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A novel dry granule preparation technology and comparison of granule properties with conventional wet system for ceramic tiles production

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Abstract: The ceramic tile manufacturing process uses a lot of energy, mainly thermal energy, and to a lesser extent electric energy. Total energy costs account for between 50% and 55% of average direct manufacturing costs. Fossil fuel combustion, such as natural gas combustion, produces carbon dioxide emissions. Therefore, energy consumption and emissions issues are vitally important for both environmental effects and process costs in ceramic tile manufacturing. The wet process of granule production systems including wet grinding and spray drying is widely used for the production of granules. Although there is high energy consumption for the water evaporation in the spray dryer, it ensures to produce high quality tile for many years. In this study, important granule properties were introduced for a novel dry granule production system. In the successful application of a dry granulation system, the conformity of produced granules is vitally important such as particle size distribution, bulk density, flow properties, and moisture of granules and conformity for the pressing process. This paper includes the comparative studies for properties of granules produced in spray dryer and new dry granule preparation systems and the full results of the industrial trials with these granules. The cost comparison of both granule production systems was also made for the same raw material usage. The natural gas consumption and water consumption were reduced respectively from 46 to 15 m^3/ton and from 540 to 95 liters/ton in the new dry granulation system while electricity consumption and maintenance costs remain almost the same in both systems.

Keywords: ceramic tile, dry granulation, energy consumption, granule characteristics

1. Introduction

Ceramic tile production consists of wet grinding and granulation, shaping, drying, decoration (glazing + digital printing), and firing stages (Mezquita et al., 2017). The granulation process is nowadays done with spray dryers. Spray drying is well-known and widely accepted technique to be used in the ceramic tile industry to obtain granules suitable for pressing (Fig. 1). Ceramic tile production requires powders with excellent fluidity and compaction properties so that spray-dried powders are typically preferred because of their overall better properties compared to other granulation techniques, such as dry tumbling or intensive mixing, which are also used in ceramic tile manufacturing. The reasons why spray-dried powders have better quality according to dry granulated powders are: the particle size distribution of spray-dried powders is finer and narrower, spray-dried granules are more spherical resulting in good flowability, more deformable due to their lower densities arising from inner cavity, and have packing efficiency and compressibility (Soldati et al., 2022; Melchiades et al., 2010; Melchiades et al., 2012). However, spray drying causes a large consumption of energy, which is mainly spent on evaporating water, and the associated CO_2 emissions. In addition, since masse slip usually contains 34 – 36% (by weight) water, and powders suitable for pressing require 5 - 7% moisture, hence there is a significant water consumption in the spray drying process. Therefore, it is estimated that spray drying

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accounts for approximately 30% of the total energy and approximately 70% of the total water used in the production of ceramic tiles on average (Soldati et al., 2022).

