Co-extrusion dies based on spiral mandrel technology

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Innovative multi-wall pipe systems need innovative production systems. And multi-layer dies represent the key factor within modern co-extrusion lines. Spider dies, basket-type dies and dies with spider-leg distribution have proved successful for single-wall products, but they do have limitations when combining more than one component. For multi-layer structures spiral mandrel pipe dies are the most suitable systems or – in most cases – the only solution. Unfortunately, there is one exception till today: PVC-U.

The paper covers some basics for layout, design and manufacturing technologies, and demonstrates examples for producing innovative multi-layer systems, including extrusion coating on prefabricated plastic pipes.

1. Optimising Layout and Design

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.

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 enough support to the experienced design engineer. Basics are shown in Figure 1.

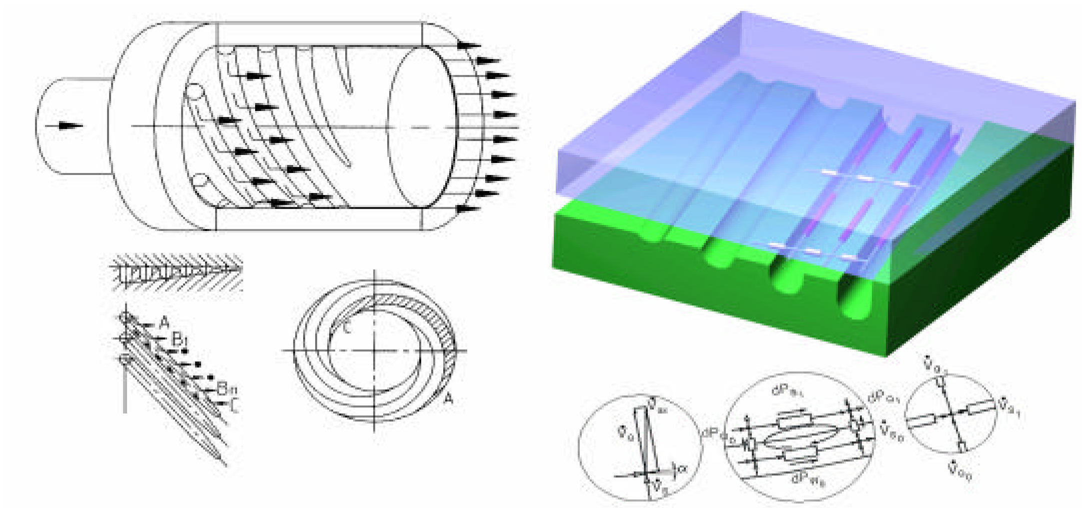

Fig. 1: Operating principle and layout basics of a spiral die

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. The method of layer formation can be very important: at a single point, sequentially, or through a combination of both.

