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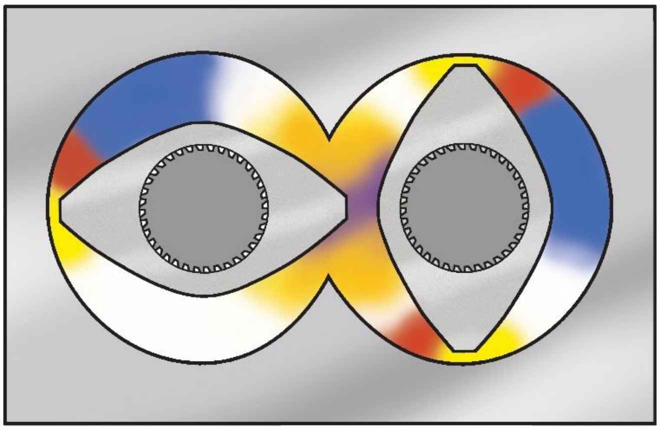
Quick overview of commercially available twin screw extruders (TSEs)

Plastics play a role in all facets of modern life. Almost every plastic part has been manufactured from a polymer compound that was processed on a twin screw extruder, including but not limited to packaging films, fibers for carpets, filaments, car interiors and windshields, structural decking, conductive electrical components and synthetic wine corks. The list is infinite, and twin screw extrusion plays an important role!

The following is a brief technical review of currently available twin screw extrusion (TSE) technologies, and an overview of the features and process advantages inherent with this powerful and industrial-proven 24 hr/day manufacturing device.

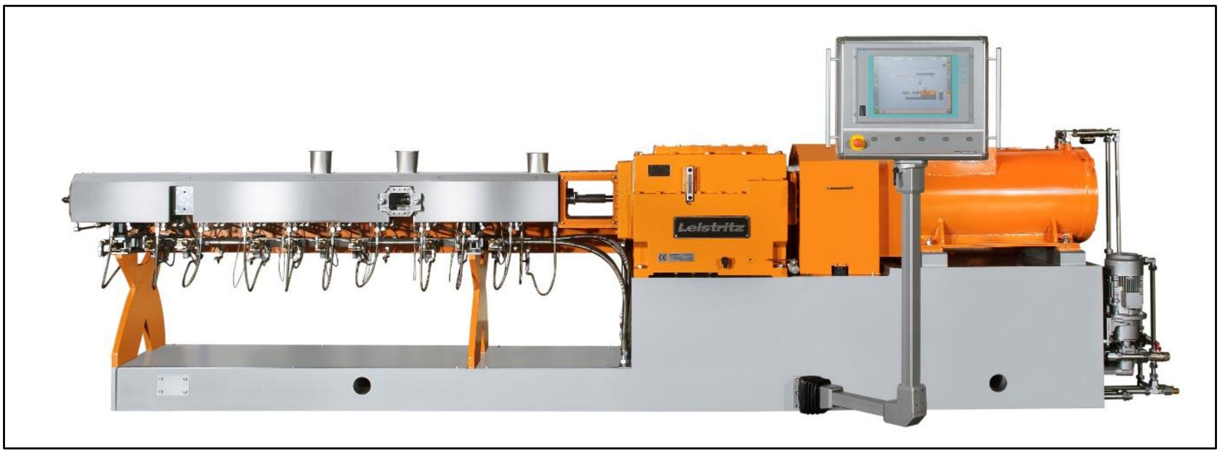
TSE technology: 2-screws interact with each other

Twin screw extruders utilize two screws that interact with each other, as compared to single screw extruders (SSEs) which use only one screw. The screws interaction in a TSE make this device useful for wide-ranging polymer processes, particularly for mass-transfer functions, such as mixing and devolatilization. As compared to SSEs, which primarily melt and pump pellets that have already been compounded, the TSE is a superior tool for continuous mixing and similar mass-transfer dependent applications.



TSE mass transfer regions: channel, extensional, overflight, apex and intermesh

Twin screw extruders are available for research and development purposes to process as little as a 50 gm batch, and for full-scale production at more than 50,000+ kgs/hr. The length of any TSE process section, referred to as the L/D ratio, is the length of the screws to the screw diameter. For instance, if the screws diameter is 100 mm and the process length is 4000 mm, the L/D is 40/1. The motor and gearbox are part of the drive train that imparts shear and energy into the materials being processed inside the barrels via rotating screws. Process control parameters include screw speed (rpms), feed rate, process temperatures and vacuum level. (at vents) Melt pressure, melt temperature, motor amperage, and various in-line sensors monitor the process to ensure a consistent/quality product. Modern TSE's utilize programmable logic controllers (PLC's) with graphical Human Machine Interface (HMI) touch-screens with data acquisition, trending and recipe management.