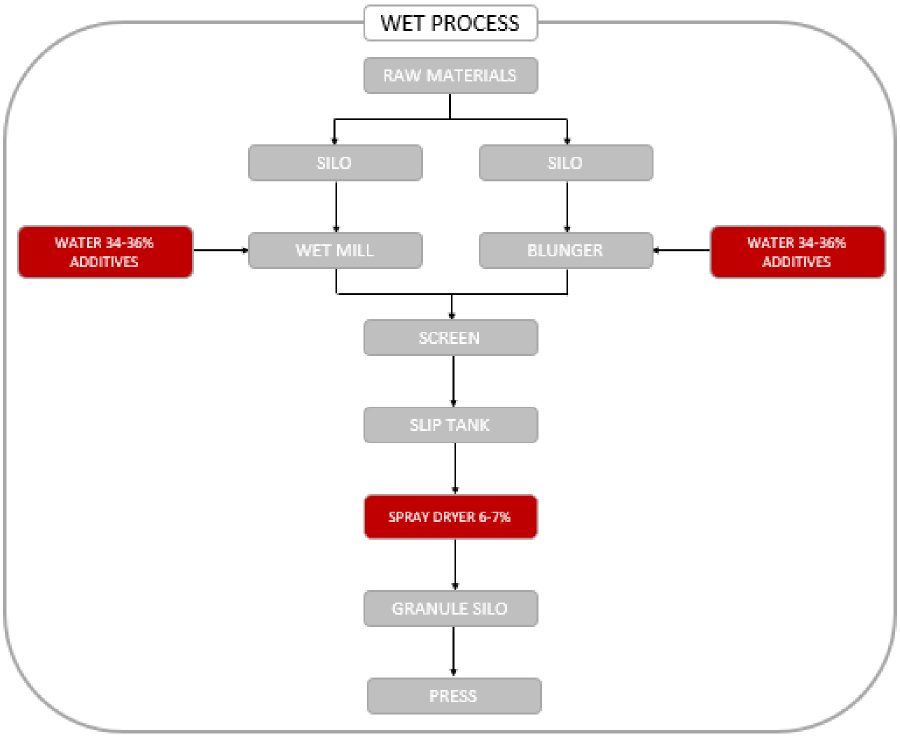


Fig. 1. The flowsheet of granule preparation with conventional wet method

In order to ensure long-term sustainability, water and energy savings become very important in the production of wall ceramic tiles. In addition, interest in the environmental impact of industrial production has been constantly growing worldwide. This leads industrial organizations to take important measures. The most important step is to avoid the energy-intensive and water-wasting spray drying step. The spray drying has undoubtedly spread throughout the world as it provides powders with suitable properties in the ceramic industry (Shu et al., 2010). Dry granulation has not found widespread use in the industry due to its undesired rheological properties and compaction behaviour in the past. However, the dry route is essentially a water-saving process, thus saving energy therefore it has been a subject of research and development over the past decade (Soldati et al., 2020a).

Hybrid systems have been developed as an alternative to dry granulation. The basis of the hybrid system is based on the co-granulation of wet and dry ground powders. In the Migratech 4.0 hybrid system, dry ground powders and wet slip are mixed in a tubular mixer, then reduced in size and dried in a fluid bed dryer (Soldati et al., 2020b). On the other hand, the droplet powder granulator consists of a modified spray dryer, from which dry ground powders can be fed simultaneously, apart from the slip (Shu et al., 2012). Although hybrid methods propose granules characteristics with similar to that of spray dried powders, both methods involve wet grinding and drying, so water and energy consumption is higher than the dry method.

A dry granulation technique developed by Manfredini & Scihanchi – Green Tech has been attracted a lot of attention recently. Compared to the traditional wet system; this dry route provides benefits such as a dramatic reduction in water consumption and a reduction in emissions. As seen in Fig. 2, this dry grinding and granulation system consists of micronization of soft and hard minerals separately, control screening, mixing of soft and hard minerals, humidification and granulation. The mechanical compression applied to fine moistened powders with FUSION activates the underlying molecular covalent and electromagnetic forces, promising the perfect compatibility of all formula raw materials and an extraordinary stability. Thus, excellent homogeneity, fluidity and density in the final granulated material and ceramic products without borders in format, thickness and typology are obtained.