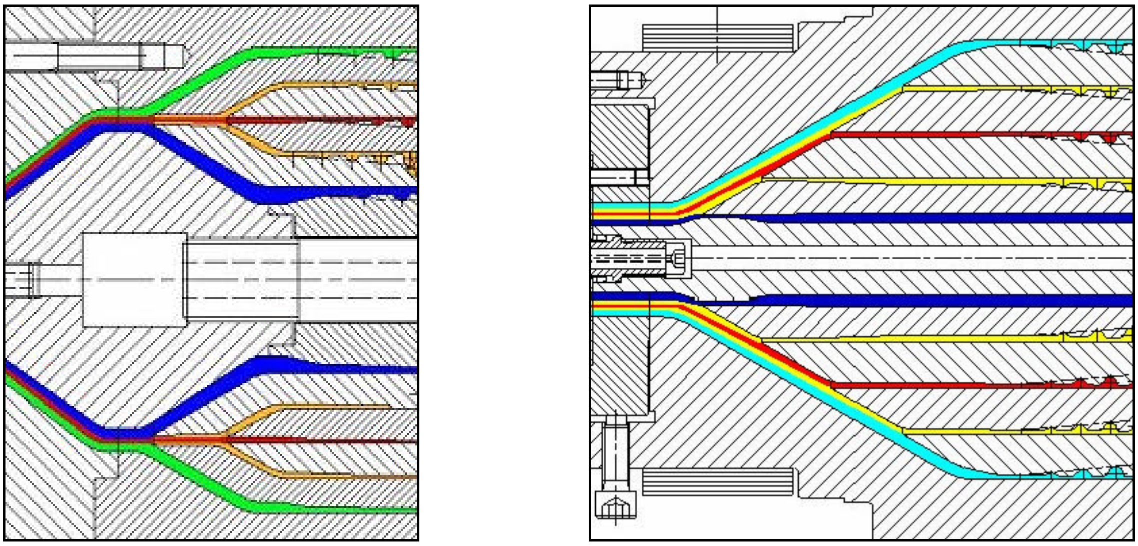

Fig. 2: Formation of the layer structure in five-layer dies

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.

Distribution of melt coming from the extruder(s) to the spiral mandrel manifold(s) can be of major importance. Figure 3 shows a system with pre-branching from 1 into 4 channels each one feeding a coat-hanger followed by a number of spirals. Layout and design of the melt pre-distributor again is performed with the aid of computer simulation.

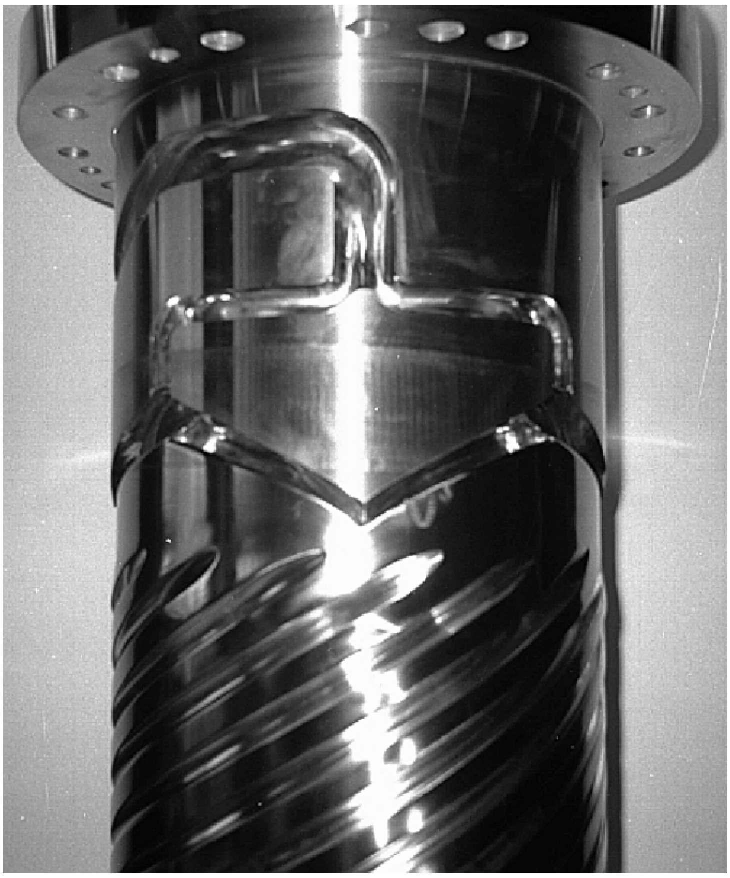

Fig. 3: Spiral mandrel manifold with pre-branching $1 \rightarrow 2 \rightarrow 4$ and coat-hanger pre-distribution

2. Merging Design and Manufacturing Technologies

Besides calculating and dimensioning the flow passages, close co-operation between design engineer and manufacturing technologist is very important. What use is a ‘streamlined’ flow channel if it is impossible to manufacture it? In other words, to some extent, dies can only be as good as the manufacturing facilities in the machine shop.

For instance, flow channels in a cylindrical wall must not have 90° angles to the opposing surface. An undercut to avoid ‘dead spots’ ensures good self-cleaning and purging and thus the shortest possible material and colour change times. Besides high-quality steel – forged and ultrasonic test approved – high-speed milling on multi-axis CNC machines provides smooth surfaces which do not need extensive manual polishing.

