Energy saving by parameter setting

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Abstract

Many plastics processing machines have heated barrels and screws. Examples are injection moulding machines, blow moulding machines and extruders. We used a servopump driven injection moulding machine to study the effect of two injection parameters: set temperature of the last barrel zone and rotational speed of the screw on energy consumption. The barrel heating energy consumed was separated out. Useful results were obtained.

Introduction

It is quite well-known that servomotor based injection moulding machines save motion energy compared to the asynchronous motor driven variable displacement pump technology. To save on barrel heating energy, a few technologies like induction heating and space-age barrel insulation material are available. These methods are hardware based.

Without purchasing new hardware, it is also possible to save energy by suitably adjusting injection moulding parameters. We study two of them here.

The first parameter is the set temperature of the last barrel heating zone. This is the zone closest to the hopper where material feeds into the barrel. Between the last barrel heater zone and the barrel feed hole is a water collar through which circulating water keeps the pellets beneath it in solid form.

The second parameter is the screw rotational speed during charging. When the cooling time (which takes place in parallel with charging) is long, one has a choice of fast charging or slow charging. In fast charging, the screw turns at maximum speed, or the maximum recommended for the material being plasticized. In slow charging, the screw turns slowly but still is able to finish the charging within the cooling time (so the cycle time is not adversely affected).

Your guess?

A low set temperature at the last barrel zone clearly reduces the heat energy consumed at that zone, but a low temperature also increases the viscosity of the melt beneath the zone, which requires more mechanical energy to turn the screw. Which of the two mechanisms dominate? Is there a net saving using a low set temperature?

As for the second parameter, fast charging increases the resistance of the melt to turning, as is shown by a higher charging pressure read at the system pressure gauge. For a servopump (a servomotor driving a hydraulic pump) driven machine, the servomotor rests after the charging is done until cooling time expires, during which the servomotor consumes almost no energy. In slow charging, the melt resistance is not as high but the servomotor works inefficiently at low load for the duration of the cooling time. Is there a net saving using fast charging?

This study finds out the answers.

The injection moulding machine

The TME150-S injection moulding machine

The TME150-S injection moulding machine is a popular general-purpose injection moulding machine with 150 tons of clamping force and 337 g (12 oz) of shot weight in PS. The screw diameter is 49 mm. It is driven by a 11 kW Daikin IPMP servopump at 130 L/min. Around the barrel is a double-wall stainless steel cover with insulation wool in between. A 5-mm epoxy cover goes on top of it to do further insulation.

With this setup and using the #3 standard mould in the Chinese Industrial Standard for Injection moulding Machine Testing, this machine has obtained an index just below the 0.4 kWh/kg of PS parts made.

Epoxy cover on top of double-wall stainless steel cover

The power meter

To facilitate the energy measurements of 5 combinations of parameters, the iPM (intelligent power meter) was used.

iPM combines a digital power meter with an injection moulding machine controller, which provides the computing intelligence. Some of its features are as follows.

1. Moveable, so it could be moved around the factory to do measurements on different equipment.
2. Based on a Schneider digital power meter, so accuracy and reliability are guaranteed.
3. Shows three performance indices.

   A. Energy consumed per hour, kWh/h. The resolution is 3 places after the decimal, 0.001 kWh/h.
   B. Energy consumed in 50 shots, kWh/50. The resolution is 4 places after the decimal, 0.0001 kWh/50.
   C. Energy consumed per kg of parts, kWh/kg. The resolution is 4 places after the decimal, 0.0001 kWh/kg.
4. There is sufficient resolution to tell the effect of injection parameters on energy consumption. iPM can be used to optimize injection parameters.
5. Different moulds and different materials affect energy consumption. iPM could keep records of the energy consumption of different moulds and materials on an injection moulding machine.
6. Motion durations and cycle time also affect the indices. They are measured with 0.01 s resolution and displayed.
7. One can specify either the test duration or the number of test shots. Only an integral number of shots will be measured. Because of that, the actual test duration can be longer than the duration specified.
8. The results are displayed on the screens as soon as the test shots are done. They could be recorded in a USB drive. Through a PC, the USB drive data could be archived or printed out. No calculation is necessary.
9. Other than the energy consumption of the machine, the energy consumption of the nozzle and barrel heating are independently measured. This allows the different barrel insulations and heating methods be evaluated with a higher degree of confidence. It also allows the effect of different barrel temperature settings to be experimented upon.

iPM, intelligent power meter

Set temperature of the last barrel zone

The TME150-S has a nozzle zone and four barrel zones, labelled 1, 2, 3 and 4. The last barrel zone is therefore zone 4.

