High-Tech extrusion with barrier-mixing screws and spiral mandrel extrusion dies

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Improving efficiency is a priority for extrusion companies and is one of the major development objectives for machine manufactures. High technology extruder screw/barrel units and extrusion dies are key factors in this respect.

Maximum melt throughput with good melt quality plus the ability to process a broad range of raw materials with the same screw are main advantages when using barrier/mixing screws in single-screw extruders.

Spiral mandrel dies are the most suitable extrusion die systems for multi-layer structures of blown film, pipes, blowmolded containers and coatings. They generate uniform volume-flow and thus excellent thickness distribution of the individual layers and in total.

The paper covers some basics for layout, design and manufacturing technologies and demonstrates special features with practical examples.

1. Single-Screw Extruders and Barrier Screws

Introduction

Optimum design for single-screw extruders is not a fully mature technology where all issues have been settled. New designs and variations of existing designs are still being developed.

Advances in extrusion technology are forced by the requirements of plastics processors. In the recent past, more rapid product changes and several new resins have led to a growing demand for a versatile high performance extrusion technology with outstanding throughput rates and excellent mixing quality for different resins, including regrinds, processed without changing screw or barrel.

Barrier-Mixing Screws

The well known barrier screws with different dynamic mixing elements can be considered as the basis of the evolutionary development of today`s extrusion systems [1]. Through the years a wide variety of barrier designs has been developed, and barrier screws are supplied by all major extruder manufacturers and by several specialist companies.

Compared to conventional metering screws with mixers, barrier screws are known for better melt quality and better output pumping stability at higher throughput rates. Like other screws, barrier screws must be combined with homogenizing elements. A dispersive mixing spiral shear element e.g. tears up melt regions of different viscosity. It may be followed by a rhomboid distributive mixing section. Both zones provide a good heat transfer to the wall of the barrel. And, due to their spiral geometry, they can be designed for balanced pressure (Fig. 1).

Fig. 1: Homogenizing section of a barrier-mixing screw

Computer simulations based on physical-mathematical models can be used as a support for layout and design, e. g. the REX software [2]. Figure 2 shows graphs for pressure and temperature profiles and how melting progresses along the screw. For mixing sections FEM or BEM simulating programmes are common practice.

