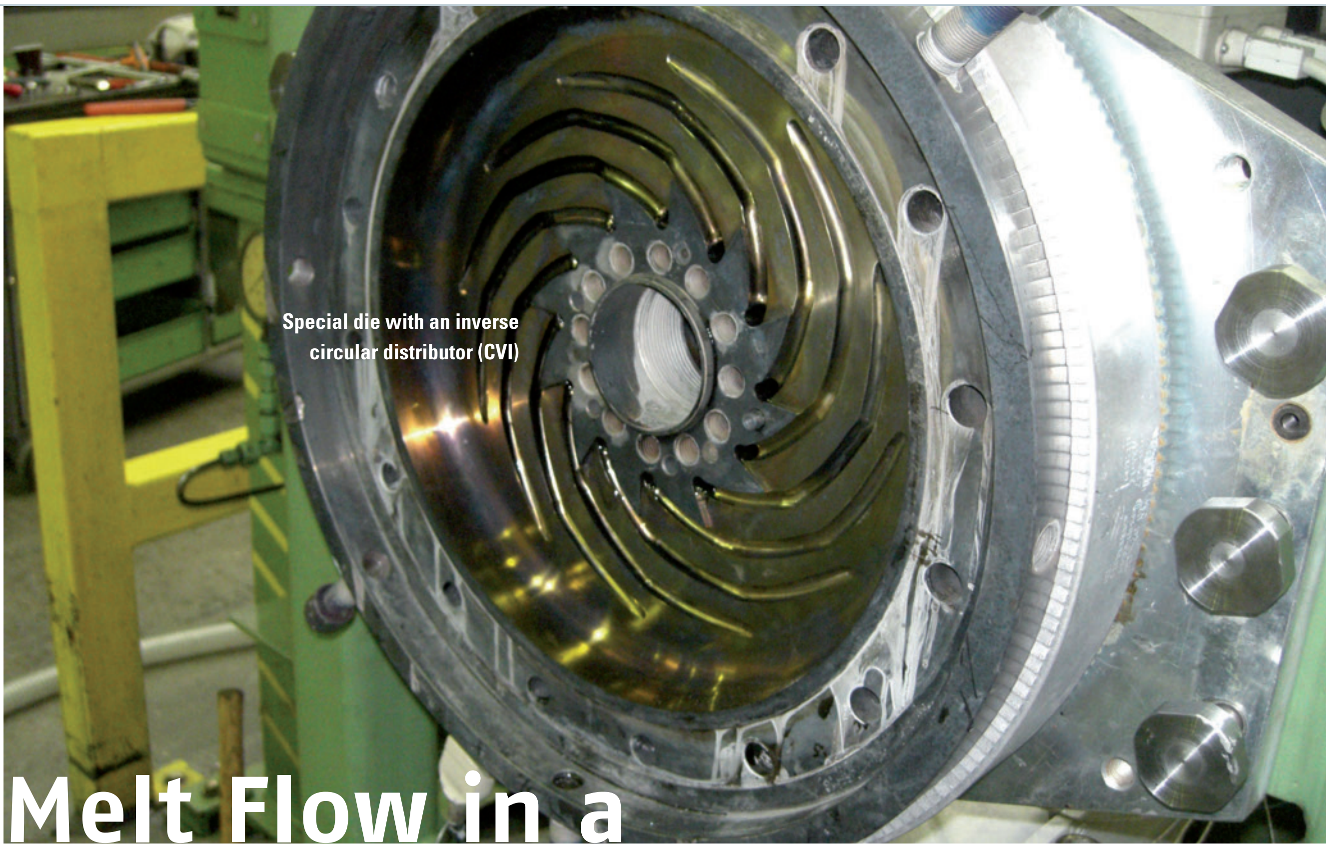

Special die with an inverse circular distributor (CVI)

Melt Flow in a Circular Distributor

Extrusion Dies. Circular distributor technology makes it possible to achieve a modular building-block system for coextruded pipes and hoses. Rapid material color change and the possibility to fulfill product specific requirements open up a broad range of applications.