In the tests, the nozzle and the first 3 barrel zones were set at 250 °C. Zone 4 was set at 250 °C, 215 °C , and 180 °C in three separate tests. 50 shots were made in each test. Water circulates through the water collar, the temperature of which varies between 39 and 42 °C. Room temperature was 33 - 35 °C， oil temperature was 34 - 38 °C.

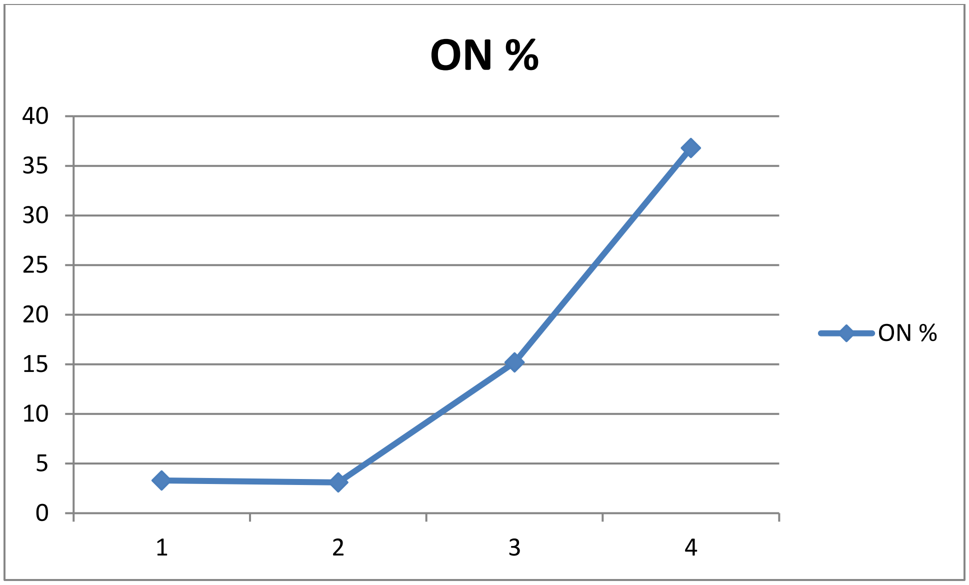
	射嘴	1段	2段	3段	4段	5段	6段		
開啓%	38. 1	3. 3	3. 1	15. 2	36. 8	0. 0	0. 0	%	ON %
功耗	0. 0642	0. 0462	0. 0429	0. 2106	0. 5080	0. 0000	0. 0000	kWh	Energy cnsmd
實時時間	1556	1556	1556	1556	1556	1556	1556	sec	Real time
開啓時間	593. 46	52. 25	48. 50	237. 68	573. 31	0. 00	0. 00	sec	ON time
型式	不使用	不使用	不使用	不使用	不使用	不使用	不使用		
清除	OFF	OFF	OFF	OFF	OFF	OFF	OFF		
平均功率	0. 1487	0. 1071	0. 0994	0. 4872	1. 1753	0. 0000	0. 0000	kW	Avg power
額定功率	0. 39	3. 19	3. 19	3. 19	3. 19	0. 00	0. 00	kW	Nom power

總功耗	0. 8719	kWh	全部清除	OFF	Total eng cnsm
總平均功率	2. 0177	kW	全部啓動	OFF	Total avg pwr

The Heater Power screen at 215 °C zone 4 set temperature

In the Heater Power screen above, **Real time** is elapsed time, **ON time** is the duration a zone heater is turned on. **ON %** is the ratio of **ON time** to **Real time**.

ON % turns out to be very useful in evaluating barrel energy consumption, especially that of the last zone. The **ON%** of the 4 barrel zones are plotted in the graph below.



ON % of 4 barrel zones

The **ON %** of zone 4 is highest as it bears the responsibility of heating up pellets at room temperature. Being next to the water collar, it lost a lot of heat by conduction.

The **ON %** of zone 2 is the lowest at 3.1%. This is because it is downstream of the compression stage of the screw. Compression produces heat by shearing as the screw turns. Furthermore, zone 2 receives heat by conduction from its neighbours, zone 1 and zone 3.