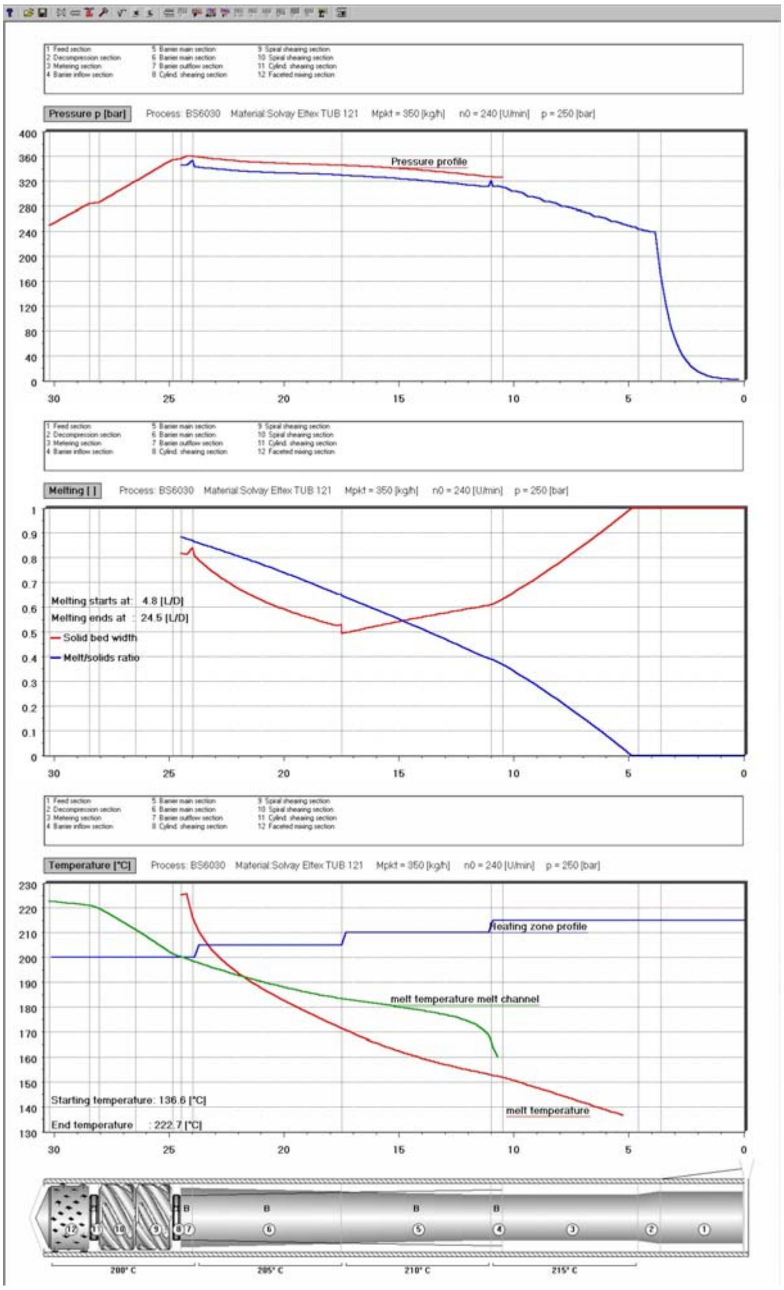

Fig. 2: Result of REX simulations

Grooved Barrel Extruders

In Europe grooved feed extruders are state of the art for most extrusion processes, in particular in the field of extrusion of polyethylenes and polypropylenes. While the metering and pumping characteristic of smooth bore extruders is defined by the sections of the screw which are partially or totally melt filled, the output behavior of grooved feed extruders is controlled by the metering processes within the feed zone. The main advantages of grooved barrel extruders are higher specific throughput rates and the fact that output is not or at least less influenced by the backpressure of the die.

Result of recent developments is a “pressure relieved” grooved section. This can be achieved by enhancing the conveying rate of the downstream sections e. g. by increasing pitch or/and channel depths. The best concept to ensure an excellent melt quality at the same time is the integration of a barrier screw design. Lower pressure leads to less cooling requirements in the grooved feed bushes, and the low pressure level enables the extruder to be started with filled hopper and without overload torque.

If such screw and barrel design is consequently applied grooved feed technology can also be applied for technical polymers with higher melting temperature like PA, PC, PET, PBT, PVDF e.a. Grooved feed sections no longer require intensive cooling but even heating. Therefore a new grooved feed design including electric heating in combination with air-cooling has been developed and introduced into practical operation, allowing the extrusion of a very broad range of polymers with polyolefines on one side and technical polymers on the other. Necessary temperature setting of the feed section will vary from 50 °C (e.g. PE-LD, EVA) to 250 °C (e.g. PA, PC).

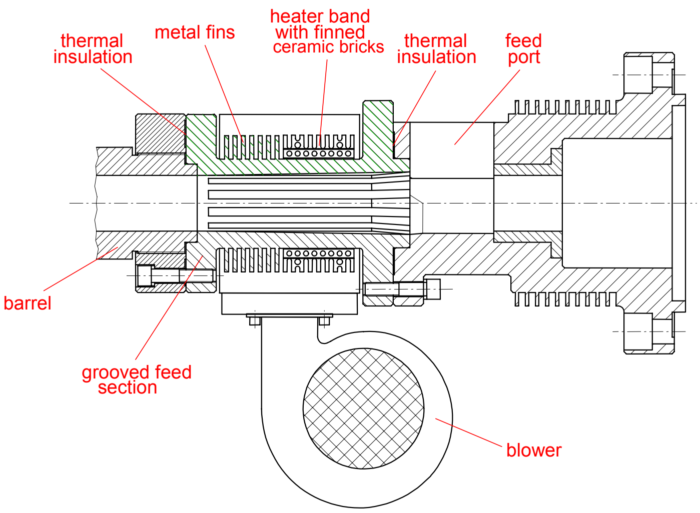

Fig. 3: Grooved feed section with electric heating / air cooling

Systems according to Figure 3 have proved successful in many applications [3].

Optimising Production Extruders

In many cases it is sufficient to install a new screw for improving output and quality. The next or wider step can be to exchange the complete plasticising unit (screw and barrel). Thus an “old” machine can be changed to “modern” with a technology according to latest state of the art.

