SPECIAL INTAKE ELEMENTS TO OVERCOME FEED LIMITATION IN COROTATING TWIN-SCREW EXTRUDERS -DESIGN FEATURES AND EXPERIMENTAL RESULTS

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Abstract
Forced and starve feeding are well known feeding methods to input material into a co-rotating twin screw extruder. Polymers in powder form and materials such as talc and mica are a challenge to introduce into the extruder. The geometry of the intake zone screw elements and the side-feed zone screw elements decide the conveying ability and the intake capacity of the extruder. The problem of lower intake capacity is solved by the use of Single Flight Shovel (SFV), Triple Flight Shovel (TFV) and Regular Flight Shovel (RFV) classified as 'FV' type elements (Patent Pending). The screw flights are designed to plough through the material similar to the working of a snowplough. Increase in intake capacity compared to Erdmenger-type and Schubkanten-type screw elements is discussed.

Introduction

The earliest co-rotating twin-screw extruders had shallow flight depths and were designed to run with filled hopper(s), in the same way an injection-molding machine or a single screw extruder is run. As technology progressed and flight depth increased, it became necessary to adopt a different approach to feed material into the extruder. This method is called starve feeding. In this approach, additional feeder(s) is used to provide a steady flow of material into the extruder. The hopper is no longer a vessel to hold the material but simply a chamber through which the material enters the extruder. While feeding polymers devoid of any other filler, the material feed rate is generally a fraction of the total volumetric capacity of the extruder. If controls are not applied, such situations can result in the breakage of the mechanical parts. In such cases, the limiting factor is the torque availability. In recent times, several applications that employ low bulk density materials such as Polymer powder, Wood powder, Talcum powder, Mica flakes, Fumed Silica, Fine Carbon have arisen. In such applications, the ability of the extruder to accept material is the limiting factor. When feeding limits are reached, the hopper gets flooded with material and quickly fills up. Several researchers have addressed this issue in the past. Stropole and Wolfe have stated, “in the compounding of polymers the limitation of throughput is not the mixing capacity but rather a volume limitation in the filler intake area due to the low bulk density and the fluidizing nature” [1]. Screw speed, free area, screw pitch, loose bulk density are some of the major factors affecting the intake zone [2]. Schüler determines that in an increasing amount of applications “there is a limitation in all the intake process by volume” [3].

Intake, melting, venting, mixing and metering are the important process zones of a compounding extruder. The function of the intake zone of an extruder is to convey and compact the bulk material. During compacting of the bulk material, the air entrapped in the material is removed. The entrapped air needs a path to escape. When a hopper gets flooded, this air has no route to escape and results in a further drop in the intake ability of the extruder. The intake zone with a hopper that is flooded with powder has far less feed capacity than a hopper that is starving due to fluidization of the powder as the entrapped air tries to escape. Several researchers have tried to model the behavior of particles when acted upon by the screw. Vlcek et al model the conveying mechanism of solids due to the frictional drag of particles against the barrel and the screw surface [4]. On the behavior of the material itself, Prescott and Barnum state that the powder flow-ability is a combined result of the influence of physical properties of the material and equipment used for handling, storing or processing the material” [5].

Performance of Erdmenger-type profile (Figure 2), Schubkanten-type (Figure 3) and SFV screw elements (Figure 4) are compared in this paper by means of experiments. The intake capacity of the SFV element compared with the normal Erdmenger-type and Schubkanten-type screw profiles are provided in the results.

Geometry of the Extruder

The co-rotating twin-screw extruder used in this work had a 40 mm barrel diameter. The screw elements had the same outer diameter of 39.70 mm. The D/d (Diameter Ratio) of the extruder was 1.71. The clearance between screw and barrel was 0.15 mm and between the screws was 0.5 mm. The screw elements with Erdmenger-type bilobed profile, Schubkanten (SK) profile and SFV profile had screw leads of 60 mm, 60mm and 40 mm respectively.

Experimental Results

An experiment was carried out with LLDPE as the base resin in powder form. LLDPE powder was prepared using a pulverizing process. LLDPE had a melt flow index of 50. Talcum Powder was the filler with a loose bulk density of 0.37 g/cc with a mass median diameter of 3.38μm as shown in figure 7. The formulation comprised 49% LLDPE, 50% Talc and 1% PE wax. These were mixed thoroughly using a high-speed mixer. This premix was fed though the extruder using a gravimetric feeder with a feeding accuracy of within 1 % (at 2 sigma confidence level). The actual outputs at which point the hopper flooded was recorded for the different types of screw elements in the intake zone.