Had the charging been faster, the material been more viscous, and the back pressure higher, zone 2 heaters do not have to be turned on at all to reach its set temperature. In fact, it often happens the set temperature is exceeded even without the zone 2 heaters turning on. This is called temperature override. To avoid it, a compromised cover can be used with perforation in zone 2 and no insulation wool there. Heat loss is increased as a result.

Barrel cover with perforation at zone 2 to avoid temperature override

Energy c means energy consumed. It measures the energy consumed for a zone due to its heaters turning on during **Real time**. It is calculated from **Nominal Power** * **ON time**/3600. The unit is kWh.

Similarly, **Average Power** is the average power of a zone during **Real time**. It is calculated from **Nominal Power** * **ON %**.

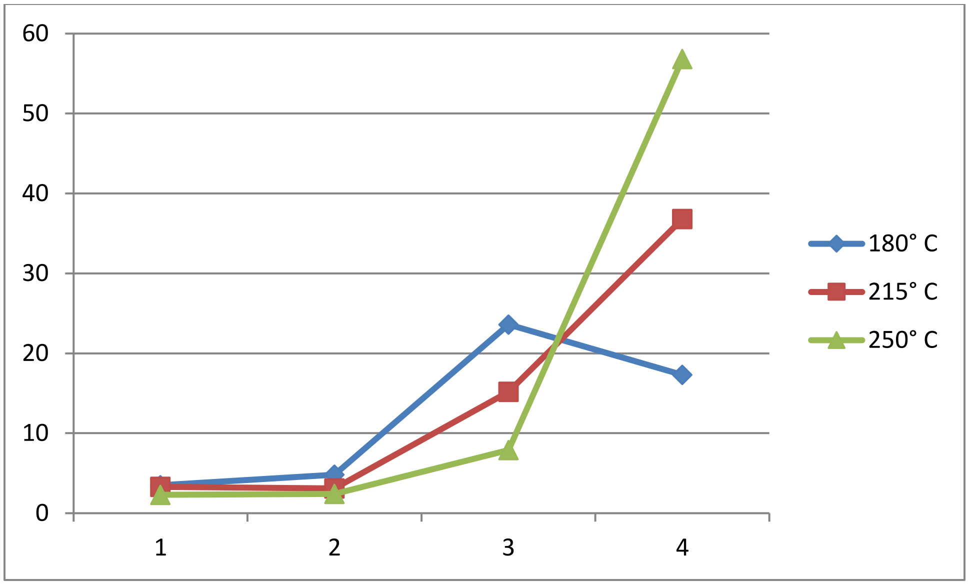
Total energy c is the sum of **Energy c** of all the zones in the barrel and nozzle.

Total average power is the sum of **Average power** of all the zones in the barrel and nozzle.

Comparison

ON %

ON % comparison of three zone 4 set temperatures is shown below.



***ON %** of three zone 4 set temperatures*

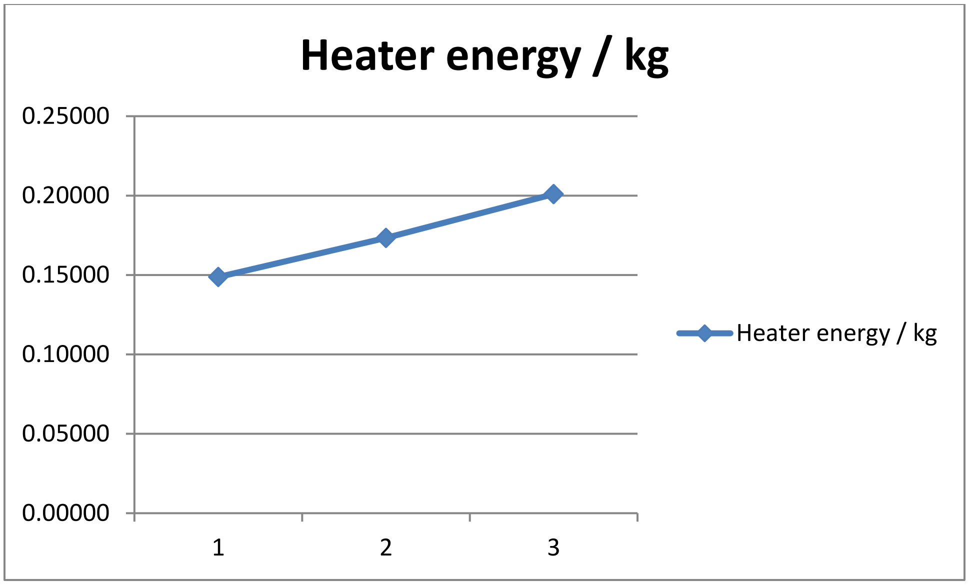
For zone 4, the **ON %** of 215 °C zone 4 set temperature is almost midway between that of 180 °C and 250 °C. So is the **ON %** for zone 3 but the order of the other 2 points are reversed.

