Characteristics and Application Technologies of HTM Twin-Screw Extruder

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CTE Co., Ltd.
1. Outline, Development Objectives and Characteristics of the HTM Twin-Screw Extruder

1.1 Outline of HTM twin-screw extruder

Compared with existing twin-screw extruders, the HTM twin-screw extruder has the very unique construction, as shown in Figure 1. The differences in mechanical construction between the HTM twin-screw extruder and conventional twin-screw extruders are shown.

1) The screw lengths in the HTM are different. The HTM is constructed with the combination of the long and short screws. At the end of twin-screw section is a single screw.
2) The screw construction is combined with the shafts & segments that is similar to those of conventional twin-screw extruders.
3) The screws; counter-rotating and non-intermeshing.
4) There are some clearance of between screws (depending upon the screw size, refer to Figure 3 later).
5) Continuous rotor segments are positioned bilaterally symmetric in the screw kneading section.
6) The screw rotation speed for a standard extruder (long screws) is ca. 800rpm (max.), while for a high-speed type it is ca. 1,200 rpm (max.).
7) A rotational speed differential is applied between the long screw and the short screw. The short screw rotates approximately 10% faster than the long screw.
8) A flow adjustment valve is positioned at the last section of the twin screw that enables regulation of the resin melt flow.
9) The strength of the gearbox is high, and it features a simple construction.

Table 1 shows screw diameters for the HTM twin-screw extruder and main specifications.

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>HTM-18</th>
<th>HTM-50</th>
<th>HTM-65</th>
<th>HTM-78</th>
<th>HTM-90</th>
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<tbody>
<tr>
<td>Screw diameter</td>
<td>mm</td>
<td>38</td>
<td>50</td>
<td>65</td>
<td>78</td>
<td>90</td>
</tr>
<tr>
<td>Screw rpm</td>
<td>rpm</td>
<td>800 - 1,200</td>
<td>800 - 1,200</td>
<td>700 - 1,200</td>
<td>700 - 1,200</td>
<td>600 - 900</td>
</tr>
<tr>
<td>Motor load</td>
<td>kW</td>
<td>57 - 75</td>
<td>75 - 150</td>
<td>135 - 300</td>
<td>200 - 450</td>
<td>250 - 600</td>
</tr>
</tbody>
</table>

1.2 HTM twin-screw extruder development objective

We have developed the new twin-screw extruder analyzing the technical aspects of numerous multi-screw extruders. Regarding composite, we have analyzed conventional twin-screw extruders with their high performance and high applicability to various applications compared with tandem-type continuous mixer-type extruders that feature high kneading performance but are limited in terms of application. After close inspection of their strengths and weaknesses, we have developed the HTM twin-screw extruder with the objectives of improving weaknesses and further extending advantages.

The extrusion of composite, from the viewpoint of kneading performance alone, leads to tandem-type, continuous mixer-type extruders, or going further back the batch-type Banbury mixer, and when compared with conventional twin-screw extruders, the higher kneading performance of the Banbury mixer is patiently obvious.

However, in actual production of compounds, the batch-type Banbury mixer is ideal for large-scale production of the same lot, but when it comes to multi-product, small-batch production of composite, this type of mixer is unsuitable. In addition, the L/D of the mixing section of a tandem-type continuous mixer is short, and its plasticizing capacity is low. Moreover, as it is a tandem type, two extruders are required, and various problems are thus associated with it such as high equipment cost, the maintenance, and energy efficiency.

Compared with those kneaders, the use of conventional twin-screw extruders is common, not only in Japan but the rest of the world.

Mechanically, two light-flight screws intermesh and co-rotate, and the raw materials (pellets and filaments) pass through the feed zone and into the kneading zone where the resin is melted by the kneading disc, compacted, mixed with the additives, and then discharged by an output, before secondary kneading and forced degassing. The melt is then finally extruded through a die head. This construction has been performed to a high degree. Screw segmentation was first to be adopted, and this enabled various composite to be handled. On account of the screws being co-rotating, no slipping effect is generated between the screws, and high screw rotation speeds can be achieved, while high kneading performance and high output are also possible. In terms of applications, a wide range of products can be handled, including compounds containing fillers, glass fibers, flame retardants, and polymer blends, through to reactive processing.