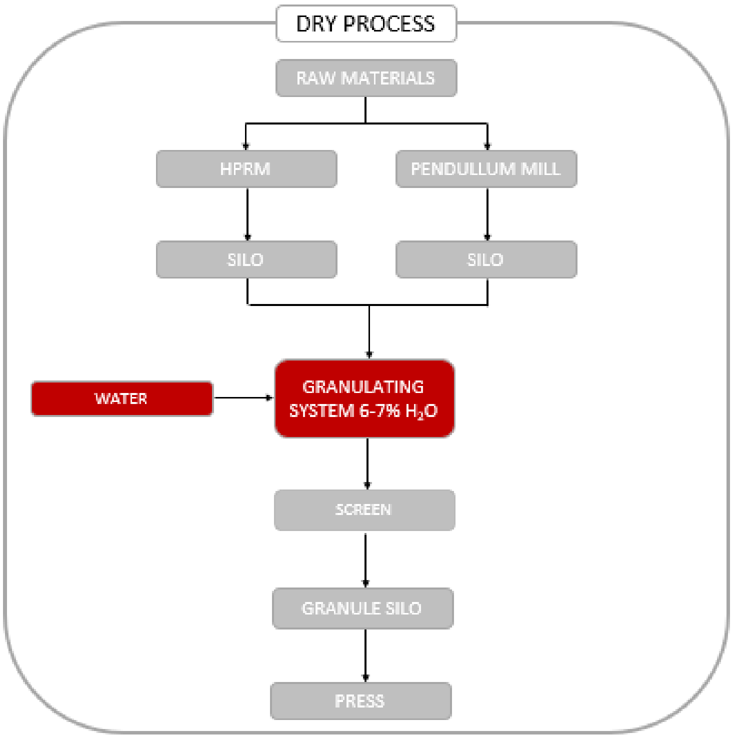


Fig. 2. The flowsheet of a new dry granule preparation system

The aim of this study was to investigate characteristics of granulated powders produced with both new dry granulation system and conventional spray dryer system and to determine the effects of these granules on wall tile production.

2. Materials and methods

2.1. Materials

In this study, the same material composition that is wall tile body composition was used for granules preparation for both the spray dryer and the new dry granulation method called the FUSION system. The raw material composition and the moisture contents of each material are presented in Table 1.

Table 1. The raw material composition and the moisture contents

Raw Materials	Percentage in the Recipe (%)	Moisture (%)
Kaolin	33.0	6.0
Feldspar	20.0	6.0
Calcite	11.0	0
Kaolinite	28.0	28.1
Bentonite	8.0	25.5
Total	**100.0**	

2.2. Methods

Dry sieve analysis was performed using 500, 425, 250, 150, and 75 μm sieves to determine the particle size distribution of the granules. Freeman Technology FT4 powder rheometer device was used to determine the bulk properties of granules such as density, compressibility, and dynamic flow properties such as basic flow energy, bulk density, air permeability. Dynamic flow properties are determined from precise measurements of axial and rotational forces acting on a special helically rotating blade through a powder sample. The basic flow energy is measured by the energy required for the downward movement of the blade and quantifies the flow behavior under constrained flow (or forced flow) conditions. Bulk properties of powders, such as air permeability and compressibility, are determined using a piston that allows air to escape while normal (vertical) force is applied to the powder bed (Karaaslan et al., 2022). Image analyses of the granules were performed using an optical microscope.

An industrial trial was conducted with the granules produced using the same recipes both the spray dryer and the dry granulation system of FUSION. In the industrial trial, which was carried out in the wall tile factory under standard conditions at Kaleseramik Factory, Can, Türkiye. The produced granules were pressed in 30x60 cm size and decorated and sintered in a rapid firing roller furnace. Then, the strength, fired density, and water absorption values of the fired products were measured for both systems.

The operating costs of conventional wet granulation system and new dry granulation system were compared. The results are obtained from the report specially prepared for Kaleseramik by Manfredini & Schianchi – Green Tech company.

3. Results and discussion

3.1. Granule size distribution and shape

The particle size distribution table and graph of the granules prepared by spray dryer and FUSION is given in Table 2 and Fig. 3., respectively. As can be seen from the results, the amount of granules prepared with FUSION in +500 μm and -75 μm size groups are higher than the amount of granules prepared with the spray dryer in those size groups. According to the optical microscope images given in Fig. 4; the granules produced by the spray dryer appear spherical, hollow, and homogeneous, while the granules produced by FUSION had a sticky and more dispersed appearance. The high amount of fine particles and the deviation of the grain shape from sphericity negatively affects the flow properties. As the grain shape deviates from sphericity, the mould cavity does not fill homogenously, and resulting in alterations in the uniformity of the body (Vari, 2004; SACMI, 2005).