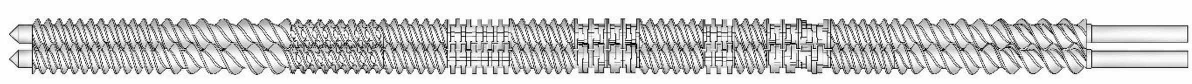
ZSE-MAXX twin screw extruder with PLC control system

Materials in different forms such as pellets, granules, powders, fibers and liquids (the "formulation") are metered into the TSE. These materials can be pre-mixed and fed, or separately and sequentially metered into the TSE. Delivery mechanisms include screw augers, vibratory trays, weigh-belts and injection pumps.

Twin screw extruders are available in these basic designs:

1. High-speed, energy input TSEs that melt the polymer early and are designed as mass-transfer devices:

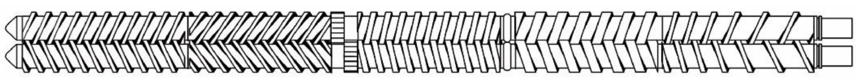
- Co-rotating intermeshing
- Counter-rotating intermeshing
- Counter-rotating non-intermeshing (or tangential)



Co-rotating intermeshing screw set

2. Low-speed late fusion TSEs that are designed to mix shear sensitive formulations (i.e. RPVC) and pump at high pressures:

- Parallel Counter-rotating intermeshing
- Conical Counter-rotating intermeshing

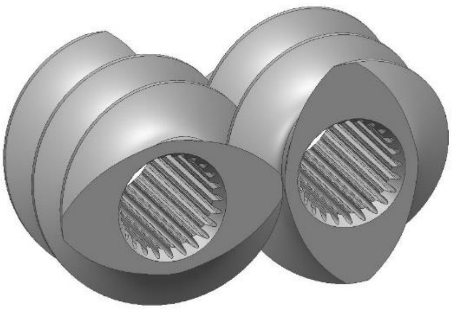


Counterrotating intermeshing screw set

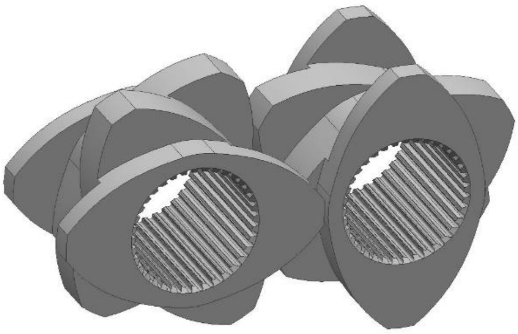
Each type of TSE has technical merit. The co-rotating intermeshing mode is deemed best for most compounding applications. The low speed, late fusion counterrotating intermeshing twin screw mode dominates the market for the extrusion of RPVC profiles. These modes comprise 90%+ of worldwide TSE installations. Tangential and high-speed intermeshing counterrotating TSEs are currently used for high-level devolatilization and specialty reactive processes.

Co-rotating, intermeshing twin screw extruder: The co-rotating twin screw extruder is the most prevalent continuous mixing device in the world. Typical applications include masterbatch and compounding processes in which fillers, pigments, dyes and additives are homogeneously mixed into the plastic matrix. High screw speeds (1000+ screw rpms are possible) facilitate the input of shear and energy into the process for efficient mixing. High surface renewal (rolling melt pools in screw channels) and high venting surface areas makes the co-rotating twin-screw extruder ideal for devolatilization processes to remove moisture and other volatiles. A controlled residence time, residence time distribution and intimate mixing associated with the co-rotating TSE makes it well suited for many reactive extrusion processes.

