2 ZSK 70 Mc for multi-layer TPO films

Direct Production of Packaging Films

Compounding. A technology was developed years ago for preparing PET for flat-film extrusion that involves neither pre-drying the materials, nor crystallizing and agglomerating the recycling materials. In order to accommodate market demand, the process has meanwhile undergone steady further development to include other materials.

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Compounding systems can be classified according to their design features, such as the number of screws and their direction of rotation, as well as whether the screws are tangential or intermeshing. A special case is represented by the ko-kneader. Its single screw achieves self-cleaning action by a combination of overriding axial oscillation and kneading bolts that protrude into the segmented screw channel - and thus prevent it from being used for flat-film extrusion.

Co-rotating and intermeshing twin-screw extruders have become standard wherever plastics are used in the chemical, food and pharmaceutical sectors. Since the 1950's, approx. 30,000 self-cleaning compounders have been built worldwide – roughly 90 % of them configured as twin-screw compounders.

This extruder type exhibits modular design for its drive, processing unit and die and is mounted atop a base frame. The processing unit is also a modular design with respect to its barrel configuration and its screw elements. These are assembled onto an involute screw shaft, making it readily adaptable to processing tasks performed in sequence. Nowadays, more and more so-called modular systems are being built that can be easily dismantled for transport, whether in containers or in frames that house both the material feed as well as the downstream equipment, thus enabling the extruder manufacturer to offer immediate and complete system operability for the customer's product.

In addition to the criteria required for numerous processes, such as heat transfer, devolatilization, reaction time or nozzle load, there are three design criteria that are indispensable when configuring an extruder type and putting it to use, as well as for scaling-up correctly, namely, screw diameter ratio D_a/D_i [-], screw torque $Md/a_,$ [Nm/cm$_,$], which is volume-specific relative to the cube of the centerline distance, and screw speed n [UpM]. All together, they determine the useable production volume, shear load and power density, as well as the filling level and compounding effect.

Fig. 1 is an application-oriented presentation of machine size and speed dependent throughput $\dot{m}$ [kg/h] vs. the specific mechanical energy input SEI [kWh/kg], often decisive for quality, which is calculated as the quotient of dissipated energy [kW] and throughput [kg/h]. All processes reaching the red limit curve of the ZSK Megacompounder Plus are still primarily torque limited and can be processed optimally with this system. This applies especially well for pack-

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aging films. Other processes run at a lower level can thus be compounded more economically on the ZSK Megavolume (beige torque limiting curve) with its 40% larger free screw volume.

PET Flat Films and PET-BO

A technology for the preparation and direct extrusion of polyethylenterephthalate (PET) has been developed by Coperion Werner & Pfleiderer of Stuttgart, Germany, that involves neither pre-drying the materials, nor crystallizing and agglomerating the recycling materials. This technology was originally introduced for flatfilm at the K1992 in Düsseldorf, Germany. In order to accommodate market demand, the process has meanwhile undergone steady further development. Transparent PET-A films are generally deepdrawn (thermoformed) and serve as packaging for fresh produce, serving plates, medicinal and technical articles and tapes, for instance, whereas the high temperature resistance semi-crystalline white PET-C films makes them suitable for microwave capable frozen food products.

This direct method is enabled by the good preparation properties and high devolatilization of the twin-screw compounder. In the homogenizing section at 270–300 °C, devolatilization is decisive, since hydrolytic degradation proceeds 5,000-10,000 faster than thermal-oxidative or thermal degradation. Any contamination by polymers, e. g., PVC, that degrade at these temperatures has to be avoided. This technology is suitable for virgin material, for all types of grinding stock or recycling materials, as well as for mixtures of these materials, and it leads directly to films, fibers or to injection molding pellets. Table 1 shows an externally performed comparison of the ZSK process with various single-screw processes.