When exchanging the extruder screw given limits have to be observed, mainly barrel length and drive system. In many cases L/D ratios are short compared to later designs. A typical field with “short” extruders is blow molding. Figure 4 gives the key operating data for a grooved barrel extruder 150 mm, 20:1 L/D for producing HDPE fuel tanks made from high-molecular weight grades and a mixture 50:50 of virgin material and regrind.

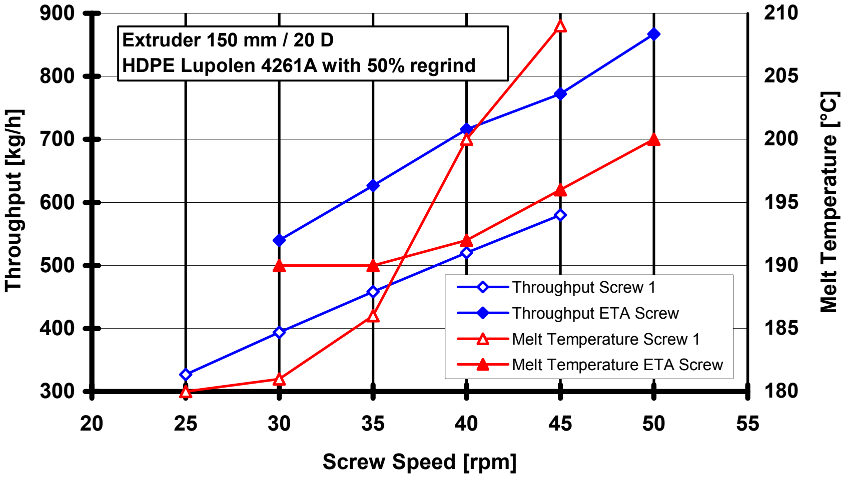

Fig. 4: Production data of grooved barrel extruder Ø 150-20D for industrial blow molding

Production capacity was increased by 30% with a new barrier-mixing screw to replace the standard screw (no compression, double-flighted feed section, Maddock-element and pin mixer).

A complete retrofit unit can be seen in Figure 5. Production data of a modernised 60 mm, 30:1 L/D pipe extruder are shown in Figure 6 and of a 60 mm, 24:1 L/D HDPE film extruder in Figure 7.