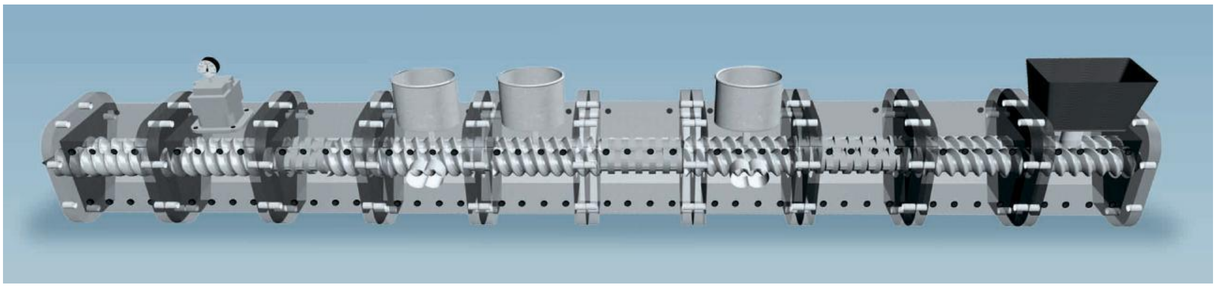
Co-rotating, intermeshing TSEs utilize a modular design for barrels and screws. By sequencing barrel modules and screw elements for different process tasks (i.e. downstream addition of fillers and fibers, degassing, etc.) the extruder can be adapted to a wide variety of processes. Screw element pairs are assembled on high-torque splined shafts. Self-wiping flighted screws convey materials in the feed zones, over mixing elements, underneath vents and pump out of the TSE. An infinite number of mixing elements are available. Kneading elements are the most common type, with the degree of dispersive and/or distributive mixing effects dictated by the width of the individual kneader, as well as the kneader stack arrangement. Depending on how many sequential unit operations are required for a given process, the L/D ratio is adjusted accordingly.



