Application Note
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Use of Bench-top Twin-Screw Extruders for development of Powder coatings

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- Extruder
- Twin-Screw
- Bench-top

Application Notes

Abstract

Twin-screw extruders are widely used for dispersion of pigments and additives into thermosetting resins for the manufacture of powder coatings. This paper outlines the manufacturing process for thermoset powder coatings and the availability small-scale twin-screw extruders together with a range of ancillary equipment, to assist the powder coating producer in development, sample preparation, colour matching and testing of the product. It also describes the key element of heat transfer in scale-up from laboratory extruders to production plant.

Introduction

The presentation will outline the process for manufacture of powder coatings and describe the application of small twin screw extruders to melt -mixing powder coating formulations, for both product development and quality control, using samples as small as 200 g, up to production of over 250 kg/h.
Pre-mixing using a bench-top change-bowl mixer will be discussed.
Extrusion of Powder Coatings using a co-rotating twin-screw extruder will be described.
Twin-screw design and the conflicting demands of torque and free volume will be explained.
Finally, the critical factors for a reliable scale-up to production plant will be considered.

Industry Background

Powder coatings are surf ace finishes (Paints) used for both decorative and protective applications. They are solvent-free products, which make them environmentally friendly, and to some extent can be re-cycled when over spray is collected and re-used.
There are two groups, Thermoplastic and Thermosetting powder coatings.
This paper will focus on the Thermosetting products.

Manufacturing process

The manufacture of thermosetting Powder Coatings involves four stages:

Pre-Mixing, Extrusion, Cooling and Flaking, Fine grinding

Pre-Mixing

Because of the numbers of different ingredients and the accuracy necessary for precise colour matching, a pre-mix is made where the individual ingredients are weighed into a blender and mixed together before extrusion.
There are two alternative methods, low speed blending or high speed mixing. In the low speed blending, the equipment can be very simple, like the traditional drum tumbling devices used in many industries, or larger trough mixers. The mixing process is low energy with long mixing cycles of 20 or 30 minutes, so the blender volumes are large.
The alternative high-energy dispersive mixer uses high-speed impellors and short cycles, so mixer volumes can be smaller for the same throughput. The other advantage of high speed mixing is the more efficient dispersion of ingredients and breaking down of resin flakes, to give a more uniform pre-mix.

Extrusion

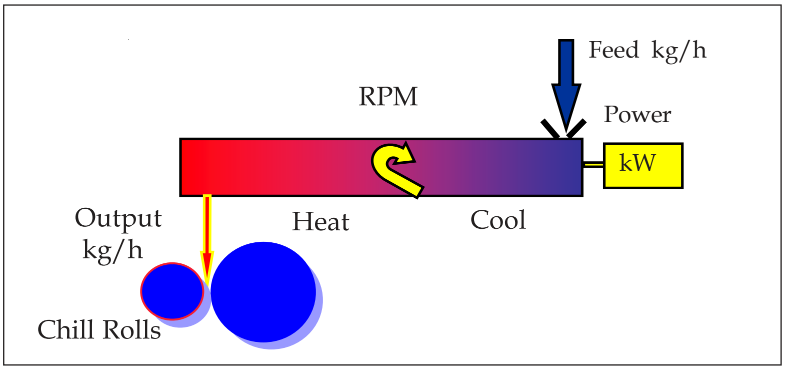
The blend of powders and resins is metered into the extruder, where it is melted and the different ingredients dispersed within the resin, using shear forces of the screws. Efficient mixing and narrow residence time distribution are key elements in this process. The melt mixing in an extruder is designed to operate as close to the melting point as possible, to minimise the risk of cross-linking reactions that will make the product unsuitable for Spraying later.

Cooling and Flaking

Once the product has been mixed it needs to be rapidly cooled and converted into a form that can be handled in downstream processes. Passing the melt through two cooled rolls to make a thin sheet and then via a conveyor belt into a flaking unit where the brittle sheet is broken into flakes usually does this.

Fine Grinding

The final stage before the powder is ready to be applied is a grinding operation, which converts the flakes into a fine powder with a narrow and well-defined particle size distribution.



Development Equipment

Before putting a new coating into full-scale production, different formulations need to be tested and sample quantities made for customer evaluation. This can be a very expensive operation if large production scale equipment is used. Not only is the quantity of materials large and costly, but also the diversion of production plant from manufacture will reduce efficiency and have a negative effect on profits. The use of small-scale equipment that closely matches the production plant will be a very profitable investment, for research and development.

Thermo Electron is one of the world's largest Instrument suppliers, and, is able to offer equipment to assist in these developments.

PRISM joined the Thermo Electron Corporation in 2001, and as part of the Materials Characterisation business, works alongside other Thermo businesses, developing and selling instruments and equipment for materials testing.

Pre-Mixing

PRISM high-speed mixers are used to pre-mix the many different ingredients, which include resins, pigments, additives and cross-linking agents. High speed mixing gives a more uniform blend because the resin flakes are broken down and the resulting powder is more uniform and easier to meter.

