COMPARISON OF DRY GRINDING TECHNOLOGIES AS A REFERENCE OF CERAMIC GRANULE TECHNOLOGICAL PARAMETERS

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1. ABSTRACT

In the ceramic tile manufacturing industry, the wet process, involving wet grinding and spray drying, is widely used for preparing granules. However, dry grinding has been becoming an important process for energy savings and for allowing different raw materials to be used in the tile manufacturing process. In this study, the dry grinding circuit design and operational parameters of a high capacity continuous dry ball mill with separator (BM), vertical roller mill (VRM) and pendulum roller mill (PM) were investigated. As is well known, particle size distribution and particle shape affect prepared slip characteristics and also the sintering behaviour and technological properties of the final product. Therefore, the particle size distribution of each grinding system was investigated for the primary raw materials of feldspar, kaolinite, granite and fired floor tile waste. The particle size distribution of each grinding system was illustrated in the RRSB distribution which allows the size distributions to be compared in terms of position parameter $d^{'}$, which indicates fineness and the parameter n, which indicates the slope of the products, whether it is a narrow or wide distribution. Finally, the analyses of the operating cost of the dry grinding systems were performed.

2. INTRODUCTION

In the ceramic tile manufacturing industry, the wet process, involving wet grinding and spray drying, is widely used for preparing granules. The grinding of ceramic raw materials is carried out in wet ball mills which are in different grinding circuit configurations. The most commonly used ball mills are for batch grinding, which is a discontinuous system. A certain amount of ceramic raw materials is filled and it is ground till the desired fineness is reached. Ball mills are also operated in continuous mode either in the long mill having diaphragm so as to divide it into grinding compartments or two/three short ball mills which are operated in serial connection. Although there have been the great efforts to improve the grinding efficiency of ball mills in the last decade, the high energy consumption and the high wear rate of grinding media still cause costs to rise in ceramic tile production. Beside the high grinding cost, water evaporation in the spray dryer has also become a major problem in wet process (1,2). In recent years, there have been a vast amount of research aimed at developing dry granulation processes, which consist of dry mills such as a vertical roller mill or pendulum roller mill and a granulator, which have various problems with granule shapes and granule size distributions that cause quality problems in the final products (3,4).

Recently, a new granule production system, called as Semi-Wet Process, has been designed to reduce granule production costs. The dry material is ground separately in the dry grinding system and added to the ceramic slurry. Hence, the bulk density is increased with the addition of dry material into the slurry. Therefore, the prepared ceramic slurry has less water content than the original ceramic slurry. This provides less natural gas consumption for dewatering of the ceramic slurry. In addition, the production capacity of the spray dryers is increased and the energy consumption is decreased by the use of the newly developed Semi-Wet System (5).

In ball mills, the particles are ground by the impact forces and the abrasion forces of balls among them or between the balls and liners of the mill. However, there is the limitation of the mill rotation speed and the ball size used in grinding. Also, the grinding bed is unconfined so that the input energy cannot be applied directly to the particles. Therefore, ball mill grinding is a very inefficient method due to the system design and the forces used in size reduction (6-7).

In this study, energy efficient dry grinding systems were sought for ceramic raw materials grinding. It is well known that the compression force is the most efficient force in grinding. It is also known that the direct force application to particles results in energy efficiency through confined grinding bed design in the grinding machines. The primary raw materials of ceramics productions, namely feldspar, kaolin, granite and fired floor tile waste, were ground in a dry ball mill with separator (BM), vertical roller mill (VRM) and pendulum roller mill (PM). Firstly, the tested materials were characterized in physical, chemical and mineralogical terms. Also the grindability of the raw materials was determined by means of the Bond Work Index (8).

As is known, particle size distribution and particle shape affect prepared slip characteristics and also the sintering behaviour and technological properties of the final product. The particle size distribution and particle shape of each grinding system were different. The Rosin-Rammler-Sperling-Bennet distribution (RRSB) allows the size distributions to be compared in terms of position parameter d', which indicates fineness and the parameter n, which indicates the slope of the products, whether it is a narrow or a wide distribution (9). Finally, the operating costs of the dry grinding systems were analysed in this article.

3. MODERN DRY GRINDING TECHNOLOGIES

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3.1. DRY BALL MILL OPERATING WITH A HIGH EFFICIENCY SEPARATOR

Until the early seventies, ball mills were clearly predominant within the dry grinding of raw materials in different industries. For moderate capacities and moderate moisture content, it is a very reliable machine with high utility and easy maintenance, but with relatively high electric energy consumption.