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"A spiral mandrel or a flat spiral die?" This was the question that had to be asked in 2006 when considering which type of extrusion die is the best to use for the manufacturing of small tubes, hoses, blown films and blow molded articles [1]. Today, it is clear that the systems that have become established are those in which the distribution of the melt (or the different melts in the case of multi-layer dies) takes place on a single plane – and not just for special applications. Circular distributors, which are also known as flat spiral dies or pancake dies, are state of the art. This applies particularly to the production of media-conveying lines for cars and other vehicles, for medical technology, for hydraulic and pneumatic systems and also for underfloor heating pipes based on PE-HD and PP, as well as for the production of barrier-layer films, medical films and multilayer blow molded articles.

Design Characteristics

In the same way as the "classic" axial spiral mandrel distributors of a cylindrical or conical design, the flat radial distributors are characterized by a uniform volume flow and hence an excellent (layer) thickness distribution, as well as the absence of weld lines and other weak points. The circular distributor technique provides ideal conditions for a modular built block system. The melts are fed in, pre-distributed and then circumferentially distributed in a block (a module), which is made up of just a few round discs. To produce multi-layer coextruded products, it is possible to stack several modules (i.e. as many modules as are required) on top of each other to give a stack die. The components of the individual modules are either completely identical, or more or less identical. A mandrel is arranged in the center for the formation of the annular gap space for the melt. This can be made with a hole in it for the pas-

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sage of air or another (cooling) medium (**Fig. 1**). By way of an option, this mandrel can be equipped with internal heating to increase the variability of layer structures and materials that can be processed.

Apart from these benefits – good circumferential distribution, no weld lines, modularity, small dimensions, low-cost manufacture – the system also offers a series of process-engineering and operational-engineering advantages:

- Short flow paths and a low melt volume, leading to short residence times and rapid material and color changes, low wall-shear velocity, and hence low
- dissipation (temperature increase),
- low pressure losses, and hence a high throughput potential,
- high flexibility in terms of layer structure (thick layers/thin layers, materials/layer structures) and number of layers,
- thermal separation and separate temperature control of the individual modules is possible,
- special versions of individual modules, e.g. for corrosion protection,
- simple and rapid dismantling, cleaning and re-assembly,
- feasibility of upgrading.

It is, however, also important to point out the drawbacks:

- Limits on high melt throughputs
- melts can only be merged sequentially (one after the other), which is not so good for certain structures (i.e. polymers with great differences in viscosity),
- pressurized areas, which place stringent requirements on the manufacturing process and requires careful bracing of the individual parts.

For extruded products with small dimensions, however, the advantages clearly outweigh the drawbacks.

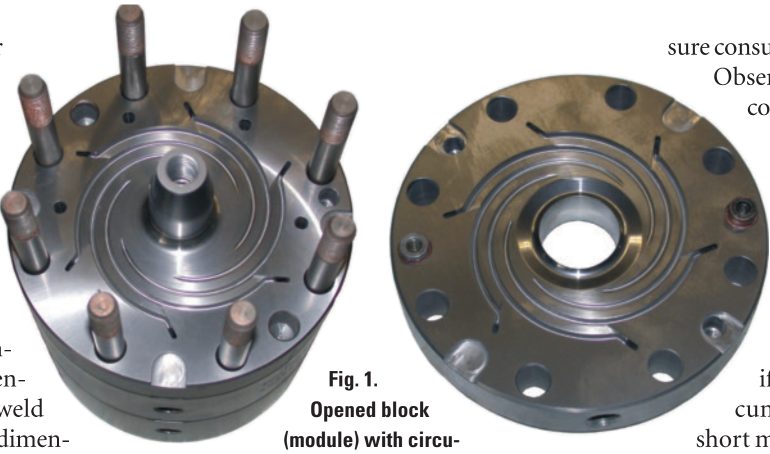

Fig. 1. Opened block (module) with circular distribution and inside mandrel

Layout and Design

Flow analyses (simulations) are conducted with analytical or numerical models in order to support the process-engineering layout and design [2, 3, 4]. The network theory developed for two-dimensional, isothermal flows is frequently used for the preliminary layout. The network model and the way in which the circular distributor works is set out in **Figure 2**.

