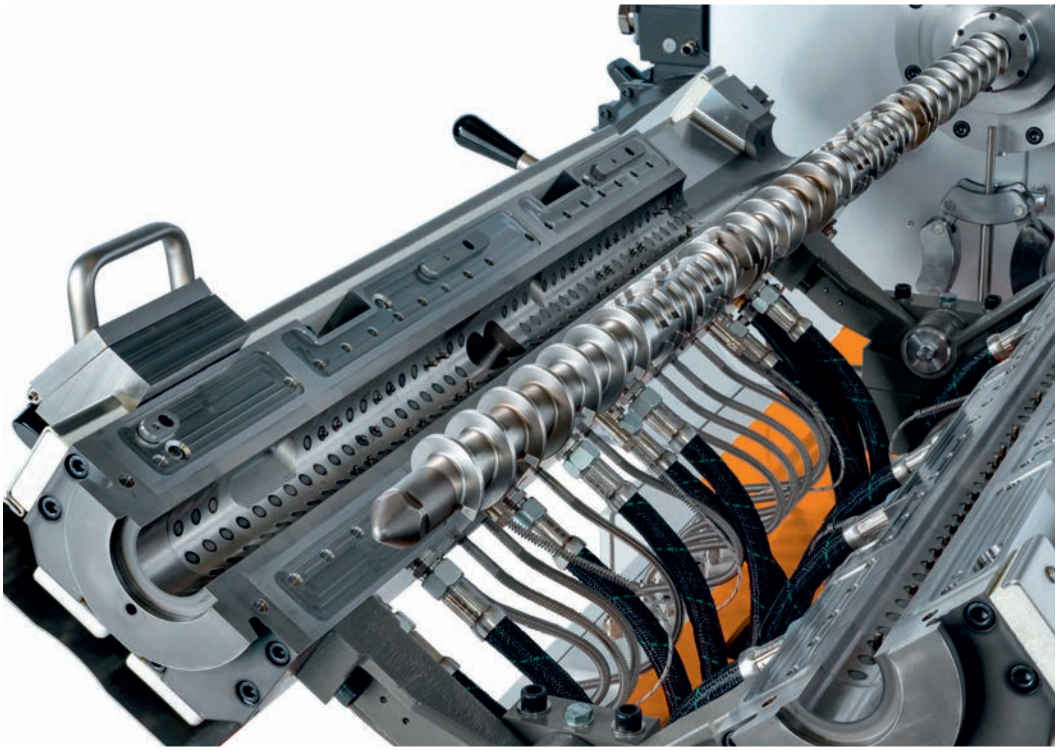
The One that Shears, Splits, and Folds Material

Gentle Compounding with High Mixing Effect and Good Scalability in the Co-Kneader

The patent on the operating principle of the co-kneader was applied for three quarters of a century ago. Compared to other extruder technologies, it features a clearly higher mixing effect while it processes the raw materials gently. Current applications for its further development range from reactive, shear-sensitive plastics to the compounding of high-performance engineering plastics.



Looking into the process chamber of the current generation of Compeo type co-kneaders we see the position of the stationary kneading pins in the barrel that comb the kneading flights of the modular screw

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August 20, 1945, the day when graduate engineer Heinz List (**Fig. 1**) applied for a patent on the principle of the co-kneader, is regarded as the birthday of this compounding technology [1]. Its special feature: as the extruder screw shaft rotates, it simultaneously reciprocates axially, and the barrel is equipped with stationary kneading pins. Its prehistory begins during the Second World War when a committee was formed at the Bayer works of the erstwhile IG Farbenindustrie [2] to develop the technology of screw machines for continuous mixing and kneading. Committee member Rudolf Erdmenger was working on co-rotating twin-screw machines, while Siegfried Kiesskalt was working on counter-rotating ones. List, a third member of the working party, was developing a single-screw machine in which the rotation of the screw shaft was overlaid by axial reciprocation and thus had a mixing and kneading effect. List called his machine a "Ko-Kneter", i.e. co-kneader, whereby "co" stands for "continuous", and had his invention protected under this name by a number of patents (**Fig. 2**). Today, these three men are considered the founding fathers of modern compounding technology [3].