The **ON %** for zone 4 is easy enough to understand. The higher the set temperature of zone 4, the more its heaters have to turn on to get to the set temperature. Due to the heat conduction to its neighbouring zone 3, the **ON %** of zone 3 is reduced by a high **ON %** at zone 4.

As all four barrel zones have the same nominal power, the energy consumed by heaters in each zone show the same pattern as the **ON %** graphs.

Heater energy

The heater energy consumed for the three zone 4 set temperatures are plotted below. The unit is kWh/kg.



1 = 180 °C, 2 = 215 °C, 3 = 250 °C zone 4 set temperature, vertical axis is in kWh/kg

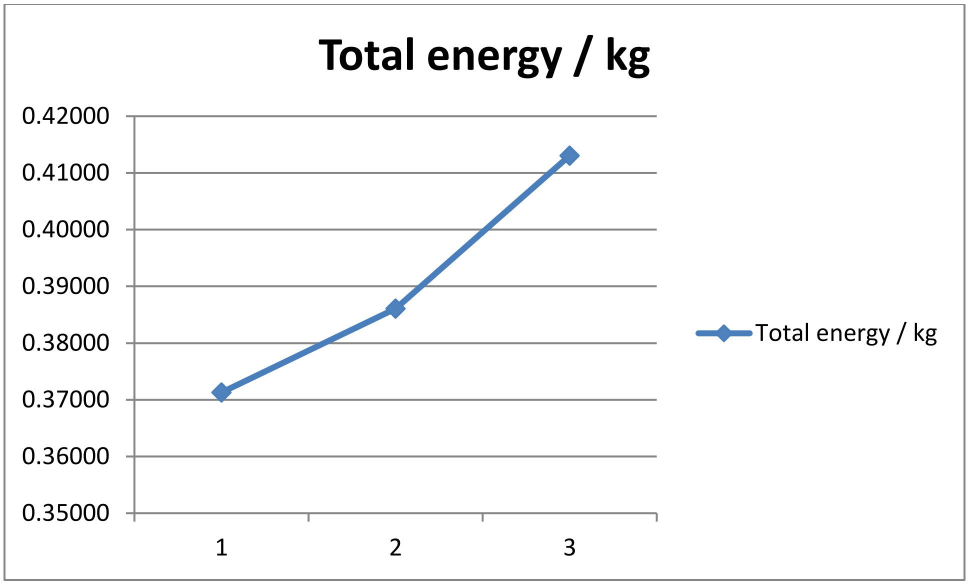
0.1487 kWh/kg at 180 °C zone 4 set temperature is the lowest heater energy / kg of all tests in this study. On the other hand, 250 °C zone 4 temperature setting is the highest heater energy / kg at 0.2009 kWh/kg.

Using 250 °C as a basis, the heater energy saving is 26% for 180 °C， and 13.8% for 215 °C zone 4 temperature setting.

kW/kg	Zone 4 set temperature		
	180 °C	215 °C	250 °C
Heater energy / kg	0.1487, lowest	0.3861	0.2009, highest
Heater energy saving	26%	13.8%	0%

Total energy

Motion energy should show the reverse trend as a lower zone 4 set temperature means a more viscous melt for the screw to turn against. The total energy (heater energy + motion energy) / kg plotted below still shows an upward trend.



