The Torque of the Twin Screw

Compounding. The ZSK MC^{18} intermeshing, co-rotating twin screw extruder boasts the highest specific torque rating currently available on the market, enabling as much as a 30 % increase in throughput. This means greater productivity and a further improvement in compound quality – not to mention great flexibility for all types of use.

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At K 2010, Coperion GmbH, Stuttgart, Germany, formerly Werner & Pfleiderer, introduced its ZSK Mc^{18}, a new, even more powerful generation of compounding extruders for plastics **(Fig. 1)**. The basic goal behind the further development of these co-rotating, closely intermeshing twin screw compounders was to strongly enhance user benefit. The ZSK Mc^{18} now offers a unique combination of top productivity, top product quality and top flexibility. The essential factor in this new development was a 30 % increase in specific torque to a peak value of 18 Nm/cm^3.

The resulting benefit can be easily demonstrated by a practical example of polybutylene terephthalate (PBT) compounded with 30 wt.-% glass fiber content: the ZSK 45 Mc^{18} achieves an output of over 1,000 kg/hour at a screw speed of 900 rpm. That is approximately 30 % more than the output achievable with an extruder of comparable size, but having only 13.6 Nm/cm^3 torque.

Compared to the previous model ZSK Megacompounder Plus, the processing window could be considerably widened, thanks to improvements and further developments. The compounder system thus fulfills not only today's market demands, but future ones, as well.

Fast Return on Investment

In developing the ZSK Mc^{18}, the company has succeeded in keeping the costs relative to machine size more or less constant. Since achievable output has been increased by up to 30 %, this sustention of costs is tantamount to a price reduction of the compounding system, i.e., the required output can be achieved by a smaller machine than hitherto.

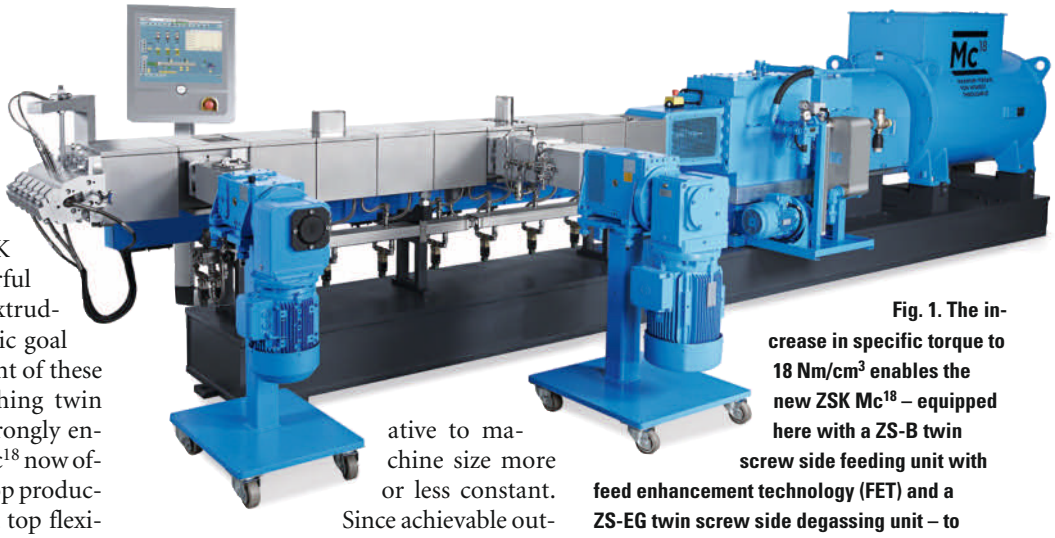

Fig. 1. The increase in specific torque to 18 Nm/cm^3 enables the new ZSK Mc^{18} – equipped here with a ZS-B twin screw side feeding unit with feed enhancement technology (FET) and a ZS-EG twin screw side degassing unit – to increase output by up to 30 % while enhancing compound quality (figures: Coperion)

Reducing capital investment costs by increasing output is much more advantageous for the user than reducing the cost of manufacturing the machine. Added to this is the fact that a smaller compounding machine (at a given output) incurs lower costs for maintenance, repairs, replacement parts, energy, installation space and, last but not least, depreciation. The machine can also be cleaned faster and more easily, thus increasing its run time. The production costs of the compound are reduced, and return on investment is achieved much sooner.