Kneading Flights: They Make it Work

To begin with, the co-kneader is, from a design point of view, a continuously operating single-screw extruder. Its operating principle, however, clearly distinguishes it from traditional designs. Its screw spiral is interrupted by two to four

In Profile

Heinz List, the inventor of co-kneader technology went to Switzerland in 1944 where his concept was picked up by Buss AG of Pratteln. The profession soon recognized the advantages of this operating principle and it established itself quickly in the world market. List served as technical director at Buss until 1965, when he subsequently founded the List AG of Arisdorf, Switzerland (www.list-technology.com). In 1988, he was included in the Polymer Processing Hall of Fame of the University of Akron, OH/USA, for his engineering achievement and the development of the co-kneader.

Following the opening of the first testing center for co-kneaders in 1947, the first systems of the type "Buss Ko-Kneter – System List" (its name in the pioneering days) for polyvinyl chloride (PVC) and polystyrene (PS) were delivered in 1950. Then followed the development of dedicated versions for compounding very different plastics, the continuous reaction of polymers and other chemical substances, as well as for compounding carbon paste mass used in aluminum production. Here the principle of the oscillating single-screw machine proved to be very well suited for adapting the free volume and shear rate level to specific requirements.

As List put it, the co-kneader became "the crystallization point of compounding plants" [1]. At Buss, this widened the vision and understanding for plant engineering as well as up- and downstream requirements, since the continuous dosing technology, efficient pressure build-up and the shaping after mixing in the viscous phase had to be developed too.

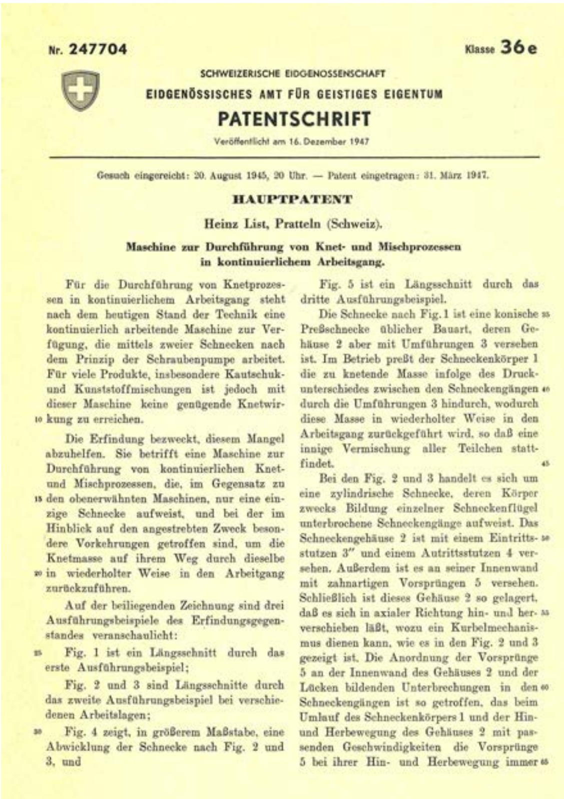
Fig. 1. Heinz List (1912–1988), the inventor of the co-kneader principle and pioneer of the process technology © List Technology

gaps per circuit in which the characteristic kneading flights work together with stationary kneading pins mounted on the kneader housing (**Fig. 3**) to comb the mass. The essential feature of this technology is the way the screw shaft simultaneously rotates and reciprocates and thereby executes a complete stroke cycle forward and back to start position (**Fig. 4**) with each rotation. This cyclical sequence avoids the disadvantage of alternative systems, such as the wide shear rate distribution of co-rotating twin-screw extruders, or the limited mixing characteristics of counter-rotating twin-screws, and provides significant advantages in terms of mixing effect and self-cleaning.

