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Differences Between Dry and Wet Route Tile Production

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Abstract: Tile production has an important place in overall ceramic production. There are different types of methods for them. Companies generally use wet route for raw materials preparation. However, dry route has been started to be used at large scale in recent years. There are some advantages and disadvantages for dry and wet route tile productions. This paper was prepared to give detail information about both methods.

Keywords: Tile, Wet route, Dry route, Production, Advantage, Disadvantage, Comparison.

Karo Üretiminde Kuru ve Yaş Yöntem Farklılıkları

Öz: Seramik sektörünün büyük bir kısmını oluşturan karo üretiminde farklı yöntemler kullanılmaktadır. Genellikle üretim ıslak yöntem ile gerçekleştirilmektedir. Son yıllarda kuru yöntemle üretim de yaygın bir biçimde kullanılmaya başlamıştır. Her iki yönteminde bir takım avantajları ve dezavantajları bulunmaktadır. Bu makale kuru ve ıslak yolla karo üretimi hakkında detaylı bilgi sunmak amacıyla hazırlanmıştır.

Anahtar kelimeler: Karo, Islak yöntem, Kuru yöntem, Avantaj, Dezavantaj, Karşılaştırma.

1. Introduction

The ceramics industry began to expand as a modern industry with new techniques and knowledge gained in the 1970s. It has since been one of the most competitive industries on the market [1]. Properties of ceramics are determined by the types of atoms present, the types of bonds between atoms, and the way the atoms are packed. Ceramics usually have a combination of ionic (which occurs between metal and ametal, and involves the attractiveness of opposing charges when electrons are transferred from metal to ametal); and covalent (between two non–metals and contains the sharing of atoms) bonds.

There are considerable differences between traditional ceramics and modern, engineering ceramics which are sometimes designed for a single specific purpose [3].

- *Traditional Ceramics*
  The word 'earthenware' for ceramic pots and jugs is an indication that their raw materials are literally obtained from the ground.
- *Advanced Ceramics*

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> Since the 1980s, new types of ceramic named as advanced ceramics have been developed. They are, also known as technical ceramics being strong and hard due to the strong ionic or covalent bonds between these elements [4].

Like other industries, in ceramic sector there have been numerous innovative approaches in both body and glaze formulations as well as new touches in the production processes thanks to the technological development all around the World. When looked through the relevant literature one can easily see the countless modifications made in ceramic body and glaze compositions to adopt them to single fast–firing procedure that is recently being very popular and alternative to conventional double–firing still being used especially in the production of sanitary wares and porcelains.

Another attempt taken is the development of new frit compositions facilitating such an adaptation of lower temperature glazes to single fast–firing in which everything is expected to be over between 35–50 min during sintering. Zircon (zirconium silicate–$ZrSiO_4$) is widely used as an opacifier to supply an acceptable level of whiteness and opacity to the ceramic glazes, so, it is one of the inevitable components in glaze formulations. However, it increases the starting cost, consequently limiting it wide usage. Therefore, a group of scientists has studied its elimination in industrial wall tile glazes without deteriorating the overall final properties. For such purpose $Al_2O_3/\Sigma R_2O$, $Al_2O_3/\Sigma RO$ and Al_2O_3/B_2O_3 ratios have been changed and their noteworthy effects on decreasing the amounts of zirconia (ZrO_2) and zinc oxide (ZnO) in the frit composition were reported. Additionally, one other study was conducted on diminishing zircon content in floor tile body through compositional modification. In that sense, a model opaque glaze was developed by modifying the alumina/silica ratio, incorporating K_2O, or using higher amount of opaque frit while diminishing $ZrSiO_4$ content in the glaze batch.

Glass–ceramics discovered in the early 1950s are ceramic materials produced by preciously controlled heat treatment of a parent glass. The chemical composition of glasses, from which glass ceramic transformation is expected, must consist of nucleation agent(s) and be capable of volume crystallisation unlike ordinary conventional silicate–based glasses inhibiting uncontrolled surface crystallisation with dendrite formation which leads to brittleness. Nucleating agents having high surface energy are quite important and their selection depend on the system, into which they are added. Glass–ceramic glazes have recently been altered for ceramic tiles. Some researches made very valuable studies on such systems [for example: $Li_2O–Al_2O_3–SiO_2$, $CaO–MgO–Al_2O_3–SiO_2$, $ZnO–Al_2O_3–SiO_2$, $CaO–MgO–Al_2O_3–SiO_2$, $ZrO_2–CaO–MgO–SiO_2$ etc.], which are unique in the suitability for single fast–firing. That is not an easy phenomenon actually since it is quite difficult to control nucleation and crystal growth within a very short period of time in new generation of industrial ceramic production. Some companies tried to adopt crystal glazes mostly known as art glazes to the table ware industry. In those glazes containing ZnO the effects of certain oxides like cobalt, copper, manganese and titanium oxides were searched for and their micro–structural characterisation with the importance of structure–property relationship determining the properties was reported in the literature.

