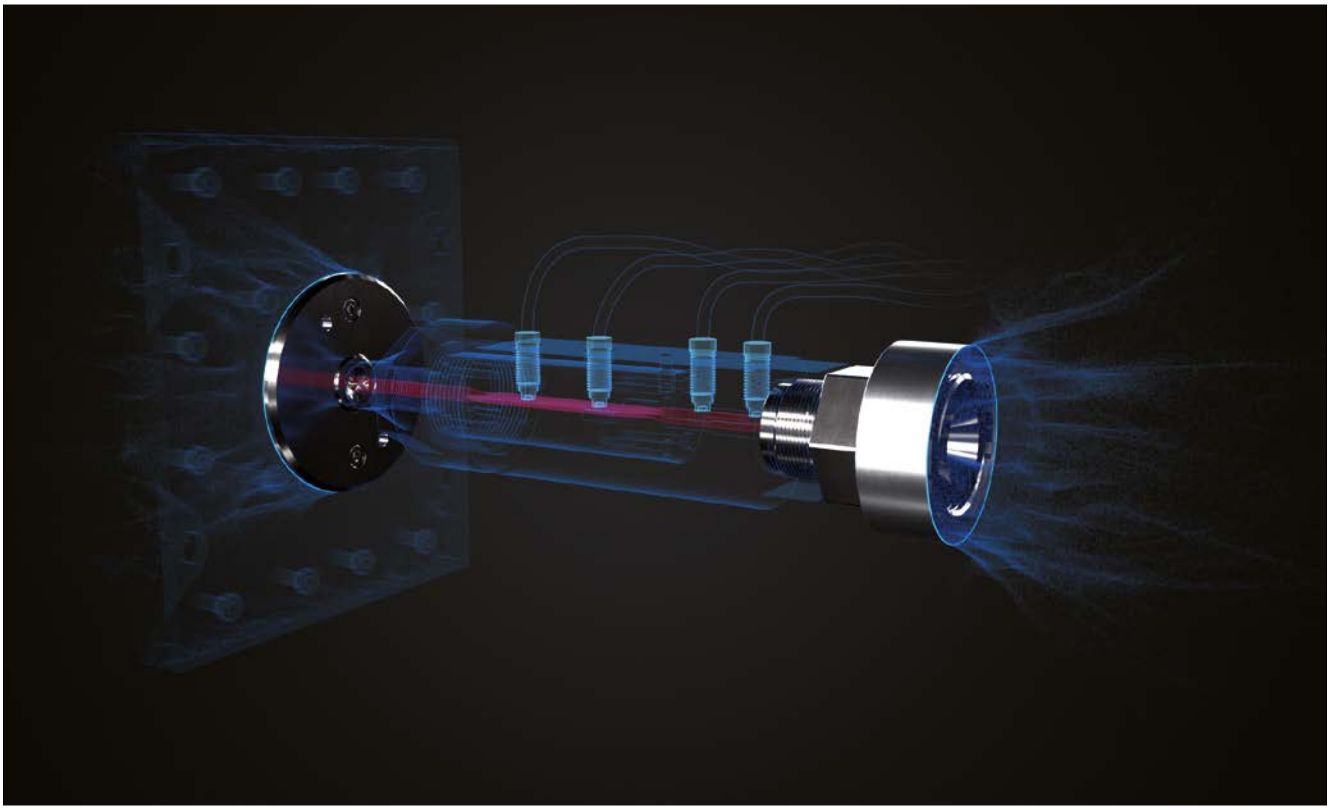
Quickly and Gently around the Bend

Darmstadt University of Applied Sciences and MHT Optimize the Hot Runner for PET Preform Production

Consider this paradox: sensitive PET is particularly demanding when being processed because it undergoes rapid thermal and mechanical degradation, yet when PET preforms are being produced scant attention is paid to designing the all-important hot runner to suit the individual product. Much more often, a manufacturer will use several cold halves and a hot one and produce articles weighing from 6 to 40 g. Darmstadt University of Applied Sciences, Germany, and mold specialist MHT conducted a research project aimed at determining how the hot runner design affects preform quality.

There is even a vacuum cleaner for dealing with it: dust generated during production is all too familiar to manufacturers of preforms (the blanks that are later blown into PET bottles). It is created by the degradation of the highly sensitive PET material and decomposition of the molecular chains upon exposure to thermal or mechanical stress. It impedes the piston movement of the needle and must be removed regularly, and that is why some toolmakers also offer suction devices to accompany their molds.

