DEVELOPMENT OF A SEMI-WET PROCESS FOR CERAMIC WALL TILE GRANULE PRODUCTION

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1. ABSTRACT

In the ceramic tile manufacturing industry, the wet process, which includes wet grinding and spray drying, is widely used for preparing granules. However, energy consumption for the water evaporation in spray dryer has become a major problem in the wet process. In recent years, there has been a vast amount of research for developing a dry granulation process that consists of dry mills such as the vertical roller mill or pendulum mill and a granulator. The currently developed dry systems have various problems with regard to granule shapes and granule size distributions, which lead to quality problems in the final products.

In this research, it is aimed to develop a new production system, known as the Semi-Wet Process. The new system consists of a raw materials dryer, dry ball mill, separator and additional high speed mixture. The raw materials having low humidity are ground to the required fineness in a dry size-reduction process. The other components of the recipe, which are prepared in a conventional wet process, are mixed with the dry prepared powder in the mixing slurry tank. The addition of dry powder reduces the water ratio of the final suspension: in other words, the bulk density of the slurry increases. Hence, a decrease is obtained in natural gas consumption for water evaporation in the spray dryer.

The application of the developed semi-wet system was carried out at the Kaleseramik Factory, which is the largest ceramic manufacturer in Turkey. The sintered wall tile ceramic rejects were ground in the developed dry grinding system to the fineness of 2% residue of 63 µm. The dry prepared powder was added by 20% to the mixing tank, such that adjusting the body composition, the bulk density of the wall tile slip rose from 1632 g/l to 1750 g/l. As a result, the natural gas consumption decreases from 11.45 €/Ton to 8.18 €/Ton. The use of semi-wet system is able to provide a profit of around 1,965,441 €/year for the current production rate at the factory.

2. INTRODUCTION

Ceramic tiles are mainly used for cladding and wall decoration of buildings and they have been the predominant products of the world's ceramic industry, annual production being about 3.215 million T.L. in Turkey, 2010 [1]. The general process of manufacturing ceramic tiles consists of procedures such as preparing the proportioned raw materials into press powders, and press forming as-received press-powders, which have a specific water content (usually 5-7%), into green tiles which are then fired into ceramic tile products [2]. Different preparation processes generally produce ceramic powders with different properties. Currently, in the ceramic tile industry, ceramic powders for wall tiles are mainly produced by wet grinding and spray drying, after which the compacts are formed by pressing [3]. Wet preparation system for wall tiles start with a crushing process, where the raw materials such as kaolin, fired ceramic waste and quartz, are reduced to a fine size distribution under 1 cm. The raw materials that compose the body are ground in a wet ball mill until reaching 2% residue on a 63 μm sieve. In addition, clays are differently separated from gangue minerals in a blunger before the mixing operation. Furthermore, calcite minerals are ground separately by controlling the final particle size of the calcite, so as not to cause problems that are able to occur owing to inconvenient particle sizes. These three slurries are homogenized in a mixing pool with the ordered ratios of each material. After screening and removal of iron impurities, the suspension is pumped into a spray dryer, according to the directions of air and product flow through the drying chamber [4-7]. The slurry makes contact immediately with 400–550 ^{o}C hot air for instantaneous drying into fine granules with a water content of about 6%, which are then used as press-powders for press forming [5-6]. The flow chart of the process is shown in figure 1.1.

