

Adhesive Processing using a Planetary Extruder

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Abstract

The large contact surface, the highly efficient and precise heating/cooling capabilities and a modular design concept, make the Planetary Roller Extruder (PRE) best suited to replace the traditional discontinuous mixing processes (e.g. Banbury mixers) of today. The PRE has additional major advantages, these include: having the ability to separate thermal energy from mechanical/shear energy and control each independently of each other. This cost effective process has now been proven over the years; e. g. in the compounding of rubber based Pressure Sensitive Adhesives (PSA).

Introduction

Traditionally, many PSA's are compounded in multi-step processes with the use of Banbury mixers, open mills for cooling and mixing of additional components down-stream or the use of High Viscosity-Mixers for adding liquids and then stored until use in a coating line. This discontinuous batch processing has high operating costs for personal, material handling and storage and is associated to the known quality problems resulting from batch-to-batch variations. For those processes, innovative technologies are in demand. One approach is the use of a PRE.

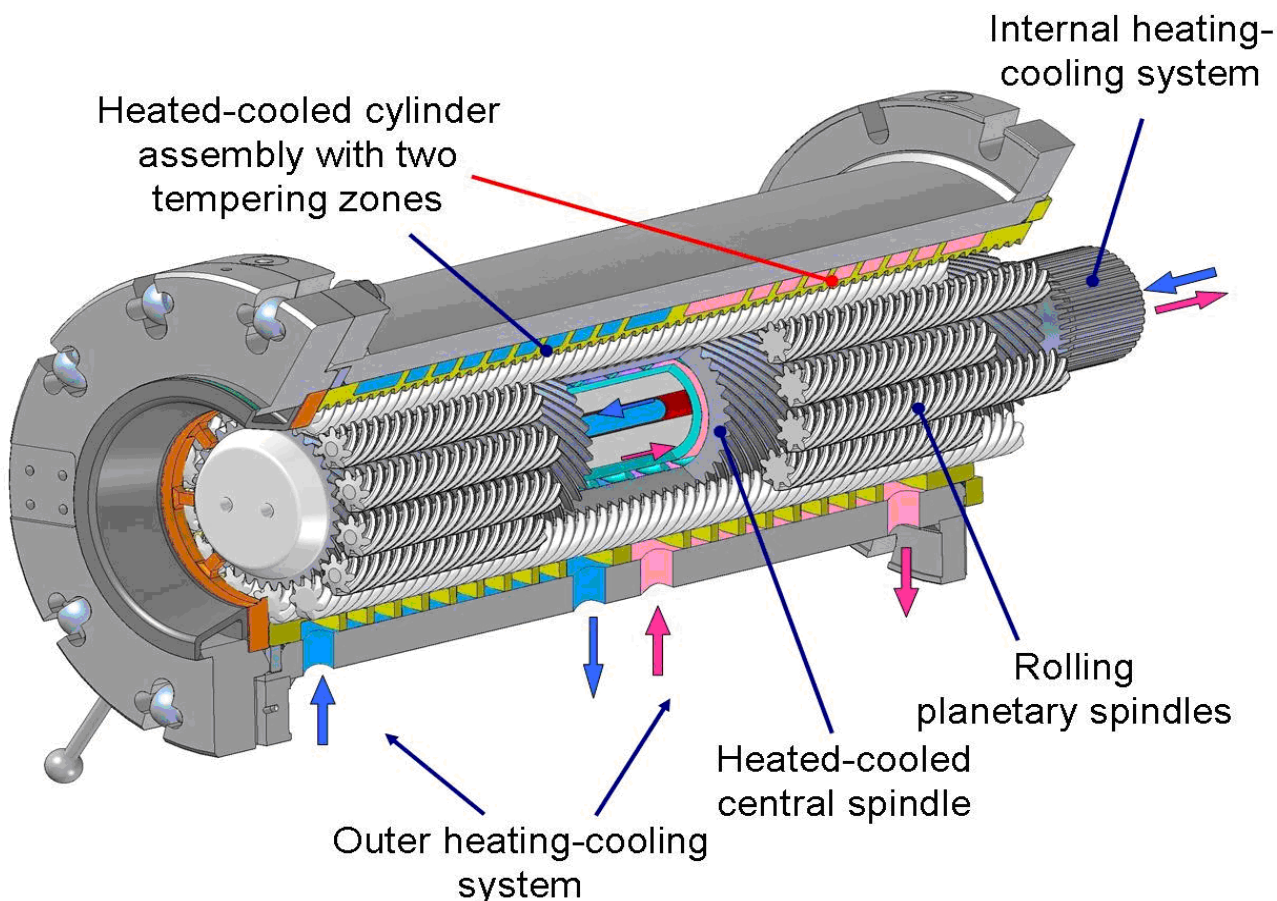


Figure 1. Sectional drawing of a planetary roller cylinder (PRE module) with driven temperature controlled central spindle, set of planetary spindles and a two zone, liquid heated or cooled barrel.