It is clear from this schematic diagram already that the design with oval channels in the two neighboring circular discs is advantageous. The distribution channels do not have any edges or dead zones at which the flow could stagnate. By superimposing the part-flows from the two channel halves as they flow into the joint gap, a finer structure is obtained than with a single-sided channel, which means that the channel length can be reduced, producing a favorable influence on the pressure consumption and the residence time.

Observations conducted in practice confirm this advantage in the case of product changes. The purging times are considerably shorter compared with dies that have axial spiral mandrel distributors.

The computer-supported layout is aimed at achieving a low pressure loss for the specified melt throughput, good circumferential distribution and short material change-over times. The production related limits and material-specific limits must be kept in mind for the layout, i.e. shear rates which ensure a rapid material or color change, on the one hand (lower limit) and do not lead to overheating or inadmissibly high pressure losses, on the other hand (upper limit).

More detailed observations of the flow processes are possible by conducting a numerical 3-D-CFD simulation with finite element models. Apart from the evaluation criteria mentioned so far, it is possible to show other physical data, such as pressure, velocity and temperature distribution, plus flow lines and distribution spectra. This data can be used to assess the operating-point dependence of a die for different throughputs and materials (see **Figure 3** by way of example).

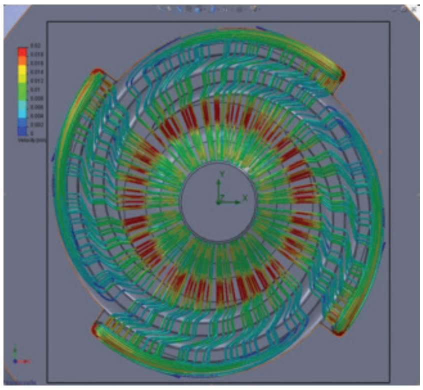

Fig. 3. CFD flowline diagram for assessing overlaps and operating-point dependence

A number of scientific papers focus, in particular, on the problem of die deflection due to the high melt pressure [5]. The coupled calculation of the flow and the deflection is of fundamental importance for modeling and simulation. When it comes to the practical dimensioning of the plates, however, this term can be ignored. In multilayer flat die systems, the intermediate modules are only subject to loading from the resultant compressive forces of the neighboring layers in each case. The pressure differences are so low →

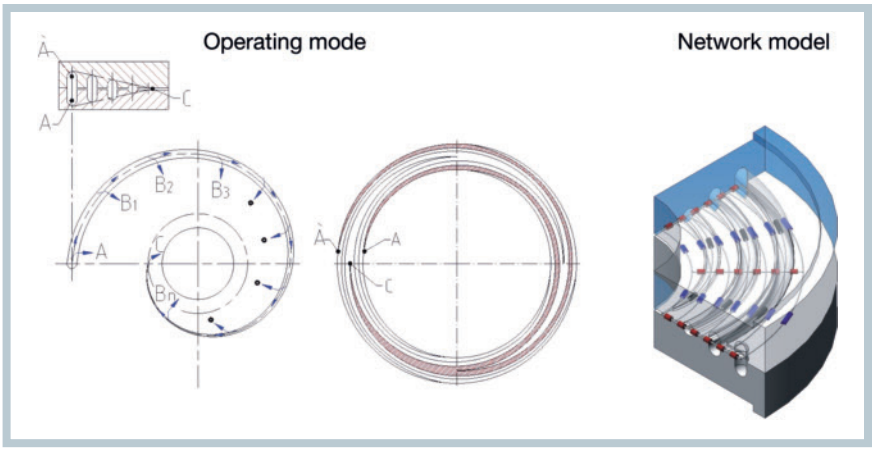

Fig. 2. Operating mode and layer structure for a circular distributor

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that the discs can be manufactured to be thin (favorable from a manufacturing technology view). The rear and front modules, or connecting plates, must be solid, for design reasons, so that the deflections occurring there are of the order of magnitude of the production tolerances.