Coating of the flow channels is gaining increasing importance. In addition to chrome and/or nickel plating, thin platings of chromium nitride and others are used, in some cases multi-layer coatings containing different materials.

3. Co-extrusion Dies

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.

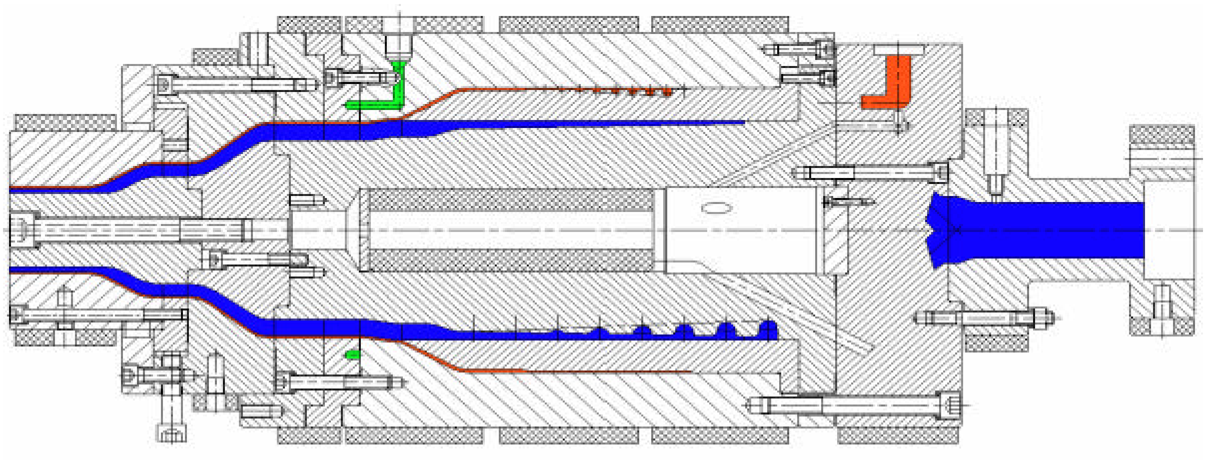

Fig. 4: 2-layer spiral die for cable conduits and the like

Figure 4 shows the cross-section of a die for producing two-layer PE pipe for cable ducting. The internal main layer can be off-grade material, e.g. DSD recylate/black, covered by a white layer of virgin PE.