As the result of analysis mentioned above, we have developed the special HTM-type twin-screw extruder with the bold concept of incorporating the advantages of both tandem-type continuous mixers and twin-screw extruders.

1.3 HTM twin-screw extruder characteristics

Various challenges were faced in realizing the above-mentioned concept and interpreting it into an actual machine. This was because as the concept of employing such a twin-screw machine for compounding is rarely seen, prior experience was of limited use, and in addition, few useful examples could be found in extruder technical books.

Mechanically, various challenges existed as how to transfer the resin melt from the twin-screw section to the single-screw section, how to incorporate the continuous kneading rotor, what rotor shape to adopt, and what relative tolerances to adopt for the two screws when designing the gearbox. However, as a result of resolving each of these challenges, the construction became a construction of the twin-screw section of a tandem-type, twin-screw continuous mixer and a single-screw extruder section docked along the same axis.

The principal mechanical characteristics are shown using a conceptual diagram of the construction as shown in Figure 2. Several characteristics are also introduced in the following.

1.3.1 High dispersion capability

(1) Shear force comparison

When comparing the kneading discs of conventional twin-screw machines and the kneading rotor of HTM twin-screw extruders, the excellent kneading performance of the HTM results from the Banbury-type shear generated in the melt through the continuous compression, mixing and grinding, and release occurring between the kneading rotor flights and interior surface of the short cylinder. On the other hand, kneading in a conventional twin-screw extruder results from applying high compression to the melt while generating shear between the kneading discs of the two intermeshing screws.

(2) Comparison of dispersion ability

For the case of a conventional twin-screw extruder, melt kneading of the resin occurs primarily through the action of the kneading discs, as discussed earlier. If, for instance, screw design is wrong, interior filler dispersion readily occurs once the resin starts to melt in the full flight section. Therefore, here we only compare the kneading disc of a conventional twin-screw extruder (Figure 3) with the kneading rotor of an HTM twin-screw extruder (Figure 4).

Regarding the degree of kneading, the indicator of shear rate is employed.

a. Conventional twin-screw extruder

Locations where resin is shredded can include where nipping occurs between the screws, but the locations where the majority of resin is subject to uniform shear are the flight depth H₀ and the kneading disc thickness H₁ shown in Figure 3.

The shear rate is defined by \( \gamma = \frac{2 \pi N \cdot \rho}{H₀} \) (foot depth), and for the same speed, the shallower the flight, the higher the shear. H₁ is decided by the intermeshing ratio of the two screws, and for this reason, conventional (twist) twin-screw extruder in recent years have employed deeper flighted screws along with higher and higher output rates. On this account, high shear at these locations cannot be expected.

H₁ can be made as thin as mechanical strength will permit, and high shear can be anticipated. Accordingly, the maximum shear rate of a conventional twin-screw machine is:

\[ \gamma > 2 \times 10^6 \, \text{sec}^{-1} \]

Note: Speed is doubled as melt flows are
in the opposite direction at the intermeshing point.

b. HTM twin-screw extruder

All resins passes through the tip clearance $H_2$ of the kneading rotor shown in Figure 4, and is uniformly kneaded. As $H_2$ can be made smaller regardless of mechanical strength, high shear rates can be easily generated.

Accordingly, the maximum shear rate of an HTM twin-screw extruder is

$$ \gamma = \frac{7n}{5} $$

c. Comparison of two machine types

Concerning $H_2$, 5 mm is considered proper when considering on the basis of a production machine base. Any thinner than this and the disc may be damaged.

If this value is inserted into the maximum shear rate equation for conventional twin-screw machines,

$$ \gamma = 2 \times \frac{7n}{5} = 0.4\text{V} $$

is obtained.

