-stream energy is plotted for the tested conditions in Figure 9, and then the reduction in barrel heating energy is plotted versus the melt-stream energy in Figure 10. The result shows that melt-stream energy is a better predictor of barrel heating efficiency and energy savings than melt temperature.

The above relationships also suggest that as resin throughput increases band-heater efficiency is likely to drop and the energy savings provided by induction is likely to increase. Future testing is planned to confirm this.

The potential economic benefit of induction barrel heating to molding processes that use the tested resins can be projected by using the energy savings data from Figure 2 and assuming an electricity cost and hours of operation per year. In Figure 11 nominal annual savings are then plotted for the four tested resins, assuming an electricity cost of \$0.015/kW-hour and 8,000 hours of operation per year.

### Process Variability Test Results

We observed two major differences between the induction system and standard band-heaters. The induction system has a faster thermal response than band-heaters and produced more uniform parts.

At equivalent power consumption levels (5.2 kW) the induction system heated the barrel about 50% faster than standard band-heaters. Figure 12 shows the deep thermocouple response in the rear (feed) zone for both induction and band-heaters. With induction heating the initial ramp-up rate of the deep thermocouple in the rear zone (before PID control diminished the power output to avoid over-shooting the target) was 19.5 °C/min versus 12.5 °C/min with band-heater. The other zones exhibited similar responses.

We believe the rapid heating is a result of how the heat is transferred to the barrel. Band-heaters must conduct heat across the contact resistance between themselves and the barrel, and then the heat must conduct through the barrel wall to heat the plastic material.

Induction heating uses an oscillating electromagnetic field that directly heats the barrel steel. The depth of heating is a function of the frequency of the oscillating magnetic field and the nXheat™ system uses a relatively low frequency that allows the energy to penetrate deep into the barrel.

With induction heating the insulation that is interposed between the induction coil and the barrel also prevents applied heat from escaping. And finally,

induction has insignificant thermal inertia. By comparison, the significant mass of band-heaters has to be heated and cooled along with the barrel.

The other advantage of induction heating was improved part weight consistency and reduced dimensional variability. Again, we ran both systems with the same mold, material and process settings (barrel & mold temperatures, injection speed/time, transfer, hold time/pressure and overall cycle time).

We saw a significant reduction in part weight and dimensional variability with shorter cycle times. On average we saw a 50% reduction the part weight variability and 25% reduction in dimensional variability with the induction system. Figure 13 shows an example of the weight variability difference between induction heating verses band-heaters. Figure 14 shows the dimensional variability difference between induction heating and band-heaters. These results indicate that induction is likely to produce more consistent parts, particularly at shorter cycle times.

### Conclusions

This study suggests that on production processes molding parts from the tested resins induction barrel heating is likely to;

- Reduce barrel heating energy consumption (compared to conventional band-heaters) by 50% or more.
- Reduce barrel heat-up times by 50% or more.
- Improve short-term part-to-part consistency by reducing part weight variability by about 50% and part dimensional variability by about 25%.

### References

1. B. Taylor, T. Womer, R. Kadykowski, *Efficiency Gains and Improvements using Different Barrel Heating Technologies for the Injection Molding Process*, SPE Antec 2007
2. E. J. Davies; P. G. Simpson, *Induction Heating Handbook*, McGraw-Hill Companies, 1978
3. US Patent 5403540; Brundage et al
4. US Patent 7041944; Pilavdzic et al

5. B. V. Karlekar; R. M. Desmond, *Engineering Heat Transfer*, West Publishing Company, 1977

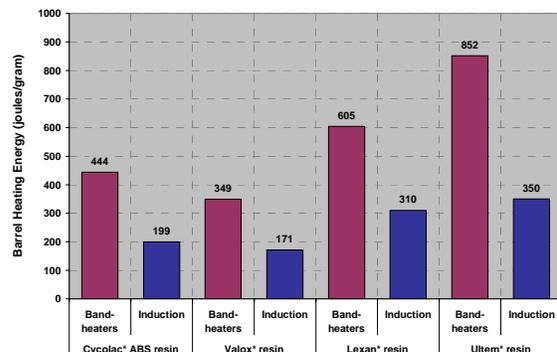
Figure 1. Band-heater Installation with Insulated Barrel Cover