Table 2. Sieve analysis of granules

Size range (μm)	SPRAY DRYER		FUSION	
	Amount (%)	**Cumulative undersize (%)**	**Amount (%)**	**Cumulative undersize (%)**
+500	23.56	100.00	30.89	100.00
-500+425	13.08	76.44	12.82	69.11
-425+250	42.24	63.36	31.82	56.29
-250+150	15.49	21.12	14.29	24.47
-150+75	4.97	5.63	5.85	10.18
-75	0.66	0.66	4.33	4.33
Total	**100.00**		**100.00**	

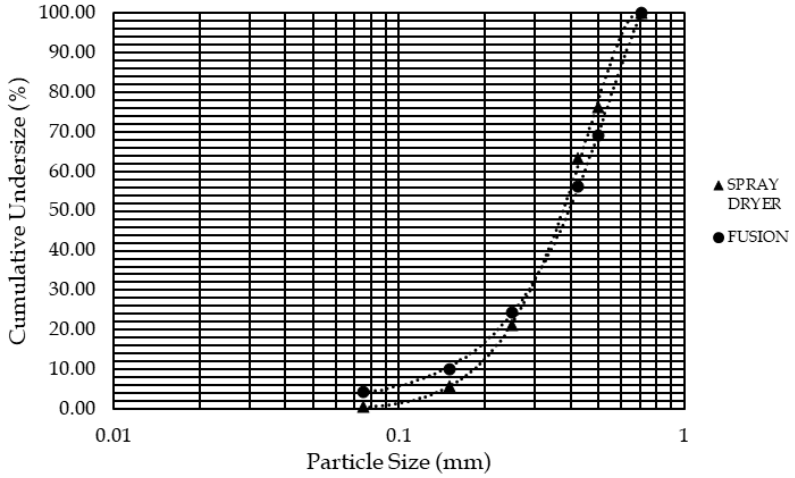
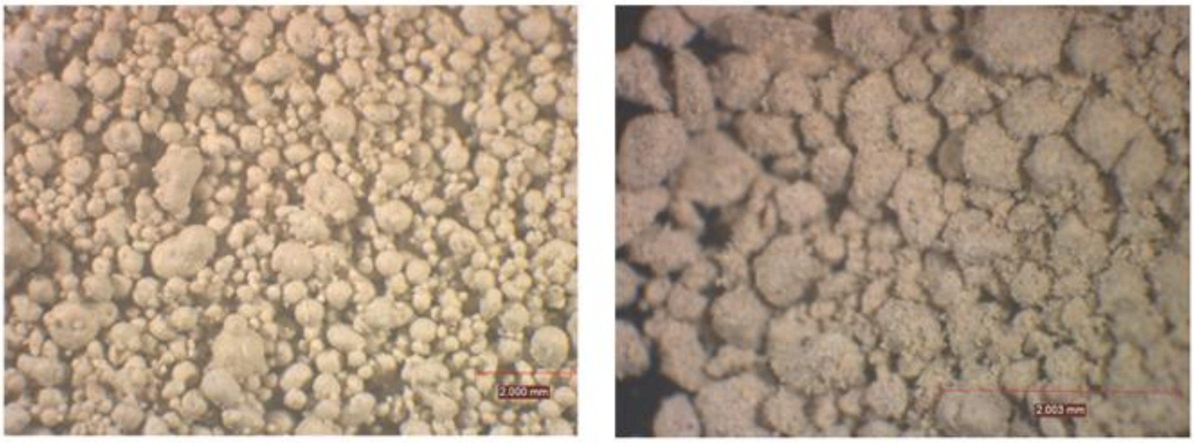


Fig. 3. Particle size distribution graphs of granules



(a) SPRAY DRIED (b) FUSION

Fig. 4. Optical microscope images of granules (a) SPRAY (b) FUSION dried samples

3.2. Density

Bulk density, tap density and humidity of the granules are given in Table 3. The granules produced with FUSION had higher bulk (1.032 g/cm^3) and tap density (1.143 g/cm^3) than granules produced with spray dryer (0.945 and 0.996 g/cm^3). Also, the granules produced with FUSION are more humid (6.8%) than granules produced with standard spray dryer (5.8%).