However, it would be much better to prevent the dust from developing at all – and the key to this lies in the hot runner. Unlike the case for high-precision technical parts, the hot runner, used in the production of billions of preforms, is often not designed with a specific article in mind. Most manufacturers combine an existing hot half (e.g. with a mold pitch of 50 mm x 140 mm) with matching cold sides of completely different contours, with the result that the same hot runner must supply preforms with 6 or 40 g, and 30 or 150 mm in length. At the same time,



The online rheometer nozzle provides information on the condition of the melt at the tip of the plasticizing unit (© MHT)

Fig. 1. Hot runner of the test mold with three platens to simulate the length of the melt runners in a 96-cavity mold (© MHT)

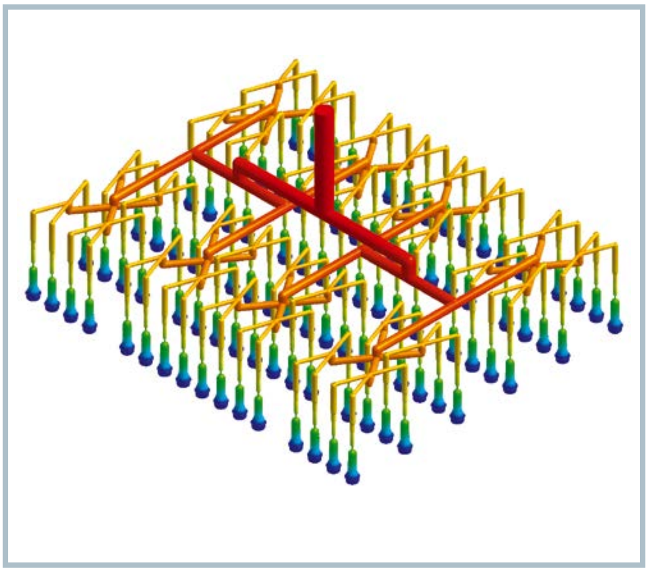


Fig. 2. The simulation shows the heat flow in a 96-fold hot runner system (© MHT)

as many as 192 cavities are common practice in the price-sensitive packaging industry. The more mold cavities and the longer the flow paths there are (as in the case of slim and thin-walled preforms), the greater the demands imposed on the hot runner.

The Institute for Polymer Technology at Darmstadt University of Applied Sciences and MHT Mold & Hotrunner Technology AG, Hochheim/Main, Germany, which holds a total of 29 patents in this field, decided to collaborate on a publicly funded research project aimed at studying the thermal and rheological conditions in preform molds and at optimizing the hot runner. Their goal was to reduce the generation of PET dust and thus enable the customer to take advantage of longer maintenance intervals.

4-Cavity Mold Simulates 96 Cavities

It all started with a technical trick. MHT built a 4-cavity test mold (preform weight: 12.5 g) which simulated the conditions in a 96-cavity mold by means of hot runners connected in series (**Fig. 1**). Integrated pressure and temperature sensors were provided to allow the viscosity of the melt to be measured at various points.

In Darmstadt, a seven-member team installed the mold plus removal unit on a KM 160-540 PX injection molding machine fitted with an LRX100 handling system (manufacturer: KraussMaffei Technologies GmbH, Munich, Germany) and also developed an online rheometer nozzle for the machine nozzle of the plasticizing unit (**Title figure**). It records the true viscosity during injection and separates the mold from the injection molding machine. This prevents machine side influences from falsifying the measurement result in the test mold. The online rheometer nozzle can accommodate up to four pressure and temperature sensors and this allows the condition of the melt after the plasticizing unit to be determined at any time.

Various inserts are available to change the geometry as required. At the same time, the team used software to simulate the entire heat flow in a (genuine) 96-cavity mold (**Fig. 2**) in order to determine whether hotspots, i.e. excessively high temperatures, or excessively long residence times, occur in specific areas of the hot runner, something which ulti- »