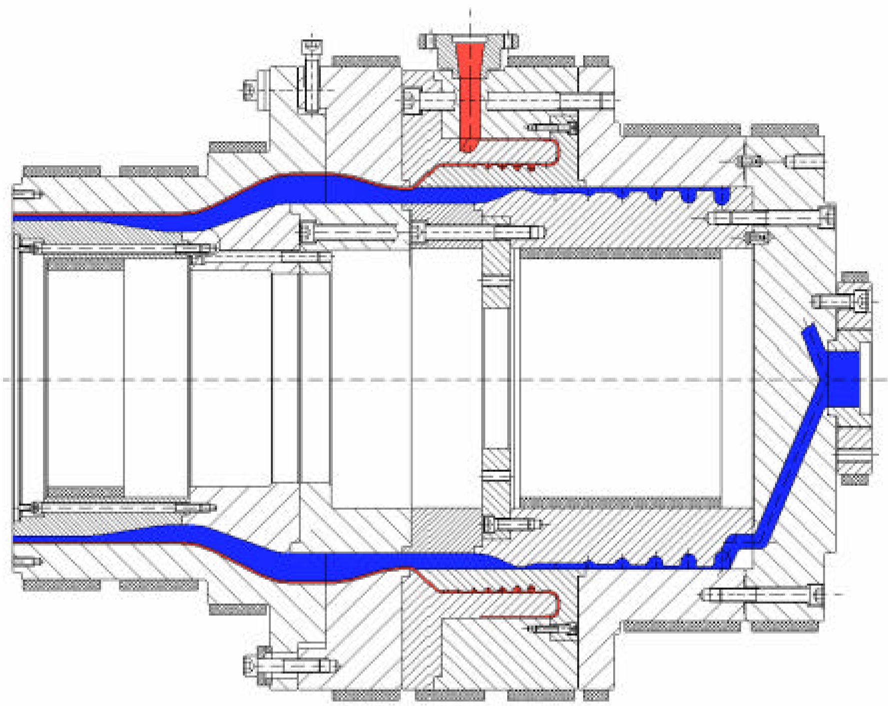

Fig. 5: Pressure pipe die with coating module

Same layer structures can be produced with a basically mono-layer die with an additional co-extrusion module, for example for the production of HDPE pipes with an outside skin layer of PP to protect the pipes during relining processes or installation in the soil (Figure 5).

At this point, it is worth referring to the importance of the area between the manifold system and the die insert. It is advisable to have a sufficiently large channel volume to dissipate stresses etc.. This space has a positive influence, for example, on making the morphological structure of certain PP grades more uniform (smooth surfaces) or for balancing out stresses, particularly with bimodal pipe materials (PE 80, PE 100).

Another typical example for this product groups is two-layer HDPE pipe for ducting of fiber optic telecom cables. The inner co-extruded layer is from PE containing silicone or the like as slip agent. The same die design is applied for HDPE sewer pipes containing a white inner layer for better TV camera inspection as well as for other two-layer pipes in which the thin inner layer must have special properties.

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 6 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.

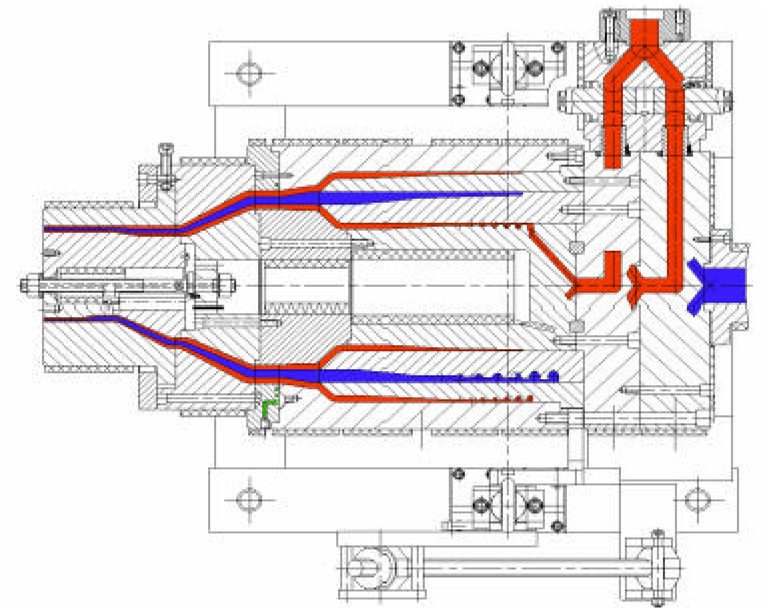

Fig. 6: 3-layer spiral die for pressure pipes

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 moulding 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 7).