Figure 2. Induction Installation (nXheat™)



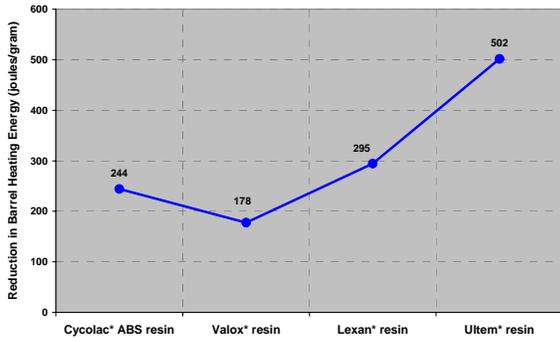
Figure 3. Barrel Heating Energy Consumption versus Resin



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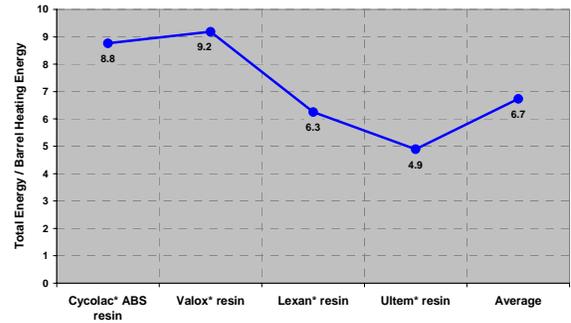
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Figure 4. Reduction in Barrel Heating Energy versus Resin



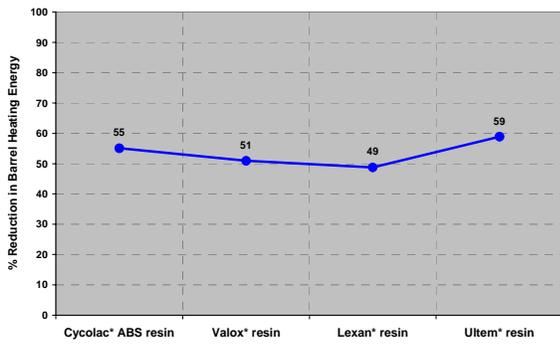
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Figure 7. Ratio of Total Energy to Band-Heater Energy (total = hydraulic motor energy + band-heater barrel heating energy)



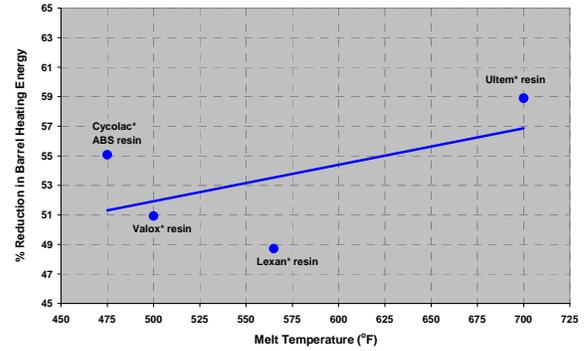
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Figure 5. % Reduction in Barrel Heating Energy versus Resin



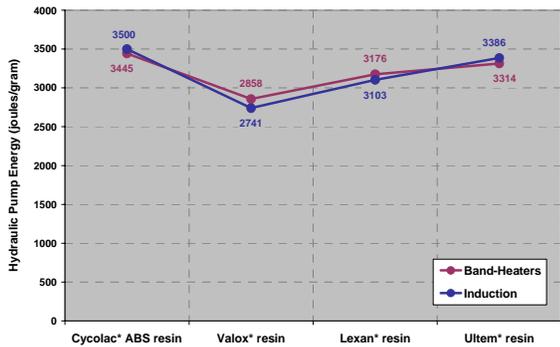
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Figure 8. % Reduction in Barrel Heating Energy versus Melt Temperature



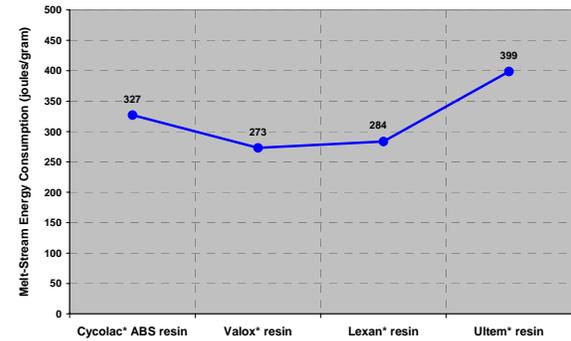
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Figure 6. Hydraulic Pump Energy Consumption versus Resin