Fig. 5: Plasticising unit for extruder retrofit

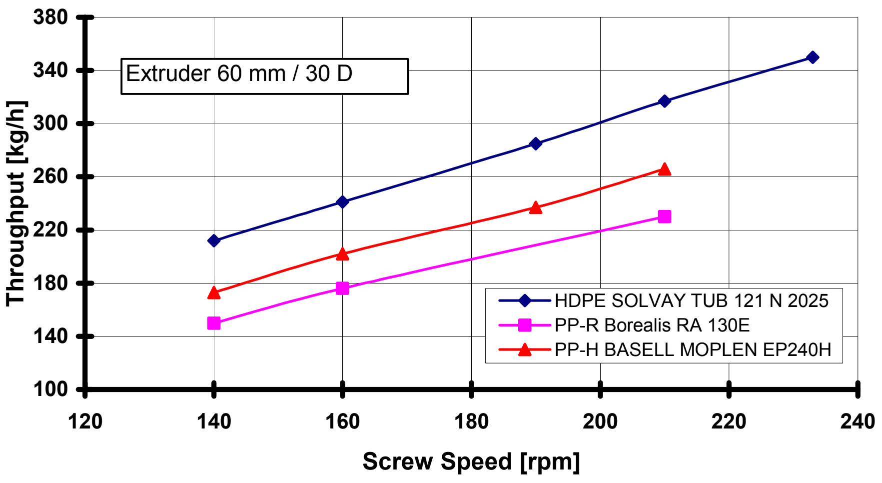

Fig. 6: Production data of pipe extruder Ø 60-30D

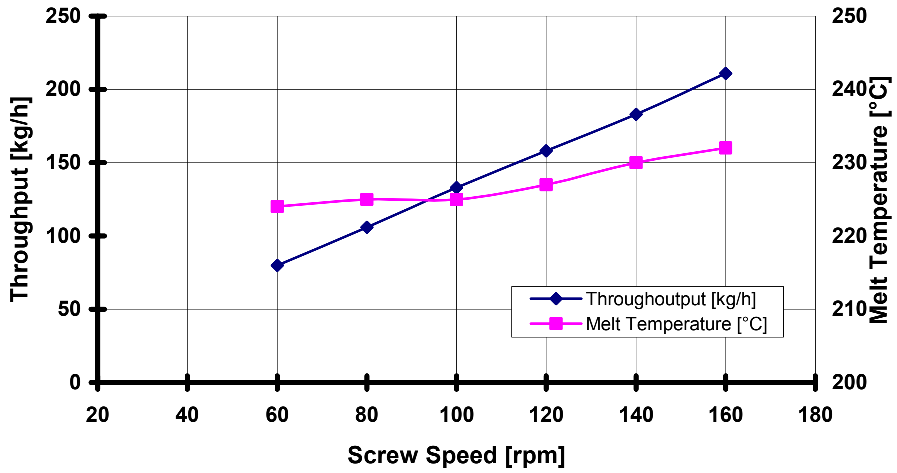

Fig. 7: Production data of HDPE film extruder Ø 60-24 D

Many such results have been achieved in various fields (film, sheet, pipes, tubes, profiles, strand coating etc.), even when modifying machines which were regarded as “modern”.

Conclusion

The combination of grooved barrel conveying, barrier melting mechanism and multiple-zone mixing can substantially enhance the performance of single-screw extruders. Furthermore, the improvements in throughput rate and melt temperature control are evident for a broad range of resins. Further developments like gearless extruders with high screw speed or melt separation techniques may base on optimized grooved feed systems.

2. Spiral Mandrel Dies

Introduction

Outstanding results are achieved with spiral mandrel dies in the form of a uniform volume-flow and product wall thickness distribution, with its wide range of different materials, and the avoidance of weld lines or other weakening points. Operational engineering advantages are based on compact design with a minimum quantity of parts and pieces and thus ease of assembly, dismantling and cleaning, and they ensure shortest possible material and colour change times.

Layout and Design

Computer simulations can sensibly be used to achieve the correct dimensioning of the flow channels. Two-dimensional network models for isothermal flows are common design tools and give reasonable support to the experienced design engineer. Basics are shown in Figure 8.

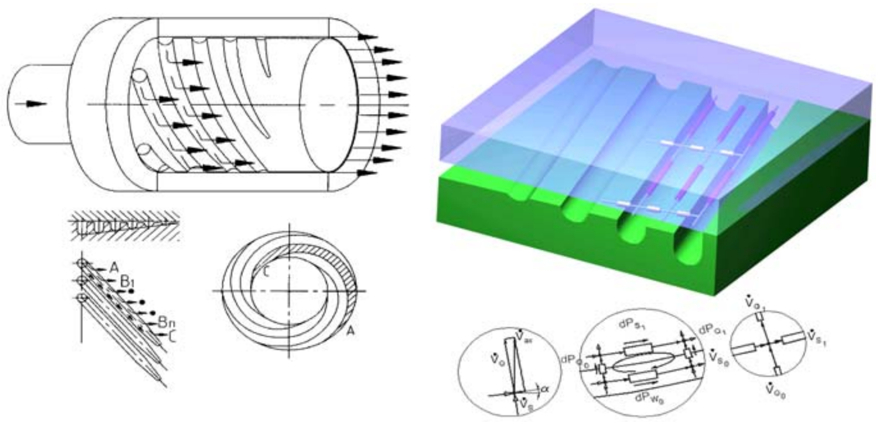

Fig. 8: Operating principle and layout basics of a spiral die

More sophisticated CFD programmes (Computational Fluid Dynamics) for simulating three-dimensional, non-isothermal flow use FEM, FDM or BEM based modelling. But they do not create “better” data, because only correct interpretation of the additional information can lead to better results. This is specifically true for multi-layer flows and interfacial behaviour. Polymers with widely differing shear viscosities and different elastic properties can have a tendency towards interfacial instability. It is nearly impossible to take all this into account in flow simulations. All computer aided layout and design is aimed at generating uniform flow and low pressure loss – a conflict situation that in some cases needs a compromise solution.

Mono-layer Dies

Typical field for mono-layer spiral dies is film extrusion. Figure 9 shows a complete package for high-output extrusion with IBC system.