A planetary roller extruder (Figure 1), is able to masticate, mix, homogenize, disperse and de-gas highly viscous substrates. Moreover it can serve as a continuous reactor for chemical conversions, for

example in the range of high viscous thermoplastic melts. Thereby, the PRE presents its superiority over traditional batch-reaction processes and diverse advantages, when compared to other extrusion processes. Already almost a decade ago, early trials with phenolic resins [1] have proven this. To the central unique features of the PRE belong, beside its remarkable large contact surface, the optimized heat transfer between processed material and heating/cooling medium as well as its modular construction and the resulting manifold of possible system configurations. Depending on size and operation mode of the PRE, a large process window

exists with scalable throughputs ranging from several kilograms up to much more than ten tons per hour.

With regard to the available contact surface area the PRE is superior by a factor five to ten in comparison to other common compounding systems, e.g. other types of extruders [2].

Contact Surface Area of a PRE

Already a simple calculation makes it clear what contact surfaces are typically available or can be achieved in a PRE (Figure 2).

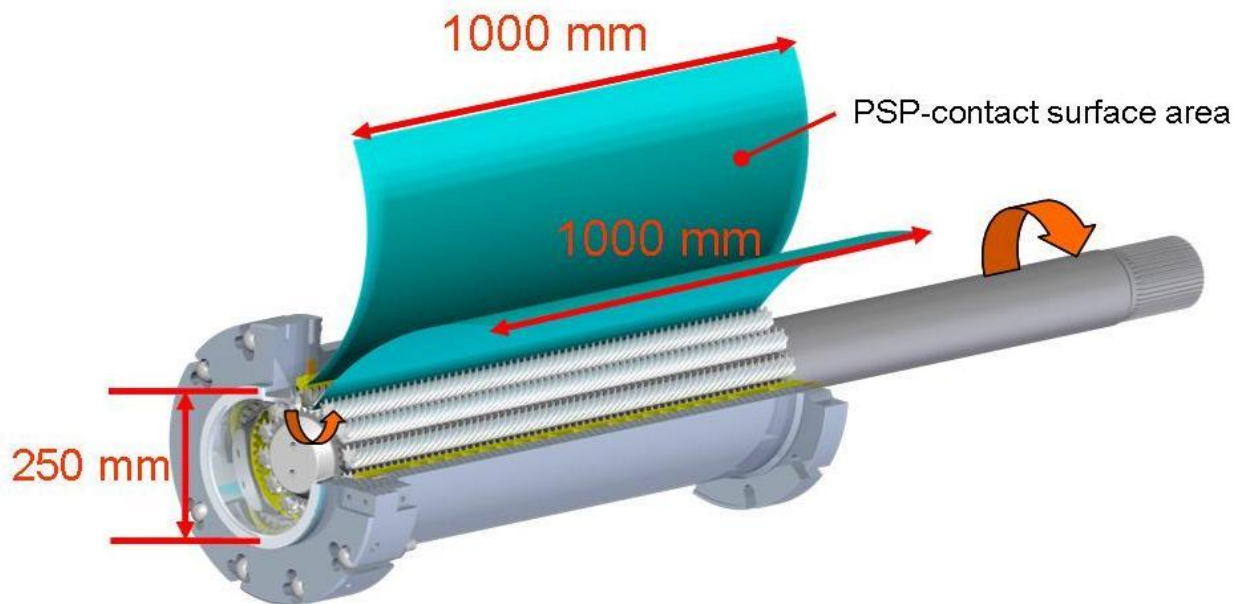


Figure 2. The valuation of the contact surface area of a planetary spindle (PSP) of a PRE module

Calculation of a PRE module of 1,000 mm length with a diameter of 250 mm, the module is equipped with a maximum amount of 14 planets. With a gear tooth module of $m = 3.5$ each of these planetary spindles has a total surface of approx. $1/6 \text{ m}^2$. This equates to a contact surface for one complete rotation to be $1/3 \text{ m}^2$.