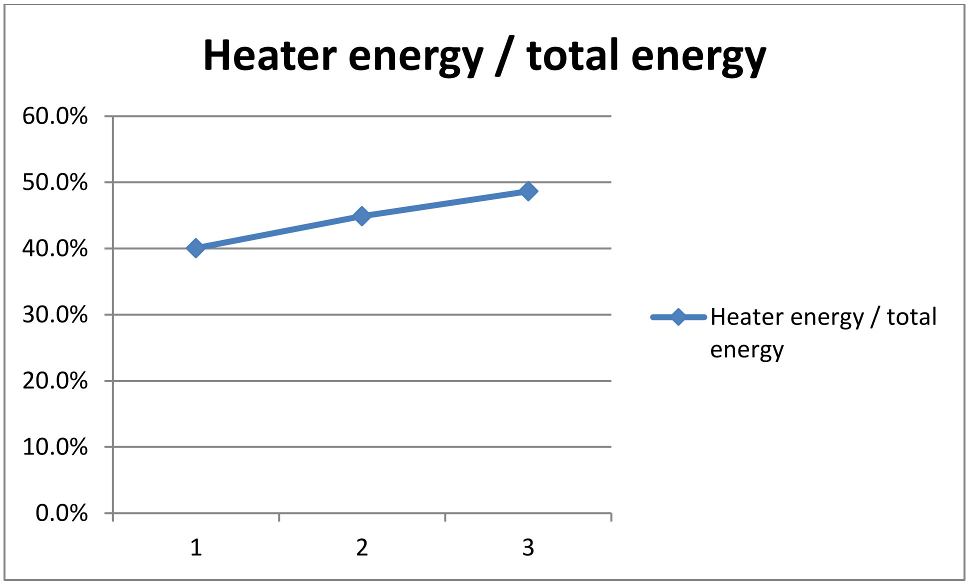
1 = 180 °C, 2 = 215 °C, 3 = 250 °C zone 4 set temperature, vertical axis is in kWh/kg

Using 250 °C as a basis, the total energy saving is 10.1% for 180 °C，and 6.5% for 215 °C zone 4 temperature setting. The total energy savings are reduced from heater energy savings alone.

	Zone 4 set temperature		
	180 °C	215 °C	250 °C
Total energy saving	10.1%	6.5%	0%

Heater energy / total energy

The heater energy as a percentage of total energy climbed from 40.1% through 44.9% to 48.6% in the three cases. Close to half the total energy is consumed in heating if the zone 4 temperature is at 250 °C.



1 = 180 °C, 2 = 215 °C, 3 = 250 °C zone 4 set temperature

Charging speed

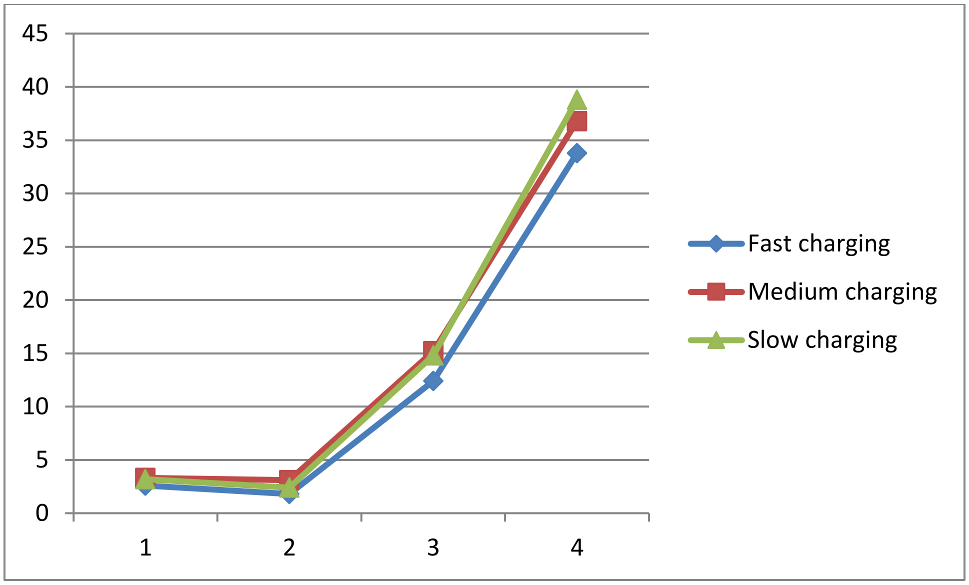
We now study the effect of charging speed on energy consumption.

The zone 4 temperature was set at 215 °C. Three charging speeds are 100%, 60% and 17%. The charging times are respectively 3.1 s, 4.7 s and 17.7 s. The cooling time is 18 s.