There have been several publications on the evaluation of phosphorus pigments, which are capable of absorbing daylight or light of certain wavelength when exposed to a light source and after, emitting phosphorescent light when the light source has been removed, in several glaze systems leading to new product achievement with phosphorescent ability in differing ceramics such as wall tile, Turkish çini, stoneware, schamot, earthenware as well as art glasses where they can directly be applied onto glass slump or added between glass layers. Of course, every different type of body may require engobe if there is intolerable thermal expansion mismatch between substrate and glaze. Since in such application’s low temperature decoration frit with phosphorescent pigment is used on

the top of transparent glaze already applied and matured, this final top layer must also satisfactorily stick to the glaze below. Otherwise decoration layer will not cover the whole ceramic surface without any defect and there will be no use of it.
As to functionality, there are new products with higher mechanical strength, antibacterial resistance supplied by certain oxides added to starting glaze chemical compositions, self cleanibility thanks to lotus effect coming from the surface morphology, photocatalytic and antifungal activity, better frost and slipping resistance, or aesthetic effects etc.

From the environmental points of view, with the concern of rapidly consuming all the available raw materials already being in use in many industrial branches and huge amount of wastes occurring during processing and threatening human life and liveable environment, it also becomes compulsory to see the evaluation of alternative raw materials and several suitable wastes (sepiolite, thermal power plant's fly ash, rice husk, limonite, different clays taken from different part in Earth crust, red mud, Si containing waste mud, electrolysis wastes, chromite wastes, albite flotation wastes, concentrator and derivative borax solid wastes etc.) incorporated into ceramic body and glaze mixtures. As a result, in most cases both alternative raw materials and the industrial wastes mentioned here have been found usable sources which could easily be evaluated up to a certain level in ceramic industry. In order to improve the attractiveness of new products the technological developments experienced in decoration especially giving the impression of three-dimensional look must also be mentioned here. Among these innovative contributions especially at the body preparation step as will be touched hereby valuable studies are being made to develop dry route tile productions possibly and expectedly replacing conventional wet route in soon future.

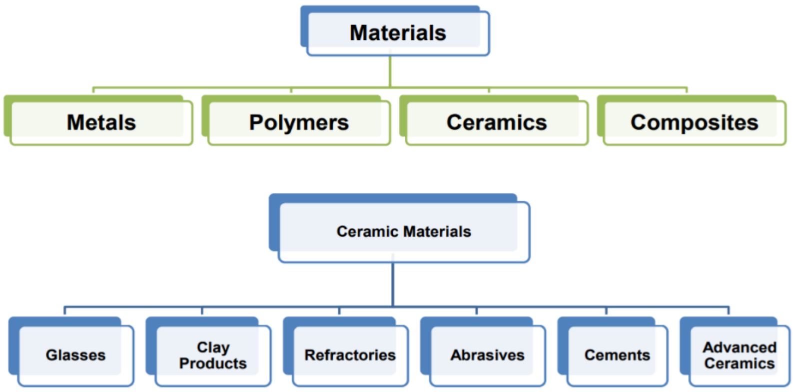


Figure 1. Classification of materials and ceramics [2].

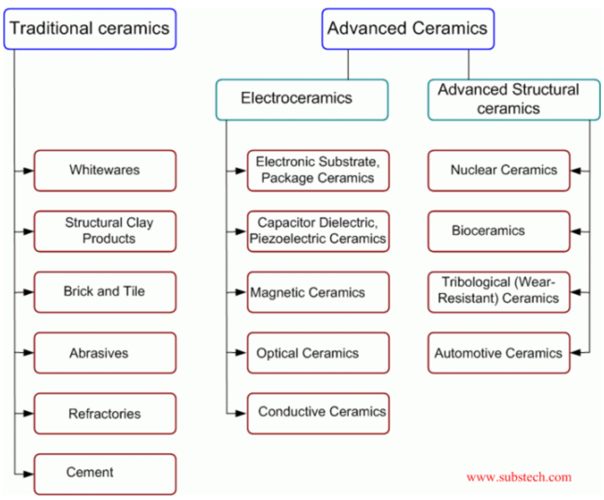


Figure 2. Detailed classification of ceramics [5].