$$\begin{aligned} &1/6 \text{ m}^2 \text{ with the teething of the cylinder assembly} + \\ &1/6 \text{ m}^2 \text{ with the teething of the central spindle} \\ &= 1/3 \text{ m}^2. \end{aligned}$$

Due to the diameter ratio, for each rotation of the central spindle the planetary spindles rotate approximately three to four times, thus the contact surface available for one rotation of the central spindle amounts to more than 1 m^2 :

$$1/3 \text{ m}^2 \cdot 3 = 1 \text{ m}^2.$$

With 14 planetary spindles this adds up to total of 14 m^2 per central spindle rotation. Thus a rotation of the central spindle at 100 min^{-1} results into a contact surface of:

$$14 \text{ m}^2 \cdot 100 \text{ min}^{-1} = \mathbf{1,400 \text{ m}^2/\text{min}}.$$

This value corresponds to an area of more than five tennis courts ($23.77 \text{ m} \times 10.97 \text{ m}$) or one fifth of a Soccer field ($105 \text{ m} \times 68 \text{ m}$).

The free volume of a module such equipped with standard spindles amounts to only around 9.4 liters. The large contact surface ensures that, also at high conveying speeds a thorough mixing and homogenization is respectively secured. The small volume is providing an increase in operational and environmental safety margins. With reactive processing a relatively small quantity of reactive components are in the extruder.

Based on a simplified description of the screw geometry in the PRE, the spindles as well as the free spaces between the spindles can be described by means of a mathematic model [3].

On the basis of this data the process behavior of the PRE can be approximately mathematically determined and described, e.g. the flow conditions as well as the compression and conveying behavior. The process data calculated in this way have a variation of less than 10 percent from the measured values, which, in light of the made simplification, can be regarded as acceptable. The empiric knowledge in this field is actually, however, still clearly superior to the calculations in practical applications.

Thermo-Dynamics in a PRE

Mainly three parameters govern the heat flow Q from the heating/cooling medium to the transported material through the wall of the cylinder assembly and the internally heated/cooled central spindle respectively:

- The heat conductance of the wall material λ ;
- The thickness of the wall h , at which due to a weighted average value to compensate the influence of the tooth pitch and height will be taken into account;
- The amount of the temperature gradient $|T_1 - T_2|$ between heating/cooling medium (T_1) and transported material (T_2).

In mathematical terms, this is represented by the relation:

$$Q \sim \lambda \cdot |T_1 - T_2| / h.$$

A differentiation can be made between two scenarios:

Maximum Heating/Cooling: The energy transfer takes place at great temperature gradient and final temperature of the transported material is depending mainly on the residence time, beside other material related factors as well as mechanical energy input.

Precise Temperature Control: A temperature of the heating/cooling medium is chosen which does not or only slightly differ from the desired final temperature of the transported material. Now the (constant) heat conductance and the thickness of the wall material define essentially the heat transfer which continues until thermal equilibrium, thus a quasi-stationary state, is reached ($|T_1 - T_2| = 0$). In order to achieve this an adequate dwell time must be available.

For both scenarios a thinner wall thickness is directly improving available heat transfer and minimizing dT .