The sample profitability calculation **(Table 1)** explains this cost advantage in greater detail. The calculation is based on a compounding line for the production of a 30 wt.-% glass fiber-reinforced polymer, e. g. polyamide (PA) or polybutylene terephthalate (PBT). The compounding extruder is a ZSK Mc^{18} with 82 mm diameter screws capable of an output of 4,500 kg/hour. The entire production line comprises the extruder itself and the entire upstream and downstream peripherals, from the raw material feeding via the pelletizing and pellet cooling units to the bagging unit.

The cost calculation for manufacturing the compound takes into account the cost of raw materials, these being the biggest item, as well as capital investment, financing and maintenance, in addition to the costs of energy and water. Given a realistic estimate of the selling price for the reinforced polymer, the ZSK 82 Mc^{18} provides a very fast return on investment in slightly less than half a year.

This profitability calculation must of course be adapted to the actual working conditions in the production facility. The pure costs of production as obtained in **Table 1** must be augmented by the costs of production space, sales and marketing, plus overhead.

The new ZSK Mc^{18} series features models with screw diameters ranging →

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from 32 to 119 mm. Including the new ZSK 82 Mc^{18}, the sizes of the available eight models are now so graduated that there is a ZSK compounding system for every output required by the market.

Fig. 2. The shafts of the twin screws of the ZSK Mc^{18} are manufactured from newly developed high-performance steel grades, ensuring reliable transmission of the high 18 Nm/cm^3 torque to the screw elements

The Improvements in Detail

The significant increase in output featured by the series has been achieved by a bundle of further developments and improvements. The entire machine concept has been scrutinized and improved throughout. A decisive contribution to the 30 % increase in specific torque has been made by the use of new high-performance materials to manufacture the screw shafts **(Fig. 2)**. These special materials, which have proven themselves in aerospace technology, ensure full torque transmission from the drive, which has likewise been completely redesigned, via the screw shafts to the screw elements. In addition, the design of the screw shaft coupling, i. e. the connection between the drive and the twin screws, has been further optimized. Thanks to these material and design improvements, the series offers the same long lifetime and reliability of operation – even under heavy stress – to which Coperion customers are accustomed.

The screw configuration in the process section is always configured to the specific requirements of each individual application. The twin screws of the extruder's basic equipment already feature highly abrasion-resistant surfaces. When processing materials that are particularly abrasive, e. g. glass fiber, fillers or hard pigments, wear protection against abrasion can be optimized for the specific application with the aid of special material solutions.

The heating/cooling system and the entire temperature control system have been redesigned suitable for the increased output capacity. The cartridge heaters in the barrels generate heat exactly where it is required, especially during start-up. The optimized cooling system ensures uniform temperature distribution in each barrel by permitting instant adjustment of the temperature profile to actual process requirements along the entire process section. The use of shrink-fit barrel liners has further improved temperature transfer from the melt in the process section to the barrel cooling system. The entire process section is equipped with new, highly effective all-around thermal insulation covers without impairing easy access to the machine. The ZSK Mc^{18} is distinguished by its outstanding energy efficiency.

