Flowing Faster and Saving Energy

Sustainable Materials. Ever more manufacturers are offering freer flowing polymer grades for injection molding. Improved reproduction of surfaces and increasing miniaturization of parts are but two of the reasons for developing such polymers. However, can these materials save energy and so contribute to sustainable parts production? Answer: it all depends on the application.

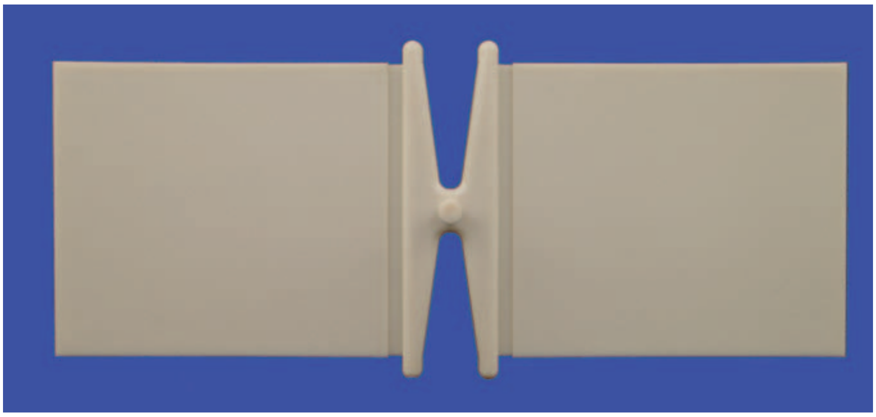

Fig. 1. The injection molded part is a simple plate (two-cavity mold). The total shot volume is about 64 cm^3

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Plastics with improved flow can score points over their conventional counterparts where large flow path/wall thickness ratios have to be overcome. A typical application is the production of plugs for the electronics industry [1, 2]. Plug housings are becoming ever complexer due to increasing miniaturization of the plugs, with simultaneous integration of more functional elements. It is characteristic of these applications that sections with large as well as those with very low wall thicknesses occur in one and the same part.

If it was not possible to produce such parts in good quality with standard settings, injection molders were left with only two options: To increase either the melt temperature or the mold temperature – or both, in the worst case. As a result, the cycle time is increased and production is made more expensive. Here the benefit of better material flow is immediately noticeable. Conversely, it raises the question what the benefit is of a freer flowing polymer, if a part can already be produced easily with the existing production set up; i. e. what the advantages are in detail of producing with lower melt temperatures. To quantify the savings, BASF SE retooled an injection molding machine to collect data about all the incoming and outgoing material and energy streams. It allows a complete energy balance to be made of the injection molding process, and the nature and magnitude of the energy savings to be identified.

The experimental conditions are oriented to the circumstances encountered in the electrical industry. The part is a simple plate (2-cavity mold) with a shot volume of about 64 cm^3 **(Fig. 1)**. As material, a PBT is used containing 30 % glass fibers (type: Ultradur B4300G6; manufacturer: BASF). It is also available in a high-speed variant, i. e. in a version with significantly improved flow, but otherwise the same properties. An all-electric injection molding machine (type: IntElect100; manufacturer: Sumitomo (SHI) Demag Plastics Machinery GmbH, Wiehe, Germany) is operated with a 30 mm diameter screw, according to the molded part.

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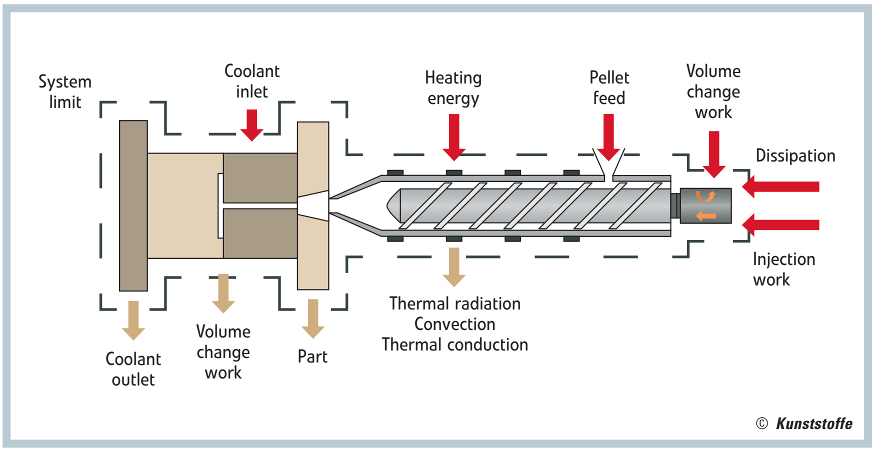