The trials were done at screw speeds of 300, 600, 900 and 1000 RPM. At every set screw speed the power consumed by the extruder was also recorded as shown in tables 1, 2 and 3. As in Figure 1, changes were only made to the intake zone consisting of the first six elements following the short-lead sealing element. Mixing elements were used in the downstream sections to achieve acceptable product quality in the output.

Results and Discussions

Experiments were conducted with three types of screw elements as in figures 2, 3 and 4 in the intake zone of the Ø40 twin screw co-rotating extruder. The output was measured at screw speeds as shown in tables 1, 2 and 3. The available power and the power utilized during the experiment with different screw elements in the intake zone are given in the table. As seen from Table 1, with SFV screw elements, torque limits were reached for the application. An improvement of nearly three times the capacity of typical intake elements was possible with the new intake elements. Torque utilization results in improvement in specific mechanical energy input into the process as seen in Table 1. The Formula for calculating the intake capacity is Capacity = Free Area x Lead x Screw Speed x Bulk Density x Conveying Efficiency x Degree-of-Fill

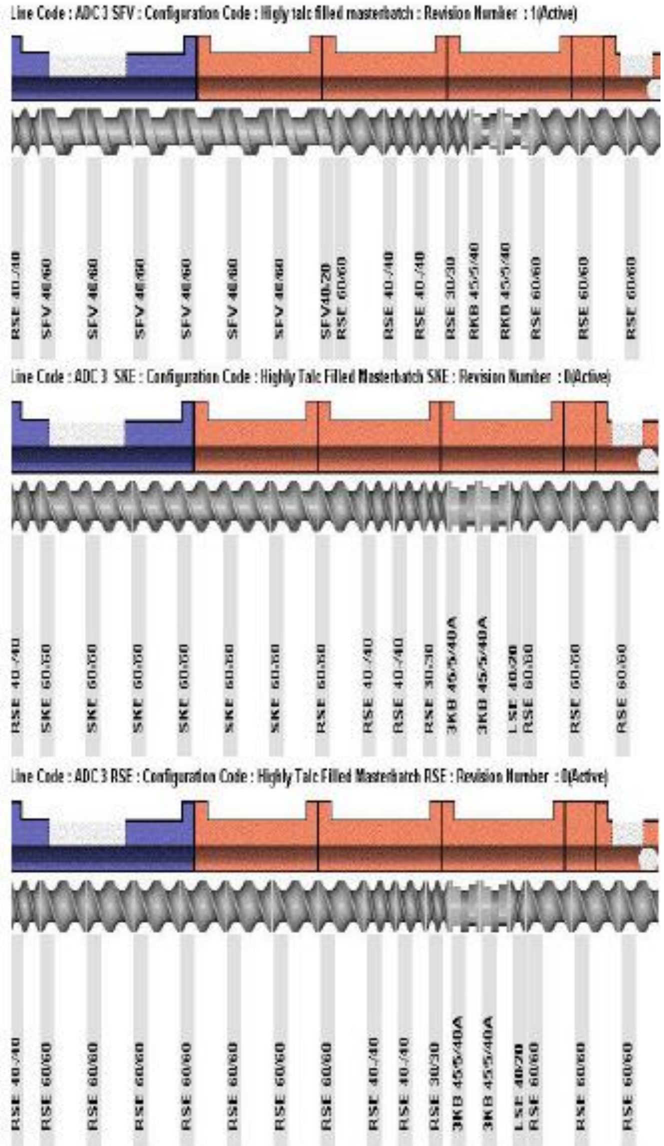

Figure1. Intake Zone Screw configuration

Since both “Free Area” and “Lead” are related to the Barrel Diameter (D), it can be seen that the Capacity of an extruder varies as the Cube of the Barrel Diameter (D). For the 40mm extruder, the Free Area is 10 cm2. For a 60mm lead intake, for material with a bulk density of 0.37, at 100% efficiency and degree-of-fill 1, the Capacity is 400 kg/h. Using a glass-walled transparent extruder shown in Figure 8, the following results were obtained. While feeding Talc that has low frictional coefficient (about 0.2), the conveying efficiency is generally about 20% for typical intake elements such as Erdmenger-type elements and Schubkanten-type (SK) elements when running with a degree-of-fill of less than 0.35. Therefore, it is possible to achieve an overall efficiency of only about 5- 7%. Once the intake zone is filled up (degree-of-fill = 1.0) or the hopper is flooded, the conveying efficiency drops further due to fluidization of particles from the trapped air escaping through the hopper.

