CONTINUOUS PRODUCTION OF ADHESIVES COMPOUNDING

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1. Introduction

Over the last few years, the production of hot-melts, sealing, and waterproofing sheets has changed due to advances in technology, with resulting improvements in quality, productivity, flexibility, and ecology. A continuous production system, featuring short residence times, high mixing power even at high viscosity, and modular/interchangeable composition of the line design, is the way to achieve these ambitious goals. The corotating twin-screw extruder is the machine which best meets these requirements.

1.1. Presentation

MARIS has been manufacturing extruders for the production and transformation of plastic materials since the early 1960s. Over the last 20 years, MARIS has been developing continuous mixing extruders with corotating screws.

Given the experience that MARIS has developed over this time, the versatility, and adaptability of their extruders, MARIS has the ability to design and manufacture lines for the continuous mixing and homogenizing of materials to produce hot-melt adhesive, reactive adhesives, sealing, and waterproofing bituminous systems.

1.2. Comparison Between Discontinuous and Continuous Production

The example used below for hot-melt production can also be considered relevant for other adhesive products and waterproof coverings, which will be briefly described later in the report. With MARIS continuous mixing-extruders, the polymer degradation is reduced to very low levels. The color and
toughness of the final product also equals that produced by the solvent process. In fact, the material in an extruder is in a confined space, virtually without oxygen, and it remains there for a very short time (about 0.5 - 2 minutes). Therefore, the "heat history" values that can degrade the material are not reached.

Another advantage of the continuous process is the low energy requirement: only 0.08 – 0.30 kWh/kg required for the production of the usual hot melt blends for adhesive tapes and structural adhesives. This result has been achieved through the dosing and distributing of the mechanical and thermal stresses in order to obtain excellent homogenization in a very short residence time, which results in a material that has not been overheated or overstressed during the production process.

\[
SPECIFIC\ ENERGY_{\text{net}}\ (\text{kWh/kg}) = \frac{E_\eta + E_r - E_c}{Q}
\]

- \( E_\eta \) screws rotational heat
- \( E_r \) convective heat from heaters
- \( E_c \) heat removed by cooling system
- \( Q \) polymer output
- \( t \) residence time
- \( \delta \) melt density

<table>
<thead>
<tr>
<th>SPECIES</th>
<th>SPECIFIC ENERGY ( (\text{kWh/kg}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIS/SBS</td>
<td>0.13 – 0.18</td>
</tr>
<tr>
<td>SBS/NR</td>
<td>0.17 – 0.28</td>
</tr>
<tr>
<td>NR</td>
<td>0.17 – 0.35</td>
</tr>
<tr>
<td>EVA</td>
<td>0.09 – 0.13</td>
</tr>
<tr>
<td>NR</td>
<td>0.20 – 0.36</td>
</tr>
</tbody>
</table>

Lastly, but not least important, it should be taken into consideration the remarkable rationalization of human, technical, and financial resources:
- The different raw materials are dosed by a gravimetric feeders; thus avoiding the need for components premixing
- The melted and homogenized components of the blend are directly sent to a stocking tank through hermetically sealed pipes. It results in an improvement of working environment conditions and a reduction in the necessary space.
- The degassing and filtering operations are carried out directly during the extrusion.
- The temperature of hot-melt produced during the extrusion is suitable for the next coating operation.
- The fire risk is remarkably reduced in comparison with the solvent and discontinuous melting methods.
- No solvent wastes or water treatment are required.
2. MARIS Compounding Process

2.1. Functional Modules
Before describing the use of corotating twin-screw extruders for the continuous production of HMPSA, it is useful to make a short characterization of the compounding-extrusion process. The process lay-out of MARIS corotating twin-screw extruders is based on the functional modules concept composed by the barrels and inside by the screws and kneading elements of variable geometry, assembled on shafts transmitting the torque (mechanical work) to the material.

The functional modules which compose an extruder for the production of hot-melt, adhesives, etc. can be defined as follows:
Thanks to the functional modules, MARIS extruders meet the process requirements of any compounding or reactive extrusion allowing the continuous control of the main process parameters, such as:
- temperature profile
- shear stress and pressure distribution along the whole material flow inside the extruder (screw profile)
- residence time distribution
- residual pressure in the degassing zone

2.2. Screw Elements Geometry
The final results of the extrusion process purpose are directly related to the geometry and the typology of the screw parts, which compose the conveying and mixing of the process zones. There are three (3) geometry types of elements used in the corotating twin-screw extruders. They are as follows:

**MELTING PLASTICISING**
Composed of one or more barrel sectors having inside transport screw elements and a block of kneading elements with suitable geometry

**MAIN FEEDING**
Composed of a barrel with upper hole and hopper; in this zone are normally assembled high conveying capacity screws elements.