Fig. 2. Thermodynamic consideration of the injection molding process. For the energy balance, the energy and material streams supplied to the system are shown on one side (red), the outgoing streams are shown in beige

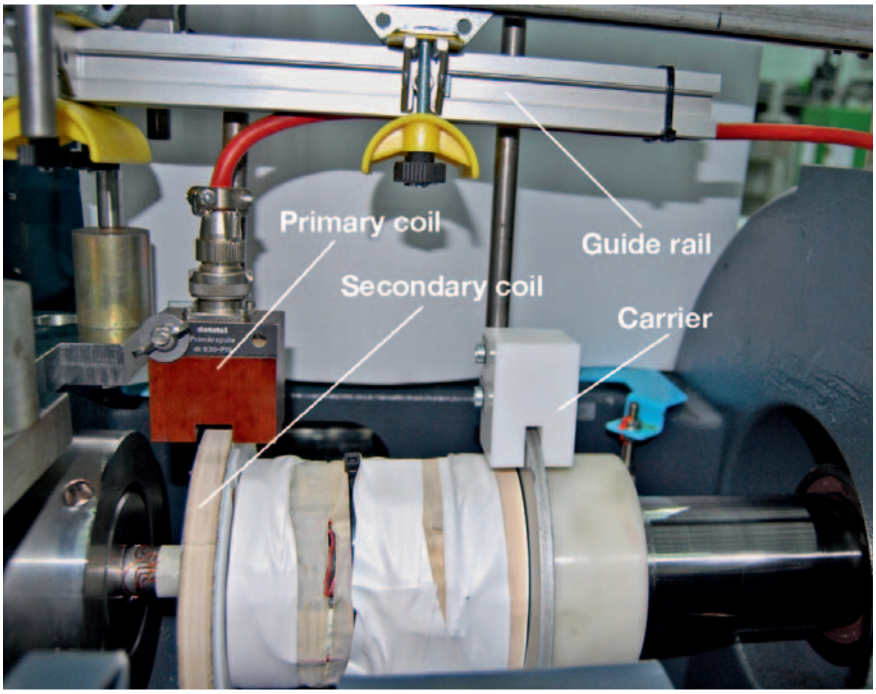

Fig. 3. Electricity supply of the strain gauge grid: The torque can be directly determined on the screw. The electricity supply takes place via induction coils, the data transmission by a telemetry system. Axial screw movement is possible

Energy Consumption in a Cyclic Process

To allow reliable information to be given about the energy consumption, it is necessary to prepare an energy and material balance for the entire process, and to measure all incoming and outgoing streams. The balance scope includes the plastification unit and mold. All the parameters supplied to the system are marked with red arrows, and the outgoing energy and material streams are identified in beige (**Fig. 2**).

Though injection molding is cyclic, it can be considered as a quasi-steady state process, and a balance made according to the first law of thermodynamics [3]. The associated formula (balance, see **box** p. 87) shows the relevant parameters for the incoming and outgoing energy and material streams, which can generally be easily recorded by means of temperature sensors, or sensors already available in the machine. The heating energy is determined via the electricity fed to the heater on the assumption that all the energy is converted into heat. The heat losses due to radiation and convection are very difficult to measure, and must be estimated according to heat transfer principles. For example, the heat transfer due to convection can be estimated from the surface temperatures and by assuming a cylinder with free convection [4].

Problem of Motor Power?

A central problem in balancing the energy streams is to determine the dissipation energy that is introduced into the plastic by the rotation of the screw. As can be seen from equation, the dissipation energy is calculated from the screw torque, the speed and time. It is difficult to determine a reliable value for the torque, since the motors responsible for rotation of the screw are frequency controlled. The electrical power supplied to the motor can be determined from the signal picked up at the corresponding frequency converters, but – according to the frequency converter manufacturer – errors of up to 30 % are possible [5]. That is too inaccurate for an energy balance. Therefore four strain gauge grids (SG) were applied to the screw to pick up the torque directly on the screw from the deformation. This permits direct measurement; there are no interposed elements such as motor or gears that might falsify the measured torque [6].