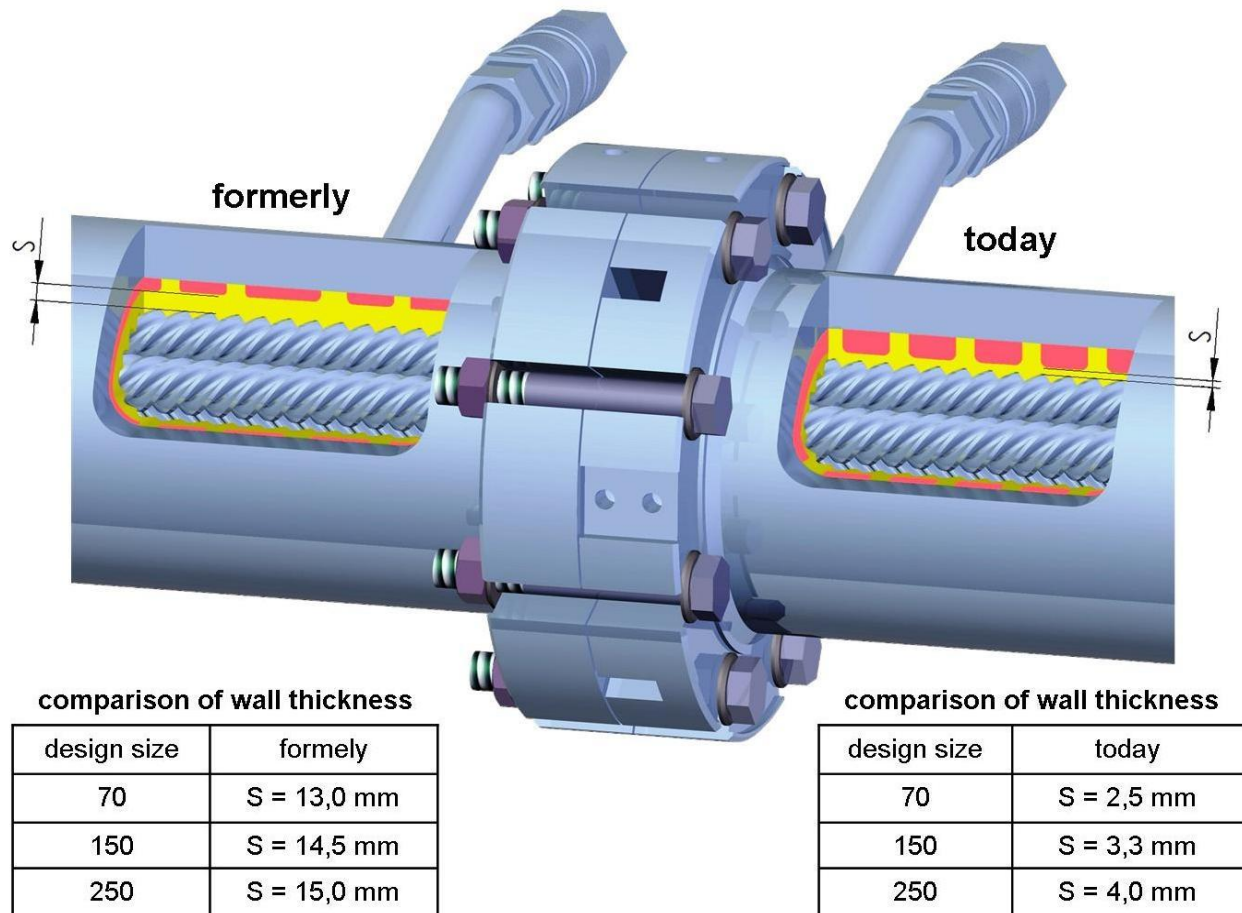


Figure 3. Comparison of the inner wall thickness (yellow) of a PRE cylinder assembly before (left) and after (right) the optimization

In both cases the specific design of the PRE has a positive effect during operation, namely:

- the large contact surface area which leads to a wide homogeneous temperature distribution in the transported material;
- the relatively thin, optimized wall thickness (“new thermodynamic”, Figure 3, on the right), which separates the heating/cooling medium in the cylinder assembly and in the central spindle from the transported material and thus enables maximum heat transfer at lowest possible dT.

Temperature peaks or low points, which e.g. could lead to decomposition and a high increase of viscosity, respectively, or even to solidification of the transported material, can be thus avoided.

Special constructional measures ensure that the steel wall of the cylinder assembly at a thickness of minimum only two to three millimeters resists

reliably the internal pressure in the extruder. At conventional construction this would require a wall thickness of minimum 13 mm. A still finer temperature control can be made possible in that the heating/cooling of the cylinder assembly can be executed in two sequentially arranged sections of a half cylinder length each.

Using the model described above, also the heat flows in the PRE could be evaluated. Thereby the deviation of measured and calculated temperature values amounted to a maximum of ten degrees and was thus very reliable [3].

Due to the more efficient possibilities of heating/cooling in the cylinder assembly and in the central spindle the PRE is not – like other extruder types – exclusively dependent on using the mechanical drive energy. Thus reducing and being able to control the resulting friction and shearing forces, still achieving a balanced and controllable heat input into the processed material at various outputs.

This has several consequences for the operation of such a device:

- The necessary drive capacity is normally lower for the PRE than for other extruder types for the same outputs.
- Deviations of temperature from the set value can easily be compensated and avoided, respectively, over the total length of the line.
- The adjustment of temperature profiles is independently possible to control the rheological characteristics of the transported material which cause friction and shearing.
- Due to the heating/cooling of the cylinder assemblies, radiation losses do not at all or only insignificantly affect the material temperature inside of the extruder.

