IMC a Revolution in Injection Molding

Matthias Sieverding, Krauss-Maffei Munich, Germany

Abstract

Direct compounding combines the continuous preparatory process with the cyclic, or discontinuous, injection-molding process. Everything involved in turning the individual components (polymer, colorizer, fillers, and so on) into a homogeneous melt takes place in a single heat cycle. The co-rotating, intermeshing twin-screw extruder is never shut down during production, so the quality of the melt at the machine’s nozzle always remains consistent. The constancy of the recipe is sustained for all individual components by a continuously operating gravimetric feeding system. This “one heat” process allows better material properties for a substantial lower price.

Why direct compounding?

In the conventional injection molding process, material preparation (in the form of granulate, for example) and production of the actual molding occur at different times and usually in different places. The polymer is generally prepared by the material manufacturer. These companies also undertake the job of modifying the raw polymer in accordance with customer requirements, say by adding glass fiber (GE) to increase strength, admixing fillers such as talcum, or preparing blends (ABS-PC). The increase in the cost efficiency of the twin-screw compounders they use for the purpose is more or less linear with throughput. Consequently, throughput (screw rpm, speed) is optimized even if the achievable product characteristics suffer as a result.

This division between preparation and processing, however, entails costs and quality impairments that are avoidable. In terms of costs, the minimum figure is approximately 0.25 — *0.35* €/kg. Investment costs for the compounding line, maintenance and repair costs, the costs for energy and human resources, packaging and transportation are all factored into this figure, as is profit.

The quality impairments are due primarily to the necessity of melting the material twice. In this respect, products reinforced by the admixture of long glass fibers provide a good example. A sophisticated process can be utilized to produce LGF granulate with fiber lengths up to 25 mm. When the material is subsequently melted in a standard single-screw extruder, however, the fibers inevitably become much shorter (picture 1), because the longfiber granulate breaks during the melt up process. In the IMC the endless roving fiber is introduced in the already molten Polymer matrix. This results in significant longer fibers, in case of PP up to 60 mm at the machine nozzle.
Subsequent reductions in fiber length on account of the mold, the hot runner, the check valve and the process parameters (injection rate, post-pressure, and so on) are ignored in this context, because these are problems that are common to all injection processes.
There are, moreover, certain products for which the conventional process is inherently unsuitable. This applies, for example, if the proportion of filler to be added is very high. We have already employed injection-compounding techniques to produce parts containing 90% iron oxide (FE_3O_4) by weight. The advantage is that the filler is also added to the polymer melt downstream. A standard single screw would be unable to handle a compound with such a high percentage of filler (melt problems, wear, etc.).
Additional economic advantages are:

- The reduction of color masterbatch due to the very good dispersion into the Melt by the twin-screw extruder.
- Elimination of the predrying in case of ABS, PA etc. due to the possibility of vent ports (atmospheric and vacuum) in the screw design.

How does a Compounder work?

The heart of an IMC is a co-rotational intermeshing twin-screw extruder. The design has been around for about fifty years, and its characteristic features are as follows:

- Very good mixing capability
- Very high throughput on account of high rotary speed (up to 1200 rpm)
- High flexibility, because made up of segments (Fig 2)

Certain features distinguish this plastifier from the reciprocating screw commonly found in injection molding machines. The most striking distinguishing feature is the material feed. Extruders of this type need lean metering, so appropriate measures have to be implemented to ensure that material discharge to the screw is adequately controlled. Feed from a full

hopper in the way a reciprocating screw is fed would result in “overfeeding". That would trigger the torque limited and shut down the machine. The number of basic components used to manufacture a given product also defines the requisite number of dosing stations. The use of premixers is practical only in exceptional cases.
Customers require close compliance with their recipe specifications, so the IMC uses gravimetric dosing systems. The advantage over the less costly volumetric systems is that gravimetric units integrate permanent self-monitoring. The system reacts automatically to fluctuations in bulk density or changes in specific density. Volumetric metering would necessitate manual adjustment and recalibration in all these circumstances. When a recipe is changed, all a machine with gravimetric metering needs is input of the new, percentage distribution parameters, a job that takes only seconds to complete.

Not all kinds of materials can be dosed by metering screws. The take-off rate of glass-fiber rovings, for example, is determined by the rotational speed of the extruder screw. The intake rate is not linear (Fig 3 and 4). A change in speed, therefore, always results in a change in GF content unless polymer metering is adjusted accordingly. In order to ensure the constancy of the mix, therefore, the IMC has a platform weighing station so that glass-fiber feed can be monitored. This throughput figure is used as a control reference value for the polymer dosing station. In this way, the ratio of glass fiber and polymer is always pegged at a constant level.

The dosing system integrated into the IMC can ensure accuracy of *+1- 0.5* % for the individual components in the mix. Fluctuations in the raw materials, moreover, can be compensated to some extent by adjusting the recipe. That means the IMC is the first machine capable of tailoring recipes to fit on a case-to-case basis. If, say, the end customers specifications (for mechanical strength, temperature resistance, and so on) necessitate a glass-fiber content of 37%, this is the figure that be set for the mix. There is no longer any need to use a more expensive precompound with 40% GF just because the manufacturer only has GF compounds in *5%* gradings.

