Development and test of a cryopulverizer for reprocessing plastic wastes

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The paper describes the development and test of an indigenous cryopulverizer for cryogrinding of PVC/polypropylene scraps and other waste plastics. This cryopulverizer has been designed for PVC scraps for a throughput of ≈ 60 kg/hr with about 85-90% of the ground product to be less than 212 μm. With this cryopulverizer, polypropylene balls of around 5 mm diameter have been ground successfully with a throughput of ≈ 35 kg/hr. Apart from PVC and polypropylene scraps, the above system will be useful for size reduction of many materials, which are difficult to grind at room temperature.

INTRODUCTION

The modern technology in milling process is cryomilling/cryogrinding. Cryogrinding is a useful technology for recycling of waste plastics for industrial applications. Cryogrinding of PVC scraps/polypropylene/waste plastics has lots of advantages over conventional grinding methods because of brittle fracture of these materials at low temperatures. Some of the significant advantages of cryogrinding over conventional grinding are: no chemical degradation of the product, finer particle size, higher throughput, lower energy consumption, no clogging and gumming of the mill, possibility to grind variety of materials which are difficult to grind by conventional techniques, inert atmosphere to prevent explosion in the grinding chamber, etc [1].

Cryogrinding is a process in which the plastic material to be ground is cooled to a desired temperature especially below the glass transition temperature by means of a cryogenic fluid such as liquid nitrogen (LN2) and ground in a low temperature compatible mill.

Three cryogenic cooling methods can be adopted for cryogrinding. They are: (i) the feed is cooled in a LN2 bath and then transported from the bath to the mill by means of a screw conveyor. The mill is cooled by the feed itself and also by the nitrogen vapour released during the cooling process. The process is grossly inefficient and the grinding temperature cannot be controlled optimally, (ii) LN2 is injected to cool-down the feedstock while it is transported through a screw conveyer. Here again, the chilled feeds as well as evaporated nitrogen cool the mill. The available enthalpy of the evaporated nitrogen is not fully utilized due to the absence of pre-cooling of the feedstock. In spite of the process inefficiency, this process can achieve all the advantages of cryogrinding and the plant is not complex, (iii) the stock is initially pre-cooled by the enthalpy of the evaporated nitrogen and the operating temperature of the mill can be controlled suitably for a specific application. Utilization of the cold gas circuit makes the process efficient. However the system becomes more complex.

The consumption of liquid nitrogen is an important factor to optimize the cost of cryogrinding. For continuous operation of the mill, the consumption of LN2 comprises of the following components:

(i) Cooling of the raw material and mill (initially) to operating temperatures.
(ii) Compensating the heat liberated in the grinding process.
(iii) Thermal insulation loss of the grinding installation and cryogen systems.
(iv) Residual coldness of the ground product, which leaves the mill.
(v) Residual refrigeration in the gaseous nitrogen being vented out.

Optimization of the above five parameters can result in the economical use of liquid nitrogen for cryogrinding.