Table 3. Density and moisture content of the granules

	Bulk density (g/cm^3)	**Tap density (g/cm^3)**	**Moisture (%)**
SPRAY DRYER	0.945	0.996	5.8
FUSION	1.032	1.143	6.8

To determine the conditioned bulk density (CBI), after the conditioning cycle, the weight of the powder remaining in the fixed bottom container volume was weighed with the instrument scale, and the density is calculated. For the same formulation, a higher density may indicate better packaging efficiency. The influence of an external force such as gravitational can play a role and in relation to the effect of interparticle forces according to the particle size, higher packaging of granules may be triggered by relative particle motion (Santomaso et al., 2003). FUSION powder appears to have a higher bulk density when uncompressed (Fig. 5).

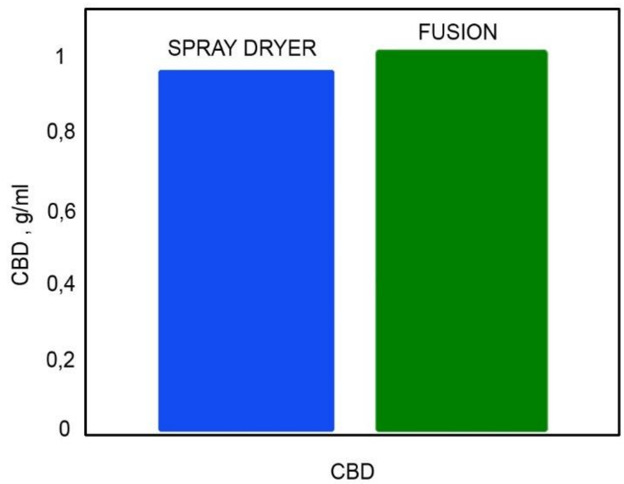


Fig. 5. Conditioned bulk density diagram of the granules

3.3. Flowability properties

In Fig. 6, the basic flow energy (BFE) graphs of the granules prepared with the spray dryer and FUSION are given. The basic flow energy is the energy required to displace a powder during non-gravity forced flow, i.e. resistance to flow in a constrained environment, e.g. flow-through feeding on a screw conveyor, etc. The flow resistance of FUSION powder in restricted media is significantly higher than that of SPRAY DRYER powder. For example, when the powder is forced to flow to fill a mould with a slide, FUSION powder flows with a higher energy consumption.

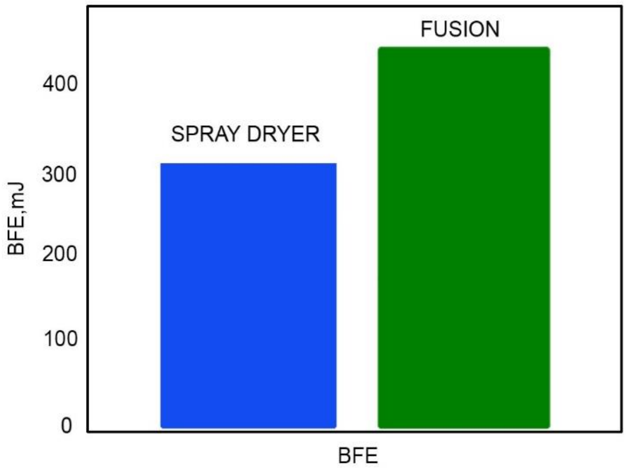


Fig. 6. Basic flow energy diagram of the granules

3.4. Air permeability

The aeration test measures changes in flow characteristics due to air ingress into the sample. It defines how a powder behaves during mixing, pneumatic transfer, and fluidisation. As seen from Fig. 7, unlike SPRAY DRYER powder, the flow resistance of FUSION powder decreases with a steeper slope, that is, it becomes more fluid as the air flow increases. The aeration rate and aeration sensitivity of FUSION powder are significantly higher. It may flow more easily at high airflows.