Due to the two movements (rotation and translation) that the screw executes,

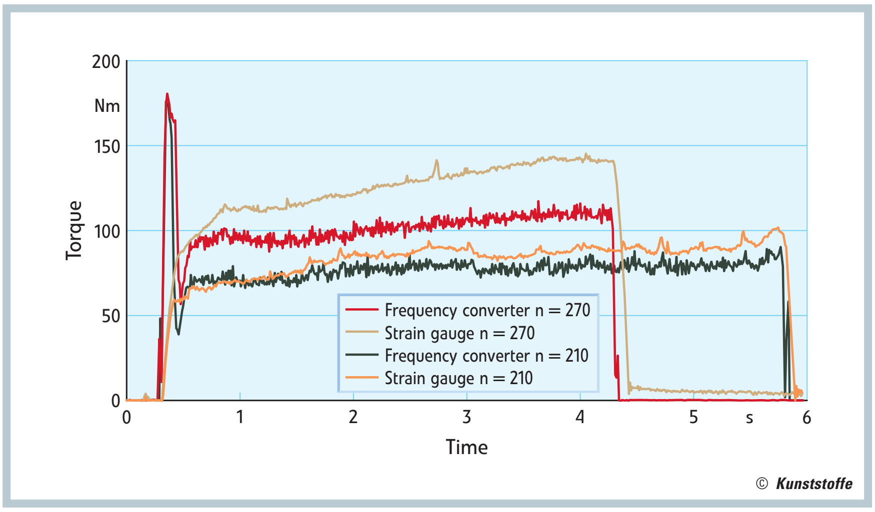

Fig. 4. Torque curves from the frequency converter and strain gauge for two plastification speeds: the strong differences between the two measurement methods are particularly clear at high torques

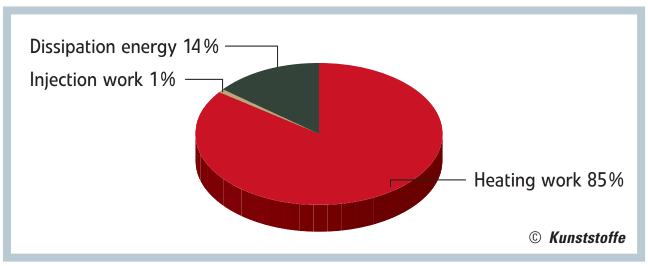

Fig. 5. The lion's share of the energy streams entering the injection molding process is accounted for by the heating work

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Table 1. The energy balance is generated in eight tests with different machine parameters

Test	Back pressure [bar]	Plastification velocity [mm/s]	Injection volume flow [cm³/s]
1	80	300	40
2	40	300	40
3	80	200	40
4	40	200	40
5	80	300	20
6	40	300	20
7	80	200	20
8	40	200	20

such torque measurement takes considerable effort. Induction coils power the electronics for amplifying the SG signals, the processed signals are transmitted via a telemetry system to a radio receiver, and evaluated and recorded by a computer **(Fig. 3)**. But the effort is worthwhile – during pre-tests on metering, the torque profiles are measured against time for two different plastification rates, as supplied by the frequency converter and the strain gauge grid. Particularly at higher torques, there is a clear discrepancy between the machine and strain gauge values. At the peak, the difference is up to 30 Nm. The error is also not linear. The curves intersect at about 70 Nm, the curves (low plastification rate), then drift further apart as the torque increases **(Fig. 4)**.