The grinding action in the ball mill is created by impact and attrition from the tumbling of the grinding media charge. With the correct grinding media grading, the capacity of the ball mill is proportional to mill power consumption.

The drying capacity of a ball mill is dependent on mill size. For small mills, there is normally no difficulty in passing the necessary amount of hot gases through the mill. The feed material moisture content can be as high as 6,5% water. However, in larger mills, due to the limitation of air velocity, the drying capacity reduces to less than 5% water. The dry ball mills are often designed with two compartments. Because of a more efficient grinding media gradation, the grinding efficiency was higher than for the one compartment mill. The mill is operated in a closed circuit with an air separator. The material discharge from the mill is transported to the separator partly by the gas flow and partly by an elevator. The material is fed to the distribution plate which is installed in the top section of the separator above the rotor (rotating cage) as shown in Figure 1. The separating air passes horizontally through the separating zone and the rotor and leaves the separator on top together with the fine fraction. The coarse material falls through the separating air to the bottom outlet due to the force of gravity. Fineness adjustment is made by the speed of the rotor and the amount of separating air.

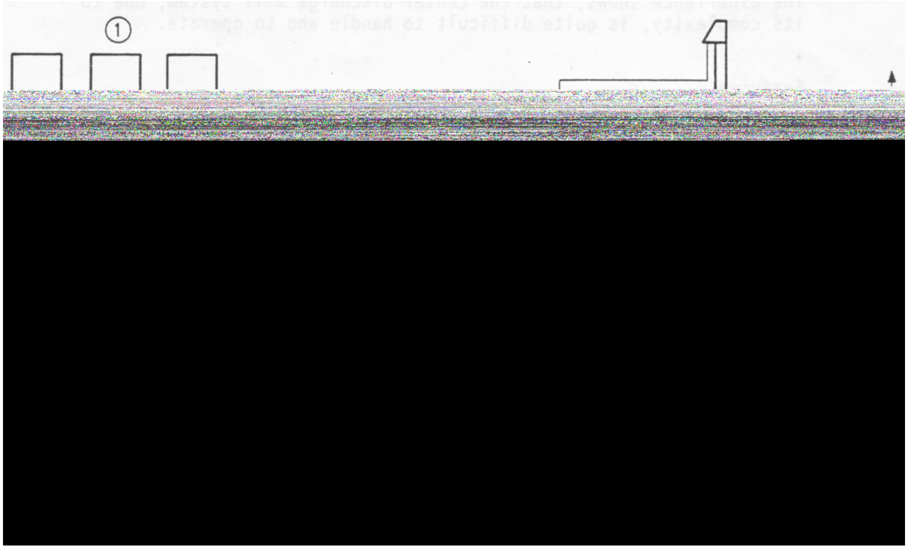

Figure 1. *Continuous Dry Ball Mill grinding system.*

3.2. VERTICAL ROLLER MILL

The vertical roller mill (VRM) is today the most common type of mill for grinding raw materials, due to an excellent grinding efficiency combined with a high production capacity as well as high drying capacity. The material is fed to the mill via an air sluice and slides down onto the rotating grinding table. Due to the centrifugal forces the material flows in a spiral movement across the grinding table and under the rollers, which are pressed pneumatic-hydraulically against the material. At the edge of the table, the crushed material overflows a dam ring which is used for control of the material layer, and is picked up by hot gas entering from below the grinding table through a nozzle ring. The hot gas dries the material and throws the coarser particles directly back onto the grinding table, while the finer fraction is carried out to the dynamic separator at the top of the mill. Rejects from the finer fraction are returned to the grinding table for further treatment, while the finished product leaves with the gas through the top and is collected in a cyclone and/or filter as shown in Figure 2.

The material between rollers and table is crushed by a combination of compression and shear, which is more energy efficient than crushing by impact, as in the ball mill.

