PRELIMINARY DIAGNOSTICS FOR CONTROL AND AUTOMATION IN THE MANUFACTURE OF PORCELAIN TILE IN BRAZIL

Dolly Santos Barbosa[1,2], Jorge Elias da Silva[3], Ricardo Antonio Francisco Machado[2,3], Dachamir Hotza[3]

[1]Universidad Nacional de Colombia, Department of Chemical Engineering, Ciudad Universitaria, Bogotá, Colombia
[2]Universidade Federal de Santa Catarina, CPGENQ/UFSC, Campus Universitario, Florianópolis, Brazil
[3]Universidade Federal de Santa Catarina, PGMAT/UFSC, Campus Universitario, Florianópolis, Brazil

1. METHODOLOGY

For the performance of this study the basic and specific Literature was reviewed, a product and a production process were selected, interviews were held with the production engineers and the process in the field was studied at great length, analysing each production stage from a control viewpoint.

The industrial process analysed refers to the manufacture of BI-a type glazed porcelain tile, size 30x30x1cm, produced in a plant located in the south of Brazil. This natural glazed porcelain can be used both in flooring and wall cladding, in domestic housing and commercial environments, and for decoration of interiors and exteriors. The production process is by the wet route, with batch milling, single firing, and forming by pressure, and corresponds to a large extent to some line of many of the companies in this sector in Brazil.

2. PROCESS ANALYSIS

The process encompasses mainly the milling, spray drying, pressing, drying, glazing and firing stages. Although the raw materials extraction and storage stages are fundamental to the quality of the manufactured product and operation problems, and include control and characterisation tests, they will not be analysed in the present work because they are processes common to several products and different production lines.

2.1. MILLING

Batch ball mills are used. The particle size distribution of the raw materials determines the relation of the ball sizes in the mill (large, medium, and small). The volume of balls is controlled by adding large and medium balls based on the measurements of their level every month However, when the milling time increases and no variations exist in the formulation, this is taken as an indication of the reduction in ball volume and the necessary adjustments are made. Viscosity and the density are manually controlled by adjusting the volumes of deflocculant and water, respectively. Although the measurements take place 5 hours after the initiation of each batch, their adjustment is only performed once a day. The adjustment during the installation of a group of values of these volumes is only made in the case of finding an error. It was found that for continuous mills there was an automatic control of these two variables[1], a greater facility being recognised for doing this in continuous mills than in batch mills[2]. The residue can be controlled by modification of the milling time or the rotation speed. In practice, the residence time in the mill (milling time) is determined on the basis of the result of the measurements of residue, bulk density, and emptying time (viscosity), recorded five hours after batch commencement. The mill rotation rate is not adjusted to control the residue, this rate is controlled through a Programmable Logic Controller, i.e., following a three-speed program defined in pre-set times, according to the composition of the mass.

2.2. SLURRY STORAGE AND HOMOGENISATION

In the storage and homogenisation stage, the slurry is subjected to sieving, and is stored, homogenised and filtered in addition to the transport operations. An inventory control is performed, together with a control corresponding to the operation and safe handling of the machines and facilities. The variables are verified: residue, bulk density and emptying time of the slurry, before it enters the spray-drying stage. If there are large variations, adjustments are made in the previous stages: mixing the slurry obtained in different batches or modifying the milling or proportioning conditions.

2.3. SPRAY DRYING

A mixed-flow spray dryer with a capacity of 16000 kg powder/h is used. It uses air heated by natural gas and forced circulation to extract the air, water vapour and fine dust. In this stage it is necessary mainly to control the particle size and moisture content. The air input temperature is controlled, reducing the effect of the temperature variations on moisture. The control is performed by measuring the temperature with a thermocouple and automatically acting on the natural gas valve in order not to allow a variation greater than 10ºC. To control the moisture, when this leaves the reference range, some of the following actions are conducted depending on the conditions: adjusting the air input temperature or modifying the pressure of the slurry pump (only when the moisture content and the particle size have high values) or changing the oldest nozzle (if the density and viscosity values are appropriate) or modifying the depression (increasing the air flow opening in the extractor by opening a valve). Manual control is performed of particle size, adjusting different variables at the same time and using as measurement device manual or electromechanical sieves. The implementation of an automatic control should be studied, the problem of the measurement in line being solved by the development of a system based on an optical image processing device[3]. Transport to the silos is performed continuously and the control of the level of the silos is manual. In order to improve the homogenisation of the moisture content and particle size it is necessary that the dwell in the silos should be at least 24 hours and that the feed to the pressing lines should simultaneously consume the powder of 2 to 4 silos.