In practical operation, these characteristics of the PRE give rise to a set of advantages, e.g.

- High and reproducible product quality due to an exact controllable reaction conditions, e.g. precise temperature and pressure profiles;
- Less emission due to controlled discharge and, if necessary, condensation of volatile by-products (gases, light ends);
- Low specific power requirement for heating/cooling and drive, respectively, in comparison with both stirred vessels or conventional extruders.

Modular Design of a PRE

The central spindle of a planetary roller extruder can carry up to eight separate modules [4]. Depending on the requested capacity of the system, modules are available in a diameter range between 50 mm and 650mm and with lengths of 400 mm up to 1,400 mm.

Capacities ranging from 2 kg/h to more than 10 t/h have been realized in the PSA industry.

Depending on the diameter of the module, up to 24 planetary spindles can be positioned in the cylinder assembly. Depending on the process, the gear tooth module of the spindles can be varied between $m = 1.5$ and $m = 10$. Moreover, planetary spindles are available in different designs. Therefore, the contact surface and the free volume in the extruder are heavily dependent on the type of spindles used. Besides the standard spindle there are for example the following designs (Figure 4) in use, each with specific operational characteristics and fields of application:

- Transversal mixing planetary spindle; A continuously thin dispersive mixing with an additional intermixing down the length
- Nap spindle; the nap spindle increases mechanical shear and residence time.
- TT2 nap spindle; increases shear and reduces residence times
- Transport and drying spindle; highest amount of volume, lowest amount of shear
- TT3 spindle; increase in amount of volume, lower amount of shear.
- Zone spindle; possible to combine physical properties as required.

Transversal mixing planetary spindle



Nap spindle



TT2 nap spindle



Transport- and drying spindle TT1



Transport- and drying spindle TT3



Zone spindle



Figure 4. Variations of planetary spindles

Approximately one dozen different system assembly parts form a toolbox out of which – depending on the customers' individual requirements – tailor-made PRE systems can be designed. Several basic classes of available aggregates can be differentiated:

- Inlet Units
(feeding, injection, lateral feeding, feed valve),
- Processing Units
(degassing, degassing between modules, dispersion and intermediate stop rings respectively),
- Outlet Units
(round die, radial pelletizer, hot cut, cutting device),
- Special Elementes
(inline- resp. online-pressure-, temperature- and colour measurement systems).

A further advantage, especially in comparison with conventional twin screw or double helix extruders, is the fact that the PRE can be operated without problems, with fill degrees of 10 percent. This provides a maximum degree of flexibility when adjusting the overall capacity of the system.

Due to its modular construction concept, PREs can be tailor-made, in order to run successively special sequences of physical and chemical process steps. The individually configurable modules, so called cylinder assemblies, can be arranged in series on one common central spindle. Each of these modules has two separately temperature-controlled zones, substances can be supplied or discharged between the modules. Measurements can be made there as well by implementation of temperature, pressure or colorimetric sensors. Depending on the type of planetary spindles employed and the type of tooth used, throughput, heat exchanging capacity and mixing of the material can be with a large process window and tolerances. This flexibility can be ideally employed when the PRE is used in reactive processing. The individual modules are designed for operating temperatures between -30 and +400 °C so that ice cream as well as high-melt index polymers can be processed in a PRE.

The Process

Figure 5 shows us a pressure sensitive process with the use of a modular 4 PRE configuration. All components or premixes (Figure 6) are gravimetrically fed into the feeding section of the PRE. The first modular section, made up of 6 Nap spindles, has the function of rubber mastication, mass temperature is controlled to approximately 160°C and initial mixing of the formulation takes place. The fill-

degree and residence time is controlled through the extruder rpm's and dispersion ring diameter. The mass is then passed into the modular 2 section where, in this case a process oil is injected, additional CaCO₃ is added over a side feeder, mixed and at the same time the mass is cooled to approximately 130 – 140°C. In the third modular section a coupling agent is injected and the mass is reduced further in

temperature. The fourth modular section is used for end temperature control, in this case approximately 110°C and a vacuum is applied to remove all volatiles from the mass. At the end of the extruder a gear pump is used to control the fill degree of the fourth section and transfer the mass directly to the coating process.