Thermo Electron Corporation offer the small PRISM bench-top mixers with easily removable bowls of 3 litre and 5 litre capacity. The bowl can be placed onto scales, and each ingredient weighed in. Once it is charged the bowl is returned to

PRISM Pilot 3 Change bowl mixer

the mixer, and the batch blended at high speed for a fixed time. The mixers are supplied with process timers to ensure repeatable processes.
After mixing the bowl is again removed and taken to the extruder where the pre-mix is to be processed.

PRISM PM 200 High speed mixer

Larger PRISM mixers are available with capacities up to 200 litres for production systems. These mixers have fixed bowls and use pneumatic valves to discharge the product.

The alternative to high speed mixing is the low energy blending. On a laboratory scale this is usually done by simply shaking the ingredients in a bag.

PRISM RB 1000 Low speed Blender

For production Thermo Electron can offer PRISM low speed batch mixers of 1000 litre capacity.

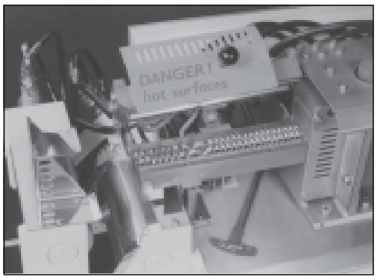
Extrusion

In the extrusion stage it is important to minimise any dead areas in the process where product could be trapped and start to react. For this reason self-wiping extruders are the preferred equipment. There are special single screw extruders, which operate through a combination of rotation and reciprocation to achieve the self-wiping properties. But like most single screws there can be limits to their conveying capacity, due to the transport properties of a single screw extruder. Use of co-rotating and intermeshing twin-screw extruders, provides an ideal means of producing thermo-set powder coatings. Firstly the screws are self-wiping which eliminates dead areas in the extruder barrel. Secondly twin screws have excellent product conveying properties, which makes them particularly useful for reworking powder fines. Thirdly the independence of screw speed and feed rate allows a far greater degree of control over the mixing process.

PRISM TSE 16 PC
Powder Coating Extrusion line

When looking at laboratory extruders, the PRISM range has the benefit of an opening barrel. This feature allows easy access to the screws and barrel if a thorough clean down is required where cross product contamination would be a major problem.

At the smallest scale, the 16mm extruder is bench mounted and can be supplied with an integral feeder and chill rolls to provide a complete extrusion line, operated from a single, simple control panel.



Open Barrel on PRISM TSE 16 PC

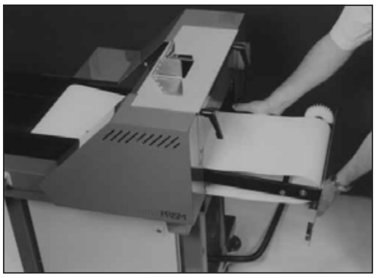
The single-phase power supply and small cooling water demand, allow this equipment to be operated on any laboratory bench. This small extruder can process samples as small as 200 g, or operate continuously at up to 10 kg/h.
The next size PRISM twin-screw is 24 mm screw diameter, and is a floor-mounted extruder with matching chill rolls and outputs in the 50-100 kg/h range.
Thermo Electron Corporation also offers a production scale extruder, the PRISM TSE 36 PC, with outputs over 250 kg/h.

PRISM TSE 24
PC Powder Coating Extrusion line

Screw removal from PRISM TSE 24 PC

Cooling and Flaking

After extrusion the product must be cooled as rapidly as possible to minimise the risk of reaction. The use of a close-coupled chill roll was described with the PRISM 16mm extruder above.
On larger systems the rolls are supplemented with a belt to convey the cooled sheet into the flaking unit. As with all powder coating process equipment, ease of cleaning is a key element to minimise downtime and maximise productivity of the line. PRISM chill roll/flakers units have easy opening and an added benefit of a removable belt cartridge.



Removable Belt Cartridge on PRISM Chill Rolls

Fine Grinding

The final step in the manufacture of powder coatings is a fine grinding to give a fixed range of particle sizes to optimise the spraying and surface finish of the article being coated. In this operation high speed mills re used in conjunction with cyclone classifiers, that are set up to deliver a narrow range of particle sizes.

There is a movement to thinner coatings in the European market, and this is forcing powder coating manufacturers to look very carefully at their grinding process to enable the coaters to achieve the this film required.

Twin-screw Geometry

When designing a twin-screw extruder, the machinery manufacturer has to set a number of fixed parameters and these will define the performance of the extruder. It is normal to adopt a common design or geometry that will be constant across the range of sizes being built.

There are two key parameters that define the properties.
(a) Motor Power and
(b) Free Volume
Because the output of the extruder is determined by its ability to melt and mix the resin, an increase in motor power will normally increase output for a given screw diameter.

The Torque transmission of a shaft is proportional to the cube of the diameter:

$$(T \sim D^3)$$

This means that to increase torque and hence power of the motor requires an increase in shaft diameter. But an increase in shaft diameter means changing the shape of the screw and reducing the free volume in the barrel.