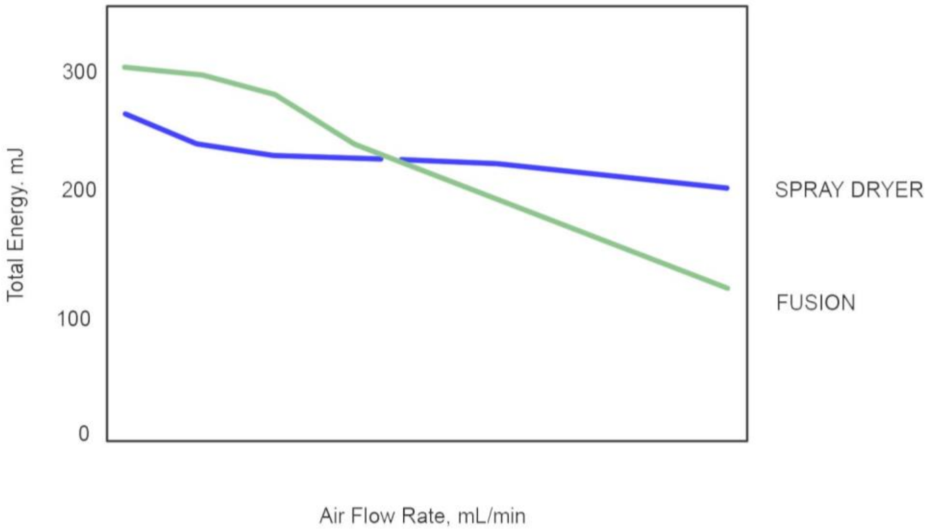


Fig. 7. Flow resistance graph of the granules

Air permeability test measures the ease with which the powder volume can conduct or release air while increasing normal stress. High pressure drop across the powder volume means low air permeability. The high pressure drop in FUSION powder also means it holds more air. Air trapping can result in lower efficiency in processes such as mould filling and air evacuation. As this powder is compressed, its air permeability is further reduced. SPRAY DRYER powder holds much less air. It has high air permeability and is not affected by the increase in compression load.

3.5. Compressibility properties

Compressibility test (Fig. 8) shows the ability of the powder to be compressed when subjected to normal stress, as a change in compressibility or density. It is the measurement of volume and packaging changes during storage and transport in processes such as direct or air compression. As the pressure increases, the density difference between FUSION and the SPRAY DRYER powder increases. The low compressibility of the SPRAY DRYER powder indicates that the powder is already well packed under its weight before being pressed, settles neatly in the mould, and has good structural integrity.