2. Ceramic Tile

Ceramic tile is a term that encompasses many diverse products from wall to floor tiles to porcelain to tiles that used on countertops. They come with a variety of finishes from smooth to rough, and from flat to irregular shape. They have either a sealed non–porous surface or a water–absorbing porous surface. Whatever type one chooses, all ceramic tiles are basically installed in the same manner [6].

3. Production of Ceramic Tiles

The stages of ceramic tile production briefly cover the preparation of raw materials for batching, forming the green body by milling, shaping, drying, and then producing final product by sintering, packaging and storage [3–4].

Slurry processing facilitates mixing and minimizes particle agglomeration. In slurry processing, deflocculants, surfactants and antifoaming agents are added to improve processing.

Ceramic tile producers usually use a maximum of 4–5 % moisture. In mills heated by hot air (indicating the drying performance) this rate can be up to 10 %. The primary crush reduces the size of the incoming material to a maximum of about 6 cm, which is about 20 cm in size. Grinding is carried out in centrifugal pin type mills, fixed or moving hammer mills and pendulum mills according to the required grain size [7–8].

4. Raw Materials for Tile Production

Because of their three–part composition of quartz, clay and feldspar ceramics can be named as triaxial materials. It is common to use tap water, usually containing a wide range of cations. Many similar products, ceramic tiles tend to be produced from naturally occurring raw materials. In most cases, these are silicates. Clay and kaolin are the most important raw materials for tile production. In general, the raw materials used in traditional ceramics are divided into three commonly known groups: silica, clay and feldspar. These groups are described below [8–9].

4.1. Silica

Silicon (Si) is the second most abundant element in the continental crust at 28.2 % and its oxide, Silica, is hugely abundant in nature, occurring in seven distinct mineral forms [10]. Quartz is the commonest form and the one most widely exploited. The other varieties are tridymite and cristobalite, which are widely distributed in volcanic glass and opal, coesite, stishovite, and lechatelierite. Silica occurs in combination with other oxides in minerals such as the feldspathoids and other silicates [11]. The only stable form under normal conditions is alpha quartz. The high–temperature minerals, cristobalite and tridymite, have both lower densities and indices of refraction than quartz [12].

4.2. Clays

Typical common components in clayey minerals are feldspars, quartz, iron oxides, hydroxides, titanium oxide, calcite, dolomite and organic substances [9, 13–14].

Without some water, clay is just a powder. It is apparent that clay needs the right amount of water to become plastic (approx. 20 wt. %). Clay particles are attracted to each other by weak electrostatic forces. Water conducts these forces [15–16]. When clay matters then there is a series of considerations:

Plasticity [17], content of colouring oxides with chromophore action [18], content of organic substances [19], deflocculability [20], capacity to develop mullite [21], content of accessory minerals [22] and metallic impurities [23].

Clays bring the advantage of plasticity and ease of workability in the green state and facilitate sintering during firing [24–26]. They are the main component of porcelainized stoneware bodies [27]. The clays chosen are prevalently kaolinitic [28]. In selecting raw material, grain size and purity are the technical counterparts to the strategic ones of availability and cost [29–30].

4.3. Feldspar

Feldspar can be defined as a group of natural crystalline aluminium silicate minerals with Na, K, Ca or Ba. Alkali feldspars are used most in ceramics [31]. Feldspars feldspathoids, eurites, pegmatites and eventually quartz is known as hard materials. Feldspars are to be considered as fluxing agents [32–35]. There are 3 types of feldspar: Microcline [$K(Si_3AlO_8)$–$K_2O.Al_2O_3.6SiO_2$], albite [$Na(Si_3AlO_8)$–$Na_2O.Al_2O_3.6SiO_2$] and anorthatite [$Ca(Si_2AlO_8)$–$CaO.Al_2O_3.2SiO_2$] [36].

