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

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ABSTRACT

In ceramic tile manufacturing industry, the wet process including wet grinding and spray drying, is widely used for preparing granule. However; dry grinding has been becoming an important process for energy savings and allowing different raw materials usage in tile manufacturing process. In this study, the dry grinding circuit design and operational parameters of high capacity continuous dry-ball mill with separator (BM), vertical roller mill (VRM) and pendulum roller mill (PM) were investigated. As is known, the particle size distribution and the particle shape have effects on the prepared slip features and also the sintering behavior and technological properties of final product. Therefore; the particle size distribution of each grinding systems were investigated for the primary raw materials of feldspar, kaolinite, granite and fired floor tile waste. The particle size distribution of each grinding systems were illustrated in RRSB distribution which allows to compare the size distributions in terms of position parameter d', that indicates fineness and the parameter n, that indicates the steepness of products either it is narrow or wide distribution. Finally, the analyses of the operating cost of the dry grinding systems were performed.

Keywords: dry drinding, ball mill, vertical roller mill, pendulum roller mill

INTRODUCTION

In ceramic tile manufacturing industry, the wet process including wet grinding and spray drying, is widely used for preparing granule. 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 at batch grinding that is discontinuous system. The certain amount of ceramic raw materials is filled and it is ground till reaching the desired fineness. Ball mills are also operated in continuous mode either in the long mill having diaphragm so as to dividing 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 last decade, the high energy consumption and the high wear rate of grinding media still cause cost raise in the ceramic tile production. Beside the high grinding cost, the water evaporation in spray dryer has also become a major problem in wet process (1,2). In recent years, there have been vast amount of researches for developing of dry granulation processes that consist of dry mills such as vertical roller mill or pendulum roller mill and a granulator, have various problems on the 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. 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 new 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 balls and liners of the mill. However, there is the limitation of the rotation speed of mill and the size of ball used in grinding. Also, the grinding bed is unconfined so that the input energy cannot be applied directly to particle. Therefore, the ball mill grinding is very inefficient methods due to the design of system and the used forces in size reduction (6-7).

In this study, the usages of energy efficient dry grinding systems were sought for ceramic raw material 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 at grinding machines. The primary raw materials of ceramics productions namely feldspar, kaolin, granite and fired floor tile waste were ground in dry-ball mill with separator (BM), vertical roller mill (VRM) and pendulum roller mill (PM). Firstly; the tested materials were characterized in terms of physical, chemical and mineralogical. Also the grindability of raw materials was determined by means of Bond Work Index (8).

As is known, the particle size distribution and the particle shape have effects on the prepared slip features and also the sintering behavior and technological properties of final product. The particle size distribution and the particle shape of each grinding systems were different. Rosin-Rammler-Sperling-Bennet distribution (RRSB) allows comparing the size distributions in terms of position parameter d' that indicates fineness and the parameter n, that indicates the steepness of products either it is narrow or wide distribution (9). Finally, the analyses the operating cost of the dry grinding systems were illustrated in this article.

MODERN DRY GRINDING TECHNOGIES

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Dry Ball Mill Operating with a High Efficiency Separator:

Until the early seventies ball mills were clearly predominant within 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 grinding media charge. With the correct grinding media grading the capacity of the ball mill is proportional to the mill power consumption.

The drying capacity of a ball mill is dependent on the 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 closed circuit with an air separator. The material discharge from the mill transported to the separator partly by the gas flow and partly by 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 gravity force. Fineness adjustment is made by the speed of the rotor and the separating air amount.