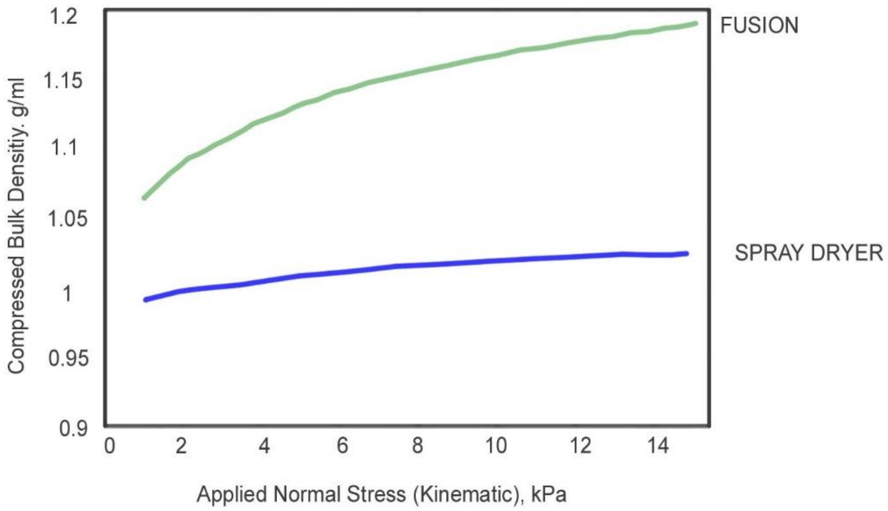


Fig. 8. Compressibility test results of granules

3.6. Industrial trials

The results of the industrial trials are given in Table 4. The dry and fired mechanical strengths of the granules produced with FUSION are considerably lower than those of the granules produced with the spray dryer. This can be explained by the larger size distribution, high compressibility and low deformability of the granules produced with FUSION. Mechanical strength can be increased by increasing the press pressure.

Table 4. Industrial trials' data

	SPRAY DRYER	FUSION
Moisture content (%)	5.8	6.8
Pressure (kg/cm^2)	346	346
Dry mechanical strength (kg/cm^2)	29.44	18.15
Temperature (°C)	1130	1130
Cycle (min)	54	54
Fired bulk density (gr/cm^3)	1.79	1.86
Water absorption (%)	17.4	14.8
Fired mechanical strength (kg/cm^2)	229	137

3.7. Operating costs

The operating costs of wet and dry granulation system are given Table 5. As it can be seen from the data's, FUSION has many advantages in terms of natural gas, water, additive deflocculants consumptions and the number of personnel per shift. Soldati, R., et al. reported water, thermal energy, electrical energy, deflocculant consumption and CO_2 emission data of wet, dry and hybrid granule preparation systems in previous studies in the literature (2022). Besides the technical results, all studies show that dry granulation systems increases sustainability of ceramic tile production from the point of environmental and economical.

Table 5. Operating costs of spray dryer and FUSION

	SPRAY DRYER	FUSION
Natural gas consumption	46 m^3/ton	15 m^3/ton
Water consumption	540 liters/ton	95 liters/ton
Electric consumption	55 kW/ton	60 kW/ton
Average additive deflocculants consumption	4 kg/ton	-
Maintenance cost	3.5 €/ton	3.5 €/ton
Personnel	3 Person/Shift	1 Person/Shift

4. Conclusions

Basic flow energy of SPRAY DRYER and FUSION granules are different. SPRAY DRYER powder, which has higher flowability in forced and free flowing state, is transferred more easily in all conditions and settles more smoothly by spreading easily to the volume it is transferred to.

Bulk densities are different and this difference increases as the powders are compressed. While the density of SPRAY DRYER powder is less affected by the compression load, FUSION powder can be compressed more with increasing pressure.

Air permeability of SPRAY DRYER and FUSION granules are different. SPRAY DRYER powder has a high air permeability and is not affected by the change in compression load. Thus, it can provide a predictable compression and/or post-sinter shrinkage profile with consistent mould filling every time. FUSION powder, on the other hand, holds much more air and as the compression load increases, its air permeability decreases. Their cohesion, yield strength and flow functions are different. SPRAY DRYER powder needs lower stress to flow. The particles of this powder spread easily by flowing over each other and properly filling the pressing mould.

The results from the industrial trials are consistent with the characterization analysis of the granules. There is a strong correlation between high compressibility, low cohesion, and high flow function and high mechanical strength values in the spray dried granulates.

In new dry granulation system, the natural gas consumption was reduced from 46 m^3/ ton granule to 15 m^3/ ton granule and the water consumption from 540 liters/ton to 95 liters/ton. While the electricity and maintenance costs remain almost the same in both systems. It is predicted that the number of workers will decrease from 3 to 1 in the dry granulation system.

Acknowledgments

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