**SIDE FEEDING**
Composed of barrels with particular presets for the introduction of hydrocarbonic resins and/ or filler into the melt polymer.

**LIQUID INJECTION**
Composed of barrel sector with a particular preset for the injection of liquid resins, plasticizer oils and solvents

**DEGASSING**
Composed of one or more barrel sectors with suitable chimney for gas extraction and screw elements to create a sealed chamber

**PRESSURE BUILD-UP**
Composed of one or more barrel sectors with compression and transport screw elements to pump the material through the die.
**Mono-lobe:** mainly used in the introduction zones when low bulk density powders with low internal friction are used, in order to increase the axial conveying capacity.

**Bi-lobal:** the most commonly used, mainly in compounding, due to the good mixing capacity and the possibility to have high channel depths for transport and, therefore, high free volumes and high productivity.

**Tri-lobal:** used in high quality organic pigment masterbatches and in special reactive extrusion.

The geometry of the intermeshing and self-cleaning screws depends on the ratio between the screws centerline $Cl$ and the screws diameter $D$: the maximum screw channel depth is obtained by the following equation:

$$H_{\text{max}} = D \left[ 1 - \left( \frac{Cl}{D} \right) \right]$$

Where:
- $H_{\text{max}}$ = max channel depth
- $D$ = external screw diameter
- $Cl$ = screw centerline

This means that, with the same screw diameter, the channel depth $H$ is inversely proportional to the screw centerline distance.

The other value which defines the geometry and the channel depth is the ratio between the external ($D$), and internal screws diameter ($d$), which establish both the free sections and the constructive limits of the multi-flight screws.
# of Flights | maximum ratio D / d | normal range D / d
--- | --- | ---
1 | depends on the element type that follows | |
2 | < 2.14 | 1.4 – 1.7 |
3 | < 1.37 | 1.2 – 1.3 |

## 2.3 Conveying Elements

In the conveying elements geometry, there is no transfer between the flow channels. The mixing effect is due to the shear rate inside the single channel.

2.3.1 Conveying Screw Element

There is no transfer between the channels.

## 2.4 Mixing Elements

The key to the success of the corotating twin screw extruder is the great flexibility of the process due to the possibility to modulate the stress and the dwell time of the material in the process zone over an extremely wide range.
The kneading elements geometry allows the increase of the radial mixing of material inside the barrel by keeping the flow channels in contact with each other.

The level of this effect depends on:

1 - **Number of Lobes**

O.A = OFFSET ANGLE  
W = ELEMENT WIDTH

O.A = OFFSET ANGLE  
W = ELEMENT WIDTH
2 - "Offset angle" between the elements (O.A)

Kneading Elements Conveying Capacity Versus Elements Offset Angle

3 - Kneading element width (W)

Kneading Elements Conveying Capacity Versus Elements Width

The following table shows an elementary and practical synthesis of the different mixing elements performances.

<table>
<thead>
<tr>
<th>O.A</th>
<th>W</th>
</tr>
</thead>
<tbody>
<tr>
<td>30°</td>
<td>0.12D</td>
</tr>
<tr>
<td>45°</td>
<td>0.12D</td>
</tr>
<tr>
<td>60°</td>
<td>0.35D</td>
</tr>
<tr>
<td>90°</td>
<td>0.35D</td>
</tr>
</tbody>
</table>

2.5 Corotating Twin-Screw Extruder Melting and Dispersion Mechanism

The necessary temperature increase for melting or softening the polymers/elastomers needs energy; in a corotating twin screws extruder this is generated via the following mechanisms:

1 **Pressure**, converted into thermal energy

A pressure differential $\Delta P$, appears along the screws every time the polymer flow meets screws or kneading elements, which tries to stop it and requires a higher pressure to overcome it; generally this is created by reverse screw elements.

$$\Delta T_p (^\circ C) = \frac{\Delta P}{C_v * \delta}$$

2 **Shear stress**, converted into thermal energy

The polymer inside the extruder, which moves with a shear rate $\gamma$ between the mixing
elements and the barrel wall and having a shear viscosity \( \eta_f \), develops a shear stress

\[ \tau = \eta_f \gamma \]

This increases the temperature according to the following equation:

\[ \Delta T \text{ °C} = \frac{t \eta \gamma^{1+n}}{C_v \delta} \]

Where:
- \( \Delta P \) = local pressure in the different parts of the screw
- \( \eta \) = polymer viscosity
- \( \gamma \) = shear rate
- \( n \) = polymer power law index
- \( C_v \) = polymer specific heat
- \( \delta \) = polymer density
- \( t \) = residential time

The combination in the screw profile sequence of these two main variables creates inside the process zones of the extruder a thermal and mixing profile, which can be adjusted according to the thermal and rheological features of the raw materials and the needs of the different compounding process phases.