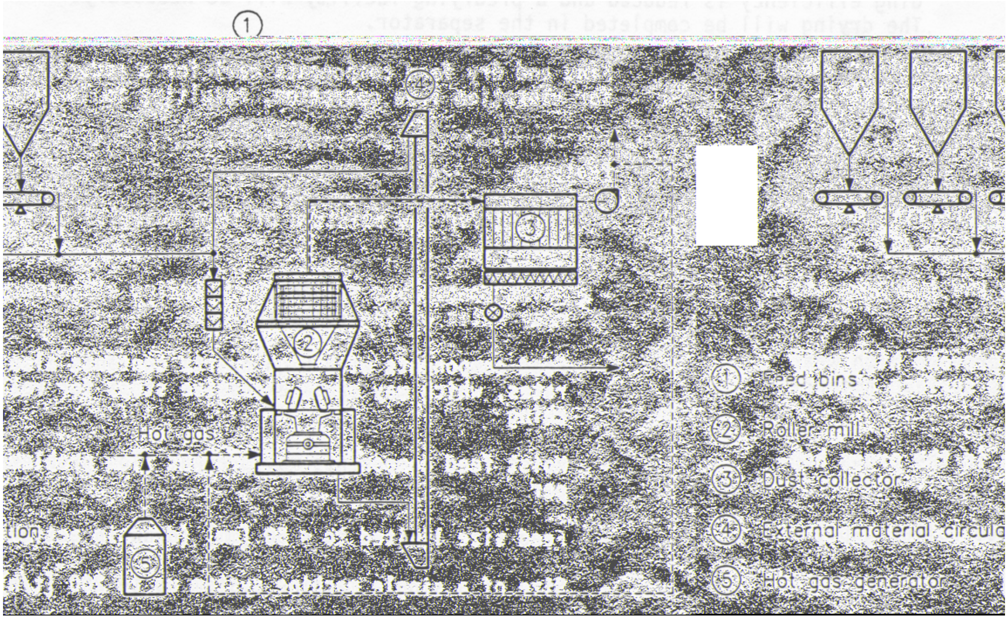

Figure 2. *Vertical Roller Mill grinding system.*

3.3. PENDULUM ROLLER MILL

The pendulum roller mill works by compression of the material bed. The pendulums mounted on a star wheel are driven by a vertical shaft. Each pendulum is fitted with a grinding roller that rotates upon its axis. The material is fed to the mill by a feeding device and drops onto the bottom of the lower mill housing. In front of each pendulum a rotary shovel is installed which picks up the material from the bottom and feeds it between the rollers and the grinding ring. The material is ground between the grinding rollers and the grinding ring. The ground materials are transported to the classifier by air. The fine particles are carried by the air while coarse particles drop back onto the grinding zone as shown in Figure 3.

Pendulum mills are suitable for fine grinding of soft to medium materials. The drying capacity can go up to 20% water within the mill. The capacity of the mill may vary from 100 kg/h to 80 ton/h depending on mill size, material and its fineness.

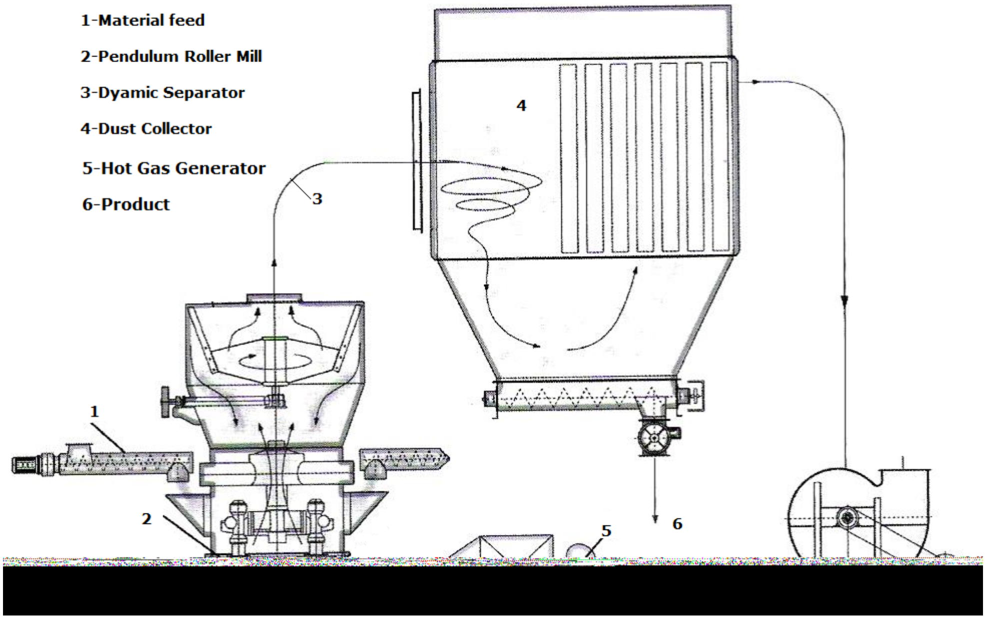

Figure 3. *Pendulum Roller Mill grinding system.*

4. METHODOLOGY AND EXPERIMENTS

4.1. MATERIALS CHARACTERIZATION

The experimental study was performed at the Kale Maden Factory, which is the raw material provider of the largest ceramic producer in Turkey and also one of the biggest producers in the world. Chemical and mineralogical analyses of the raw materials tested, namely feldspar, kaolin, granite and fired floor tile waste, are shown in Table 1 and Table 2.