4.4. Other Minerals
4.4.1. Wollastonite

Wollastonite (natural calcium silicate) can play the role of fluxing activity lowering the maturation point of ceramic bodies [37–38]. It consists of 48.5 wt. % CaO and 51.5 wt. % SiO_2 but sometimes iron, manganese or magnesium may replace Ca [39].

4.4.2. Lithium minerals

There have been numerous researches previously done, main conclusions of which are: lithium addition into the body results in the glassy phase activity during the consolidation process [40–41].

4.4.3. Natural chromite

Cr oxides are important for providing several colours to ceramics and are employed with other compounds. Ferrochromium fly ash, and particularly natural chromite have been examined as a source of Cr compounds in colouring unglazed ceramic tiles [42].

4.4.4. Zircon

The major sources of zircon (ZrSiO4) are granites. Its most serious reserves are in Australia and South Africa being the main suppliers in the World [43]. Zircon is one of the widely used components in ceramic production (especially in ceramic glazes as an opacifier). It is mainly used in a wet–milled (micronized) version thanks to its high refractive index [44].

5. Wet Process in Ceramic Industry

Wet processing is a traditional process known for ceramic production. In ceramic tile manufacturing industry, it includes wet grinding and spray drying and is widely used for granule preparation. The grain size of starting raw materials should be reduced first. Some of the most common reasons for reducing particle size are to:

- create appropriate particle sizes,
- improve material blending and prevent segregation,
- increase the material's surface area,
- control material's bulk density,
- liberate impurities,
- reduce porosity of the particles and,
- modify shape of the particles.

There are 2 ways for reducing the particle size: Crushing and grinding. Crushing is the method with which the reduction of large lumps from cm size to 1–2 mm is made for subsequent further reduction. Most industrial grinding cycle are operated under wet conditions. The mass flow rate of the output of the circuit must remain reasonably constant with a preset value of the representative size, accomplished by abrasion, impact or compaction by hard media such as balls or rolls [45].

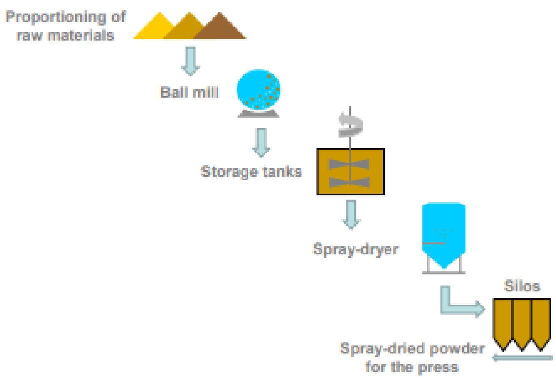


Figure 3. Raw materials preparation by wet route [45].

5.1 Milling

In terms of milling the most difficult to the least difficult is dense fused materials, sintered materials, and precipitated powders. Materials being not brittle to some degree, metals or soft plastics for example, cannot easily be milled. A slip consists of a liquid, usually water, and suspended ceramic particles [45]. Wet milling reduces the particle size for fine grained slips and disperses the agglomerates in both fine- and coarse-grained slips. One of the primary reasons for expending time and energy to granulate powders is to increase the apparent density of powders before forming. Usually, in powder this can be controlled by selecting a narrow particle size distribution. In some body preparation systems, there is also a moisture distribution effect where larger particles contain more moisture than smaller ones. There are many methods of preparing granules for pressing operations, the majority of which can be separated into two categories: wet and dry. Among the wet prepared powders, spray drying is, by far, the most accepted and widespread process. Dry granulation processes have acquired several aliases including moist palletisation, spray granulation, and slip palletisation [46].

5.2. Wet Granulation

Spray drying is accomplished first by mixing dry, finely ground powders with water (typically 65–72 % solids by weight) to form a slurry, which is then atomized inside the drying chamber by either a slotted, spinning centrifugal disc or a spraying nozzle. Hot, burned gases evaporate all but 4–6 % of water from each drop, leaving a hollow, smooth, spherical agglomerate. In spray dryer, material is moved due to the vibration and streaming air. The structure of these granules looks like blackberries [47]. It is possible to achieve varying granule morphologies by spray drying [48]. The average size of a droplet is inversely proportional to atomizing energy, air flow rate in two–fluid nozzle. Flocculated slurries (or slurries containing large agglomerates) lead to denser granules [49]. The main goals of using wet system with spray dryer are [50]:

- Quality improvement of final product,
- Far lower costs,
- Usage possibility of more economical raw materials,
- Nearly no water consumption,
- Eliminating pollution coming from the spray dryer,
- Higher production level from the kilns.