Flighted screw elements

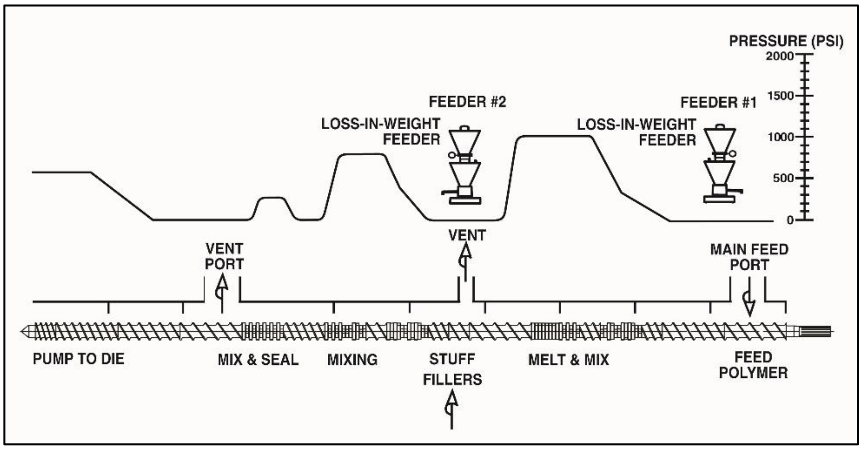


Kneading elements for mixing

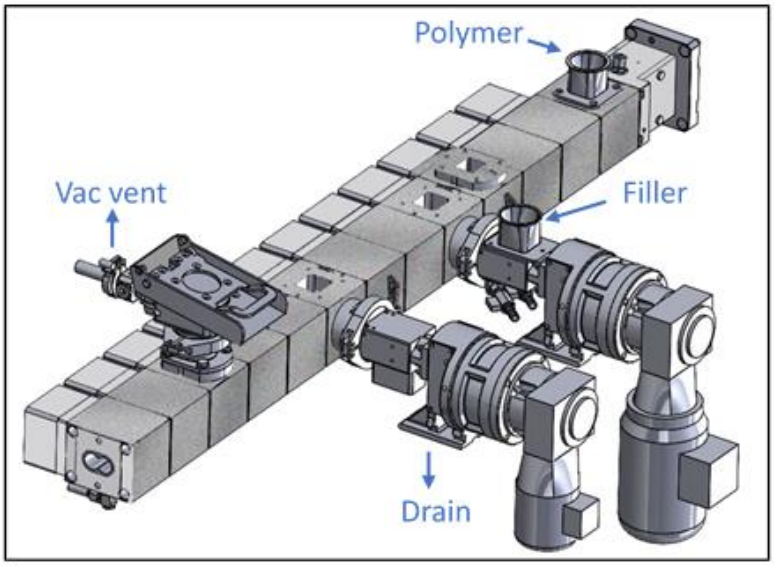


Modular barrel assembly

The feed rate and screw rpms are independent and used in concert to optimize compounding and devolatilization efficiencies. The pressure gradient in the twin screw extruder is determined by the selection of screws and operating conditions. Flighted elements are strategically placed so that there is a zero-pressure zone underneath downstream vent/feed sections, which facilitates downstream feeding and prevents vent flooding. Downstream introduction of materials into a molten polymer is often assisted by a side stuffer, that utilizes a twin screw auger to push materials into the TSE process section. Liquid injection is also common. Sequential feeding may eliminate upstream premixing operations.



Controlled pressure gradient in a co-rotating TSE



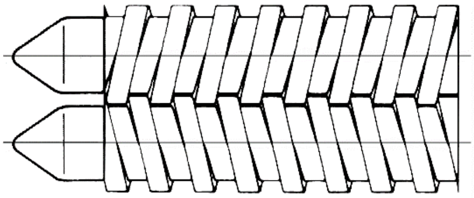
Example sequential unit operations in a TSE

The OD/ID ratio (outside screw diameter/inside screw diameter) and resulting channel depth are important design parameters. As the channel depth increases the cross section of the screw shaft (and corresponding torque transmission) decreases and vice versa. For co-rotating TSEs OD/ID ratios range from 1.4 to 1.8/1. It is important to find the optimum balance between free volume and torque for the best design balance, as these parameters often determine attainable throughput rates. There is always a trade-off between volume and torque.

Counterrotating intermeshing, low speed, late fusion (LSLF) TSEs: The LSLF counter-rotating twin-screw extruder is characterized by a gentle melting effect and narrow residence time distribution at low screw rpms (less than 50 rpms) combined with high-pressure pumping capabilities. This combination is particularly useful when processing a thermally sensitive PVC, or similar formulations. Screws are one-piece, and are often cored for liquid cooling, which is a preferred design feature for RPVC and similar temperature sensitive processes. Barrels can be one-piece or modular.

Looking into the feed throat, the screws rotate outward to facilitate feeding of the material on both screws. In the screw intermesh region, the flight of one of the screws penetrates the flight depth of the second screw and the velocity of the screws in the intermesh is in the same direction. In this region, referred to as the calendar gap, rotational forces of the screws in the same direction initiates an acceleration and stretching effect as the materials pass up and through the calendar gap that results in an extremely effective extensional mixing effect. Much of the screw length essentially functions as a mixing device as materials continually experience the extensional mixing and shear effects associated with the calendar gap. Screw deflection inherent with calendar gap mixing prohibits the use of high screw rpms and limits attainable L/D ratios. Gear mixers and blister rings can also be specified to impart distributive and planar shear mixing effects. Multi-start screws are specified under vents to increase the surface area of the melt and devolatilization efficiencies. Positive displacement pumping discharge elements pressurize the die at high-pressures.

It is important to note that closely intermeshing, counter-rotating twin-screw extruders can pump materials in a C-shaped, non-drag flow chambers, making this device the only extruder (except a ram extruder) that can function as a positive displacement pump. Single-screw and co-rotating TSEs both pump the melt via drag-flow.

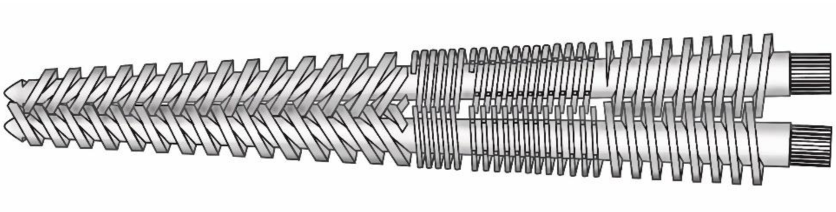


Positive displacement counterrotating discharge screw elements

There are 2-types of counterrotating intermeshing LSLF TSEs:

Parallel screws with the same diameter for the length of the screws: Parallel counterrotating TSEs are typically longer than the conical design, and the screw geometry relies on geometric changes to the flight gaps, the flight count, and changes in pitch to achieve the desired processing conditions.