Pressure Sensitive Adhesive Process

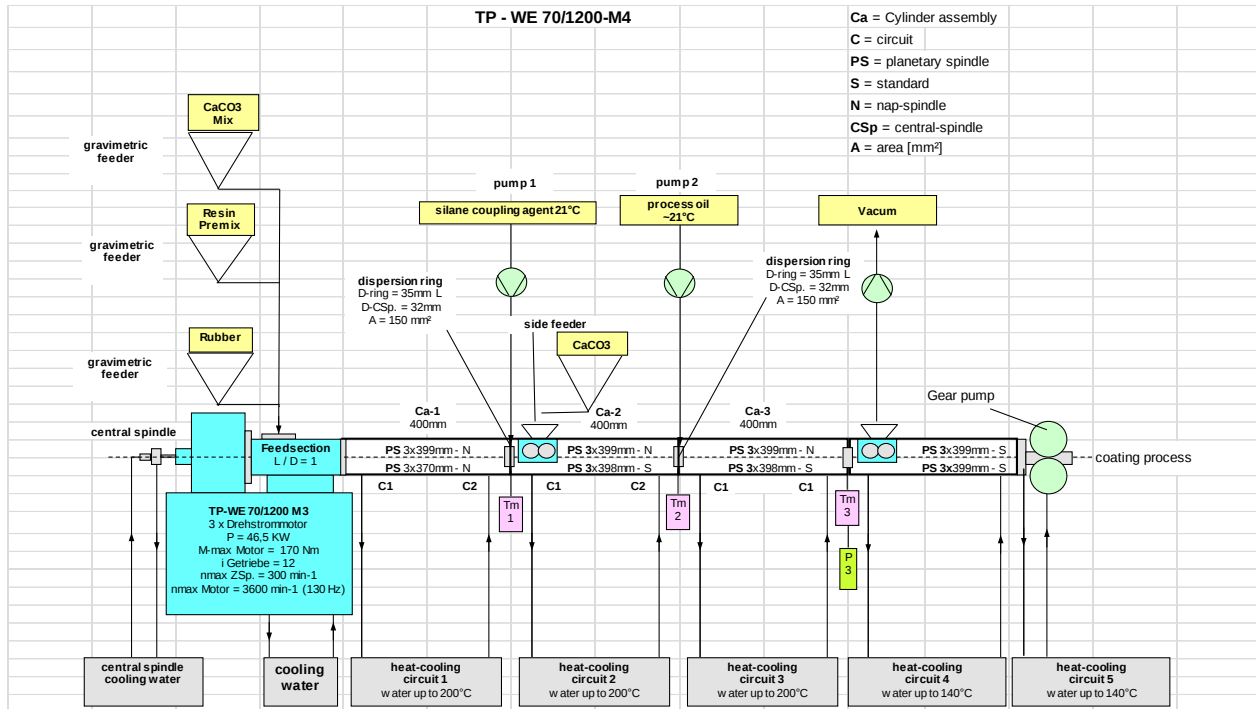


Figure 5 Process Example

Sample formulation

COMPOSITIONS	FORMULATION
Rubber	21 - 47%
Filler	13 - 39%
Resin	13 - 34%
Plasticizer	4 - 20%
Miscellaneous	0,5 - 2,5%
Solvent	5 - 60%
Polyethylene	5 - 10%

Figure 6

In that it is not possible to feed rubber bales continuously into an extrusion process. The rubber bales need to be pre-handled for a continuous feed into the PRE. One method is to grind or chop the rubber to the size shown in figure 7. This process is part of the production line and done in a continuous

manner. During the chopping or grinding process the rubber is also coated with CaCO_3 or Talc to keep the rubber pieces from sticking to each other. After this the rubber pieces are transported to a 100 – 200 litre holding tank that will be used to re-fill the gravimetric feeders.



Figure 7: Ground or chopped rubber

Conclusion

Planetary roller extruders are characterized by a great flexibility, process adaptability with a number of modular options available. Combined with an independent control of temperatures, pressures, mixing potential, residence times, fill degrees, degassing efficiency, thermal and mechanical energy

all make the PRE a top choice for continuous extrusion processes.

These characteristics are largely made possible due to the immense contact surface of the PRE. This provides a rapid, intense and very homogeneous mixing of materials to be processed with a separately controlled shear loading (either low or high shear). Simultaneously a large contact surface creates,

together with a minimal wall thickness, the ideal conditions for an excellent transfer of heating/cooling energy. Achieving the best temperature control for material processing, in comparison to single and twin screw extruders. With this property profile and machine adaptability, the PRE is superiorly suited for

performing all the requirements of processing a PSA formulation. This has been proven in the cost effective and high quality processes of today.

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