2.4. PRESSING

The material is formed by differential uniaxial pressing with a double effect in two pressing lines with a hydraulic press of 2000 ton-f and with four cavities. The press has its own automatic pressure regulator. In order to prevent possible later damage, an hourly verification is carried out of the pressing pressure. Although bulk density is one of the most important control parameters in the production of ceramics, since bulk density uniformity needs to be assured not only for a body but for the 4 bodies located in the different cavities[4], this is not measured at the exit of this stage, since the mercury displacement method is an expensive process[5]. However, studies and developments have been conducted to measure this by radiation[6], by ultrasonics[7], or by estimating this through moisture measurement[2]. The pressing rate is manually defined depending on the consumption of the bodies in the kiln. An automatic control of this velocity could maintain a high productivity in this stage and assure processing continuity throughout the following ones. However, this control affects the interaction of the variables of at least three stages, which can at some moment have production problems. Those considerations are made manually for taking the decision to vary the pressing speed.

2.5. DRYING

Drying is performed in a vertical dryer by the circulation of hot air. For heat transfer, natural gas combustion at two burners and the hot air coming from the kiln are used. Automatic control of the dryer is based on measuring temperatures by means of thermocouples in three sections: burner input, burner output, and stabilisation temperature (at the effective exit of the pieces). When variations occur in the air input and output temperatures, the air/fuel ratio is modified, maximum variations of 5ºC being allowed. In the stabilisation area the internally recirculated quantity of air is modified depending on the measured temperature (if the temperature is above the reference value the hot air of the dryer is mixed with air at ambient temperature). With this control, maximum variations are obtained of ±10ºC, this being sufficient for the pieces to leave the dryer at the temperature required by the glazing process. Additionally, the temperature of the piece is verified by means of an infrared sensor and only in the case of a fault is the transport line stopped in the glazing area until the temperature at the dryer exit is stabilised or the temperature setting of the dryer is modified.

2.6. GLAZING AND DECORATION

Glaze and ink preparation requires verification and measurement of bulk density, colour, texture and emptying time. For the glaze suspension, the residue is also measured. In the body application stage, four applications are made: water, engobe, glaze and ink. For rapid and good absorption of the engobe and glaze it is necessary that the temperature of the piece should be appropriate before application of the water, which is why its control is indispensable. This control was described in the previous stage. The weight of the coating is an indicator of the thickness of the ink and glaze layer. A manual and off-line control is performed of the weight of the applied glaze, measuring it with a digital balance and making the corresponding adjustments hourly. Since the work is done with silicone rollers, precise measurements cannot be made of the applied ink weight. A variation in the values of the bulk density and emptying time of the ink and glaze suspension can alter the shade and colour of the product. A correction must be made if the values are outside the limits when these variables are recorded and verified. Thus, for example, if the density is below its required value, water is added (for engobe and glaze) or the screen printing vehicle (for inks), or in contrast if it is higher, suspension with a greater density is added. A visual and manual inspection is carried out for the separation of pieces with surface defects before spending energy and materials on their processing in the following stages. Faced with the undeniable benefits, a measurement based on an optical system with an image processing software may be suggested. Solutions of this type have not yet been successfully implemented, since they display difficulties in the detection itself of the defects and in the rough ambient owing to the presence of dust and water [2].

2.7. FIRING

Firing is the stage in which the main modifications in the properties of the ceramic material occur. A horizontal roller kiln of 120 m is used, with natural gas as fuel for heating. The kiln is divided lengthwise in strips, each of which has a thermocouple and an actuator for automatic modification of the air/fuel ratio in the corresponding burner. The measurements are centralised in a computer and, depending on the temperature setting in each area, a signal proportional to the error (difference between the measured and the reference temperature) is sent to each actuator. The temperature profile is recorded to monitor the firing curve. The size of the piece, which is a function of the linear shrinkage, is measured hourly with a slide calliper and, depending on this value, the peak temperature of the cycle is adjusted. Depending on the size of the body and the presence of defects, the rollers drive motors can be adjusted, thus modifying the residence time and therefore the firing cycle. The variable water absorption is measured once in each shift (8 hours) and if the value is outside the accepted limits, the other variables are verified to decide whether the kiln temperature or pressing pressure needs to be modified. If in end product contains defects due to the presence of organic matter (black core)[8,9] and cracking due to residual moisture, the air flow of the extractor is manipulated to modify the uptake of gases in the kiln preheating section or the residence time in the kiln or the pressing pressure or the spray-dried powder moisture content. It is necessary to work at the minimum air flow limit that allows the smallest possible presence of defects without increasing excessively the cost of natural gas. Other suggested actions are that of optimising the temperature profile in the kiln or causing the kiln atmosphere to be more oxidising [10].