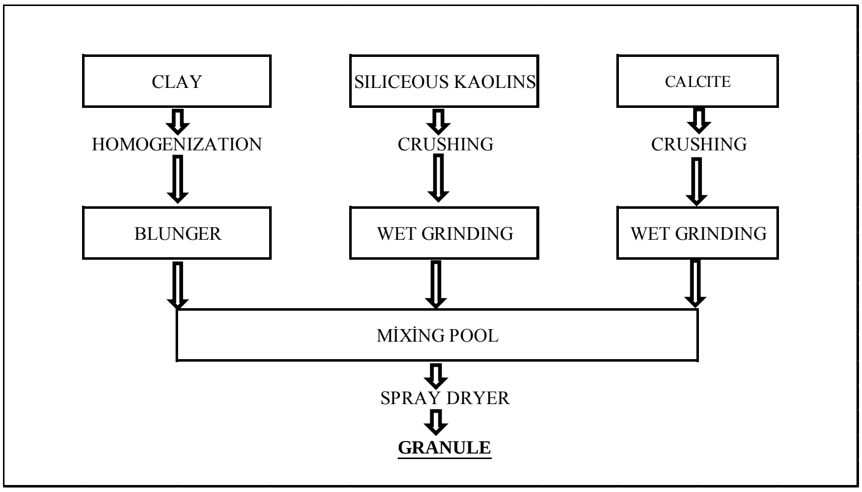

Figure 1.1 *Wall Tile Press Powder Preparation Systems.*

The technical command of raw materials wet grinding and the excellent performance of spray-dried powders have led to wide-scale industrial application of the spray drying process in the last 40 years. However, the high energy and water consumption involved in spray drying, in addition to pollution emissions, remain major issues, especially in developed areas such as European countries [7-8]. The final ceramic slurry has water content of about 36%, which is evaporated in spray dryer by 400–550 ^{o}C hot air, generated by natural gas. Hence, water content of the ceramic slurry directly affects the natural gas consumption accordingly the water evaporation costs in spray dyer.

High energy consumption in spray dryer, the dewatering of the suspension into the press powders with a water content of about 6% is achieved entirely by heating evaporation, which consumes a huge amount of energy [4]. This energy is generated by natural gas. Especially after drying work, the hot air is cooled down into tail gas with temperatures between 90°C and 130°C, which can hardly be reused with high efficiency in developing countries such as China and thus directly discharged with considerable excess heat energy [4].

A new production system, called the Semi-Wet Process Semi-Wet Process, has been planned in order to reduce grinding and granule preparation (spray dryer) costs of the present process. Dry material is added to the ceramic slurry, which consists of clay, calcite and soft-medium raw materials slurries in the mixing pool. Bulk density is increased with the addition of dry material into the slip. Hence, the final ceramic slurry has less water content than the previous ceramic slurry had. This indicates less natural gas consumption for dewatering of the suspension. The product capacity rises and energy consumption decreases by the new semi-wet system.

3. METHODOLOGY

3.1. THE CURRENT WET PROCESS AND DEVELOPED METHODS

3.1.1. TECHNICAL AND ECONOMIC ANALYSIS OF CURRENT WET PROCESS

A new preparation method that consists of a hammer crusher, raw materials dryer, dry ball mill and a separator has been developed for wall tile press powders. The water absorption ratio must be more than 10% by mass for wall tiles [9]. Firstly, the present process for wall tiles starts with a crushing-screening unit. At that part, the aim is to prepare raw materials, such as siliceous kaolin, calcite and wall tile wastes for wet grinding feed down to 1 cm particle size. In addition, clay materials are prepared at a homogenizing process plant. Secondly, the raw materials and wall tile wastes that are crushed down to 1 centimetre particle size are moved to silos for wet grinding in wet system ball mills. On the other hand, clay materials are removed from such impurities in a blunger. These two slurries are homogenized in a mixing pool at ordered ratio and the bulk density of the final slip is 1632 g/L for wall tile. The mixing ceramic slurry is separated from iron impurities in a wet magnetic separator and sieved on a vibrating screen. Detailed technical cost distribution of Crushing-Sieving Plant given in order in Table 2.1 and Table 2.2

Cost	€/Ton
Labour	0.697
Electricity	0.188
Maintenance	0.147
Transport Factory to Storage Area	0.385
Amortization	0.182
TOTAL	1.6
Particle Size	-10 mm
Capacity	50 Ton/h

Table 2.1. *Cost Analysis for Hard Materials Crushing-Sieving Plant.*

Table 2.1 indicates that the hard material crushing process has a capacity and energy loss because of the labour costs on the current crushing system.

Cost	€/Ton
Labour	0.697
Electricity	0.162
Maintenance	0.529
Transport	0.147
Storage Area to Factory	0.382
Amortization	0.588
TOTAL	**2.506**
Particle Size	-8 mm
Capacity	8 Ton/h

Table 2.2. *Cost Analysis for Wall Tile Wastes Crushing-Sieving Plant.*

The final ceramic slip is pumped to spray dryer, in which the ceramic granules are produced. Table 2.3 indicates the grinding costs of the wall tile body composition.

Cost	€/Ton
Labour	0.359
Electricity	1.432
Maintenance	0.059
Alumina Ball	0.403
Amortization	0.144
TOTAL	**2.397**
Particle Size (-150 +63 μm)	Max. 2-3%
Capacity	1400 Ton/Day

Table 2.3. *Grinding Cost Analysis for Wall Tile Body Composition.*

Table 2.3 indicates that the grinding cost of the wall tile body composition is 2.397 €/Ton and the electricity cost is 1.432 €/Ton because of inefficient grinding in the present process.