The melt from the extruder is forced through the startup valve into the Shot-pot (Fig *5).* The startup valve dumps the substandard material that is commonly produced as the machine starts up - hence the name. When production is in progress, too, the constancy of the recipe is monitored within parameterizable bandwidths and the material can be dumped if necessary. This is to ensure that “foreign matter” cannot make its way into the Shot-pot.

The accumulator acts as a buffer to bridge the periods in which the Shot-pot cannot accept the inflow of material. The melt from the extruder is buffered here during injection and in the post-press phase (Fig 6a). When post-pressing ends, this material is transferred to the Shot-pot (Fig 6b). The controller automatically adjusts mass throughput and accumulator filling time to suit the process. If the cooling time is reduced, for example, throughput is increased accordingly.

Application Areas
Pure Plastification and Blending

In this field we need a maximum screw length of 20 L/D. The screw includes a plastification zone, an atmospheric or vacuum degassing and a metering zone (Fig 7). The throughput is calculated by cycle time and shot weight.
The specific energy of the plastic grade results out of the enthalpy diagram. Multiplied with the hourly throughput results the necessary screw motor power. The screw speed is 600 rpm or higher, depending on the maximum allowed material temperature.

With the same screw design a blending of different Polymers (ABS-PC, etc.) is also possible. All components are given into the same feed throat. Mixing and blending takes place simultaneous. During the melt up process a wide viscosity range is passage. This gives optimal conditions for dispersion and division of the polymer. This is also valid for masterbatch. Only the maximum melt temperature must to he taken into account.

Longfiber reinforcement

The plastification zone of this machine is identical to the screw design of the pure plastification extruders. The glass fiber is introduced in the melt in form of rovings or chopped fibers. In combination with a degassing zone, this results in a extruder length of 26 L/D (Fig 7). The product quality/mechanical values depend on the glass fiber length. This length is influenced by:

- Screw configuration
- Screw speed (rpm)
- Product viscosity
- Number of rovings
- Throughput
- Melt pressure

According to out experience at this point in time, a screw speed of higher than 300rpm is not recommendable. The economical advantage of this technology becomes clear by the following example, based on the prices of August 2001.
PP 0,82 € /kg GF 2,00 € /kg

Single Components		Compound	Difference
70 % PP	0,57€/kg	Long fiber	
30 % GF	0,60 €/kg	PP + 30% GF	
	1,17 €/kg	2,00 €/kg	0,83 €/kg (> 40%)

Introduction of fillers

The screw length, here is 36 L/D (Fig 7). The plastification zone is the same than before. The filler, as the glass-fiber, is introduced in the melt downstream the plastification zone. The screw configuration is built up in a way, that down to the atmospheric vent port the segments are only particular filled. This guarantees that the air, which is trapped in the filler evacuates downstream. Otherwise the air would blow out of the feeding point witch results in dosing problems. Downstream of these vent port an intensive mixing and homogenization with kneaders is possible. Moisture and other unspecific, volatile constituents can be removed in the following vacuum degassing zone. The throughput of this machine is defined on one side by the pure plastification work, on the other side through the amount, the content, the bulk density and the particle size of the filler. Beyond this, crystalline fillers or small glass bubbles, which should be dispersed undestroyed, limit the maximum screw speed.

Reactive compounds

These are compounds mixed in order to promote a chemical reaction (cross-linking, for example). In many cases the finished product has to be molded right away, because the compound cannot be melted for a second time. If the manufacturer opts for precompounded material, the properties of the finished product depend on the length of time between production of the compound and molding, among other factors.

Natural-fiber compounds

The incipient shortage of fossil raw materials, in conjunction with steadily growing global awareness of environmental issues will lead to the increasing use of renewable raw materials. In many instances, substituting natural fibers (NF) for glass fibers (GF) is often accompanied by a reduction in weight. Many automotive manufacturers are already using NF to a limited extent in series production.
The C class of Daimler-Chrysler, for example, includes 33 parts in which these raw materials are used. A telling argument in the case of these extremely temperature-sensitive parts (smell of burning, etc.) is that injection compounding dispenses with an entire melting process. The results of certain tests with 30 % fibers in a PP Matrix achieved the standard of a car maker:

E-Module 3100 N/mm^2
Flexural strength 81 N/mm^2
Impact strength 16 kJ/m^2

Conclusion

KM has already sold machines for some of the applications outlined above, many others are at the quotation or initial testing stage. The echo from the market is above what we expected. At this time 50% of the customers are from the automotive sector, where the driving force is the need to reduce material costs while at the same time improving component quality. The machine's main potential, however, is in enabling completely new applications for which injection molding has not been used in the past. Replacement within the pool of standard injection molding machines, therefore, will take place to no more than a minor extent, whereas these machines are poised to drive a market expansion for injection molding.

Bibliography

Fig I: Kunststoffe 83 (1993) Faserverktirzung beim Verarbeiten langfasergeflllllter Thennoplaste; H.J. Wolf