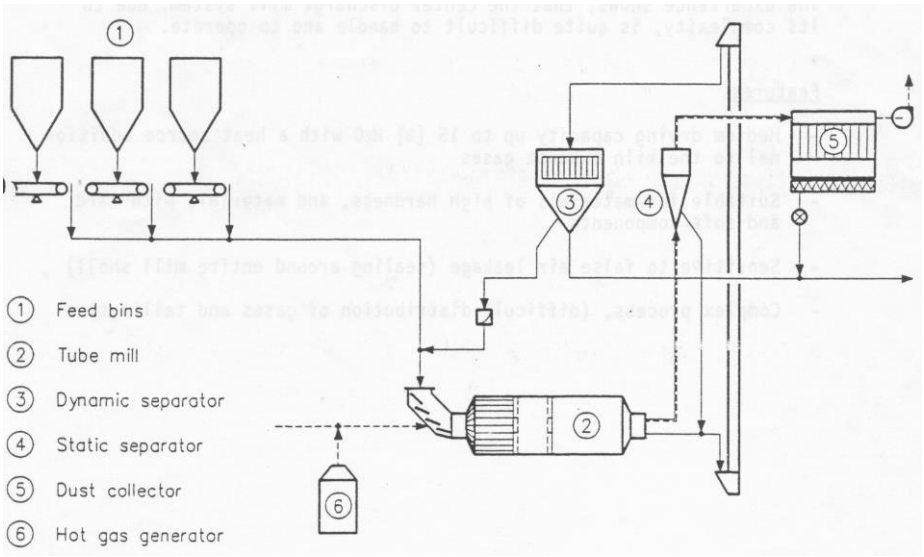


Figure 1. Continuous Dry Ball Mill grinding system.

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 materials 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 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.

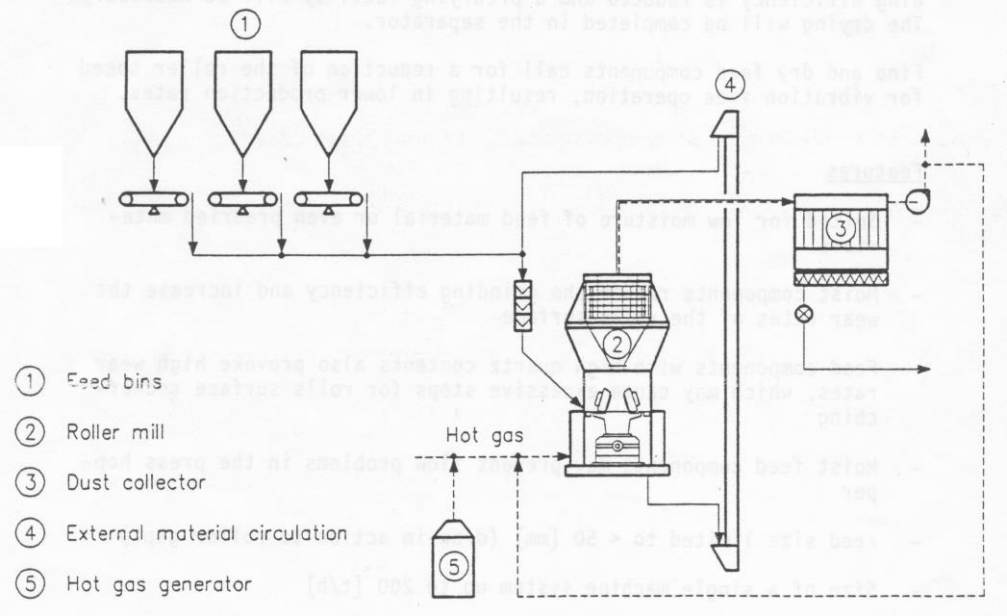


Figure 2. Vertical Roller Mill grinding system

Pendulum Roller Mill:

The pendulum roller mill works by compression 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 taken within 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.