In one processing step, the user of this processing method obtains such important advantages as:

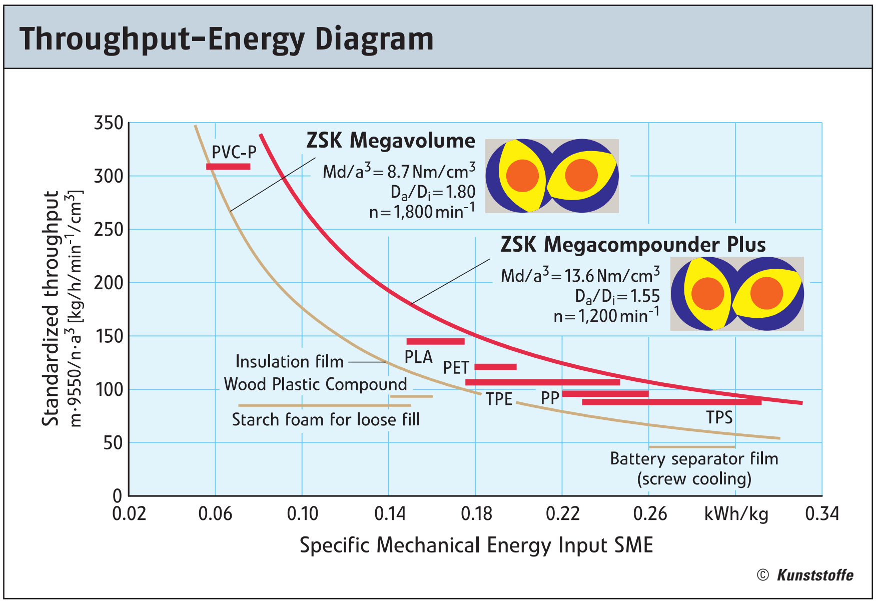

Fig. 1. Selection of the most economical extruder as a function of energy and space requirement

- Very high final product quality. Perfectly transparent material with no yellowing is the result, since the degradation of intrinsic viscosity (iV) during processing is limited to a minimum of only a few percentage points. Thermoforming behavior, surface quality and tactile properties are also better than in products damaged by long drying processes;
- High degree of flexibility, since only a few minutes are required to change formulation and color, and only 30–60 min for the entire system, thanks to the good self-cleaning action in the twin screw;
- Simplified logistics, since pelletized virgin material and various kinds of regrind (grinding stock, agglomerate, flakes) can be compounded jointly, even those with differing iV's;
- Savings in time and energy, since predrying and crystallizing are eliminated.

In the ZSK process, throughput is limited neither by pre-drying capacity nor by screw size. For example, a ZSK 92 Mc Plus with 92 mm screw diameter achieves a throughput of 2,200 kg/h. A 200 mm single screw would be required to achieve the same throughput. Thanks to energy entering via heat conduction under continuous recirculation, unmolten areas cannot form – which is often the reason for arranging single screws in cascade for high throughputs. Table 2 provides an overview of the throughput volumes achievable by machines of a given size. These throughputs are, of course, dependent on viscosity.

	ZSK	Single screw	Single screw
Devolatilization	High-vacuum	no	yes
Pretreatment	no	precrystallization to 30 % or agglomeration; predrying to 20 ppm	precrystallization to 30 % or agglomeration
Value of iV achieved [dl/g]	0.75	0.70	0.65
Film quality	very high	high	low
Flexibility	high, direct compounding capable	low, approx. 6 h required for formulation change	high, but pre-compounded materials required
Energy requirement	60 %	100 %	70 %

Table 1. Comparison of various extrusion processes for producing A-PET film. Starting conditions: A-PET with an iV of 0.79 dl/g, moisture content 3,000 ppm, virgin or return material

Processing Steps in the Compounder

Gravimetric feeders dimensioned for the corresponding components are used to transport the material to the feed input. Fiber waste can also be used if previously shredded and compacted into freeflowing, metered bulk material.

The processing unit of the ZSK Megacompounder is made up of eight 4D long (D = diameter of the screw) barrel modules, i. e., is 32D long. The screw is adapted to its specific processing tasks (solid material intake, plasticizing, homogenizing, devolatilizing, discharging) with corresponding screw elements.