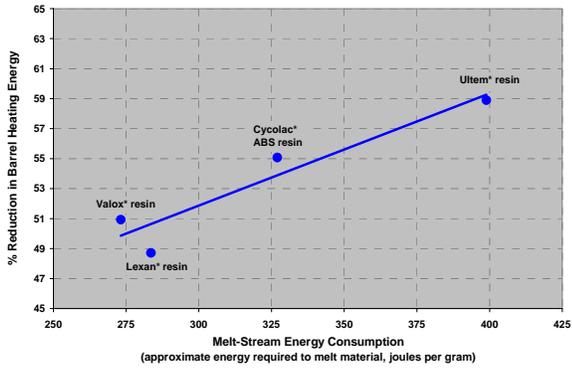
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Figure 9. Melt-Stream Energy Consumption versus Resin



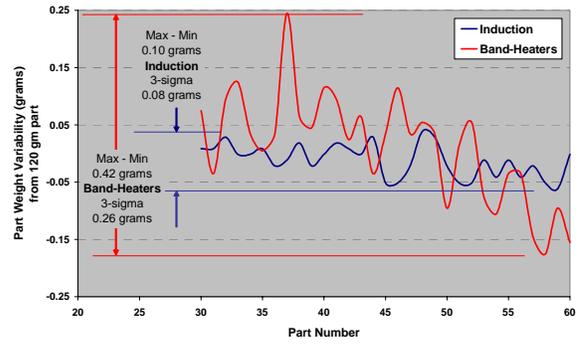
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**Figure 10. % Reduction in Barrel Heating Energy vs Melt-Stream Energy**

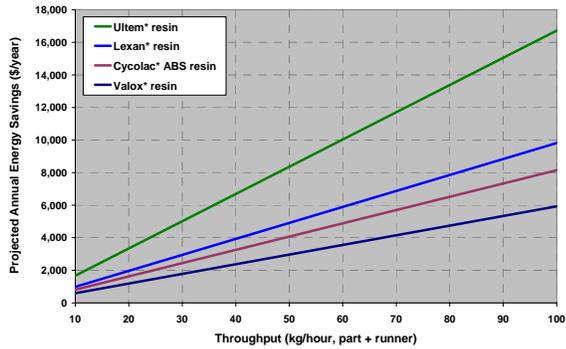


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**Figure 13. Part Weight Variability Comparison**

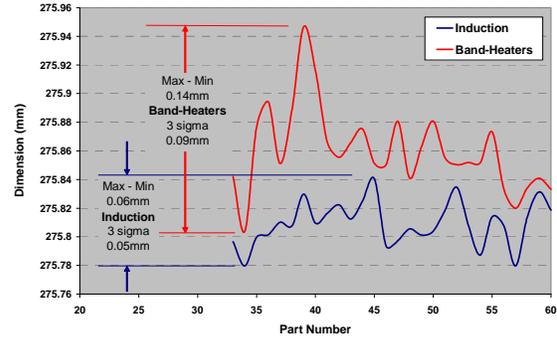


**Figure 11. Projected Energy Savings with Induction**  
(assuming 0.015 \$/kW-hour electricity cost and 8,000 operating hours per year)

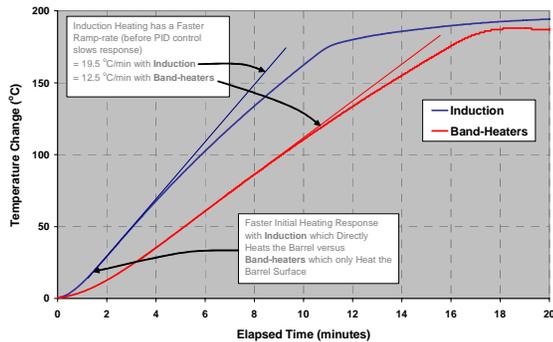


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**Figure 14. Dimensional Variability Comparison**



**Figure 12. Heat-up Time Comparison**



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