On the other hand, $H_2$ can theoretically be set as thin as desired without limit, but when taking into consideration resin degradation/heat generation resulting from excessive shear, experience at our company points to a minimum value of 0.5 mm.

Accordingly, the maximum shear rate of an HTM twin-screw extruder is

$$ \gamma = \frac{7n}{5} $$

This represents a shear rate of almost 5 times that of conventional twin-screw machines.

As shown above, one can see that a large difference exists in terms of the screw shear force.

Moreover, the HTM twin-screw extruder can be outfitted with a number of kneading rotors with different tip clearances for which shear force can be arbitrarily set in order to accommodate various filled materials. Through continuous combination of these rotors, high quality composite can now be realized.

Figure 5 shows a number of kneading rotors with different tip clearances.

Basically, these rotors are combined continuously in sets of 3 (feed/feed/transfer), with the first kneading section comprised of a bilaterally symmetrical group of 3 segments, and the second kneading section after the open vent a single segment (refer to Figure 2). Depending on the application, an all-rotor configuration can be employed from the first kneading section to the second kneading section.

1.3.2 Low-temperature control of resin melt and higher discharge

(1) Low-temperature control

Recently, high output from twin-screw extruders has been achieved through the move to higher torque and screw rpm. On the other hand, due to high screw rotation, low-temperature control of resin temperature has become difficult. If the resin temperature at the die head for an HTM twin-screw extruder and a conventional twin-screw extruder is compared, when extrusion parameters (screw diameter, rpm, output, etc.) are equal, HTM enables temperature to be lowered by about 10 - 20°C. This does not apply to all compounds, but we have received the excellent reputation from users on the point.

The following points can be considered as primary reasons.

a. Conventional twin-screw extruder

1) Heat generation in kneading section...The raw material that has already been melted, compounded, and forcibly degassed passes from the twin-screw section via the flow regulation valve to the single-screw section. For a molten material that fills the head section under pressure, heat generation is minimal as the head section is a single screw.

For the above reasons, the HTM extruder enables low temperature control of the resin melt.

(2) Higher output

Generally speaking, if a twin-screw extruder is operated at high speed, malalignment of the screw design is expected to result in a proportional increase in the resin temperature. However, for the reasons stated above, the HTM extruder improves greatly low temperature control for resins from low viscosity through to high viscosity, even under high-speed operation. On this account, resin degradation is minimal, and property degradation can be suppressed.

For these reasons, it can be said that the HTM extruder can operate at high speed and with high output rates for a variety of composites.

1.3.3 Feed neck phenomenon

In the beginning, it was stated that the demand for composite requiring a high level of technology such as automotive compounds, electrical wire applications, and electric insulation compounds, could be anticipated in Japan to a certain extent.

These compounds tend to be filler-rich in terms of loadings, and moreover, the filler particles are often micro-particles. The smaller the size of the filler micro-particles, the higher the air and moisture content, and the air forms insulation layers within the resin. This makes it more difficult for load to be applied from the heaters and screw rotation, and the resin thus becomes more difficult to melt. In conventional twin-screw machines, the two screws are fabricated so that they intermesh and the flights are continuous. On this account, the resin and air/gas move only in line with the flights.
Figure 6 shows the movement of resin and gas in a conventional twin-screw extruder. The filler that contains a large volume of air is fed in the extruder together with the resin, and during the resin-melting step, air and gas are squeezed out and they try to return to the feed section along the flights. As the amount of air and gas is considerable, the effect is one whereby the raw materials that are being fed are pushed back. This is known as the feed back phenomenon.

In addition, highly-composite containing wood flour particles contain large amounts of moisture in addition to air, and their compounding is even more challenging.

When processing materials that readily exhibit the feed neck phenomenon, the material take up rate is not accelerated even when one tries to increase production through increasing screw rpm, and on this account, the resin temperature becomes even higher and wood flour stretching and color change occur.