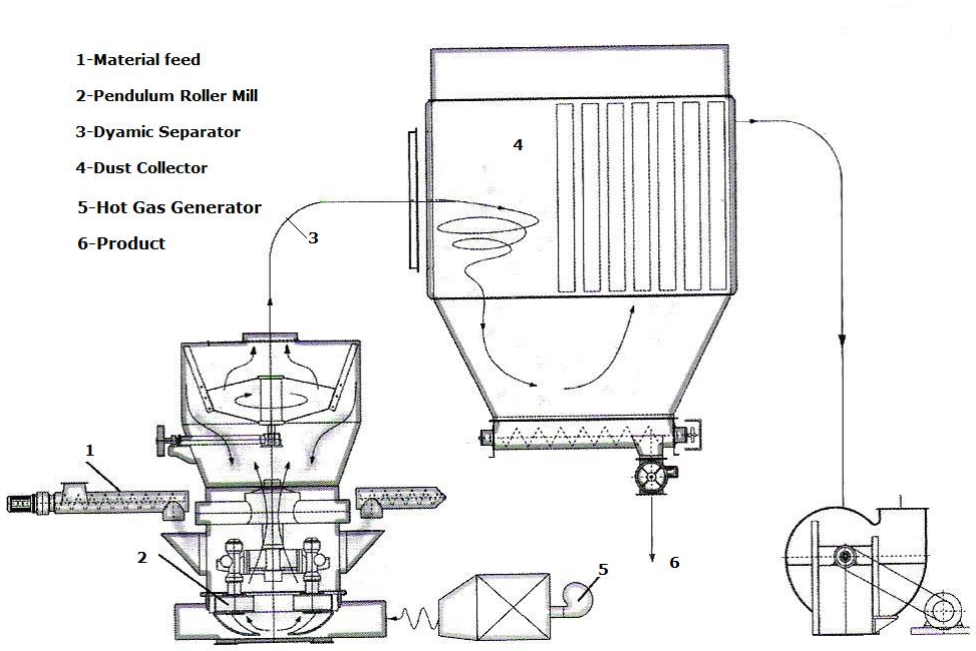


Figure 3. Pendulum Roller Mill grinding system

METHODOLOGY

Materials Characterization

The experimental study was performed in 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 which are feldspar, kaolin, granite and fired floor tile waste, are shown in Table 1 and Table 2.

Table 1. Chemical analyses of the raw materials

Sample ID		Feldspar	Kaolin	Floor Tile Waste	Granite
Chemical Analysis	K.Z.	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 2. Mineralogical analyses of the raw materials

Sample ID	Feldspar	Kaolin	Floor Tile Waste	Granite
XRD	Quartz	Quartz	Quartz	Quartz
	Albite	Kaolinite	Müllit	Orthoclase
	Biotite	Anatase	Albite	Albite
	Clinoclore	Alunite		Illite
	Magnesite			Kaolinite

Grinding Tests and Particle Size Distributions:

The raw material of feldspar, kaolin, granite and fired floor tile waste were ground in dry-ball mill with separator (BM), vertical roller mill (VRM) and pendulum roller mill (PM) in Kale Maden Factory. 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 particle 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 diameter larger than d. The position parameter d^{l} 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 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^{l} 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^{l} 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 Figure 4-5-6 and Figure 7.