By the time module 3 is reached, i. e., just after plasticizing begins, most of the moisture released during warm-up escapes via atmospheric venting. Vacuum devolatilizing then follows at an absolute pressure of 1 to 10 mbar from modules 5 to 7. In this large zone, any residual moisture is removed as well as all low-molecular components still present or occurring as a result of material degradation. The deciding factors for good devolatilization ▶

Machine size	Output kW	Max. speed rpm	Troughput kg/h
ZSK 32 Mc Plus	20	400	30 to 90
ZSK 40 Mc Plus	42	400	60 to 180
ZSK 50 Mc Plus	82	400	120 to 360
ZSK 58 Mc Plus	126	400	190 to 570
ZSK 70 Mc Plus	226	400	340 to 1,000
ZSK 92 Mc Plus	503	400	750 to 2,200
ZSK 119 Mc Plus	773	300	1,100 to 3,400
ZSK 133 Mc Plus	1131	300	1,700 to 5,000

Table 2. Installed power and throughput in the direct processing of PET on the ZSK Megacompounder Plus

include the length of the devolitalizing zone, large melting surface, due to partial filling, and constant renewal of the surface by intensive circulation. Ancillary venting equipment is recommended for gas removal. With this arrangement, no residue from the degassing vent can return to contaminate the melt.

Influence of Processing Parameters on Viscosity Reduction

Since the condensation of PET is a balance reaction, iV and, with it, final product quality can be influenced by simply changing the processing conditions in the ZSK without any addition of coupling agents. Generally speaking, high mechanical load on the melt and a weak vacuum expedite the reduction process, whereas short residence times and high screw-filling levels slow the reaction down. That is why the ZSK Megacompounder Plus produces the best film quality at high torques and low speeds.

Discharge Ends

Due to PET's low melt viscosity, a gear-type pump is always used to reduce extrusion pressure. Its efficient pressure build-up decisively contributes to maintaining low melt temperature. A follow-up filter with an automatic screen changer restrains any remaining contaminants. The fineness of the mesh is defined by the requirements of the final product manufacturer. The finest screens are utilized by manufacturers of fibers and biaxially oriented films. The filtered melt is extruded through a flat-sheet die or turned into fibers by monofilament dies.

Production System for Multi-layer Films

As described, this approach to direct extrusion is suitable for multi-layer films. This is demonstrated by a Danish film manufacturer who has succeeded in using his system to co-extrude triple-layer films (Fig. 2). This plants combines a ZSK 119 Mc with a ZSK 70 Mc for 2.5 t/h throughput, as well as one ZSK 92 MC with two ZSK 50 MC to obtain a throughput of 1.6 t/h. The reasons for selecting this plant concept, rather than one with three single-screw extruders and pre-drying, were the very short time required (30 min) for changing materials and/or colors, the high mechanical and optical quality of the films, as well as energy savings from eliminating pre-drying which ultimately resulted in a 40 % reduction of energy costs.

	ZSK	Single-screw cascade
Screw diameter	133 mm	250 mm / 275 mm
Dwell time	< 30 s	ca. 180 s
Melt temperature	230–250 °C	255–280 °C
Specific energy	0,17 kWh/kg	0,26 kWh/kg
Installed load	1,000 kW	2,200 kW
Production area	40 m^2	120 m^2

Table 3. Economic and quality advantages from the direct extrusion of 5 t/h BOPP with the twin-screw extruder

PP-BO and TPO Films

PP-BO films are mainly used for packaging foodstuffs, but also for adhesive tapes, textiles, tobacco and flowers. A production line with a ZSK 133 Mc is shown in Fig. 3. An elbow adapter is required for discharging from the ZSK which is mounted perpendicular to the film equipment so that the screws can be pulled easily.

Constant demands for increased throughput are also increasing the proportion of twin-screw extruders used for PP-BO, since that is where their advantages pay off the most.

Compared to conventional single-screw cascades, the intermeshing twin-screw co-extruder offers the following advantages leading to better product quality:

- Higher processing flexibility,
- Direct incorporation of additives, fillers and colors,
- Better compounding and melt homogeneity,
- High devolatilization capacity,
- No product deposits thanks to self-cleaning,
- Smaller machine sizes, lower residence time, melt temperature, energy requirement and production area (see Table 3).