The HTM extruder features the following merits for overcoming these difficulties:

1) The two screws are non-intermeshing, with a fixed gap between each screw (refer to Figure 4).
2) The resin feed is fed forward along the screw flights, but opposed to this, the gas and air pass through the screw gaps and escape to the feed and vent sides.

Figure 7 shows the movement of resin and gas in the HTM twin-screw extruders. The gas that is generated in the melting phase of the resin and the air carried with the filler escape to the feed and vent sides by short-cutting via the screw gap. On this account, the raw material take up rate does not decline to a large degree, and one can say that the HTM extruder is suitable for highly composite containing fine powders. The non-intermeshing screw mechanical construction of the HTM twin-screw extruder is a major characteristic compared with deep flight, intermeshing twin-screw machines in that it allows air and gas to escape via the screw gap without having to forcibly feed materials to the extruder. On this account, it can be viewed as an optimum twin-screw machine for the production of composite that require advanced technology such as those for automotive, electrical cable, and ecology applications.

1.3.4 Resin flow adjustment valve
The fact that a resin flow adjustment valve is positioned in the final part of the screw section enabling control of the passage of the resin melt has already been mentioned in the equipment outline section. Here, we introduce application of the valve.

The primary application is to prevent surging. When the packing ratio of the twin-screw section decreases and a surging phenomenon occurs, closing the valve controls passage of the resin melt, and the packing ratio is stabilized. As a result, the surging phenomenon is improved.

Another important characteristic is that residence time of the resin melt in the twin-screw section of the extruder can be arbitrarily controlled by closing and opening the valve. This characteristic can be utilized in dynamic cross-linking reactions carried out in twin-screw machines. Moreover, as the screws are separated by a gap, the cylinder internal volume is greater than a conventional machine, and the residence volume is thus greater. In other words, the HTM extruder enables extrusion that runs counter to the functionalities of conventional extrusion — a high degree of kneading can be applied to the resin melt, filler can be thoroughly compounded in, and the residence time of the resin melt can be extended.

In actual operation, a resin can be compounded with a residence time between 3 and 7 minutes using a 50-mm-diameter screw and at 300 rpm with the valve closed.

1.3.5 Gear box strength

With the gear box of the HTM extruder, the mechanical construction is one in which only the long screws bear the die head back pressure from a screw thrust load perspective. On this account, the thrust bearing has the same construction as that of a single-screw extruder, and a large thrust bearing can be used.

In other words, a large head pressure can be borne with a simple gear box that is similar to the one used in a single-screw extruder, and in this account, it can accommodate a strong head pressure and strength can be made large. A flat die can be attached directly without a gear pump when using the HTM extruder, and direct sheet extrusion can be readily handled.

2. Application Technology for the HTM Twin-Screw Extruder

Numerous application technologies exist in the automotive, flame-retardant electrical cabling, and ecology areas that can leverage the aforementioned characteristics.

Reasons why these compound are said to be difficult include 1) high loadings of microparticle fillers that are difficult to feed into the extruder, 2) high loadings of magnesium hydroxide that clings to the screw, 3) high loadings of wood flour that are difficult to feed, contain high levels of moisture, and generate gases.

When compounding these with the HTM extruder, common equipment configurations apply for a wide range of applications, so a resin/non-dried wood flour compounding will be described here as a representative example.

2.1 PP/non-dried wood flour compounding

In the conventional compounding method for PP/filled wood flour (relative weight = 80% - 95%), both the wood flour and PP are almost always either pre-dried in a heating mixer or continuously predried in the twin-screw extruder.

Compared with this, the HTM extruder doesn't require the wood flour (average moisture content = 4% - 10%) and PP pre-dried, and the resulting compound can be readily pelletized.

Pre-drying of the wood flour is not necessary so this translates to vastly simpler equipment, a smaller building to house the equipment, and energy savings, among other benefits. Needless to mention, equipment costs are significantly lower, while compounding costs are also considerably lower.