While feeding most other polymer material with a medium frictional coefficient (about 0.4), the conveying efficiency is 30 % even at a higher degree-of-fill. With Calcite (frictional coefficient 0.74), the conveying efficiency is the highest (about 50%) at a high degree-offill. With these materials, the increase in degree of fill does not significantly decrease conveying efficiency. Therefore, the highest capacity is achieved when the screw flights are fully filled. This is the reason why a flooded hopper always creates a torque overload with most polymers.

Production trials have been carried out with PET Flakes using TFV Elements (Figure 5) for forced (or crammer fed intake) and RFV elements (Figure 6) for the side-feeder zone (for feeding Mica, Talc or Carbon powder). In both cases, intake capacities were increased by a similar order of magnitude (an improvement of over 100%) as described in these experiments.

Mechanism causing high conveying rate

The similarity to the working of a snowplough is the right way to understand the reasons for the large improvement in conveying rate. The angle the plough makes to the surface has a tremendous impact on whether the material moves forward or to the side. The objective of the snowplough is to move the material to the side as opposed to the working of the FV modified elements. When the snowplough faces downwards in the forward direction (while making a small angle perpendicular to the direction of motion), it successfully throws material to the side. On the other hand, if it opens its face to the material, material will not be thrown to the side but get carried forward. The regular Erdmenger and the Schubkanten profile elements work like a normal snowplough throwing the material sideways rather than forward. The FV modified elements have the capacity to shovel the material forward creating a large improvement in conveying rate.

Although, these elements are generally used in the intake zone before the solid material forms a melt, they can also be used in any zone that is partially filled after melting. This is because the flow of material can itself create the effect of cleaning. Importantly, wiping profiles do not always clean, since the cleaning action requires transfer of material forward during the act. If material is pushed backwards or in a radial direction, cleaning does not occur.

Conclusion

The FV modification (patent pending) has the capacity to transform most feed limited application into torque limited ones thereby increasing the efficiency of the extruder. The improvement in efficiency arising from reduced specific mechanical energy input further boost output capacity of the extruder. These elements are used to enhance the conveying capacity at the intake zone, at the side-feed zone or at the vent zone.

References

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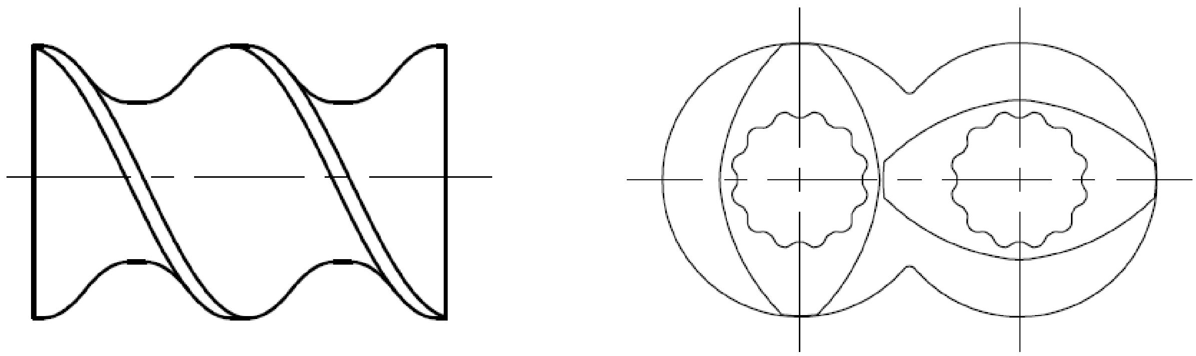