Sample ID		Feldspar	Kaolin	Floor Tile Waste	Granite
Chemical Analysis	L.O.I.	2,62	8,54	0,88	1,77
	SiO_2	65,79	66,04	69,84	75,25
	Al_2O_3	18,36	23,48	19,82	13,93
	TiO_2	0,53	0,69	1	0,41
	Fe_2O_3	0,28	0,35	1,71	0,81
	CaO	1,22	0,19	0,53	0,5
	MgO	1,97	0,03	0,61	0,16
	Na_2O	8,54	0,03	1,83	2,28
	K_2O	0,49	0,2	3,42	4,86

Table 1. *Chemical analyses of the raw materials.*

Sample ID	Feldspar	Kaolin	Floor Tile Waste	Granite
X R D	*Quartz*	*Quartz*	*Quartz*	*Quartz*
	Albite	*Kaolinite*	*Mullite*	*Orthoclase*
	Biotite	*Anatase*	*Albite*	*Albite*
	Clinochlore	*Alunite*		*Illite*
	Magnesite			*Kaolinite*

Table 2. *Mineralogical analyses of the raw materials.*

4.2. THE GRINDING PROCESS USED

The feldspar, kaolin and granite raw materials and the fired floor tile waste were ground in a dry ball mill with separator (BM), vertical roller mill (VRM) and pendulum roller mill (PM) at the Kale Maden Factory.

The Ball Mill: The grinding tests were carried out in conventional closed circuit system with a ball mill and a high efficiency separator. The mill diameter is 3100 mm and length is 4950 mm. The mill is lined by alumina liners. Alumina balls are used as grinding media. The installed power is 430 kW; however, around 400 kW power was being drawn during the tests. The separator rotor speed can be adjusted between 0-520 rev/min to obtain the desired particle size distributions. In the tests, it was operated at a speed of 420 rev/min.

The Vertical Roller Mill: The mill used has the grinding table diameter of 1830 mm. There are 3 rollers which are pressed pneumatic-hydraulically to the rotating table. The installed power is 460 kW; however, around 340 kW power was being drawn during the tests. The separator rotor speed can be adjusted between 0-320 rev/min to obtain the desired particle size distributions. In the tests, it was operated at a speed of 240 rev/min.

The Pendulum Mill: The mill grinding ring diameter is 1830 mm. There are 5 grinding rollers. The material is ground between the grinding rollers and the grinding ring. The installed power is 600 kW; however, around 450 kW power was being drawn during the tests. The separator rotor speed can be adjusted between 0-300 rev/min to obtain the desired particle size distributions. In the tests, it was operated at a speed of 230 rev/min.

4.3. PARTICLE SIZE DISTRIBUTIONS

The particle sizes of the ceramic raw materials will usually range between 1 and 45 microns for floor tiles and 1 and 63 microns for wall tiles. The relative amounts of particles of different sizes can be illustrated by frequency curves, but more often the distribution is characterized by cumulative curves showing the fraction of the materials that is coarser or finer than a certain size.

The function most widely used for describing the particle size distribution (PSD) is that proposed by Rosing and Rammler (RR) also referred to as the Rosin-Rammler-Sperling-Bennet distribution (RRSB).

It can be written as follows:

$R(d) = 100\exp((-(d/d^1)^n)$

R(d) is the percentage by weight of particles with a diameter larger than d. The position parameter d^I corresponds to the diameter with a residue of 36,8 % and indicates the fineness level of the distribution. The exponent n is a measure of the spread or dispersion of the distribution.

Usually the PSD is presented in an RRSB diagram as shown in Figure 4-5-6 and Figure 7, d^I indicates the position of the line in the graph, and n is the slope of the line. Products ground in the same mill will usually have the similar n values, while d^I will vary with grinding time.

The particle size distributions of the tested materials in cumulative curve and also in the RRSB distributions are illustrated in Figures 4-5-6 and Figure 7.