A pre-feasibility study was conducted to determine the economic and technical differences between the current process and the planned method. Raw materials costs and natural gas consumption of the current process (spray drying) are shown in Table 2.4.

Current Cost Analysis (€/Ton) (M1)	Raw Materials Composition	11.75
	Natural Gas (1632 g/L)	11.45

Table 2.4. *Cost Distribution of the Current Wet Process for the Wall Tile Body.*

Table 2.4 indicates that the bulk density of wall tile slip is about 1632 g/L. On the other hand, natural gas consumption cost is 11.45 € per ton.

3.1.2. DEVELOPED METHODS AND ITS PARAMETERS

A new production system, termed the Semi-Wet Process, has been developed in order to reduce natural gas consumption in dewatering the slurry. Figure 2.1 shows the flow chart of the semi-wet process.

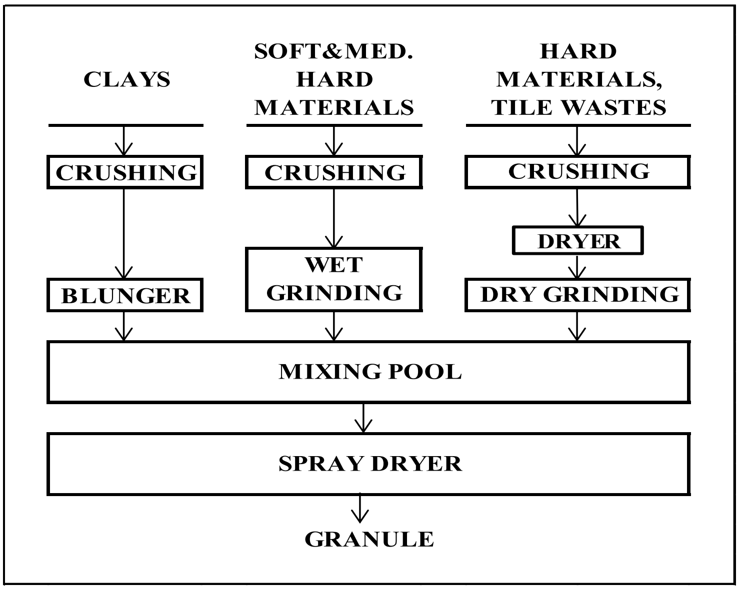

Figure 2.1 *Semi-Wet Process.*

As indicated in Figure 2.1, hard raw materials such as feldspar, tile waste and siliceous kaolin are crushed down to 3 mm particle size by a hammer crusher, which is suitable for crushing hard materials. After the crushing process, drying application is needed unless the moisture content of the raw materials is below 1%.

Raw materials that are crushed under 3 mm size are dried until containing a humidity of less than 1%. Moreover, dry materials such as wall tile wastes are ground by a dry ball mill until reaching 2% residue on a 63 μm sieve. In addition, particle size separation is supported by a separator, which works in a closed circuit with a ball mill to keep the particle size in an ordered ratio.

Finally, dry material is added to the mixing pool, in which clay slurry and other soft and medium-hard materials are homogenized. The pool is modified to achieve homogenous mixing of wet and dry particles with the addition of a turbo rotary wing. A piston pump is used for efficient pumping of the slurry that has a water content under 36%. The spray drying process needs to be modified with respect to the nozzles because of the high bulk density of the slip. The atomizers are spray pressure nozzles, through which slurry is pumped at high pressure. The spray nozzles are mounted on a series of radially arranged lances in the middle of the chamber, hot air being fed into the top of the chamber [5]. Hence, bigger nozzles are needed to pump the high density slurry into the chamber.

4. EXPERIMENTAL

Firstly, cracked pieces of wall tiles, which were taken from Kaleseramik raw materials storage area, were crushed and ball milled. Then, dry ground waste was passed through an ASTM # 100 mesh sieve and the particle size distribution of the sample was checked by the Malvern Microplus Mastersizer (Table 3.1).

d_{90} (μm)	d_{50} (μm)	d_{10} (μm)
28.81	5.23	0.48

Table 3.1. *Ground and Sieved ASTM # 100 Mesh Wall Tile Waste.*

The chemical and mineralogical analysis of the wall tile wastes used in this study is presented in Table 3.2.

Chemical Analysis	**L.O.I.**	**SiO_2**	**Al_2O_3**	**TiO_2**	**Fe_2O_3**	**CaO**	**MgO**	**Na_2O**	**K_2O**
	0.57	63.91	20.95	0.78	1.62	8.67	0.71	0.74	2.08
XRD	Quartz(%33), Anorthite(%36), Diopside(%3), Mullite(%3), Glass Phase (%26), Others (%2)								

Table 3.2. Wall Tile Waste Chemical and Mineralogical Analysis.