Capital investment ZSK 82 Mc^{18} twin-screw extruder including peripherals (e. g. material feeding, pelletizing, bagging), installation and commissioning; total		4,000,000.00 EUR
Productivity of compounding line Gross operating hours per annum, 3-shift Output Production capacity Machine load factor Net number operating hours per annum Net annual production (= raw material consumption) Start-up and production scrap (3 %) Quantity sold per annum	 7,560 h/a 4,500 kg/h 34,020,000 kg/a 90 % 6,804 h/a 30,618,000 kg/a 918,540 kg/a	 29,699,460 kg/a
Material costs (net production) PBT or PA (67 % = 20,514,060 kg/a à 2.10 EUR/kg) Glass fibers (30 % = 9,185,400 kg/a à 1.50 EUR/kg) Additives (3 % = 918,540 kg/a á 5.00 EUR/kg) Total	 43,079,526.00 EUR/a 13,778,100.00 EUR/a 4,592,700.00 EUR/a	 61,450,326.00 EUR/a
Fixed costs Depreciation (17 % of 4 million EUR) Maintenance and spare parts Interest Total	 680,000.00 EUR/a 144,000.00 EUR/a 120,000.00 EUR/a	 944,000.00 EUR/a
Variable costs Direct wages (20.00 EUR/h for 6,804 h/a; 6 employees) Additional labor costs (75 % of wages) Energy costs (0.13 EUR/kWh x 0.25 kWh/kg x 30,618,000 kg/a) Water costs (4.00 EUR/m^3 x 0.5 m^3/h x 6,804 h/a) Total	 816,480.00 EUR/a 612,360.00 EUR/a 995,085.00 EUR/a 13,608.00 EUR/a	 2,437,533.00 EUR/a
Total annual production costs Quantity sold per annum Production costs		64,831,859.00 EUR/a 29,699,460 kg/a 2.18 EUR/kg
Profitability Selling price Turnover per annum (selling price x quantity sold) Gross profit (turnover per annum – production costs)		 2.50 EUR/kg 74,248,650.00 EUR/a 9,416,791.00 EUR/a
Return on investment time (investment sum / profit)		**0.42 a**

Table 1. Simplified profitability calculation for the production of glass fiber-reinforced polymer with a ZSK 82 Mc^{18} (not including costs of production space, sales, marketing and overhead)

Proven Screw Diameter Ratio

The screws of the series feature the same diameter ratio as their predecessors, namely $D_o : D_i = 1.55$, where D_o is the outer diameter and D_i is the inner diameter of the screw. The company introduced this screw diameter ratio as early as 1985 with the Supercompounder series. This ratio still

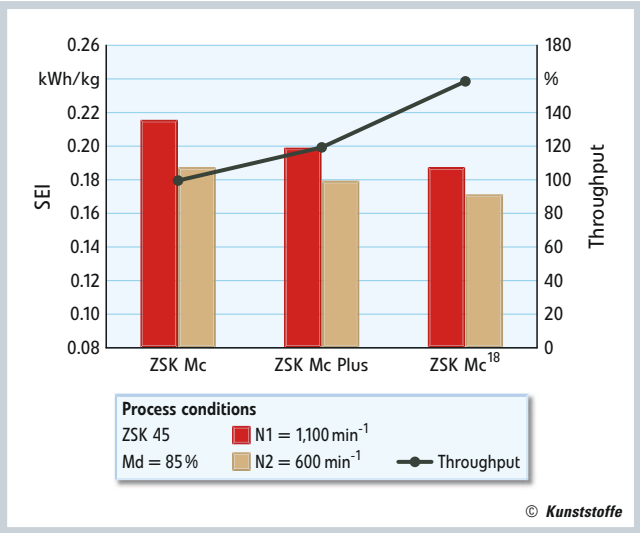

Fig. 3. When compounding PA6 with 30 wt.-% glass fibers, a ZSK 45 Mc[18] is capable of 60 % higher output than a ZSK Megacompounder of the same size at approx. 30 % less specific energy input (SEI)

represents the very optimum in terms of transmissible torque and free volume. A lower ratio reduces the free volume of melt in the screw channels, and hence reduces output. A higher ratio generally reduces the mechanical stability of the twin screws, and the consequently reduced screw crest width makes for increased susceptibility to wear. Even more unsatisfactory, however, is the fact that only a reduced torque can be transmitted, which means that some polymers, and especially those requiring a high energy input, cannot be adequately compounded, even at a reduced rate of output.

This unchanged screw diameter ratio is also advantageous inasmuch as it readily enables scale-up and modernization of an existing ZSK Megacompounder Plus to the new ZSK Mc[18].