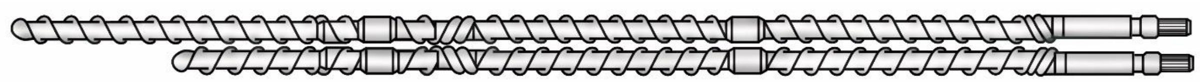
Conical screws decrease in OD size from feed to discharge: The high volume associated with the feed zone of a conical TSE is helpful when feeding low bulk density powders. Another unique feature of the conical design is that the radial clearance between screws and barrel can be altered to assist in desired changes to mixing and the overall process.



Counterrotating conical TSE design

Specialty/niche twin screw extruders: These designs account for less than 5% of the current twin screw overall market and include:

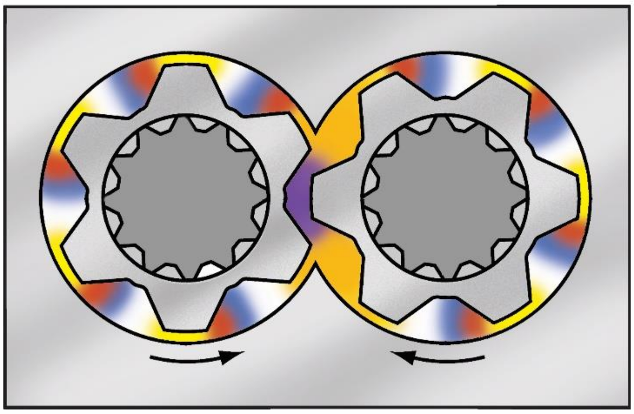
Counterrotating non-intermeshing (CRNI) twin-screw extruder: As the name implies, has non-intermeshing screws. The screws and barrels are modular. The design of each screw is often mirrored on the other screw, but not always. The screws can have forward or reverse flights, different helix angles, thick or thin flight thicknesses, multiple screw starts, and other unique screw design features. Different root diameter/flight depths can be specified, and screw elements can be matched or staggered at different points along the process length. A wide variety of mixing elements are available.



Counterrotating non-intermeshing screw set

Screws rotate inward which can assist in pulling materials into the feed throat, and downward in vent zones, thus resisting vent fouling and vent flow. A single screw can be extended to simulate the pumping characteristics of a single screw extruder. Due to absence of an intermesh and the associated geometric limitations, the non-intermeshing mode can be specified at 100+ to 1 L/ D for specialty processes that require a long residence time.

Counterrotating intermeshing high speed twin-screw extruder: The screws are counterrotating and intermeshing, however the mixing mechanism is shifted from the calendar gap to lobal mixing elements, which allows for screws rpms of up to 500 with minimal screw deflection. Up to six lobes (hexa-lobal mixers) are possible at a 1.5/1 OD/ID ratio, which translates into more mixing events for each screw rotation as compared to other TSE designs. This design has proved to be particularly beneficial at mixing of multi-phase, shear sensitive formulations at comparatively lower screws rpms than the co-rotating, intermeshing TSE.



End view hexa-lobal mixing elements

Additional front-end devices are integrated with TSEs and include filtration systems, gear pumps, diverter valves and a wide range of material handling and downstream equipment based on the intended process. The downstream equipment of a twin screw extruder is primarily divided into pelletizing and direct extrusion operations. Compounding processes generally make pellets as an intermediate product for processing on injection molding machines or single screw extruders. Various type pelletizing systems are available, including strand cut where the strands are cooled and cut, and hot face cut where molten strands are cut at the die plate in water or air. Alternatively, a final part such as films, sheets, filaments, fibers, profiles, tubes and a specialty parts can be directly extruded from the TSE. It is also now common for TSEs to be integrated with single screw extruders for unique coextrusion applications, or into various type molding systems.

It quickly becomes evident that the twin-screw extruder is a powerful and flexible manufacturing tool that makes many wide-ranging polymer processes possible. Fortunately, there is a range of co-rotating and counterrotating TSE technologies that are available to meet the needs of a diverse and complex plastics industry. Developments will continue to expand the range and improve the quality of products that are manufactured via TSEs, taking advantage of the unique geometric capabilities inherent with 2-screws.

Don't hesitate to contact Leistritz Extrusion to help plan your project, prepare a quotation, schedule a test in our USA process development laboratory, or to discuss twin screw technologies in general.

We look forward to working with you in the future!

Team @ Leistritz Extrusion

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