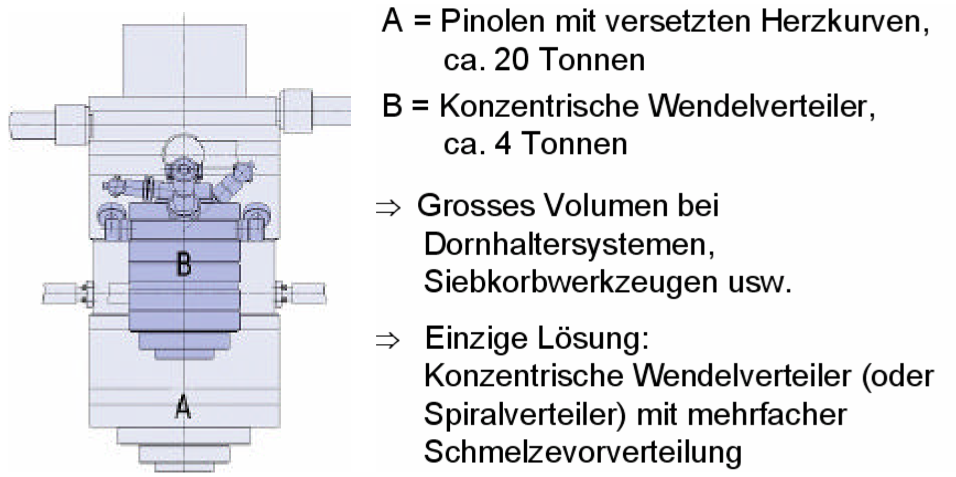

Fig. 7: Size comparison of 6-layer parison dies for plastic fuel tanks

In Figure 8 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.

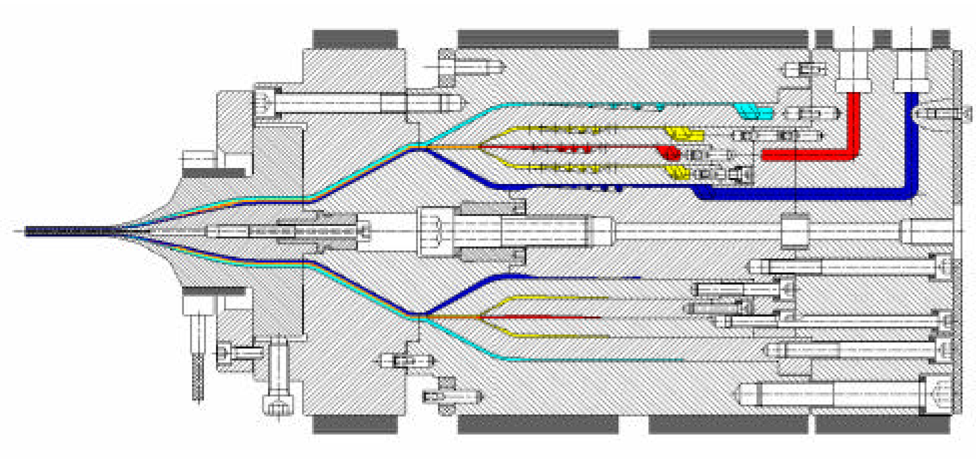

Fig. 8: 5-layer die for corrugated tubing

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.

This ratio, naturally, is not wide enough for using a manifold for thin layers (barrier resin or adhesive) for thick layers with much higher throughputs. Such variability, for instance, is required in laboratory systems and for product development. Figure 9 shows an example of a modular system with interchangeable modules which can be positioned one after the other.

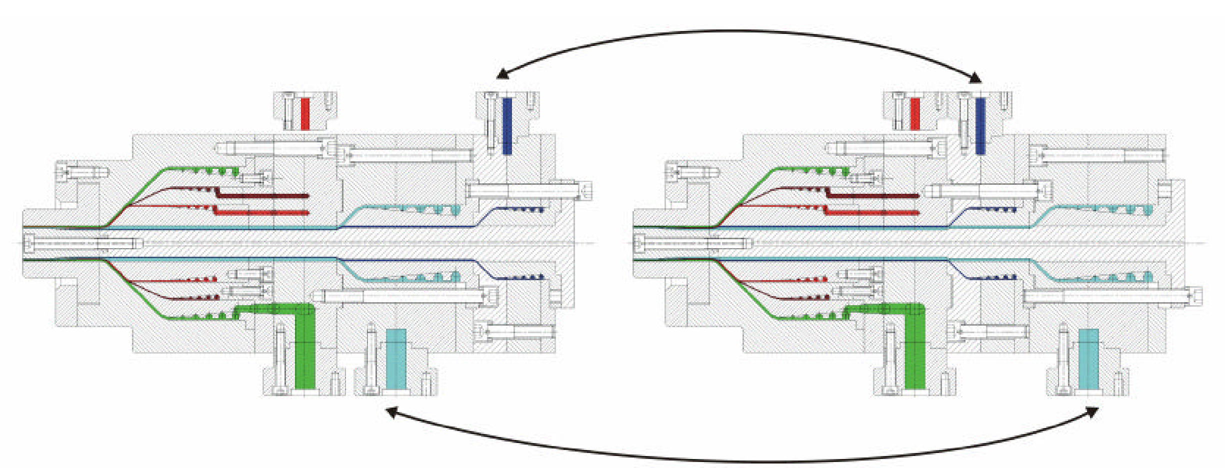

Fig. 9: 5-layer die with modular design

4. 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 10).