Fig. 9: Blown film die with outer and inner bubble cooling

The spiral mandrel is fed from an external melt pre-distributor in a way that eliminates spiral flow lines, ensuring high-clarity film with isotrope optical and mechanical properties. The die has an unobstructed centre for incorporating internal cooling etc. The IBC system is of new design. Particular attention was given to avoiding condensation of volatiles and for ease of handling, in addition to high cooling capacity. The design principle allows stacking of modules for building co-extrusion dies.

Co-extrusion Dies

For multi-layer structures spiral mandrel dies are the most suitable systems or – in most cases – the only solution [4]. Coextrusion dies for blown film extrusion are available on the market with concentric and with non-concentric spiral mandrels. The latter with conical or radial arrangement and thus as a multitude of stackable disks (‘stack dies’ or ‘pancake dies’).

Figure 10 demonstrates a 3-layer ‘stack die’ with conical spiral mandrels and all the features outlined above.

Fig. 10: 3-layer blown film die with inverse melt pre-distribution

Besides films, pipe extrusion is a major area for spiral mandrel (co-)extrusion dies both mono- and multi-layer systems. Pipes with two or three layers are produced with various materials in sizes from less than one millimetre (medical tubes), over a range of a few millimetres (automotive industry) up to 630 mm (sewers etc.) or maybe more. In many cases two-layer products are produced with three-layer dies, not operating one of the three extruders or running the same material in two neighbouring layers.

Figure 11 shows a three-layer die for larger polyolefin pipes for connecting one main extruder centrally and with a side arrangement of the ancillary extruder for inner and/or outer layer. The branching adapter in front of the two side feed ports has a valve in each feed channel for either running three-layer products or two-layer pipes with inner or outer skin layer.

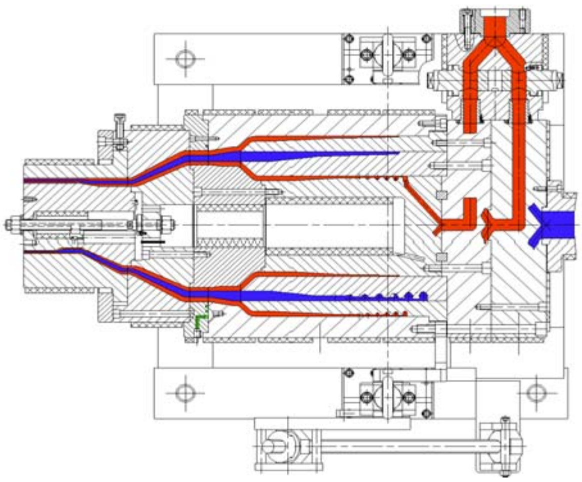

Fig. 11: 3-layer spiral die for pressure pipes

Until now, four- or five-layer pipes are mostly used in smaller sizes and produced mainly with engineering thermoplastics. A typical example is automotive tubing based on polyamide with additional layers for achieving special properties like a barrier, electrical conductivity etc. Another five-layer product is PE-X hot water pipe containing an EVOH barrier layer.

No other construction principle offers (with acceptable dimensions) anywhere a similar possibility to combine a multiple of melt streams into a tubular layer structure like spiral mandrels. An example in the area of industrial blow molding shall demonstrate a comparison of die sizes. For producing multi-wall fuel tanks and filler pipes six-layer co-extrusion heads are used with die diameters up to 1000 mm (Figure 12).

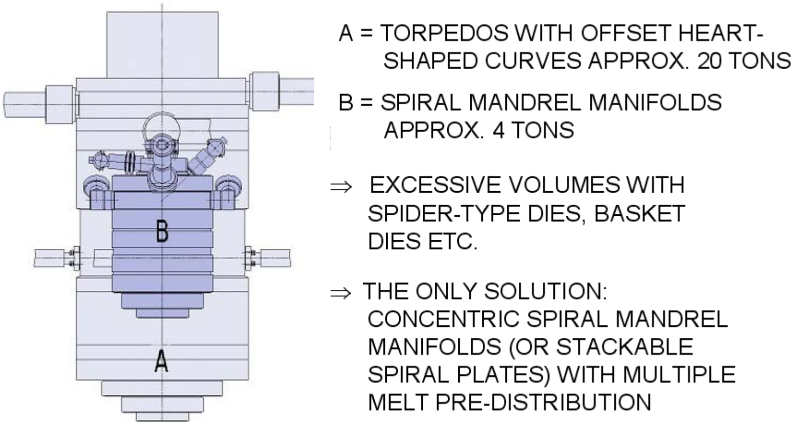

Fig. 12: Size comparison of 6-layer parison dies for plastic fuel tanks

In Figure 13 you can see the compact design of a system with five concentric spiral mandrel manifolds, in this case for small corrugated pipes (e.g. automotive tubing). All extruders are arranged for side-feeding or from above to create a free area in the centre in order to allow passages for air our other fluids, for bigger sizes the installation of water cooling pipes.