Moreover, as the wood flour is not scrolled, product color is extremely good (close to natural wood). In PP/wood flour construction material applications, avoiding the scouring and burning of wood flour is the paramount factor.

Figure 8 shows the configuration of a PP wood flour compounding system.

2.2 Other equipment

As the HTM extruder can compound filler (e.g., wood flour: weight ratio = 80% - 90%) in high loadings without the need for drying, it can also compound highly-filled automotive master-batches and non-halogenated flame retardant compounds for electrical wiring in essentially the same configuration as shown in Figure 8.

(1) Highly filled master-batches for automotive applications

The wood flour feed section shown in Figure 8 is changed to one for fine talc powder, and the compounding system becomes an automotive PP/talc (weight ratio = 50 - 80%) master-batch production line.

(2) Non-halogenated flame-retardant compound for electrical cabling

The wood flour feed section shown in Figure 8 is changed to one for magnesium hydroxide, and the compounding system becomes an electrical wire flame-retardant compound (weight ratio = 40 - 75%) production line.

These examples have a simple configuration, but in the field of twin-screw extruders, the equipment can be said to be very easy-making.

(3) Rigid PVC/wood flour compound

Compounding twin-screw extruders are broadly classified into those for general-purpose resins (including engineering plastics) and those for PVC. PVC twin-screw extruders generally have a shorter L/D, deep flights, and operate at low rpm. The resin is not subjected to high shear rates.
and the melt is extruded from by a few flights at the screw tip. This is because PVC decomposes if subjected to high shear rates.

The HTM twin-screw extruder is the complete opposite in terms of machine construction and kneading methodology. However, though utilizing the extruder’s ability to control resin temperature at low levels, high shear, high rpm compounding of PVC/wood flour compounds is possible with a twin-screw extruder.

Figure 9 shows the configuration for a PVC/wood flour compounding system.

In this layout, PVC and non-dried wood flour are dewatered, and kneaded in the twin-screw section of the HTM twin-screw extruder, and the melt is extruded from the single-screw section in tandem configuration, without raising the resin temperature. A weight ratio of 50 - 80% wood flour is achievable in compounding.

(4) Rigid PVC and high inorganic filler loading

If the wood flour section shown in Figure 9 is substituted with an inorganic filler section, the unit becomes a PVC compounding system for high inorganic filler loadings.

Compounding with inorganic filler weight ratios of 40 - 70% is possible.

<table>
<thead>
<tr>
<th>Resin/filler</th>
<th>Model</th>
<th>Screw rpm (kg/hr)</th>
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<tbody>
<tr>
<td>PP + wood flour (60%)</td>
<td>HTM-65</td>
<td>300</td>
</tr>
<tr>
<td>PP + wood flour (60%)</td>
<td>HTM-78</td>
<td>450</td>
</tr>
<tr>
<td>PVC + wood flour (60%)</td>
<td>HTM-65</td>
<td>150 - 200</td>
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<tr>
<td>PVC + wood flour (60%)</td>
<td>HTM-78-140</td>
<td>200 - 300</td>
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<tr>
<td>PE + Mgf(OH)_2 (50%)</td>
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<td>300 - 400</td>
</tr>
<tr>
<td>EVA + Mg(OH)_2 (50%)</td>
<td>HTM-78</td>
<td>900</td>
</tr>
</tbody>
</table>

Mgf(OH)_2 : Magnesium hydroxide

This fact more than anything shows that the HTM twin-screw extruder has a high potential that exceeds the conventional wisdom of high speed/high rpm twin-screw extruders. Table 2 shows the output rates for each of these compounds when using the HTM twin-screw extruder.

**Conclusion**

The characteristics and application technologies of the HTM twin-screw extruder from CTE are epoch-making, and can not be found in other types. Moreover, it can be said to be a next-generation twin-screw machine that can challenge areas that were previously inaccessible by conventional twin-screw extruders in terms of technology and cost.

For your information, in our plant a 55-mm-diameter test machine is ready for any type of the user’s requirement anytime.