Dry wall tiles wastes were added to the wall tile body slip compositions in amounts of 10%, 15% and 20%, 25% and 30% by mass to evaluate the sintering behaviour of the body (Tables 3.3, 3.4, 3.5 and 3.6).

COMPOSITION WALL TILE			UNIT	DK-ORJ	DK PK 0	DK PK 1	DK PK 2	DK PK 3	DK PK 4	DK PK 5
RAW MATERIAL	CALCITE UNIT	CALCITE		12	12	12	12	12	12	12
		KAOLIN		1.5	1.5	1.5	1.5	1.5	1.5	1.5
		TOTAL		**13.5**	**13.5**	**13.5**	**13.5**	**13.5**	**13.5**	**13.5**
	KAOLIN UNIT	KAOLIN		6.5	6.5	6.5	6.5	6.5	6.5	6.5
				16	16	16	16	16	16	16
				3	3	3	3	3	3	3
				5.5	5.5	5.5	5.5	5.5	5.5	5.5
				8	8	8	8	8	8	8
				10	10	10	10	10	10	10
		TILE WASTE		8	-	-	-	-	-	-
		TOTAL	%	**57**	**49**	**49**	**49**	**49**	**49**	**49**
	CLAY UNIT	CLAY		29.5	29.5	29.5	29.5	29.5	29.5	29.5
		GREEN TILE		6.5	6.5	6.5	6.5	6.5	6.5	6,5
		TOTAL		**36**	**36**	**36**	**36**	**36**	**36**	**36**
	GENERAL TOTAL			**106.5**	**98.5**	**98.5**	**98.5**	**98.5**	**98.5**	**98.5**
DOSAGE	CALCITE			12.7	13.7	12.3	11.6	11.0	10.3	9.6
	KAOLIN			53.5	49.7	44.8	42.3	39.8	37.3	34.8
	CLAY			33.8	36.5	32.9	31.1	29.2	27.4	25.6
	DRY GROUND WALL TILE WASTE			**0**	**0**	**10**	**15**	**20**	**25**	**30**
	SLURRY MIX			100	100	100	100	100	100	100

Table 3.3 *Dry Ground Wall Tile Waste Addition to Body Compositions.*

WALL TILE BODY		UNIT	DK-ORJ	DK PK 0	DK PK 1	DK PK 2	DK PK 3	DK PK 4	DK PK 5
SINTERING BEHAVIOUR	PEAK TEMPERATURE	°C	1150	1150	1150	1150	1150	1150	1150
	FIRING CYCLE	min	36	36	36	36	36	36	36
	DIMENSIONS	mm	49.92	49.94	49.92	49.90	49.88	49.85	49.83
	SHRINKAGE	%	**0.32**	**0.28**	**0.32**	**0.36**	**0.40**	**0.46**	**0.50**
	WATER ABSORPTION	%	**17.45**	**16.72**	**16.58**	**16.89**	**16.94**	**16.87**	**17.20**
	COLOUR	L	75.37	74.8	74.99	74.57	74.8	75.2	75.2
		a	6.7	6.07	6.81	6.93	6.81	6.57	6.64
		b	17.64	18.27	17.81	18.34	18.21	17.5	17.9
DILATOMETER	α300	$*10^{-7}K^{-1}$	64.75	64.16	64.08	63.89	63.53	63.61	63.64
	α400		67.26	66.86	66.63	66.49	66.20	66.25	66.04
	α500		70.75	70.39	70.09	70.02	69.75	69.81	69.33
	α600		81.82	81.55	80.82	80.94	80.65	80.74	79.41
GREEN STRENGTH		kg/cm^2	15.75	14.15	15.35	13.37	12.45	11.33	11.23
DRY STRENGTH			36.01	37.84	38.18	33.16	26.73	30.11	30.05

Table 3.4 *Sintering Behaviour of the Wall Tile Body Compositions.*

Table 3.3 and Table 3.4 show that dry prepared wall tile wastes that have a moisture content of less than 1% can be added to the wall tile body composition. No viscosity problems were observed in the slurries. The dilatometer results and the green and dry strength of the body are significantly close to the standard body properties. The changes in both water absorption and shrinkage percentages are shown in Figure 3.1.