Pipe Dies

Whenever the requirements on the melt throughputs for the thick layers in multilayer composites are not too high, the circular distributor principle has become established for dies for small pipes and hoses. This applies particularly for applications in the automotive industry, e.g. for 3 or 5-layer fuel lines based on polyamide. The modular structure is particularly appreciated, which makes it possible, for example, to expand a three-layer system into a five-layer system **(Figs. 4 and 5)**.

The special features clear from the longitudinal cross-section in **Figure 4** are the possibility of thermally separating the individual modules through air gaps and the use of heating/cooling units for improved thermal control of the system, i.e. separate, polymer-specific heating at different temperature levels. An optional internal heating system that can be fitted can also bring additional advantages.

The nozzle unit incorporates a two-part mouthpiece. The end section sits in a clamped platen (ring), which remains on the system, in its centered position, when there are changes to the dimensions. The new end section is placed, in a functionally accurate manner, in the centering seat on the clamped centered plate.

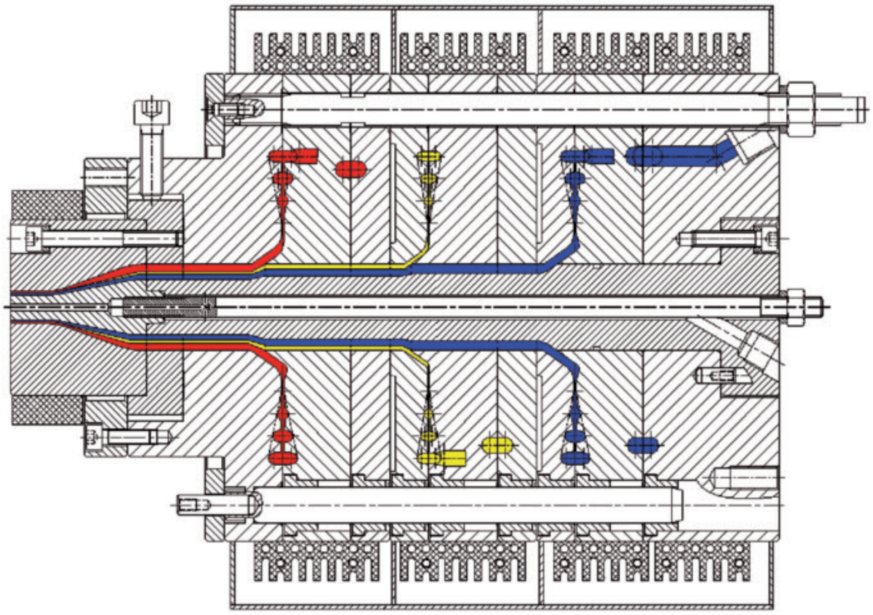

Fig. 4. Diagram of a circular distributor die for three-layer pipes with thermal separation

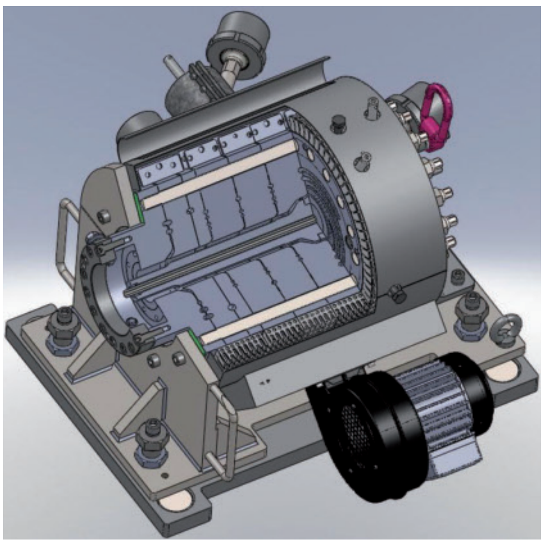

Fig. 5. 3-D model of a five-layer die for attaching nozzles for smooth and corrugated pipes

This system permits considerably shorter changeover times.