TPO films are of course mainly applied on automobiles, but here they can serve as an example of a complex multi-layer film system with 2 ZSK 70 Mc (Title photo). Especially for feeding and gravimetric metering of all components the equipment is more expansive than in PET and PP film extrusion plants. This is also true of the more complex EpcNT control system for the metering units, extruders and down-stream equipment.

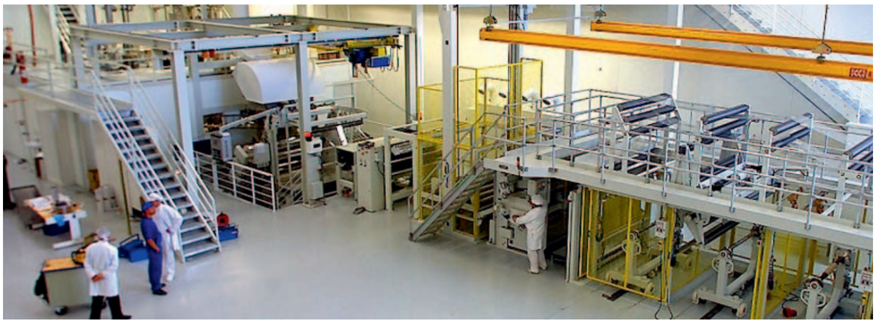

Fig. 2. PET system for a troughput of 1.6 t/h 3-layer films with a ZSK 92 Mc and 2 ZSK 50 Mc

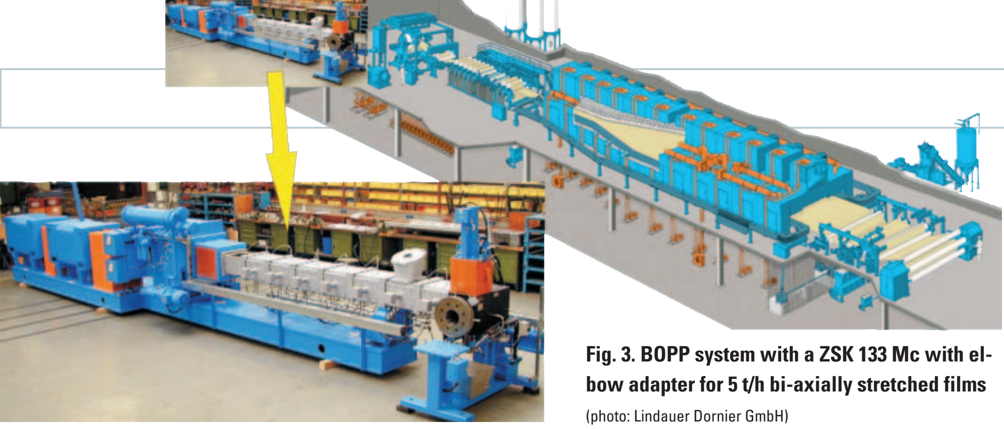

Fig. 3. BOPP system with a ZSK 133 Mc with elbow adapter for 5 t/h bi-axially stretched films
(photo: Lindauer Dornier GmbH)

Biodegradable Packaging

In the preparation of biodegradable plastics, technologies are often combined that come from food and polymer processing technologies already proven in use with co-rotating twin-screw compounders. For a long time, starch-based products were the focus of new developments that also made use of co-extrusion technology, but due to high costs were applied only for niche applications, e. g., for mulch films. Nowadays a trend toward large systems is developing that uses polylactides (PLA) whose secrets of success are good reproducibility and economy of scale. They are mainly used in the food packaging area, either alone or as blends.

One of the first starch-based applications was based on the cooked and expanded starch known in the food and chemistry field. Here starch is broken down in the extruder in seconds using water at 150 to 200 °C and, when necessary, chemically modified or mixed with softeners and plasticizers. In a die it is expanded to a starch foam by the vaporizing water and dried. The extrudate is then ground in order to utilize its thus created functional properties in the food and chemistry fields. The degree of expansion determines the foam texture of the air-dried and ground extrudate which is used as bulk packing material and loose-filling styrofoam substitute. Its growth is strongly affected by product temperature at the die and aided by higher specific mechanical energy input. Both increase its solubility in water.