3. Continuous Hot-Melt Production Raw Materials for Adhesives

Different polymer types are used as carriers for the production of adhesives; the most important are:

- Polyethylene vinyl acetate
- SBS, SIS, SEBS blocks copolymers, or their blends
- Natural rubber blends with SIS or SBS block copolymers
- Natural rubber
- Linear polyester
- Polyurethane via reactive extrusion

As tackifer:

- Natural colophon
- Synthetic coumarone or hydro-carbonic resins

As plasticizer:

- Paraffin and naphtha oil
Additives and fillers

- Antioxidant, pigments
- Inorganic fillers, cellulose esters
- Chemical reactants

3.1 Continuous Compounding Process
As we have seen before, the process lay-out of MARIS corotating twin-screw extruders requires the careful design of the functional modules sequence and the process parameters in conjunction with raw materials features.

This allows the maintenance of the level of energy transferred to the compound, close to the requirements due to the enthalpic and rheological features, in order to reach high level of mixing-homogenization effect, but without overstressing the adhesive compounds.

Multi Stage Feeding
The multi stage feeding of the different components without pre-mixing is imposed by the rheology and thermal behavior of raw materials.
In fact, it is important not to submit all materials to the same thermal stress, because they have very different physical-chemical and rheological properties.

Since SBS and/or SIS are more viscous than the tackifier resins, it is preferable not to feed them at the same point because the low resins viscosity would make it difficult to soften the rubber.

**Multistage Screw Configuration**

The main feeding port is fed:
1. The rubber crumbs or granules
2. The antioxidant, the process additives, and the pigments. All these powder materials, used in small quantities, could be premixed and dosed with a gravimetric feeder.

The rubber is softened with dispersing and mixing elements and the viscous mass is homogenized before the introduction of tackifier resins

**Natural Rubber Mastication**
The natural rubber based adhesives require a step of mixing to reduce the molecular weight and the presence of entanglements. The natural rubber mixing is strongly influenced by screw configuration and speed rate, barrel temperature, and residence time.

**Tackifier Melting and Mixing**
The tackifier resin flakes can be introduced into the extruder through special jacked side feeders fit to convey low melting point resins.
If the resins are supplied in hot liquid form, they can be injected through a gravimetric dosing pump directly into the barrels. The separate feeding available between the different feed ports is a very important benefit of the twin-screw extruder. The proper location of feed depends on the viscosity of the rubber phase and the melt temperatures of the different solid resins to be used.

**Oil and Solvents Feeding and Mixing**
The liquid components, such as oils, solvents, or re-melted adhesive, are injected into the preset barrels with a liquid injector through gravimetric dosing pumps.

In this zone the mixing elements act to distribute the oil or solvent in the compounds. After the oil/solvents feeding, the final melt viscosity is achieved. To avoid cleaning operations in the extruders due to the change of colors, it is possible to use paste pigments dosed and injected directly into the last part of the connection pipe to the coater or packaging unit, and mixers with one or more static mixer inside the pipe.

**Vacuum Degassing and Finishing**
After the last homogenization, the hot melt is degassed by a vacuum pump to remove air bubbles, moisture, or any volatile matters. In the final section of the extruder, which produces the pressure build-up, the viscous mass is pumped out and the adhesive can then be finished in different ways:

a) Through a circular section die directly connected to the stocking and filtering system before the coating or the packaging line

b) Through an underwater pelletizer, i.e. GALA type, the adhesive coming from the extruder is forced through the die having a series of holes in a circular pattern. The polymer emerging from the die holes is cut into pellets by rotating blades and is solidified by the water passing through the underwater cutting chamber. The water transports the pellets to a centrifugal dryer where the pellets are dried and discharged.

c) Using a gear pump, a special profile die, and rod down stream pulling equipment, it is possible to produce a continuous line of adhesive stick.
TECH 31 Technical Seminar Speaker

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Alessandro Maris is a member of the board of directors at F.III MARIS S.p.A. and president of the family company’s United States branch located in East Brunswick, N.J. After receiving his Science Technical Institute diploma at Law University, he joined the family company and advanced to his current position.