The heating/cooling unit has chains of ribbed ceramic stones with heating conductors and tension ropes, which align themselves uniformly on the housing wall. The special ceramics with optimized heat conduction ensures very good operating characteristics for heating and cooling as well as good energy efficiency.

The 3-D model in **Figure 5** similarly shows these heating/cooling units and, in addition, the complete structure with the connection adapters for the extruder and a mandrel design for die core centering in the case of corrugated pipe dies. The setup time can be considerably shortened through internal die core centering. This model also clearly shows the modularity and, with this, the option of varying the layer structure in the product by switching modules. In the normal case, the internal mandrel has to be changed in order to guarantee perfect flow conditions at the merger points and in the parallel zones.

In the circular distributor, the melt is normally conveyed from the outside inwards. The direction can also be reversed, however, so that the melt runs from the inside outwards (CVI system). Distributors of this type are employed for special, single-layer products. The aim of the CVI system is to give the melt the dimensions of the product over as short a route as possible once it has left the extruder or the melt pump. To do this, the melt is distributed by circular channels in a radial configuration pointing towards the outside once it has passed through a short predistributor, which is necessary for supporting the mandrel and for allowing the medium to pass **(Title photo, Fig. 6)**. This is followed by a flow channel, which should be as short as possible, up to the die opening. All in all, CVI dies offer the best conditions for gentle treatment of the material.

A special feature is visible on the open distributor: the variable-length gap area between the channels, which constitutes

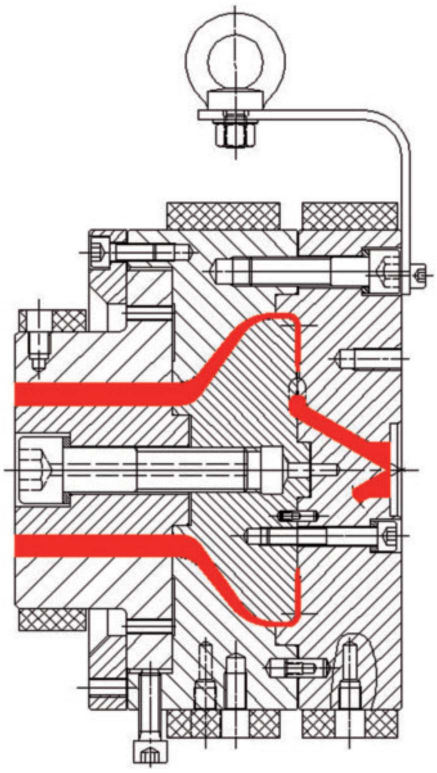

Fig. 6. Diagram of a special die with an inverse circular distributor

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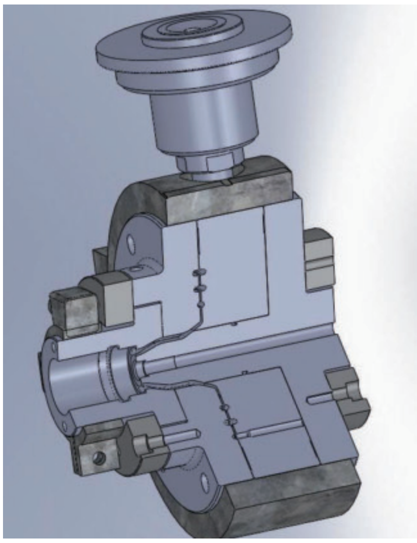

Fig. 7. Circular distributor plate and single-layer die for micro-hoses

a further degree of freedom for achieving an optimum distribution, alongside the channel length, the channel depth profile and the gap width. Here too, it is clear that the distributor geometry does not take the form of an Archimedean spiral, which is why the term "circular distributor" has been selected.