Improved Compound Quality and Increased Output

From a compounding standpoint, the most interesting aspect is the improvement in compound quality. The high specific torque permits an increase in the filling level of the twin screws, even when processing materials that require a high energy input. The result is higher throughput with a simultaneous reduction of melt temperature in the process section – in other words: improved energy efficiency plus gentle treatment of the melt for an improved quality of compound. An additional benefit lies in the extended range of applications, which makes for much greater flexibility:

- In standard applications, e. g. the compounding of products with medium to high energy requirements, output may be up to 60 % higher than that of a ZSK Megacompounder of the same size **(Fig. 3)**, since the increased torque permits a higher screw speed with an increased filling level of the twin screws. Lower shear energy input and shorter dwell time in the process section together bring about a reduction in specific energy input (SEI) while maintaining the same high quality of compound.
- In the case of shear-sensitive polymers, the higher specific torque likewise permits an increased filling level of the twin screws. Thus, given a moderate screw speed, the thermal load on the melt is negligible, an effect further supported by enhanced temperature control of the process section. Here, too, the bottom line benefit is an improvement in compound quality.

For the operating personnel in particular, the new design of the machine represents an enormous advance. The improved insulation covers on the process section reduce the risk of accident to minimum, while access for cleaning and maintenance has been simplified. The entire piping and wiring systems have been installed in such a way that the machine can be readily kept clean and always looks neat **(Fig. 4)**.

Thanks to these characteristics and features, there are typical areas of application:

- The dispersion of additives and pigments is the decisive quality criterion in the manufacture of masterbatches. The self-cleaning action of the twin screws permits rapid changeover from one product to another. When necessary, ease of access to all parts of the extruder enables more intensive cleaning in the shortest reasonable time.
- When it comes to the production of filled and reinforced polymers, the filling and reinforcing materials are very homogeneously mixed into the matrix polymer due to the excellent mixing behavior of the twin screws. The high output ensures cost-efficient operation of the compounding line. Here, too, rapid changeovers are possible from one product/color to another.
- When compounding glass fiber-reinforced polymers, such as PBT und PA, the high specific torque permits oper- →

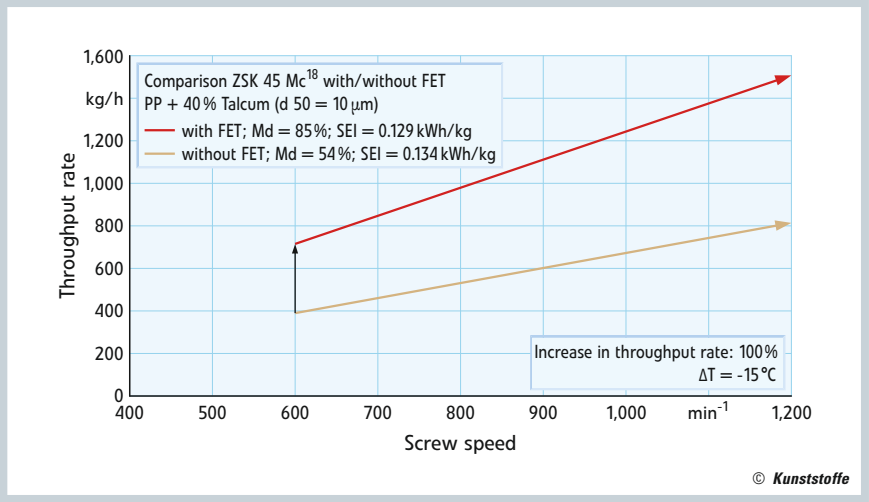

Fig. 5. FET installed in the feeding zone reduces specific energy input (SEI) and increases output

ation at a higher screw speed with an increased filling level of the twin screws. A ZSK 58 Mc^{18}, for example, is capable of output rates of up to 2,000 kg/hour when compounding PBT reinforced with 30 wt.-% glass fibers.

Peripheral Equipment for Increasing Performance

In compounding processes with feed limitations, the feed capacity can be considerably increased by adding Feed Enhancement Technology (FET). This patent pending technology equips the feed zone with a porous, gas-permeable segment, to the exterior of which a vacuum is applied. The resulting gas extraction enables the feed zone to take in as much as two to three times the volume of material. FET can similarly be used on a side feeding unit. Thus, even when processing low bulk density products, twin screw filling levels, and hence output, can be increased by up to 300 %, depending on the product, while at the same time reducing specific energy input and improving compound quality **(Fig. 5)**.