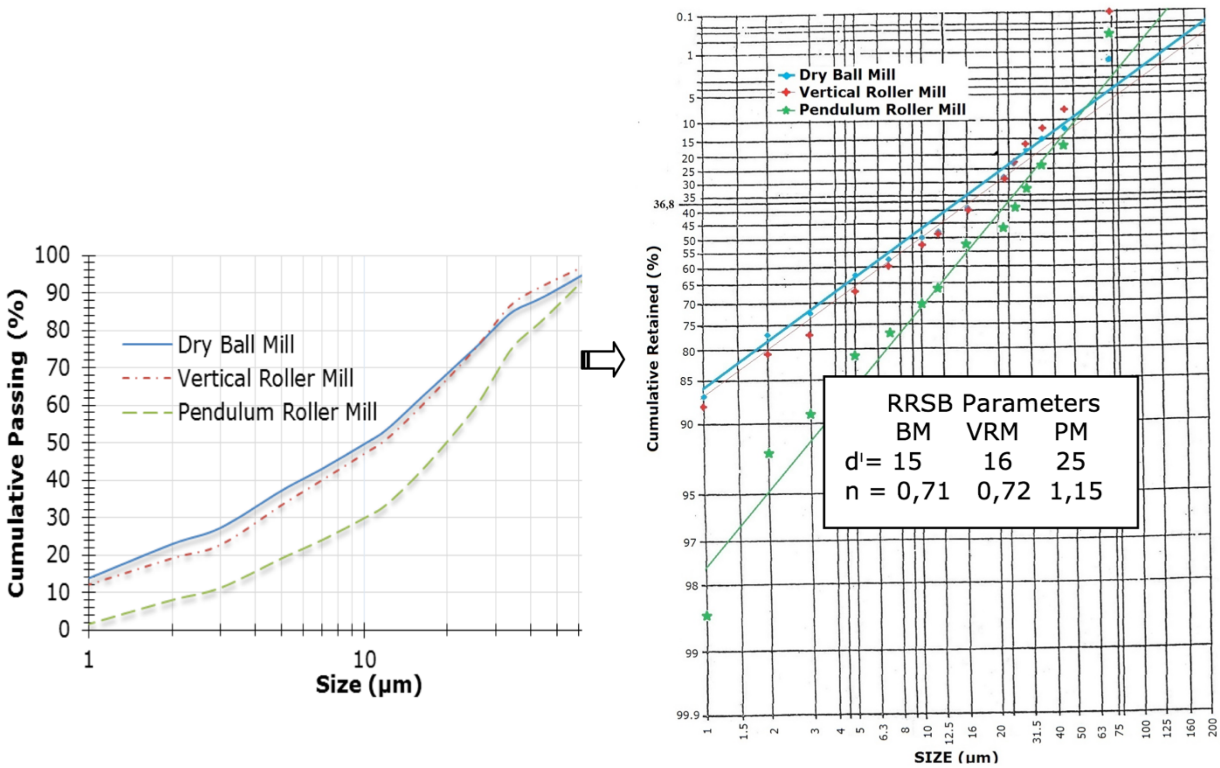

Figure 4. *Feldspar particle size distribution.*

Sample ID		**Feldspar**	**Kaolin**	**Floor Tile Waste**	**Granite**
Bond Work kWh/s.ton		**20,0**	**12,4**	**15,1**	**18,3**
Moisture content, %		**2**	**13**	**0**	**8,2**
+63 Micron 4% Energy Consumption kWh/ton	Dry Ball Mill	62	45	54	58
	Vertical Roller Mill	57	36	46	52
	Pendulum Roller Mill	61	39	52	56

Table 3. *Energy consumption of the three grinding systems.*

A comparison of various grinding systems involves quite a few different factors, of which the most important are grinding capacity, drying capacity, energy consumption, and feed size, and maintenance and investment costs

Energy savings could be achieved through utilizing energy efficient dry grinding-separation systems. Also, the addition of dry ground raw materials to increase the final slip density which is fed to spray dryer in semi-wet granule preparation. Dry grinding and the dry granulation technologies provide further energy savings in tile manufacturing.

Particle size distribution and particle shape affect prepared slip characteristics and also the sintering behaviour and technological properties of the final product. The research on this area has also been undergoing at the Kale Research and Development Centre and at Istanbul Technical University.

6. CONCLUSION

It can be concluded that BM, VRM and PM produce different particle size distributions for the tested feldspar, kaolin, granite and fired floor tile waste. The RRSB distribution can be effectively used in defining the particle size distribution of different grinding systems. Therefore, particle size distribution and particle shape must be considered in the prepared slip characteristics, its sintering behaviour and the technological properties of the final product. Although VRM and PM are energy efficient grinding systems due to the grinding forces used, the wear rate and other operational cost parameters must also be considered for the optimum selection of grinding systems.

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