6. Dry Method in Ceramic Industry

This technology was chosen for the advantages in terms of both the production process and environmental sustainability. It produces a dry granulate (without the use of fluidised bed dryers) with excellent characteristics of homogenisation, flow and density and guarantees perfect blending of all the raw materials present in the formulation and excellent stability in the subsequent stages of pressing, drying and firing. The result is a high–quality finished product that maintains the same levels of water absorption (< 3 %) and green, dried and fired breaking load and the same drying and firing cycles. The tile surface is also extremely uniform and ideal for matt and gloss applications. Fusion also completely eliminates natural gas consumption in the production process and consequently reduces CO_2 emissions.

Unlike spray drying, where nearly 100 % of product is of appropriate size and moisture content for pressing, the pelletized body in the initial stages has a relatively large fraction which is over– and under–sized and must be recycled. The undersized fraction is easily collected by a cyclone attached to the fluid bed dryer. This "superfine" powder may be added directly to the next batch. The oversized fraction, > 25 mesh, can be ground and returned to the fluid bed dryer or added directly to the press powder [47].

If the water content is less than 1 % by volume, this process is called dry grinding. Free moisture content of a material should be as low as possible for dry milling. Dry milling also avoids the formation of hard agglomerates as there is no liquid present [46].

The dry granulation can be used to form granules without requiring a liquid solution. In this process the primary powder particles are aggregated under high pressure. Swaying granulator or a roll compactor can be used for the dry granulation [51]. The densification of the granules can be described like a creation of a snow ball.

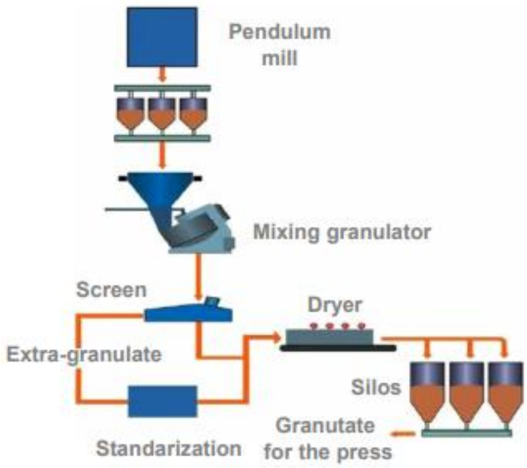


Figure 4. Raw materials preparation by dry route [45].

7. Agglomeration

An agglomeration or also called granulation can be done as wet or dry but it is to note that with dry agglomeration a certain amount of wetness in the system is also needed. Wet granulation is done in a spray dryer (Figure 5) [52].

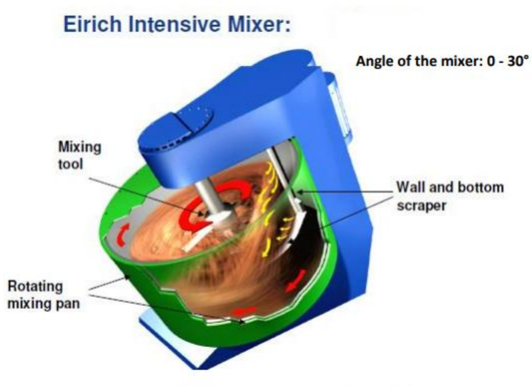


Figure 5. The mixer being used in dry process [53].

8. The Comparison of Dry and Wet Milling

Wet milling;
- Low power usage,
- No dusting,
- Higher rotational speeds,
- Good homogenisation,
- Smaller particle size availability compared to dry milling,
- Narrower particle size distribution than dry milling,
- Compatibility with spray drying and casting process.

Dry milling;
- No need for drying powder,

- Avoiding the reaction of the powder/liquid,
- Less media and lining wear than wet milling,
- Start/stop at any time,
- Easier to optimise.