For starch-based film applications, the starch is first cooked, then a biodegradable, hydrophobic polymer (e. g., derivative cellulose, polycaprolactone, PVA, PLA, PHB) is metered in via ancillary feed, and the mixture is plasticized and emulsified (Fig. 4). This often involves reactive blending in order for both phases to become compatible. Following vacuum devolatilization for cooling, it is discharged and strand pelletized. Useful mechanical properties were found to be limited to starches in the disperse phase, thus limiting starch content to less than 60 %.

At this time, PLA-based biopolymers are in the process of overtaking starch-based products. The Cargill Dow 140,000 t/a PLA system has played a major role in this. There are several interesting applications for it in compounding and pelletizing technology. Among these are polymerization in the extruder, underwater pelletizing following reaction, filling, reinforcing and dyeing. The latter is not decisive, since its main applications are transparent films and packaging. In this process, as well, the PET process described above has proven itself with its strong vacuum for avoiding hydrolytic degradation which would cause irritation due to the resulting stickiness of the discharging polymer melt (Fig. 5). This technology is also suitable for the PLA blends coming into use as well as to modify the functional properties of other biodegradable polymers.

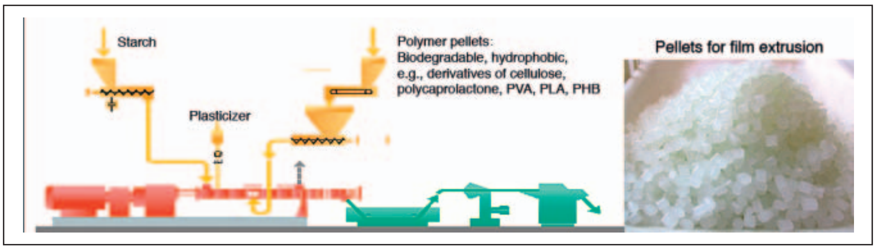

Fig. 4. Compounding biodegradable starch-plastic blends for thermoformed or mulch films

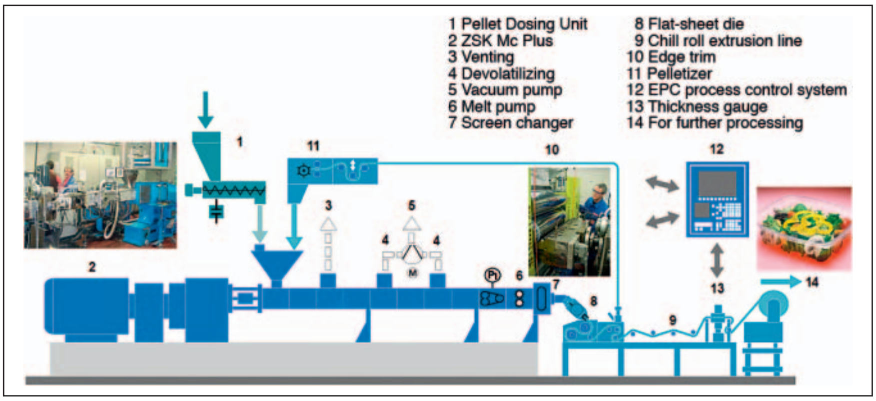

Fig. 5. Direct extrusion of undried PET or PLA to thermoformed film for packaging foodstuffs

Nanocomposites

Targeted functional properties corresponding to specific use requirements are built into films for food packaging as well as for technical goods – until now generally by using coextrusion layers within a multi-layer composite. In part, this has involved complex procedures and high costs that reached their engineering and economic limits, for example, in the well-known 7-layer PP film with an EVOH oxygen barrier median layer.

That is why work on nanocomposites also involves packaging films, in order to reduce or eliminate barrier layers and bonding agents. Increased research is being done into the layered silicates (montmorillonite) abundant in nature which of course can be used in biodegradable films. In addition to their barrier effect, layered silicates aid in hydrophilizing the surface for printing with aqueous inks and in matting the surface as an anti- reflective layer. Nanometals and nano-metal oxides are kneaded in as antibacterial component (e. g. nanosilver) and as UV protection, for scratch resistant or self-cleaning surfaces (lotus effect). Nanotubes and fibers serve as antistatic treatments with defined surface resistance. ■

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