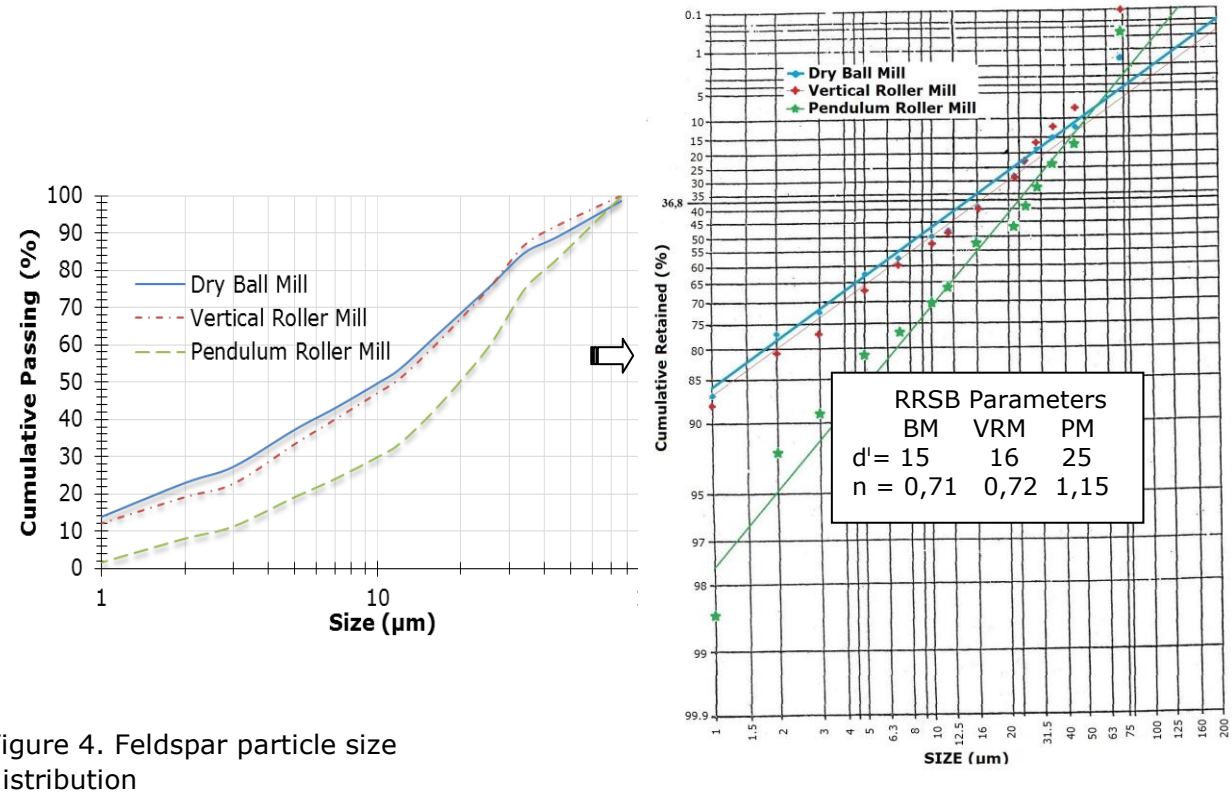


Figure 4. Feldspar particle size distribution

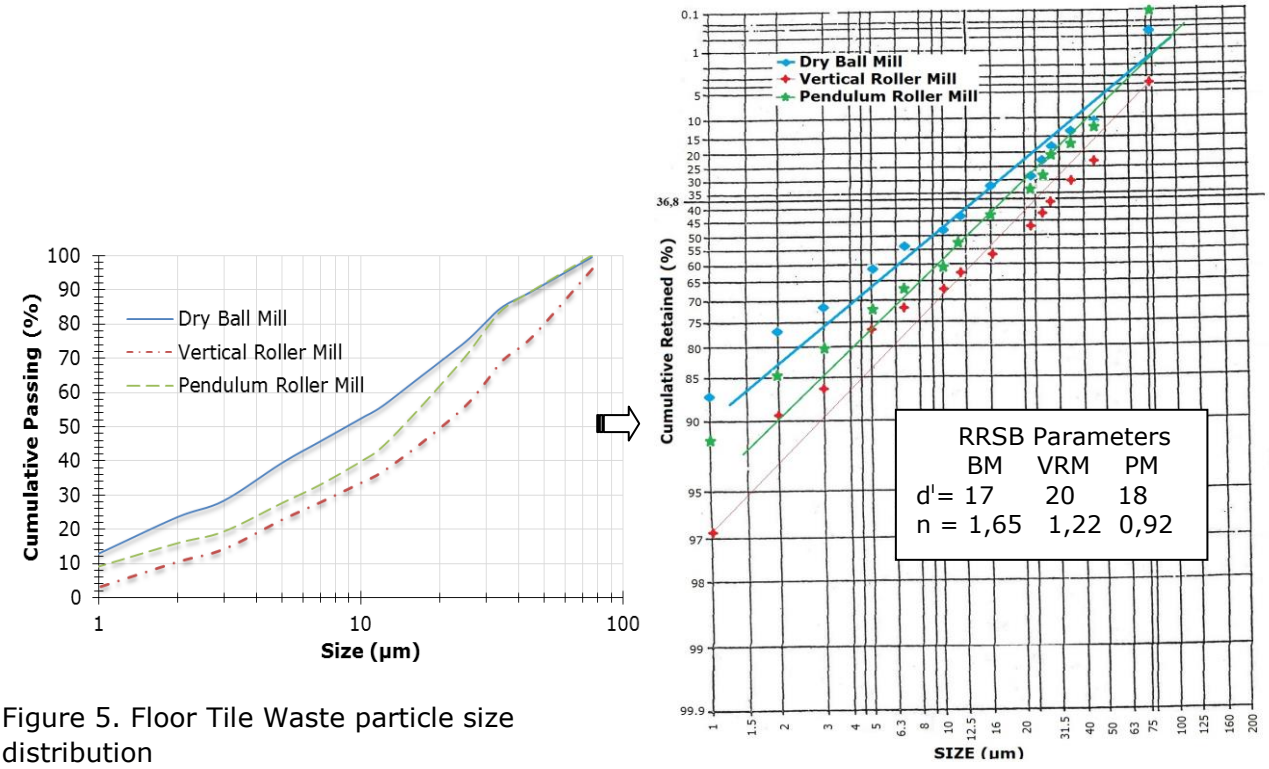


Figure 5. Floor Tile Waste particle size distribution

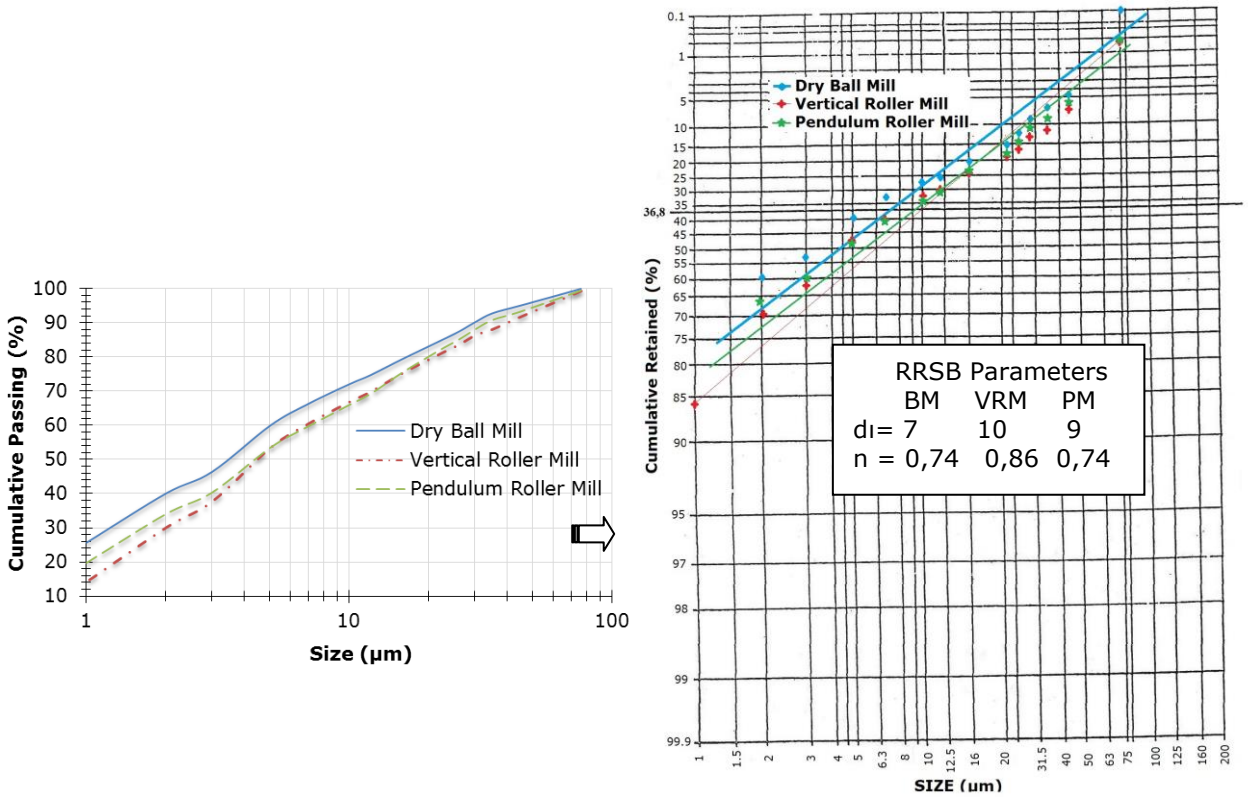


Figure 6. Kaolin particle size distribution

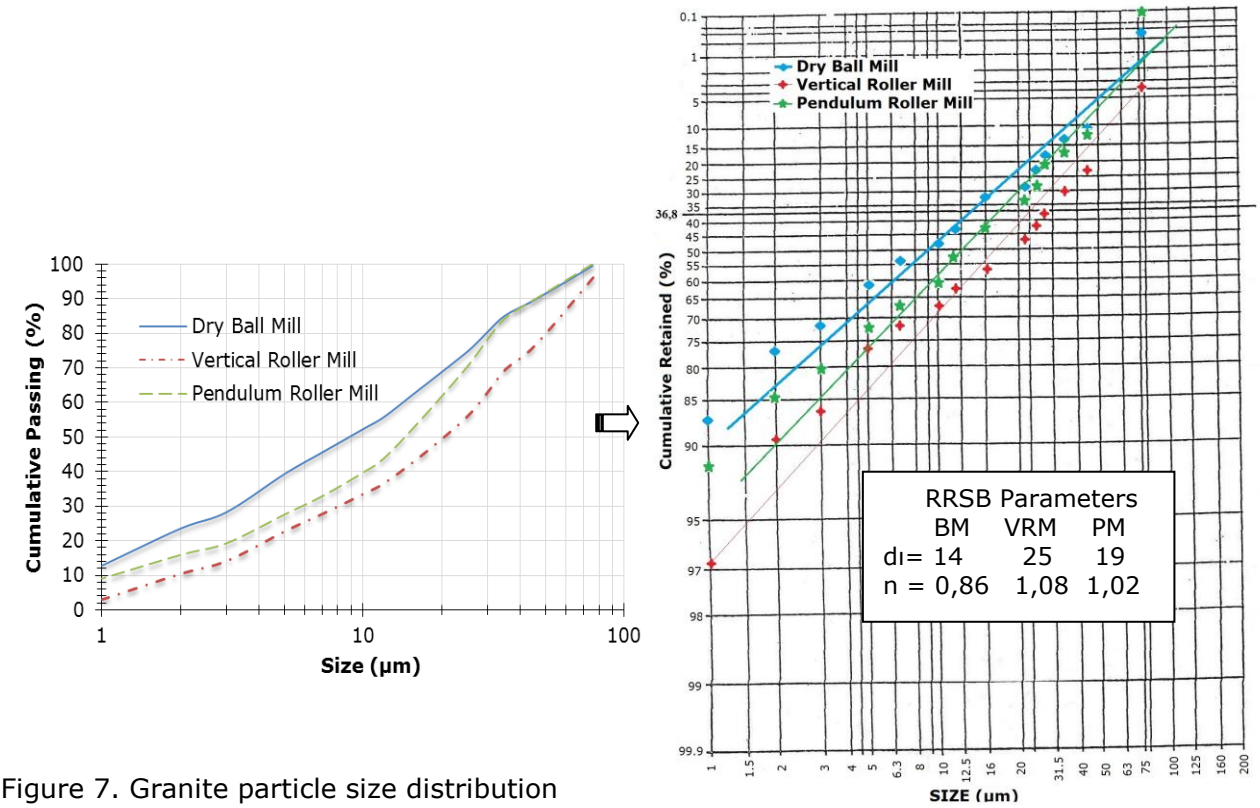


Figure 7. Granite particle size distribution

RESULTS AND DISCUSSION

As seen in Figure 4-5-6 and Figure 7; the ball mill has produced finer and wider size distributed powder than the VRM and PM. However, the energy consumption of BM is higher than the VRM and PM.

The maintenance costs for kaolin grinding is around 1,5 Euro/ton which is similar for the tested mill as kaolin is suitable for grinding all these three mills. However, the maintenance cost for grinding of feldspar, granite and fired floor tile waste in the VRM and PM is almost three times higher than the maintenance cost of BM. It can be explained that these materials are not suitable in grinding VRM and PM due to the high abrasivity. The material Bond work index, moisture content and the measured energy consumption are given in Table 3.