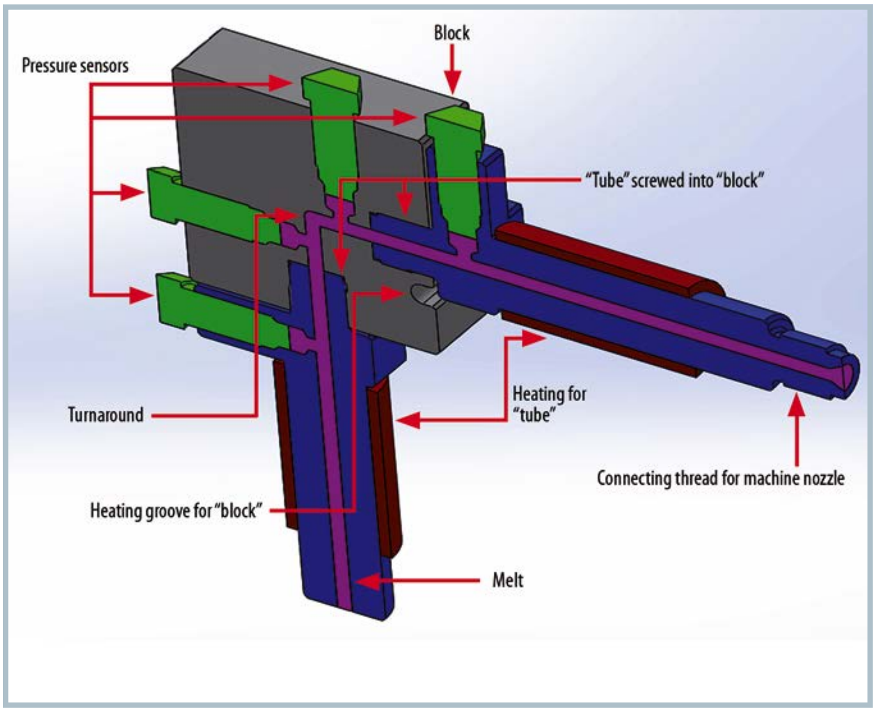


Fig. 3. Experimental setups with a melt runner of 4 mm diameter for the rheological simulation (© Darmstadt University of Applied Sciences/MHT)

mately cannot be ruled out with any conveying system.

Preform manufacturers should be aware of such zones because, in addition to dust formation, the molecular-chain decomposition can also impact part quality and impair the barrier and bursting-pressure resistance as well as taste neutrality. As a rule, hot runner systems are therefore designed in such a way that both the pressure requirement and the residence time of the melt in the system are minimized, with allowance made for the influence of bends and changes in diameter. The researchers in Darmstadt carried out numerous trials and designed their own mold (**Fig. 3**) for the purpose of studying straight and curved melt channels of different diameter and the behavior of various polymers. A total of nine models were used, namely 180°, 90° and 45° angles, with diameters of 4 mm, 6 mm and 8 mm.

The outcome: for visco-elastic liquids, such as polymer melts, reduced pressure losses can be expected at bends (**Fig. 4**). Whether this is due to the elastic properties in the form of normal stresses or instead to shear effects requires further investigation. Since the influence decreases with increase in melt channel diameter, however, it would seem obvious to regard the shear effects as being the cause.

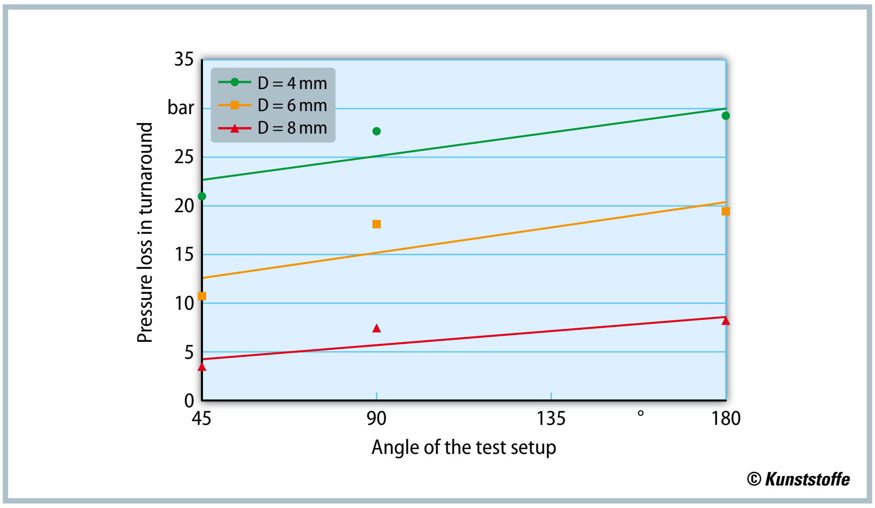


Fig. 4. The larger the diameter of the pipe, the lower are the pressure losses due to cross-sectional discontinuities (source: Darmstadt University of Applied Sciences)

Dust Formation Varies with PET Grade

Preliminary tests involving the 4-cavity experimental mold revealed that dust generation varies extensively with the grade of material obtained from the various manufacturers, and so the university team decided to study this phenomenon to establish which grades were more susceptible to degradation. They even produced dust themselves and established that it was a gaseous substance composed of cleavage products, called oligomers, which escaped from the PET and then condensed on the metallic mold surfaces.

They employed thermal analysis to investigate the PET grades. As the processing temperature was around 280 °C, the holding time at this temperature was particularly interesting. Thermogravimetric analysis (TGA) afforded a way of checking if degradation occurred and, if so, at what degradation rate (mg/min).