Figure 2. Erdmenger Bi-lobed Screw element

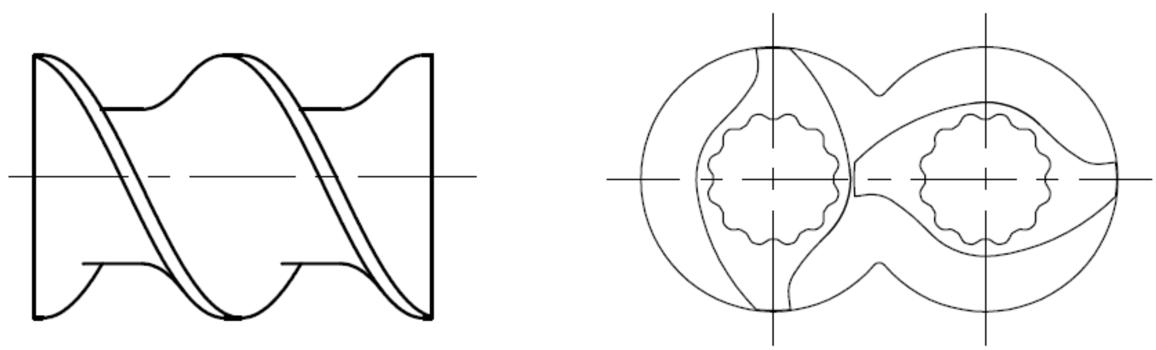

Figure 3. Schubkanten Screw Element

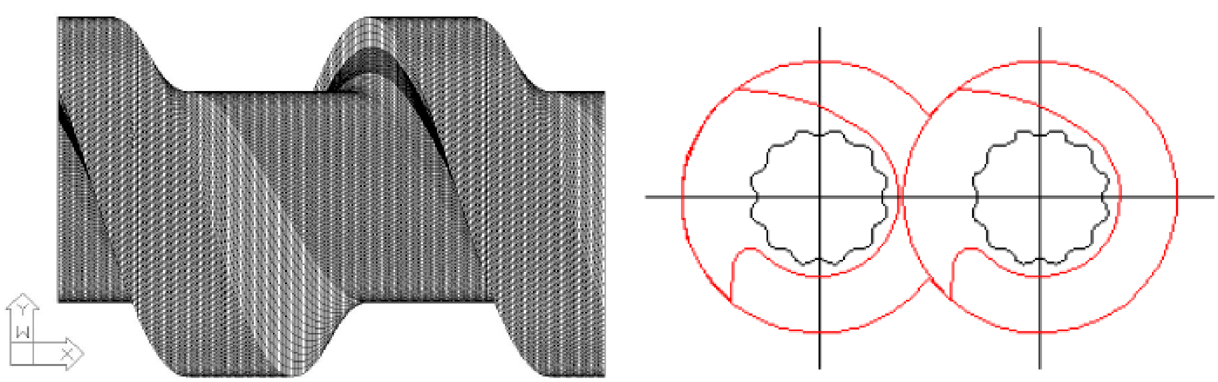

Figure 4. SFV Type Screw Element

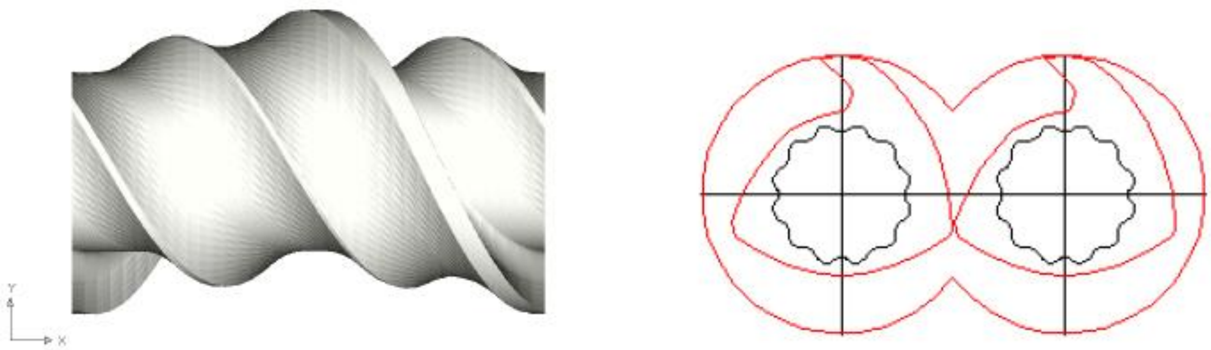

Figure 5. TFV Type Screw Element for Forced Intake

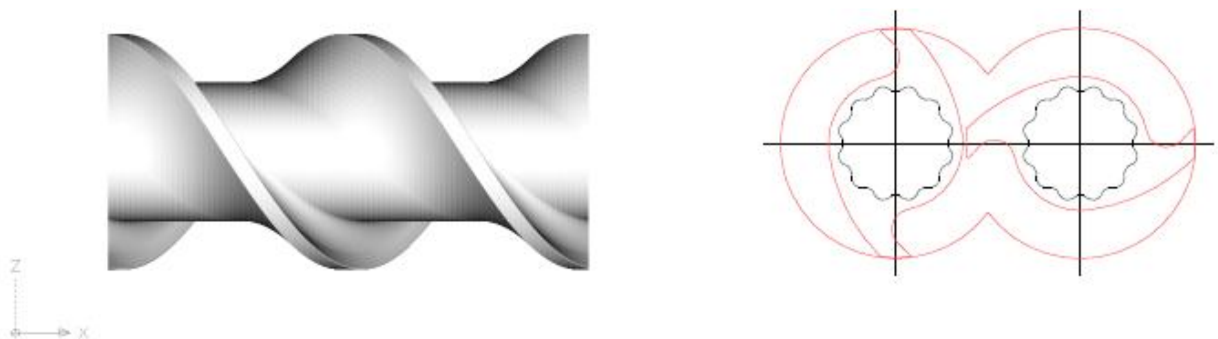

Figure 6. RFV Type Screw Element for Side-feed Zone

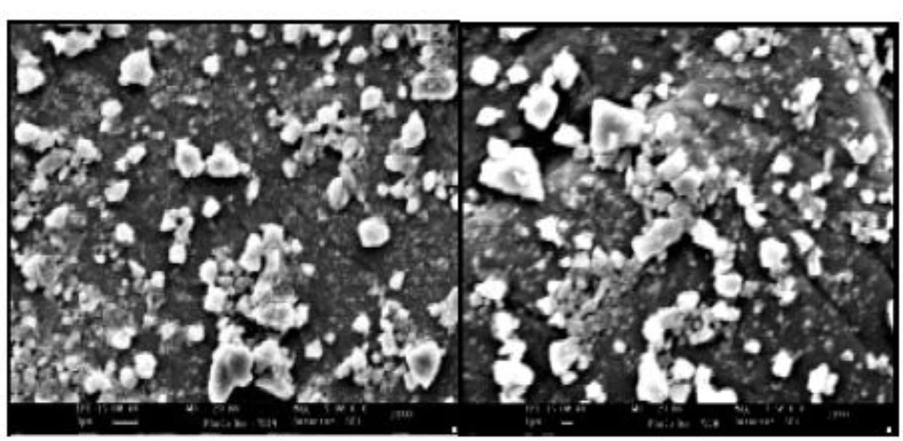

Figure 7. SEM Pictures of Talcum Powder

Figure 8. Glass walled transparent Extruder

Screw Speed (RPM)	Power (kW)	Output (kg/h)	Available Power (kW)	Specific Energy (kW h/kg)	Power Utilization (%)
300	10.21	50.00	12.75	0.20	80.08
600	22.73	140.00	25.50	0.16	89.14
900	35.47	210.00	38.25	0.17	92.73

Table 1: With SFV screws in the intake zone of the extruder

Screw Speed (RPM)	Power (kW)	Output (kg/h)	Available Power (kW)	Specific Energy (kW h/kg)	Power Utilization (%)
300	5.51	28.00	12.75	0.20	43.22
600	12.15	63.00	25.50	0.19	47.65
900	18.55	84.00	38.25	0.22	48.50
1000	20.79	84.00	42.50	0.25	48.92

Table 2: With Schubkanten type screws in the intake zone of the extruder

Screw Speed (RPM)	Power (kW)	Output (kg/h)	Available Power (kW)	Specific Energy (kW h/Kg)	Power Utilization (%)
300	6.26	28.00	12.75	0.22	49.10
600	11.92	42.00	25.50	0.28	46.25
900	19.22	70.00	38.25	0.27	50.25
1000	21.76	84.00	42.50	0.26	51.20

Table 3: With Erdmenger-type screws in the intake zone of the extruder