Medical Technology

The extrusion of single-lumen and multi-lumen medical hoses is particularly demanding – firstly, in respect of the stringent specifications that apply when (special) plastics are used in medicine (toxicity, purity, hygiene, etc.), and, secondly, through the compulsion to miniaturize.

The dies were initially derived from the familiar designs for thin cables and lines and designed as so-called cross-head dies with mandrel distributors and, subsequently, axial spiral mandrel distributors [6]. Since 2004, extrusion dies for micro-hoses have also been built employing circular distributor technology, for both mono and co-extrusion [1, 4]. The advantages outlined at the outset are of overriding importance here.

Figure 7 shows a distributor disc where all the channels for the pre-distribution of the melt and for full circumferential distribution are in a single plane. "Single-platen dies" of this type have a particularly small melt volume, which is one of the main requirements in terms of residence time, temperature control, and handling during assembly and cleaning, etc. In the 3-D model, it is possible to see the pre-distribution in a second plane. The individual design will be a function of the specific circumstances.

Circular distributor technology is particularly suitable for small co-extrusion dies for two and three-layer products **(Fig. 8)**. Two-layer dies can be designed in such a way that, by rotating one platen, it is possible to switch the allocation of the extruders for the inside and outside layer.

In addition to being used in the small-dimension range for catheter applications and infusion hoses and the like, circular distributor dies are also in use for bigger hose dimensions – from single-layer plasticized PVC hoses through to five-layer special products for a large number of applications in medical and pharmaceutical technology.

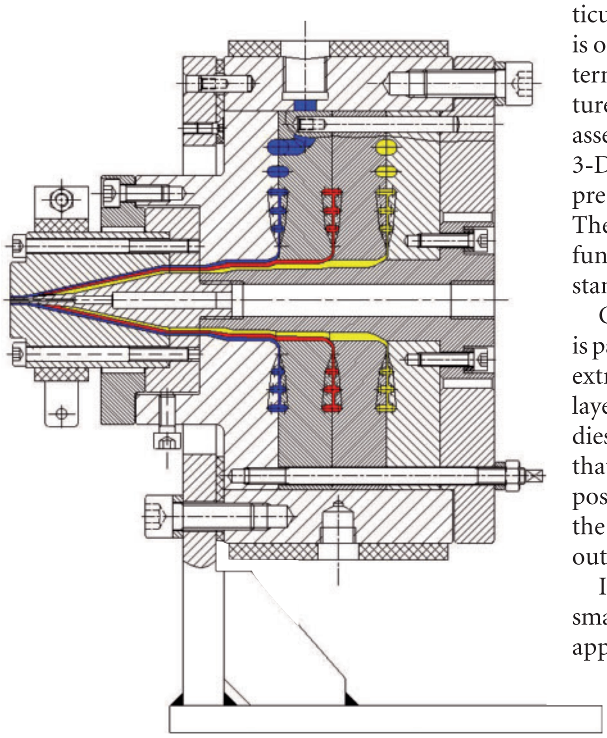

Fig. 8. Diagram of a three-layer die for micro-hoses

Barrier Films

Stack dies or pancake dies have been in use for many years in the production of high-grade packaging films [8] – with seven, nine **(Fig. 9)** or eleven layers in recent times. The circular distributor concept is particularly suitable for systems with small die diameters for the production of primary bubble on double-bubble or triple-bubble systems [7]. The technology has become established precisely for this application **(Fig. 10)**.

In the case of blown film dies, the free space in the center is particularly important for the passage of heating and cooling media. Alongside this, all the advantages of circular distributor technology come into play, right through to the option of retrofitting additional layers.