A ZS-EG twin screw side devolatilization unit can enhance reliability, even at very high throughput rates. The unit is flange-mounted laterally on the process section and equipped with deep-flighted twin screws. Due to their direction of rotation, the twin screws keep the melt in the processing section without any product escaping. Fumes or gases are extracted safely by the axially open screw channels. The ZS-EG side degassing unit is highly efficient, even in cases where the product has a high gas or moisture content, thus ensuring a constantly high quality of compound, as the following case examples show.

At its plant in Krefeld, Germany, Bayer MaterialScience achieves a uniformly high quality of polycarbonate compound with the ZS-EG, since material cannot accumulate in the twin screw degassing unit and falls back into the processing zone. Solvay Advanced Polymers, USA, achieves a higher output of polyphthalamide (PPA) by using a twin screw side degassing unit, since the gas flow channel is always open. Moreover, shorter downtimes for cleaning and maintaining the new ZS-EG generation further increase output.

The latest generation of Coperion die heads has also been adapted to the very high output. For applications with highly abrasive products, they can be equipped with a special wear-protected die plate. This technology, developed and proven in practice at Lanxess, comes into play exactly where shear stress in the compounding process is at its highest, namely in the holes of the die plate. These holes are equipped with highly wear-resistant sleeves that considerably prolong the useful life of the die plate. A double-digit percentage increase in runtime can be achieved, for example, when compounding polymers with a standard glass fiber content of 20 to 50 wt.-%. If abrasion does occur in some of the holes and affects the strand, only the hard metal sleeves need to be replaced, which can be done at very low expense.

Rapid Market Acceptance

The first system sold by Coperion was the machine exhibited at K 2010, equipped with 82 mm diameter screws. This ZSK 82 Mc^{18} is used by Kafrit Industries, Israel, to produce compounds and additive masterbatches. Additional customers that have meanwhile opted for the new series include Colombian masterbatch producer Comai Ltda., Cartagena de Indias, and Ensinger GmbH of Nufringen, Germany. Ensinger plans to use its machine for compounding glass or carbon fiber-reinforced engineering plastics, such as polyamide.

So far Coperion has received orders for more than 30 ZSK Mc^{18} machines. Their main areas of application include engineering plastics and white, additive and black masterbatches: User benefits include, first and foremost, high specific torque, extreme flexibility, improved temperature control and simplified handling and operation.

At Fakuma (18 to 22 October 2011 in Friedrichshafen, Germany), Coperion will present the concept of its new ZSK Mc^{18} series (hall A6, booth 6208). ■

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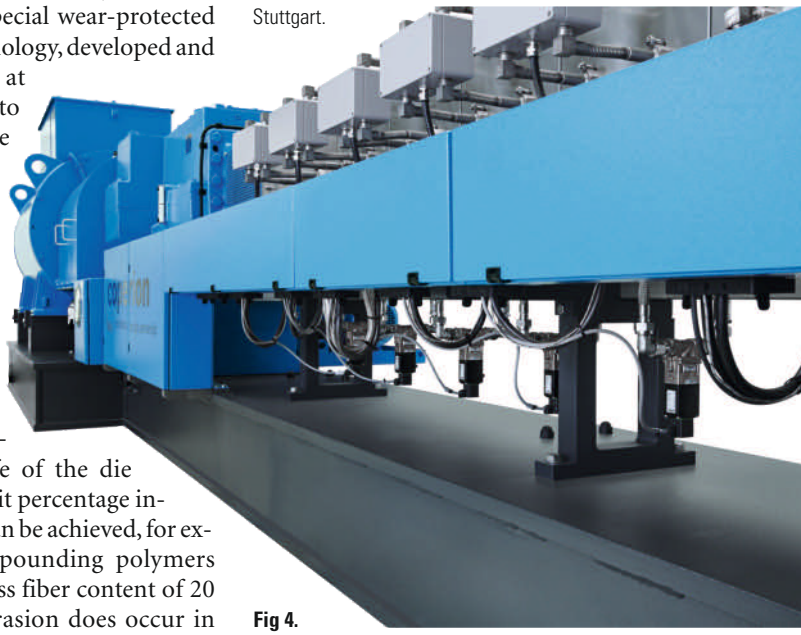

Fig 4.
The improved machine design permits easy access for cleaning and maintenance