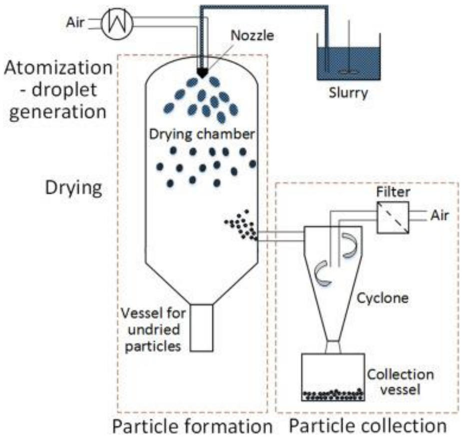


Figure 6. Spray dryer [52].

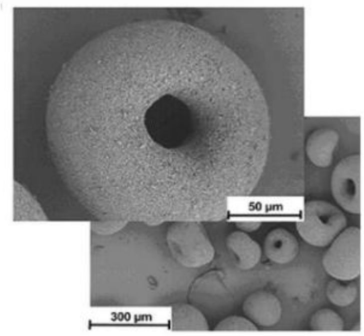


Figure 7. Doughnut structure out of the spray dryer [52].

9. Particle Size Distribution, Shape, Moisture and Bulk Density

Particle size distributions for spray dried powders can be tailored by proper selection of nozzle orifice diameter, feed pressurization, and slip viscosity.

Figure 8. Morphology achieved with dry method [54].

Figure 9. Morphology achieved with wet method [54].

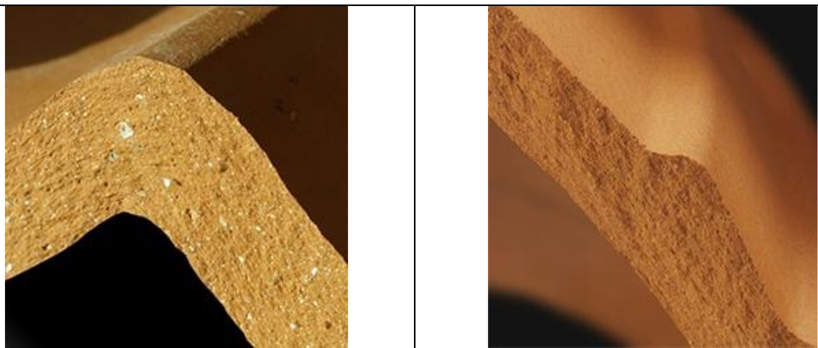
They are relatively narrow distributions compared with dry granulated size distributions. Figure 7 inhibits the difference in cumulative size distribution for spray dried, dry (or spray) granulated, and crushed filter cake particles. Dry granulated powders appear solid, spheroidal, with a rough outside surface [54].

10. Firing and Pressing Properties of Dry and Wet Tile Production

In one of the previously done studies ten fired samples of each pressing were measured for size. Shrinkages were calculated based on cavity size. As expected, the spray dried and dry granulated powders compacted at 360 kgs exhibited less shrinkage than samples compacted at 200 kgs. Shrinkage differences occurs between samples. Spray dried powders exhibit approximately 0.2 % greater shrinkage than the dry granulated powders at both tested pressures [54].

(a) (b)

Figure 10. Brick produced a) by wet method b) by dry method [55].



(a) (b)

Figure 12. Surface morphology of brick produced a) by wet method b) by dry method [55].

11. Operation Cost

Many difficult–to–measure factors must be weighed before an economic decision for a body granulation plant can be made. Since experience with spray drying abounds, there is much less risk involved in choosing it over dry granulation. Spray drying is guaranteed to deliver a consistent product, assuming the equipment is being run in an appropriate manner. There are, however, large initial investment savings which can be realized by choosing a dry granulation plant over a spray drying plant. The operating costs of a granulation plant consist of the cost of energy, both thermal and electrical, the labour, the raw materials, and the energy required for the firing process. Several studies exhibit that the different dry granulation techniques use in average only 65 % of the electrical energy required in the wet process. Comparison of several operating systems in Italy, Spain, and Brazil indicate that the dry granulation processes use only 15 % of the thermal energy required in a wet process. This is not surprising, as in the dry granulation processes only 6 % water needs to be evaporated whereas in the wet process up to 35 % water needs to be removed. Table 2 explains the symbols and data used in the thermal energy consumption equations [47].