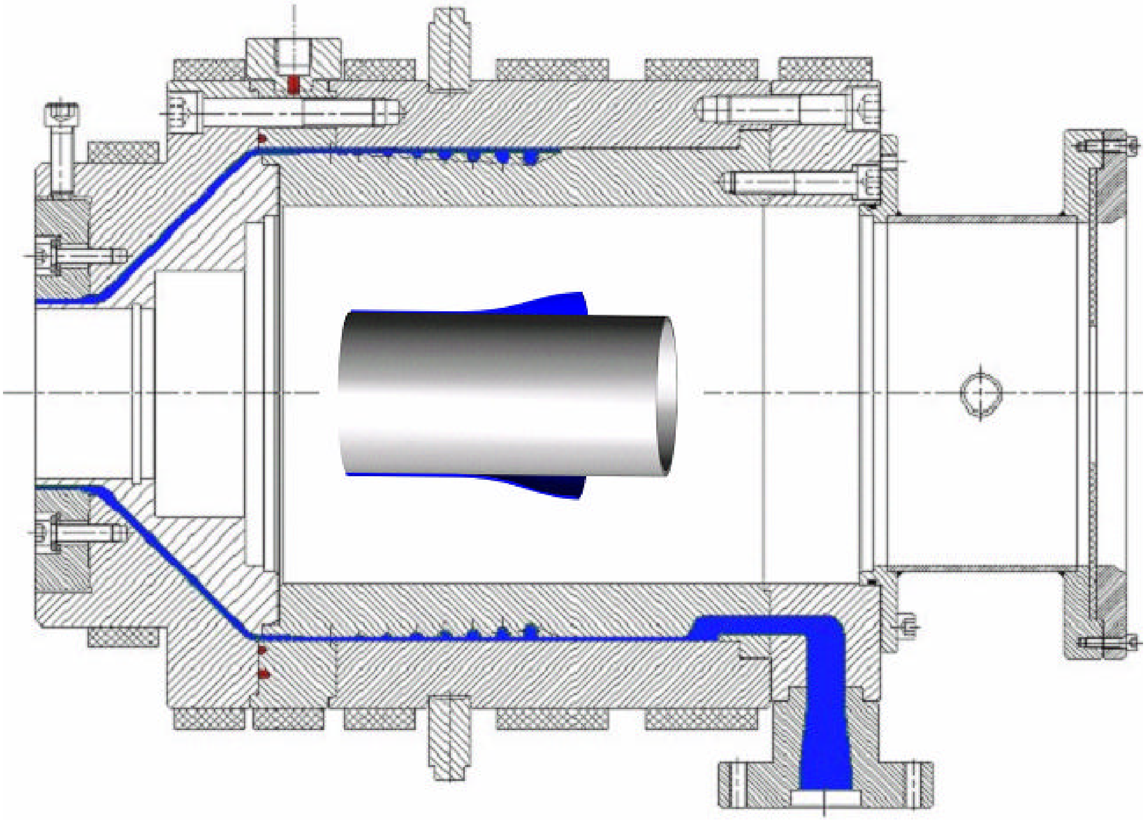

Fig. 10: Pipe sheathing die

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.

5. Conclusion

No other design principle offers anywhere near as many possibilities for pipe 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.

The dies can be designed for all product and production requirements - except for processing PVC-U.

Since the PE and PP pipe market will continue to grow constantly over the next few years and pipes made of engineering plastics will also increase their market share - not least because of the advantages of multi-component systems - the extrusion dies presented in this paper will continue to gain in importance. Most probably - or specifically - this will also be true for extrusion coating systems which allow to develop innovative product specialties.

All figures are originals of ETA Kunststofftechnologie GmbH, Troisdorf