During the first half of the 20th century it became possible step by step to produce plastics on an industrial scale. In view of increasing production quantities and growing demands for reproducibility, those systems became interesting that could compound continuously (**see Box**).

From the Idea to a Wide Range of Applications

The success that a screw machine can achieve for a single application depends on how well its strength profile corresponds to the specific requirements [5]. As systematic investigations have meanwhile shown [6], this suitability can be evaluated



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PATENTSCHRIFT

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HAUPTPATENT

Heinz List, Pratteln (Schweiz).

Maschine zur Durchführung von Knet- und Mischprozessen in kontinuierlichem Arbeitsgang.

Für die Durchführung von Knetprozessen in kontinuierlichem Arbeitsgang steht nach dem heutigen Stand der Technik eine kontinuierlich arbeitende Maschine zur Verfügung, die mittels zweier Schnecken nach dem Prinzip der Schraubenpumpe arbeitet. Für viele Produkte, insbesondere Kautschuk- und Kunststoffmischungen ist jedoch mit dieser Maschine keine genügende Knetwirkung zu erreichen.

Die Erfindung bezweckt, diesem Mangel abzuhelfen. Sie betrifft eine Maschine zur Durchführung von kontinuierlichen Knet- und Mischprozessen, die, im Gegensatz zu den obenerwähnten Maschinen, nur eine einzige Schnecke aufweist, und bei der im Hinblick auf den angestrebten Zweck besondere Vorkehrungen getroffen sind, um die Knetmasse auf ihrem Weg durch dieselbe in wiederholter Weise in den Arbeitgang zurückzuführen.

Auf der beiliegenden Zeichnung sind drei Ausführungsbeispiele des Erfindungsgegenstandes veranschaulicht:

Fig. 1 ist ein Längsschnitt durch das erste Ausführungsbeispiel;

Fig. 2 und 3 sind Längsschnitte durch das zweite Ausführungsbeispiel bei verschiedenen Arbeitslagen;

Fig. 4 zeigt, in größerem Maßstabe, eine Abwicklung der Schnecke nach Fig. 2 und 3, und

Fig. 5 ist ein Längsschnitt durch das dritte Ausführungsbeispiel.

Die Schnecke nach Fig. 1 ist eine konische Preßschnecke üblicher Bauart, deren Gehäuse 2 aber mit Umführungen 3 versehen ist. Im Betrieb preßt der Schneckenkörper 1 die zu knetende Masse infolge des Druckunterschiedes zwischen den Schneckengängen durch die Umführungen 3 hindurch, wodurch diese Masse in wiederholter Weise in den Arbeitsgang zurückgeführt wird, so daß eine innige Vermischung aller Teilchen stattfindet.

Bei den Fig. 2 und 3 handelt es sich um eine zylindrische Schnecke, deren Körper zwecks Bildung einzelner Schneckenflügel unterbrochene Schneckengänge aufweist. Das Schneckengehäuse 2 ist mit einem Eintrittsstutzen 3″ und einem Autrittsstutzen 4 versehen. Außerdem ist es an seiner Innenwand mit zahnartigen Vorsprüngen 5 versehen. Schließlich ist dieses Gehäuse 2 so gelagert, daß es sich in axialer Richtung hin- und herverschieben läßt, wozu ein Kurbelmechanismus dienen kann, wie es in den Fig. 2 und 3 gezeigt ist. Die Anordnung der Vorsprünge 5 an der Innenwand des Gehäuses 2 und der Lücken bildenden Unterbrechungen in den Schneckengängen ist so getroffen, das beim Umlauf des Schneckenkörpers 1 und der Hin- und Herbewegung des Gehäuses 2 mit passenden Geschwindigkeiten die Vorsprünge 5 bei ihrer Hin- und Herbewegung immer