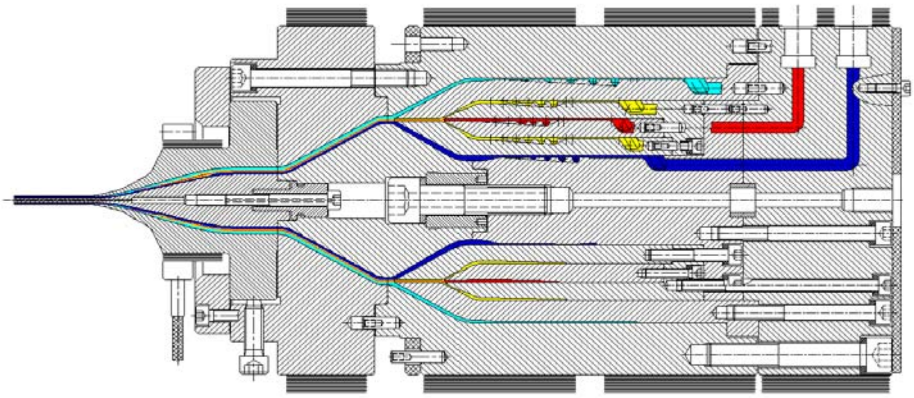

Fig. 13: 5-layer die for corrugated tubing

At this point, its worth to say a few words about flexibility in co-extrusion. Although spiral mandrel systems, by far, offer the greatest flexibility with respect to different materials and melt throughputs, layer thickness variations are limited to some extent. This is simply a result of *pressure loss, critical shear rates* and *residence time* criteria. In general, operating windows for each layer (min./max. mean layer thickness) can be calculated within a ratio of 3:1 till 4:1.

Extrusion Coating

Another spreading method of producing plastic pipes with an external skin layer is coating prefabricated pipes using crossheads, similar to the sheathing of steel pipes or cables. Typical examples for such a system are under-floor heating pipes made of PE-Xa with an outside EVOH coating, or composite PE-X or PP pipes with an aluminium barrier in the middle of the wall.

Coatings are also used on prefabricated PE 100 pressure pipes. The inner pipe is manufactured according to the given standards and marked accordingly. The colour of the protection layer is selected for the specific use, e.g. gas or drinking water (Figure 14).

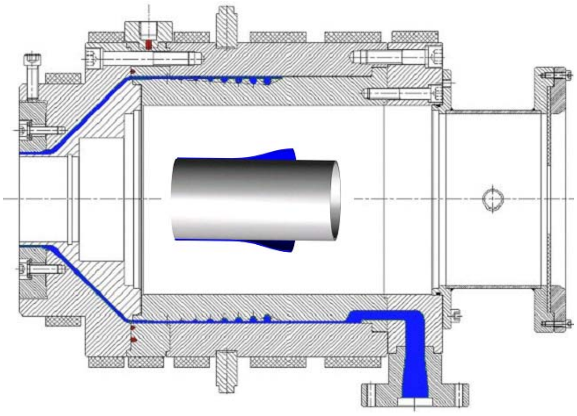

Fig. 14: Pipe sheathing die

Extrusion coating allows easy introduction of detection wires and the like. In some cases a two-layer coating is applied for achieving special surface effects.

Such coatings are also applied on double-wall corrugated pipes for applying a smooth outer layer, and on long distance heat conducting pipes with urethane foam insulation. Outside and internal coating of tubular woven fabrics is another special example.

Conclusion

No other design principle offers anywhere near as many possibilities for multi-layer extrusion dies as the spiral mandrel technology. The advantages are, on the one hand, the reliable and economical production of the pipes, and on the other, the wide variety or possibilities for product development.

All figures are originals of ETA Kunststofftechnologie GmbH, Troisdorf

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