Further Saving via Cycle Time Reduction

The aim of the tests is an energy comparison between a standard PBT (Ultradur B4300G6) and the rapid-flowing alternative. To this end, the two grades are processed with the same viscosity. The fact that the high-speed material reaches the viscosity of the standard grades at lower melt temperature, due to its better flow, is reflected in the processing temperatures (255 to 285 °C). →

Test (same cycle)	Energy saving compared to standard grade [%]
1	12.6
2	11.0
3	10.9
4	9.0
5	9.4
6	10.9
7	9.2
8	6.3

Table 2. The energy savings of the high-speed material determined as a function of the machine parameters (for the same cycle times of 38 s) are up to 13 %

Test (shorter cycle)	Energy saving compared to standard grade, shorter cycle [%]
1	29.7
2	28.1
3	28.5
4	27.3
5	26.3
6	28.3
7	26.4
8	23.9

Table 3. If the lower cycle time (32 s) for using the high-speed material is taken into account, the potential for energy saving increases to almost 30 %

! Balance

$$\overbrace{\int_{t_1}^{t_2} \dot{Q}_\mathrm{h}\mathrm{d}t}^{\text{Heating energy}} + \underbrace{\int_{t_1}^{t_2} \dot{m}_\mathrm{K}\left(h_\mathrm{gr} - h_\mathrm{ft}\right)\mathrm{d}t}_{\text{Enthalpy stream plastic}} + \overbrace{\int_{t_1}^{t_2} \dot{m}_\mathrm{W}\left(h_\mathrm{W,ein} - h_\mathrm{W,aus}\right)\mathrm{d}t}^{\text{Enthalpy stream cooling water}} + \underbrace{\dot{V}_\mathrm{sp}\int_{t_1}^{t_2}\mathrm{d}t_\mathrm{sp}\int_{p_1}^{p_2}\mathrm{d}p_\mathrm{sp}}_{\text{Volume change work}} + \overbrace{\int_{t_1}^{t_2} M\omega\mathrm{d}t_\mathrm{pl}}^{\text{Dissipation}} = 0$$

The balance is made using the first law of thermodynamics: the dissipation energy is calculated from the screw torque, the speed and time.

For each grade, eight trials are run **(Table 1)**. The proportion of the total energy supplied to the plastic that is accounted for by heating energy is very high and amounts to 85 % **(Fig. 5)**. The dissipation energy introduced by shearing and the injection work play a more subordinate role. The various machine settings have hardly any influence on the distribution. These results apply for a screw with 30 mm diameter; the energy distribution would be different for larger screw diameters.

The results of the material comparison show that simply using a freer flowing grade can already save up to 13 % energy **(Table 2)**. For the experimental methodology, the cycle time was kept constant at 38 s for both materials. The comparison between the test points further shows that the energy saving is greater at high injection speeds. That is plausible, since the better flow of the material makes itself most noticeable here. However, the differences between the individual tests are somewhat low, since most of the input energy is supplied via the heater. The better flow would become noticeable in the injection work, though it only makes up a small proportion of the total energy consumption.

If we now additionally take into account that the use of a flow-enhanced material can shorten the cycle time due to the lower melt temperature, this results in a further energy saving. Based on the 255 °C used and with the same demolding temperature of standard and high-speed grades, a cycle time reduction of 6 s for the part can be calculated via the cooling time formula. Since the heating time also decreases for shorter cycle times, the high proportion of heating energy is reflected particularly positively in the overall balance **(Table 3)**. In the best case, total energy saving of almost 30 % is possible.

Summary

The use of freer flowing polymers, besides better mold filling and surface reproduction, also permits a significant energy saving. A prerequisite for this is that it should also be possible to fill the part with a standard grade. With relatively small screw diameters, such as that used here, which is representative of plugs or similar small parts for the electrical industry, there are large savings potentials of up to 30 % resulting from the high heating energy contribution. Such parts are often made from PBT, e.g. Ultradur (High Speed) from BASF. The greater the screw diameter, however, the less is the influence of the heating energy and the lower is the savings potential, since the dissipative energy proportions increase.

For large parts, such as traditional engine compartment components (engine covers, air intake manifolds), which are not made of PBT, but of PA (polyamide, preferably PA6), the flow-enhanced grades bring other advantages to the fore. Injection pressure and locking force are lower, allowing the processor to manufacture using smaller machines. This, too, provides significant added value, since the operating costs for an injection molding machine increase disproportionately with its size. These arguments have persuaded BASF to expand its range of flow-enhanced engineering plastics [7, 8]. After Ultradur High Speed (PBT) and Ultramid A High Speed (PA66), BASF has now also presented its first flow-enhanced PA6 compound, Ultramid B3WG6 High Speed, at K 2010. ■

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