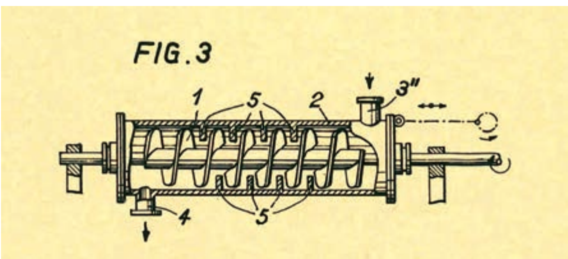

Fig. 2. Title figure and sketch from Heinz List's patent specification no. 247704 [2]

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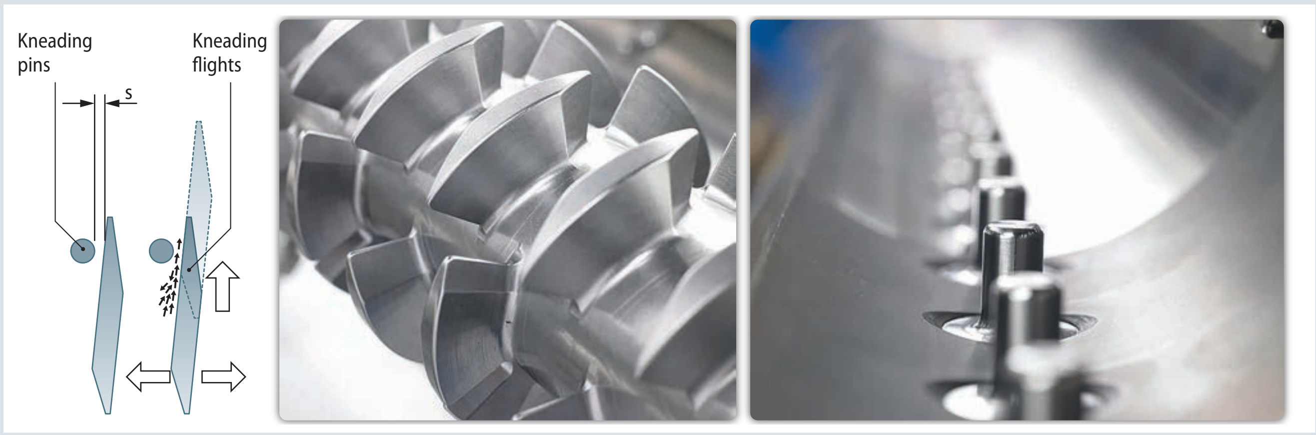
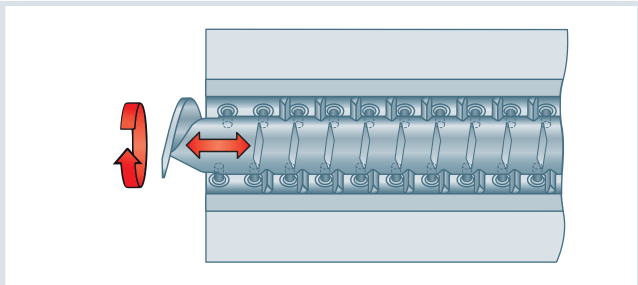


Fig. 3. In operation, the plastic mass is sheared in the shear gap (left) between the kneading flights (center) and kneading pins (right) [4]
Source: Buss; graphic: © Hanser

Fig. 4. Interaction between screw shaft rotation and reciprocation Source: Buss; graphic: © Hanser



$$\frac{G1}{G2} = \left(\frac{D1}{D2}\right)^x$$

G1, G2: co-kneader throughput 1 or 2 [kg/h]
D1, D2: screw diameter of co-kneader 1 or 2 [mm]
x: exponent (lies between 2 and 3, varies with each process)

in advance by modern analytic methods, if the strength profile of the considered systems is known. The co-kneader has numerous advantages that can be summed up under the headings gentle compounding, high mixing effect, and reliable scale-up. The shear required for melting and dispersing (fragmentation) develops in the shear gap s between kneading flights and kneading pins (**Fig. 3**) which is proportional to machine size D_o. Thus – in contrast to other screw machines – the shear rate is directly proportional to the rotational speed n of the screw shaft and independent of machine size.