Comparison

ON %

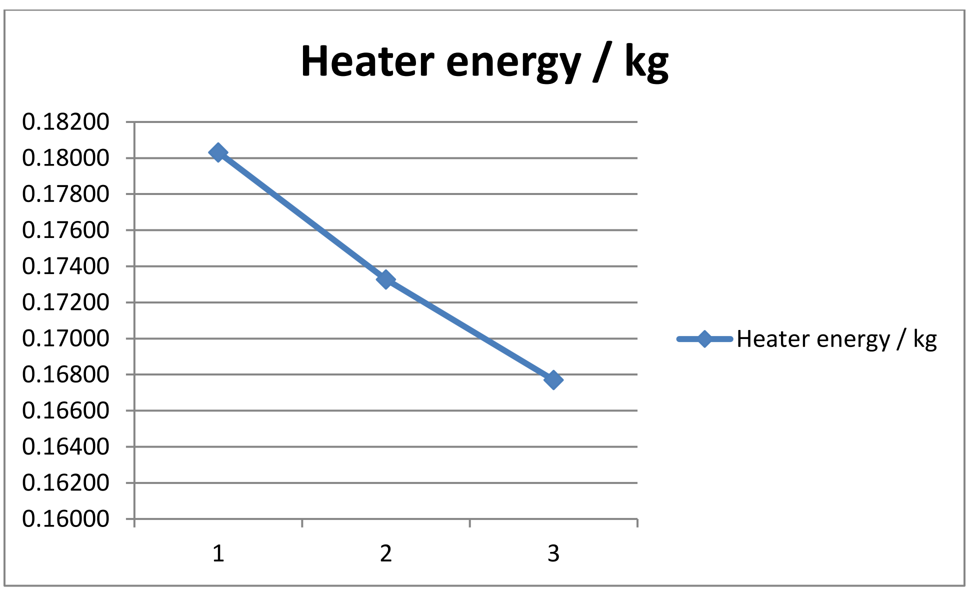
Higher charge speed produces more shear heating, so resistive heating needed is reduced. The **ON %** differences are there but they are small.



ON % *of 4 zones*

Heater energy

Heater energy / kg plotted below for the three charging speeds also show reduced heater energy at fast charging.

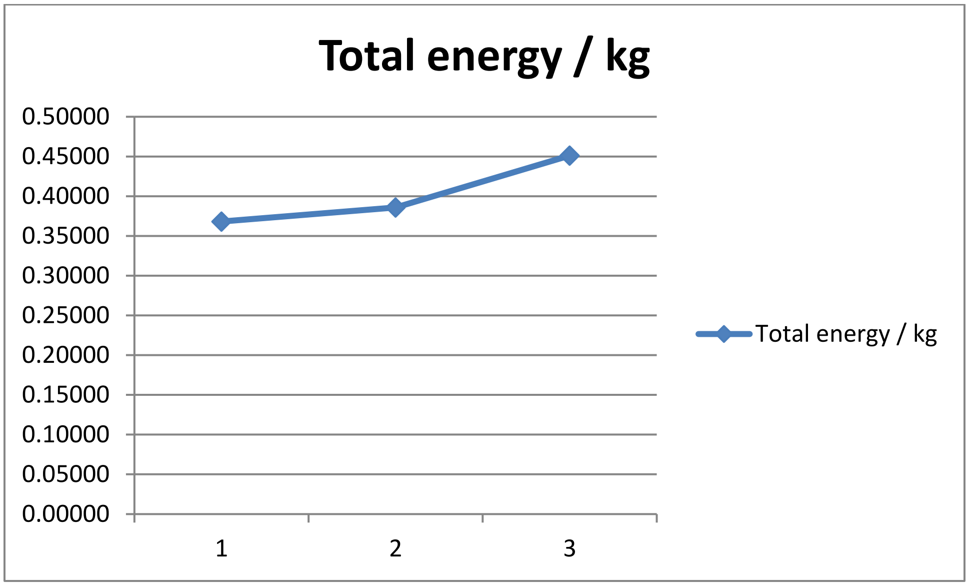


1 = Slow charging, 2 = medium charging, 3 = fast charging, vertical axis in kWh/kg

Using fast charging as a basis, medium charging uses 3.3 % more heater energy, slow charging uses 8% more heater energy.

Total energy

Total energy shows the reverse trend.