OVERALL DESCRIPTION OF THE CRYOPULVERIZER

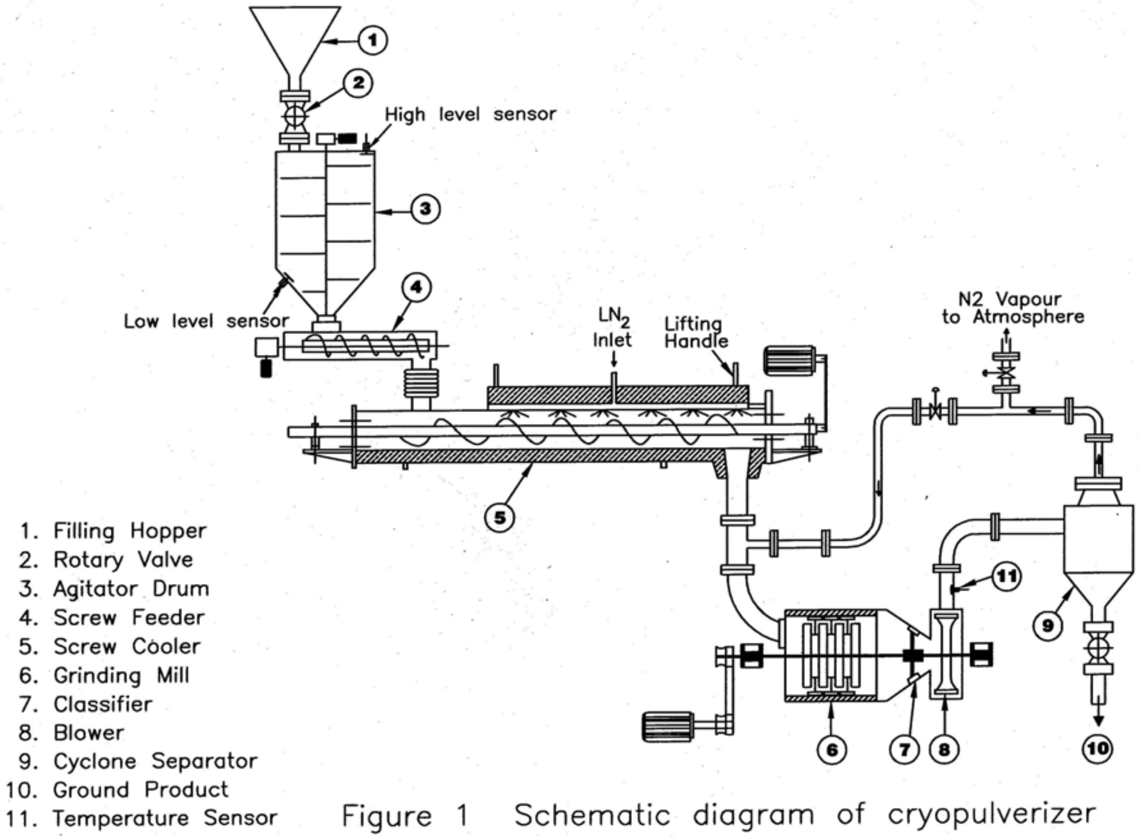

Figure 1 Schematic diagram of cryopulverizer

A cryopulverizer (Figure 1) has been designed and developed for the specific need of grinding ≈ 60 kg/hr for PVC scraps of less than 4 mm in size to obtain 85-90% of the ground product less than 212 μm which is required for manufacturing of battery liners.

The grinding mill is provided with 12 numbers of SS-304 hammers out of which 8 numbers are L-shaped hammers and 4 are T-shaped hammers. The cryopulverizer is totally designed and fabricated using stainless steel and materials compatible to liquid nitrogen temperature. The bearings of the cryopulverizer operate at room temperature. The gland seals of the cryopulverizer are provided with special arrangement such that ambient nitrogen vapour is supplied continuously through the gland seals so that no ambient moisture is sucked into the grinding chamber during grinding as well as warm up period [2]. A temperature sensor mounted on the blower exit is connected to the PID controller for regulating the liquid nitrogen supply by switching on and off of the solenoid valves in the liquid nitrogen supply line.

The working of the cryopulverizer can be described as follows. From the filling hopper (1), the material to be ground enters to the agitator drum (3) via the rotary valve (2) electric power of which is controlled by the low and high level sensors mounted in the agitator drum. A controlled rate of material is transferred from the agitator drum to the screw cooler (5) by the screw feeder (4), which has a provision to control the feed rate. While the material to be ground is transported in the screw cooler before entering the grinding zone of the mill (6), liquid nitrogen from the storage container is supplied through insulated transfer line and is sprayed on it to cool it to the desired low temperature preset by the PID controller. The material is ground to the desired particle size as per the adjustment of the classifier blades (7) in the mill housing. The ground product is separated from the cold nitrogen vapour in the cyclone separator (9) and is collected in the collecting bin. Part of the cold nitrogen vapour from the cyclone separator is recycled to the mill for utilization of enthalpy and the rest is vented to atmosphere.

In the present design, part of the cold nitrogen from the cryopulverizer is vented to the atmosphere for maintaining the system pressure. The enthalpy of this cold nitrogen vapour can be utilized for pre-cooling of the room temperature raw material by suitable heat exchanger to achieve optimal consumption of LN2.

EXPERIMENTAL STUDIES WITH THE CRYOPULVERIZER

Throughput and fineness

Experimental studies have been conducted with PVC scraps of less than 4 mm size and polypropylene balls of 5 mm diameter to determine the optimum speed of the mill for maximum throughput and particle size distribution. It has been observed that at around 4000 rpm mill speed and cooling the PVC scraps to approximately to -90°C, the desired throughput (≈ 60 kg/hr) and fineness (85-90% of the ground product less than 212 μm) are achieved.

Experimental studies on cryogrinding of polypropylene balls of 5 mm diameter show that this material has to be cooled to -130°C and ground at a mill speed of 3400 rpm to achieve a throughput of 35kg/hr. The particle size distribution of the cryoground PVC and polypropylene are shown in table 1.

Table 1 Particle size analysis of cryoground products

Partice size (μm)	Residual weight (%) (PVC powder)	Residual weight (%) (Polypropylene powder)
>1000	0.0	0.5
850 –1000	0.4	7.3
500 – 850	3.3	31.5
300 – 500	2.8	23.7
212 – 300	5.9	15.1
150 – 212	10.5	7.0
106 – 150	34.8	10.1
<106	42.3	4.8

LN2 consumption

From the experimental studies it has been estimated that approximately 2.5 kg of LN2 is required per kg of PVC ground product and 3.5 kg of LN2 is required per kg of polypropylene ground product. However, there is a great scope to reduce the LN2 consumption by incorporating pre-cooling section using waste cold nitrogen vapour from the mill [2].

Electrical power consumption

Typical power consumption of the cryopulverizer for achieving 60 kg/hr PVC grinding is approximately 15 kW-hr.

CONCLUSION

A cryopulverizer that could be operated down to liquid nitrogen temperature (-196°C) has been designed, developed and tested for cryogrinding of PVC scraps and polypropylene balls. The throughput of this cryopulverizer is ≈ 60 kg/hr for PVC scraps with fineness of 85-90% of the ground product less than 212 μm and a throughput of 35 kg/hr for popypropylene balls. The cryopulverizer has been used successfully to grind 4 tons of PVC scrap so far. The technology has been transferred to a leading industry in India.

A remarkable advantage of the developed cryopulverizer is the absence of fiber in the ground product in comparison to conventional grinding wherein considerable fibers are generated by the high grinding zone temperature causing chemical degradation of the plastics. It is very difficult to grind polypropylene to fine powder in conventional grinding mills. Apart from PVC and polypropylene materials, the cryopulverizer will be quite useful for size reduction of many materials, which are difficult to grind by conventional techniques.

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