The average shear gaps of approx. 0.01 D_o (D_o/s ≈ 100) are considerably narrower than those of single screw extruders, but clearly wider than with co-rotating twin-screw extruders. This results in moderate and narrowly distributed shear rates for gentle and simultaneously highly effective compounding. This makes it possible for shear- and temperature-sensitive polymers and additives, as well as highly viscous materials to be compounded without temperature peaks, or at lower temperatures, where it is important to minimize thermal or mechanical damage to the product.

Thanks to the size-independent shear rate, the process can be transferred and rescaled simply and safely to machines of different machine sizes (**Equation 1**). The methods and configurations developed on laboratory and pilot scale can be transferred directly to production scale, mostly without time-consuming process adaptations.

The large number of layer inversions of the product stream between kneading flights and kneading pins – 2^{48} over a distance of 4.8 L/D [7] – has a very well distributed mixing effect (**Fig. 5**), so that the co-kneader can be considered a superior system for distributive mixing due to this high number of foldings. This is decisive for materials whose structure should be maintained as far as possible, for example, electrically conductive carbon blacks. Very high filler contents of up to 90 % can also be worked in.

Besides complete axial cleaning (**Fig. 4**) by the array of kneading pins, the core diameter of the screw shaft is scraped closely. Thus, the pins act much like the second or neighboring screw of a twin- or multi-screw extruder. The scraping and cleaning of all surfaces in the processing section, as shown in **Figure 5**, eliminates deposits and dead spots. The results include operationally reliable processing with narrow residence time windows [6] that are less subject to inner influences, such as wear to the processing parts, and to other influences, such as dosing fluctuations. With reactive compounds, this enables long operating times without bladeouts.

Variable Configuration

Further, in part derivative features result from the operating principle and structural design. Thus, each section of the

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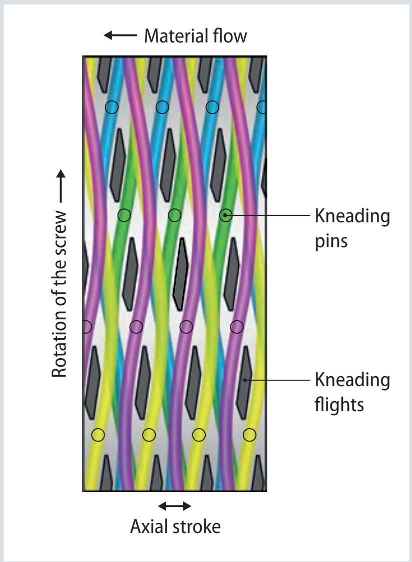

Fig. 5. Mixing effect of a four-flight screw element spread out in the plane and abstractly represented using the kneading pin paths that arise during one complete revolution of the screw shaft. The plastic mass is sheared, split, and refolded between the kneading pins and the kneader flights passing them in real operation Source: Buss; graphic: © Hanser

modular constructed barrel and screw shaft forms a separately tempered zone, also in series with other modules, to ensure controlled surface conditioning. Each kneading pin position can serve as a measuring point for mass temperature. The temperatures measured diverge very little from real product temperature, since the temperature sensor mounted in the kneading pin is surrounded by melt. Process stability can thus be documented at any time, thereby enabling online monitoring of product quality.

Kneading pins with through holes can be used to inject liquids directly into the melt. In this way, the mixing-in process begins immediately and thus avoids smearing the barrel wall as in all alternative systems. Precise positioning of injection at any pin position enables precise reaction control in reactive processes, as well as a uniform reaction rate due to the narrow dwell time distribution.