Table 1. Consumption comparison between dry and wet system [45]

Incidence	Dry System	Traditional Wet System
Water (L/t)	36	266
Electricity (kW/t)	39	55
Natural Gas (mc/t)	3.9 with 12 % humidity in the raw materials	45
Personnel	2 People	3 People
Global Maintenance Costs (€/t)	5.5	7.5

Table 2. Wet process–consumption [55]

Wet Process	Consumption
Water consumption	0.47 – 0.59 m^3/Mg d.s.[a]
Electrical energy consumption	50 – 54 kWh/Mg d.s.
Thermal energy consumption (in HHV[b])	442 – 462 kWh/Mg d.s.
CO_2 direct emissions[c]	80 – 84 kg CO_2/Mg d.s.

Table 3. Dry process–consumption [55]

Dry Process	Consumption
Water consumption	0.12 – 0.16 m^3/Mg d.s.[a]
Electrical energy consumption	31 – 35 kWh/Mg d.s.
Thermal energy consumption (in HHV[b])	88 – 108 kWh/Mg d.s.
CO_2 direct emissions[c]	16 – 20 kg CO_2/Mg d.s.

12. Recent Development on Tile Production with Dry Route

Strategy Europe 2020 declares several objectives, one of which is regarding to climate change and energy sustainability [56]. In 2014, the EU declared its 2030 policy, driving continuous progress towards a low–carbon economy [57–58]. Since 1990, the European ceramic tile industry has been adopting innovative technologies and implementing energy saving actions to decline its energy consumption and CO_2 emissions [59–60]. However, implementation of EU–ETS scheme affects the economic situation of ceramic companies directly due to the allowances to buy and indirectly through electricity costs, monitoring system and auditing costs [61]. Figure 4 depicts the preparation of raw materials by the most popular dry method available. Tables 2 and 3 inhibit the consumptions in the wet and dry process respectively [55]. In wet process CO_2 direct emissions are lower than dry method. However, the wet method is the most popular method due to the better technical properties of the final granulate obtained [62–64]. Finally, the wet method facilitates electricity generation [65]. New developments in dry grinding and granulation systems with the significant reductions achieved have been successfully used in some countries, such as Brazil [66–67]. Especially water, thermal energy, electricity consumptions and CO_2 direct emissions were considerably reduced [68]. Pneumatic dry granulation (PDG), an innovative technology, supplies many advantages, like much faster processing speed, low cost, little or no material wastage, low dust etc. [69–72].

13. Recent Progress in Wet Granulation

Reverse wet granulation is a new granulation method involving the immersion of the dry powder formulation into the binder liquid followed by controlled breakage to form granules [73–75]. By steam granulation instead of water steam is used as binder, giving the advantages of the higher ability of the steam to distribute uniformly and diffuse into the powder particles, spherical granule production with larger surface area, and shorter processing time eco–friendly (no involvement of organic solvents) [76–78]. In moisture–activated dry granulation (MADG), by adding a small amount of water to the mixture of slurry, binder and other excipients agglomeration is facilitated [79–80]. Melt granulation is an appropriate alternative to other wet granulation techniques used for water sensitive materials. Additionally, compared to the conventional wet granulation process, it proposes several advantages [81-82].

14. Conclusions

This paper compares the differences between dry and wet route ceramic tile production. This comparison contains granule quality, cost, milling behaviour and firing behaviour of ceramic tile. As mentioned, wet and dry method have certain advantages and disadvantages. Although wet method has higher granule quality than that of dry method, latter one is more economical and has a lower cost. Wet and dry processed granules have different shape, density, flowability. Spray granulation can contain donut shape, so, low density but it has better moisture content, because of that better flowability. On the other hand, dry granulate has higher density but it causes roughness at the surfaces of granules and due to lower moisture content flowability may be a problem. Particle size distributions are much lower for spray–dried powders than dry granules. Therefore, particle size distribution and homogenization may lead to a problem with dry method. Spray–dried powders have a lower stiffness angle than dry granulated dusts due to surface roughness differences. Spray dried powders exhibit a higher after press expansion than dry granulated powders of the same composition. Spray granulated can fill the pressing mould due to the good flowability, because of that compact density is higher than dry granulated ones, so firing behaviour of two methods is different. Higher green density means lower firing shrinkage and less problems. Spray–dried powders form stronger compacts than dry granules and stick to steel moulds more than dry technical powders due to the moisture content. Installation and production costs support dry granulation processes.

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