Prospects

Traditionally, the parison dies for the blow molding of hollow articles have been equipped with mandrel distributors. When it comes to continuous coextrusion, however, heads with axial spiral mandrel distributors have become established, both for multilayer food packaging and for large-scale industrial packaging and six-layer fuel tanks with excellent barrier properties. On account of the analogy with pipe extrusion, ideas have been put forward for transposing circular distributor technology to parison die heads [9]. The open center of the mandrel offers space for the pull rod of the wall thickness adjustment unit (axial mandrel adjustment, **Fig. 11**).

In the case of pipe dies, the limits for high layer throughputs have been addressed, i.e. limits due to an excessively high pressure loss, which can lead to problems with maintaining tightness. As far as the pressure loss is concerned, the predominant share is that of the flow resistance in the die unit (die exit). The throughput can be increased by the extent to which this resistance can be reduced. The selective approach to be adopted here is to increase the draw down ratio, i.e. to extrude the polymer from a bigger die (orifice diameter and gap width). In the case of polyamide, high under-drawing ratios are standard practice, and with PE-HD and PP, the initial developments are highly promising. →

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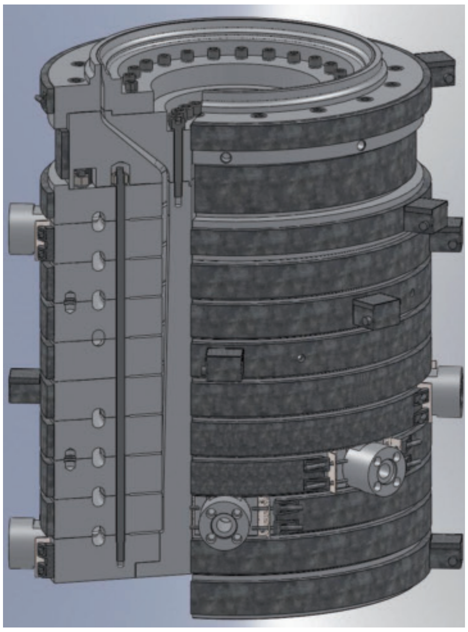

Fig. 9. 3-D model of a nine-layer blown film die (Ø 500 mm)

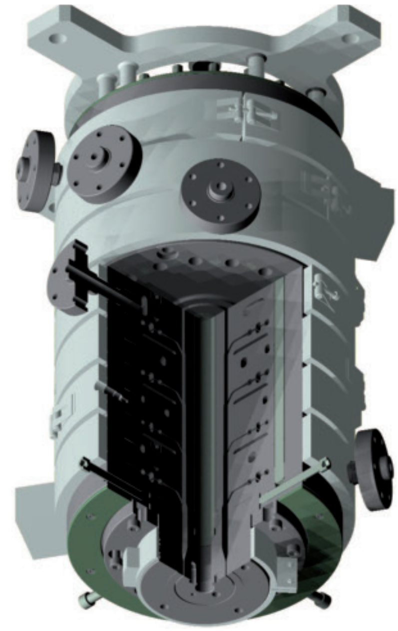

Fig. 10. Seven-layer blown film die for biaxially-stretched films (double/triple bubble)

In many areas, use is increasingly being made of plastics that place special requirements in terms of thermostability and temperature control. These include fluoropolymers (PFA, ETFE, FEP, etc.), high-temperature thermoplastics (PAEK, PSU, PPS, PI, etc.) and cross-linking plastics (PE-X). The circular distributors with channels in the two neighboring discs are superior to nearly all other die designs for these "sensitive" materials. Surface coatings are frequently sufficient for corrosion protection. Otherwise, corrosion-resistant materials will be used.

When multilayer dies are built, it is also possible to combine dissimilar melt distribution systems, such as coaxial spiral mandrel dies for the main layers and circular distributors for the thin adhesive layers. Customized solutions are repeatedly seen to be superior to the standard versions.