A Growing Variety of Applications

Many processers who deal with a wide range of products regard the co-kneader as their system of choice due to its distinctive all-round characteristics. It has also established itself as the technology leader in special niches. Manufacturers of high-purity insulation for medium to high voltage cables profit from precise temperature control during reactive extrusion. Halogen-free flame-retardant sheathing compounds require a combination of highest loads, reactive extrusion, and the maintenance of low temperature limits. In semiconductive compounds, the gentle distribution of conductive, highly structured additives, such as carbon black, graphite, or carbon nanotubes are the key (**Fig. 6a**), and the compounding of highly-viscous masses plays a deciding role with fluoropolymers, silicone rubbers, and others.

Applications in medical technology include the production of compounds for handling liquids (such as blood bags or infusion agents), sterile packaging for medicines, as well as antibacterial and antiviral-equipped compounds for various applications, and glues required for bandages. Thanks to moderate shear rates together with good mixing properties, the co-kneader enables potentially migrating additives to be included in very small amounts (**Fig. 6b**).

Where temperature and/or shear-sensitive recipe components play a role, the moderate shear rates enable compounding within narrow operating windows (**Fig. 6c**). Examples include compounds on a polybutylene terephthalate (PBT) basis or high-temperature resistant polyamide (PA), thermosets that have to be compounded below the crosslinking zone, and natural fiber-reinforced materials. Here the applications range from electronics components to components for the engine room and weight-optimized airplane or vehicle parts.

Summary and Outlook

Co-kneader technology is used for applications in which its special strength profile can be used in a targeted manner. With today's methods [5, 6], precise application profiles can be generated. They enable a reliable preselection of the best-suited compounding system. In the future, as well, specific configurations will be implemented on the basis of targeted series of tests. The inclusion of further developments and current inventions, such as two- to six-flight or 3D-printed free-form process parts of the current series, are carrying proven technology over into the applications of the future. ■

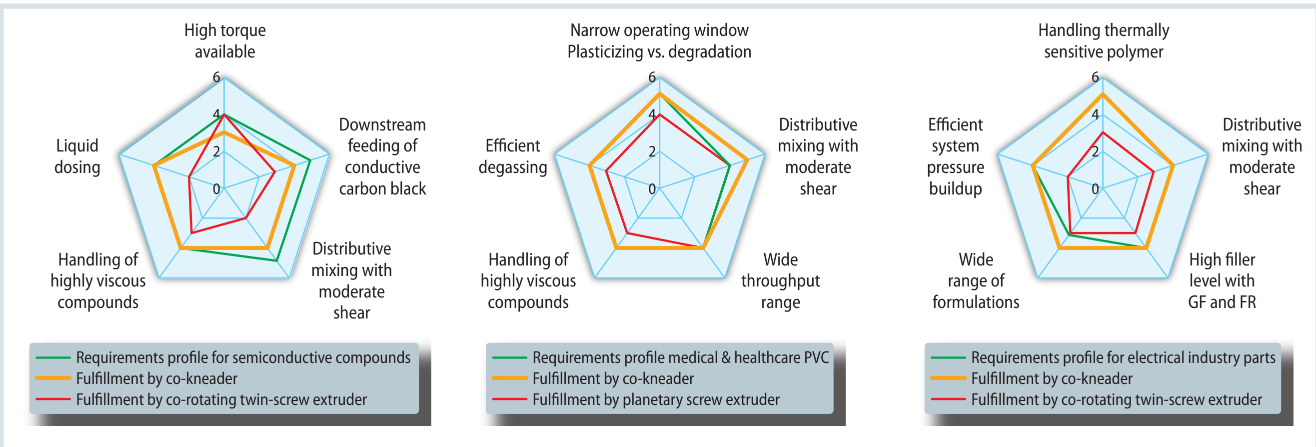

Fig. 6. Technology comparison: degree of fulfillment of requirements for manufacturing a) semiconductive compounds for high-voltage cables, b) PVC compounds for medical technology, and c) parts for the electrical industry, each in comparison with a competing compounding technology; GF = glass fibers, FR = flame retardants [5] Source: Buss; graphic: © Hanser