Table 3. Energy consumption of three grinding systems

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

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 the tile manufacturing. The particle size distribution and the particle shape have effects on the prepared slip features and also the sintering behavior and technological properties of final product. The research on this area has also been undergoing in Kale Research and Development Center and at Istanbul Technical University.

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, the particle size distribution and the particle shape must be considered on the prepared slip features, its sintering behavior and the technological properties of the final product. Although VRM and PM are energy efficient grinding system due to the used grinding forces, the wear rate and other operational cost parameters must be also considered for the optimum selection of grinding systems.

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REFERENCES

1 - Reed, J., *"Principles of ceramic processing,"* United States of America,1994.

2 - Sacmi, *"Applied Ceramic Technology,"*, Volume 1-2, Editrice La Mondragora S.R.L., Imola, Italy, 2002.

3 - Vari, A., *"Raw Materials Preparation and Forming of Ceramic Tiles,"* Sala, Modena, Italy, 2004

4 - Clement, S. ve Prutyan, H., " Narrowing Down Equipment Choices for Particle Size Reduction," *Chemical Engineering Progress*, , **98**, 50-54, 2002.

5- Ergin, H., Kılıc, M., Durgut, E., Kayacı, K., Altıntas,A., Yıldırım. Y., Development of a Semi-Wet Process for Ceramic Floor Tile Granule Production, Advances in Science and Technology, **92**, 115-120, 2014.

6 - Brusa, A., "Continuous grinding – a process applicable to tile production," *Tile & Brick Int.*, **10**, 252−257, 1994.

7 - Fuerstenau, D. W., Abouzeid, A. Z. M., "The energy efficiency of ball milling in comminution," *Int. J. Miner. Process.*, **67**, 161– 185, 2002.

8 - Ipek, H., Ucbas, Y., Yekeler, M. ve Hosten, Ç., "Dry grinding kinetics of binary mixture of ceramic raw materials by Bond milling," *Ceram. Int.*, **31**, 1065–1071, 2005.

9 - Villegas-Palacio, S., Dinger, D. R., "PSD effects on firing properties of porcelains, I-II," *Am. Ceram. Soc. Bull.*, **75**, 71-83 1996.