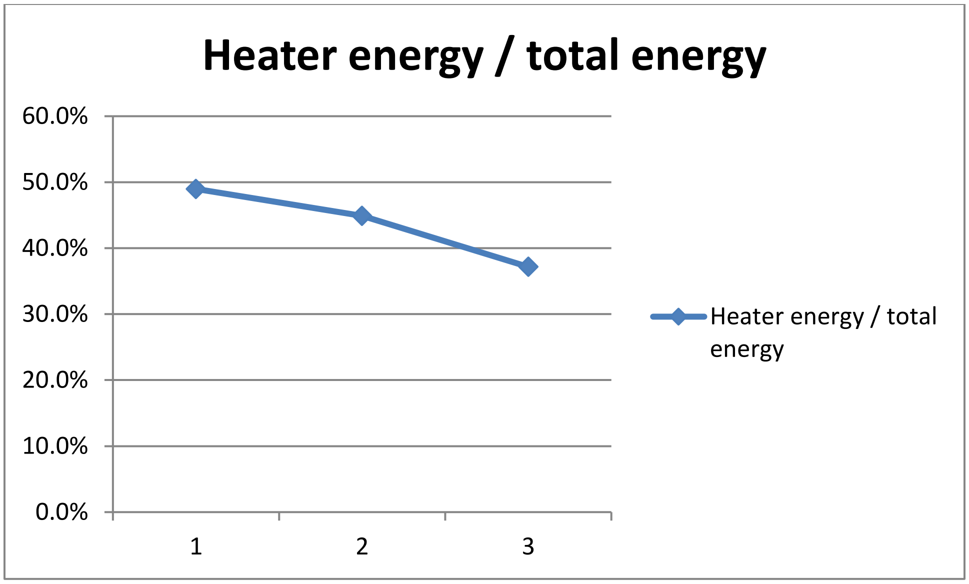
1 = Slow charging, 2 = medium charging, 3 = fast charging, vertical axis in kWh/kg

At 0.4512 kWh/kg, fast charging produces the highest total energy / kg of all the tests in this study. On the other hand, slow charging produces the lowest total energy / kg at 0.3682 kWh/kg.

Using fast charging as a basis, medium charging save 14.4% total energy, slow charging saves 18.4%.

kW/kg	Charging		
	Slow	Medium	Fast
Total energy / kg	0.3682, lowest	0.3861	0.4512, highest
Total energy saving	18.4%	14.4%	0%

Heater energy / total energy



1 = Slow charging, 2 = medium charging, 3 = fast charging

The heater energy / total energy ratio ranges from 49% for slow charging through 44.9% for medium charging to 37.2% in fast charging.

Once again we see heater energy is almost half of total energy in slow charging.

In cases where cooling time is short, we cannot slow down charging much before it affects cycle time. Thin-wall moulding would fall into this category.

Although the index total energy / kg is per kg of extruded plastic, a slow screw rotational speed on an extruder would take longer to plasticize this kg of material. Using slower charging to reduce energy consumed may not be useful in extruder as it affects production rate.

Charging

Charging consumes the most motion energy of all motions in an injection moulding cycle. This is because charging pressure is high and the duration is long. Looked at in a different way, it has the biggest potential for energy saving. We have found a low screw speed is one such method.

A study on how charging pressure changes with back pressure and screw speed would shed more light in this regard. The sharp rise in total energy / kg with screw speed is estimated to come from the square relationship in the I^2R heating of the servomotor as current I increases with loading. This heat energy is lost and wasted. It is postulated a bigger servomotor, which heats up less, can also save energy.

Conclusion

Parameter optimization could significantly save energy consumed, and without any investment in hardware.

180 °C set temperature of the last zone has saved 10.1% total energy in this study.

17% charging speed has saved 18.4% total energy vs 100% charging speed.

The combination of the above has a potential to save a quarter total energy.

Total energy saving		Zone 4 set temperature		
		180 °C	215 °C	250 °C
	Slow		18.4%	
Charging speed	Medium	10.1%	6.5% | 14.4%	0%
	Fast		0%	

Read 14.4% up and down, 6.5% left and right

180 °C set temperature at the last zone gave the lowest heater energy / kg in this study. 250 °C set temperature at the last zone gave the highest heater energy / kg.

17% charging speed gives the lowest total energy / kg in this study. 100% charging speed gives the highest total energy / kg.

Heater energy/total energy could be up to 49% which means that saving heater energy is as significant as saving motion energy.

iPM makes measurement of energy conservation a bliss. The Heater Power screen is especially useful.

Epilog

It would be interesting to repeat the same tests on an asynchronous motor drive system (fixed or variable displacement pump) to see if the charging speed trend is the same and how the savings compare to those measured in this study. After all, there are so many machines driven by asynchronous motors still in use.

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