Progress in the layout and design of the spiral mandrel distributor systems can be expected with optimization algorithms for the automatic optimization of the distributors. These are currently being developed at different places [10, 11]. ■

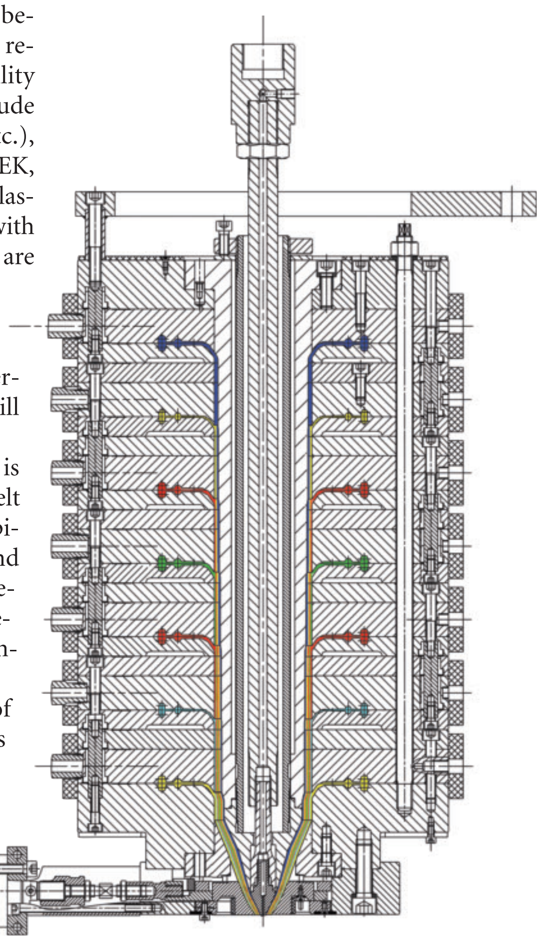

Fig. 11. Diagram of a multi-layer parison die head with axial and radial wall thickness control

(figures: ETA Kunststofftechnologie)

REFERENCES

1 Fischer, P.: Wendel- oder Spiralverteiler? Extrusion 04/2006, pp. 43–45

2 Michaeli, W.; Blömer, P.: Flat spiral dies – rheological design with network theory, Journal of Polymer Engineering 24 (2004) 1–3, pp. 137–153

3 Fritz, H. G.; Cretu, M.: Design Concept for Stacked-type Spiral Dies, Kunststoffe international 94 (2004) 6, document number PE102895

4 Burmann, G.: Extrusionswerkzeuge für die Schlauchextrusion. Handbuch zur 3. Duisburger Extrusionstagung „Extrudierte Produkte/Verpackungen für die Medizin- und Pharmaindustrie", 8/9 March 2006

5 Michaeli, W.; Blömer, P.; Scharf, M.: Rheological and Mechanical Design of Pancake Dies, Kunststoffe international 97 (2007) 1, pp. 30–33

6 Lechmann, U.: Werkzeugtechnik für die Mikroschlauchextrusion, Handbuch zur SKZ-Fachtagung „Mikroschlauchextrusion für die Medizintechnik", Würzburg 10. November 2005

7 Burmann, G.: Werkzeugtechnik für biaxial gereckte Schläuche, Handbuch zur 5. Duisburger Extrusionstagung „Technologien und Trends extrudierter Folien – mehrschichtig, orientiert, veredelt", 12/13 March 2008

8 Wortberg, J.: New Spiral Mandrel Dies, Kunststoffe plast europe 88 (1998) 2, pp. 12–15

9 Fischer, P.; Michels, R.: Moderne Schlauchköpfe mit Wendelverteilern. Handbuch zur SKZ-Fachtagung „Blasformtechnik 2006", Würzburg, 26/27 April 2006

10 Cretu, I. M.: Analyse, Auslegung und Optimierung von Wendelverteilersystemen, Dissertation, Stuttgart University, 2008

11 Wortberg, J.; Saul, K.; Köhler, P.; Lupa, N.: Automatisierte Optimierung von Strömungskanälen zur Verbesserung des Spülverhaltens von Kunststoff-Extrusionswerkzeugen, WAK Zeitschrift Kunststofftechnik / Journal of Plastics Technology 5 (2009) 2, pp.130–153

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