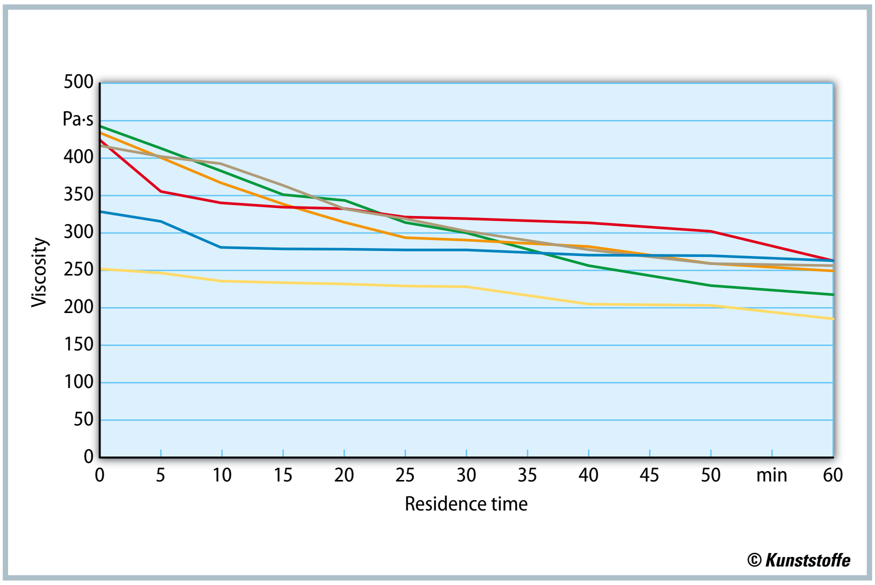


Fig. 5. Degradation as a function of residence time for different PET grades at the same shear rate. Darmstadt University of Applied Sciences and MHT can already simulate dust formation in advance of PET preform projects in order to counteract it with design measures (source: Darmstadt University of Applied Sciences)

The Authors

Prof. Thomas Schröder teaches at the Institute of Polymer Technology at Darmstadt University of Applied Sciences, Germany; thomas.schroeder@h-da.de

Christian Tilsner M.Eng. is Head of Development at MHT Mold & Hotrunner Technology AG, Hochheim/Main, Germany; ctilsner@mht-ag.de

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Part of the analysis consisted in performing differential scanning calorimetry (DSC), in which a time-dependent temperature profile was applied to the material and the difference between the amount of heat added and removed was recorded. This reflected the amount of energy generated by changes in the physical state and by chemical reactions and allowed conclusions to be drawn about the thermal stability and chain length of the polymer. When residence times and temperatures were varied independently of one another, a strong dependence was observed between residence time and crystallization temperature.

A high-pressure capillary viscometer was also used in the studies. This made it possible to determine viscosities at different shear rates. By keeping the polymer warm in the barrel for different periods of time and then running a shear rate profile, the team was able to simulate the change in viscosity due to thermal degradation (**Fig. 5**).

Hot Runner for Rapid, Gentle Material Transport

Overall, the studies showed that the various PET grades differed significantly in chain length and apparently had been provided with additives which influenced the crystallinity. The university team developed an equation for calculating whether a disruptive amount of PET dust would be produced during production, based on material grade, preform weight, maximum residence time and hot runner volume.

The findings from this basic research were incorporated into a new hot runner that was designed to transport the material rapidly and gently. Installed in a 96-cavity prototype mold with a pitch of 50 mm x 140 mm, it was in continuous operation at a customer of MHT for one year. During the test phase, preform quality and dust formation were regularly checked, data measuring systems read out and wear parts inspected. It turned out that dust formation was indeed greatly reduced, even though the proportion of recycled material was around 70 %.

Market Launch at K 2019

The new two-plate hot runner, which is currently undergoing further development and is due to be launched at the K in October, consists of several standardized individual elements that are inserted into the manifold block. The melt is fed centrally and the melt runners are naturally balanced. To preload the system, springs are installed at the point where the melt is transferred from between the cross manifold and the two sprue bushings of the hot runner manifold. As a result, it is fully sealed and leaktight when cold or hot. An adapter plate supports the use of different components in the piston housings, whether of the Legacy or Vulcan II series (manufacturer in each case: MHT). The latter are characterized by rapid accessibility, longer service life and lower heat loss.

The collaboration between Darmstadt University of Applied Sciences and MHT shows how basic research and industrial production can mutually benefit each other. Not surprisingly, therefore, they are already working on the next joint development. ■