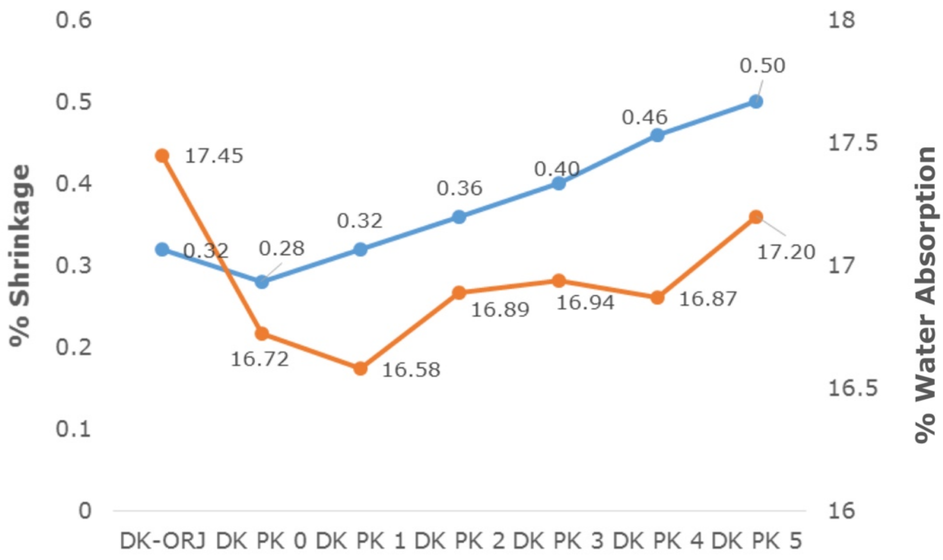

Figure 3.1. *The changes in both water absorption and shrinkage percentages of the samples.*

Figure 3.1. shows that the dry prepared raw materials such as the fired wall tile wastes with a moisture content below 1% can be added to the wall tile body composition in a quantity of 20% without having negative effects on the sintering properties of the body.

5. RESULTS AND DISCUSSION

The total granule preparation costs, which include the costs for raw materials, crushing-screening, grinding and natural gas consumption (spray drying), are shown in Table 4.1.

Current Cost Analysis (€/Ton) (M1)	Raw Materials Composition	11.75
	Crushing-Screening-Transport	1.74
	Grinding (Wet Ball Mill)	2.40
	Natural Gas (1632 g/L)	11.45
	TOTAL (€/Ton)	27.33

Table 4.1. *Cost Distribution of the Current Wet Process for Wall Tile.*

Table 4.1 indicates that the total powder preparation cost is 27.33 € per ton. The vast amount of the cost comes from the natural gas consumption, except the raw materials costs.

Wall tile waste products, which were added to the wall tile body compositions in amounts of 20%, are ground down to 63 micron with a 2% screen residue. As a result, wall tile body slip density increases from 1632 g/L to 1750 g/L while natural gas consumption decreases from 11.45 €/ Ton to 8.18 €/Ton. The cost analysis of the wall tile body obtained by the new system is given in Table 4.2.

Cost Item	**M2**
Raw Materials Composition	11.75
Crushing-Screening-Transport	1.49
Grinding	2.21
Natural Gas Consumption	8.18
TOTAL (€/Ton)	23.61

Table 4.2 *Cost Analysis of the Granule Preparation Process for the Wall Tile Composition.*

Table 4.2 indicates that spray drying cost reduces from 11.45 €/Ton to 8.18 €/Ton for wall tile body composition. Total granule preparation cost of the body slip decreases from 27.33 €/Ton to 23.61 €/Ton. The use of semi-wet system can provide profit around 1,965,441 €/year for the current production rate in the factory.

6. CONCLUSION

In the semi-wet system, the process that crushes the hard materials down to 3 mm is supported by a hammer crusher because of the physical characteristics and particle properties of the raw materials involved. The raw materials are dried in a rotary dryer to reach less than 1% moisture for efficient grinding. The dry prepared powder was added in an amount of 20% to the mixing tank such that, adjusting the body composition, the bulk density of the wall tile slip rose from 1632 g/l to 1750 g/l. As a result, the natural gas consumption decreased from 11.45 €/Ton to 8.18 €/Ton. The use of the semi-wet system is able to provide a profit of around 1,965,441 €/year for the current production rate at the factory. The Semi-wet Process can be used in producing wall tile granules. Dry prepared raw materials such as sintered wall tile wastes that have a moisture content of less than 1% can be added to the wall tile composition in an amount of 20%. Thus, the bulk densities of the slip rise rapidly. As a result of the benefit of the dry material addition to the body slip, the water content of the slurry decreases and spray drying costs are considerably reduced.

ACKNOWLEDGEMENTS

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