Melt mixing of powder coating products is not a high energy process in comparison with many thermoplastics extrusions, and in addition many extruders are used to process fines which have very low bulk density. This means that for a powder coatings extrusion, free volume is often more critical than absolute motor power. In fact one of the manufacturers of large production extruders has recently offered 50% higher output from the same sized extruder by increasing free volume (ref 1).

Scale-up and Heat Transfer

Heat transfer in an extruder is dependent on the ratio of surface area to volume. This means that if you double the diameter of the screws, then volume (and hence throughput) will increase by 8 times while surface area, and (hence heat transfer capability) will increase only 4 times. In other words, the ratio of the barrel surface area available for heat transfer to the volume of material in the extruder is **inversely proportional** to the barrel diameter.

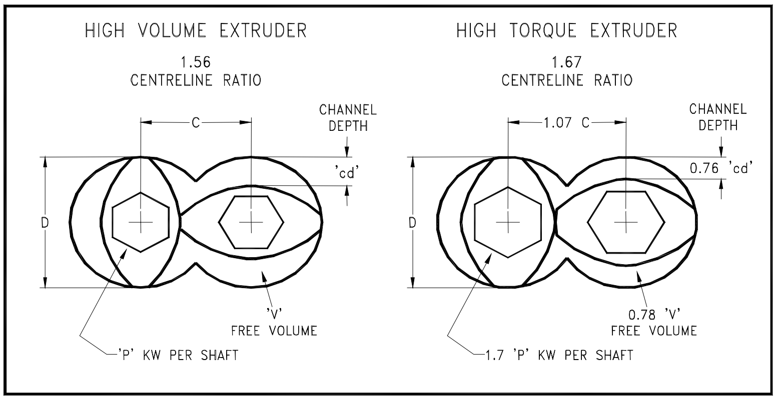
This chart shows for the PRISM range of twin screws, how there is three times the barrel surface area available for heat transfer for every unit volume on our 16 mm twin screw in comparison to our 48 mm production extruder. So the key factor for reliable scale-up from a small to a large twin-screw extruder is to run “Adiabatically“ on the small extruder.

In a truly adiabatic operation, there is no heat transfer between the barrel wall and the polymer melt. In reality this is difficult to achieve, however it can be approached with the following steps.
Allow the extruder to heat up to a temperature that matches the melting point of the resin to be processed.

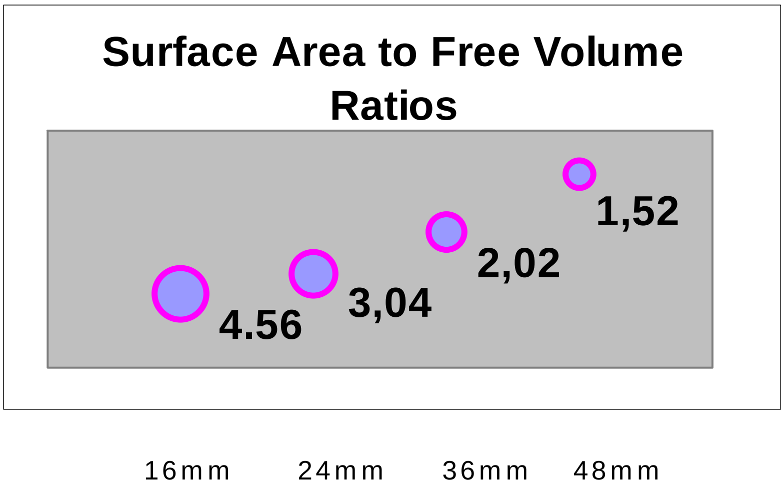
Begin extrusion and monitor melt temperatures either within the barrel or at the discharge of the extruder.

If these are very different from the barrel temperatures, align the barrel to match the melt. However a word of caution, because melt thermocouples embedded in the barrel wall are greatly influenced by the temperature of the metal itself. I have seen many operators try to reduce processing temperatures in a twin-screw compounder by cooling the barrel. They do see an apparent reduction in the melt temperature, only to find that there is no difference in the product discharge temperature. That is an expensive way to heat water, and a process that will not scale reliably.

If melt temperatures are still outside the limits, then you should make use of the several degrees of freedom in a twin screw extruder to modify processing parameters such as screw speed and feed rate.
In the extreme, if these measures do not work, then step changes such as the screw configuration itself should be reviewed.



Comparison of two twin-screw geometries for same screw diameter



Conclusion

The demand for Powder Coatings has shown consistent growth over the last 20 years as this environmentally friendly process has replaced wet paint in many traditional applications.
As products are developed for new applications, including wood and glass coatings, and the use in automobile finishing becomes established, it will be important for the powder coating producer to stay at the forefront of this technology.
Use of small and flexible process equipment to support these developments will continue to be a key element in a company's research, development and quality control.

Referenses

(1) Coperion Sales literature for MEGAvolume ZSK

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