2.8. CLASSIFICATION

The dimensional tolerance, curvature and defects of rectangularity are measured with a photocell on the tile separation and pre-selection line. If the set references are not met, a hatch automatically opens to withdraw the defective pieces. The surface defects and the shade definition are also continuously inspected, visually and manually. The value of the bending strength is verified weekly by sampling; if it is outside the allowed range the other variables are reviewed in order to act on the pressing pressure, kiln temperature or composition of the mass. If the curvature exceeds the specification, adjustments are made in the kiln temperature. It has been verified that the changes in the setting temperature of the peak temperature modules lead to changes in curvature [10]. Automatic curvature control can be implemented after studying all the interactions of the adjusted variable (kiln peak temperature) on the other variables, in order to avoid undesirable effects.

3. FINAL CONSIDERATIONS

The automatic control loops found in each stage are summed up in Table 1. We found practically one automatic control loop per stage (in those cases where there is more than one loop, they all refer to same type of variable: temperature). None of these loops involves variables of more than one stage and in their majority they are integrated to the main equipment ex factory which entails a difficulty in interacting with the variables associated with these loops.

FACILITY	AUTOMATIC CONTROL LOOP
Mill	Control of the rotating speed
Spray dryer	Control of air input temperature
Press	Control of pressing pressure
Dryer	Control of input, output and stabilisation temperature
Kiln	Control of temperature at different points throughout the kiln

Table 1. Automatic control loops

Several of the manually performed corrections involve actions in foregoing stages to the one in which the measurement is being made. The more distant is the action of the measured variable, the more time will pass while the product is being processed outside specifications. The problem of acting on a variable in the same stage, for instance in the case of the kiln, is that the actions will be more drastic in order to counteract the problems that should have been corrected in previous stages, sometimes with not very good results. However, correcting variables in other stages requires making a multi-variate analysis, which highlights an interaction between the variables that are not singled out one by one and therefore the need to verify other variables in order to make the decision regarding which action to take. The study can ratify already established controls or propose advanced loop and control strategies (multi-variate, nonlinear, predictive, adaptive…)[11,12,13,14].

We can conclude that the level of automation and control found does not allow integrated correction of the process to eliminate the existing deviations in the production line. Supervision and automatic control have hardly been performed locally in each process stage, which makes the plant less efficient from an operational viewpoint than it could be. That leads to a compromise of final product quality because small deviations, which influence their quality, cannot be corrected in the course of the process. Consequently, there are high losses in production and an operational cost that could be minimised through integration of the production processes and an increased degree of automation[11,15].

Although some problems of on-line measurement have been solved, the persistent difficulty of measuring certain control variables makes us think of the possibility of using technologies like neural networks in order to use them, through an identification process, as virtual sensors [16,17]. It is also feasible to think about exploring the use of a model of neural networks with prior knowledge, in order to predict, for certain end product properties and characteristics, the best values of certain variables chosen according to their importance. The critical analysis conducted in this study shows that there is a great potential for this type of tool for integrated process control and supervision, making the elimination possible of various critical points that lead to higher costs and jeopardise final product quality. The ceramic tile industry has a high possibility of increasing its flexibility and productivity through an increased degree of process automation.

ACKNOWLEDGEMENTS

The authors wish to thank the company whose production line served as a case study for the analysis of the process. They also thank the Universidad Nacional de Colombia for allowing Dolly Santos to conduct her doctorate studies at the Universidad Federal de Santa Catarina, Brazil.

REFERENCES

[1] SÁNCHEZ, E., CANTAVELLA, V., LLORENS, D., MOLTÓ, C., FOUCARD, L., MIRALLES, L. y CUESTA, E. *Control automático de la densidad y la viscosidad en molinos continuos*. Qualicer 2006. IX Congreso Mundial de la Calidad del Azulejo y el Pavimento Cerámico. Castellón: Cámara Oficial de Comercio, Industria y Navegación, 2006. vol 2 pp PBC 123-136.

[2] MALLOL, G. *Control y automatización en la industria cerámica. Evolución y perspectivas*. Qualicer 2006. IX Congreso Mundial de la Calidad del Azulejo y el Pavimento Cerámico. Castellón: Cámara Oficial de Comercio, Industria y Navegación, 2006. vol 1 pp Con 47-72.

[3] DI GIUSEPPE, A. y REVEL, G.M. *Medida automatizada de la granulometría del polvo atomizado para el control del proceso en línea*. Qualicer 2006. IX Congreso Mundial de la Calidad del Azulejo y el Pavimento Cerámico. Castellón, 2006. vol 3 pp PBC 363-378.

[4] SILVA, J. E., *Controle de processo*. Curso de Tecnologia Cerâmica. SENAI, Tijucas, Santa Catarina. 2001.

[5] AMORÓS J.L., SÁNCHEZ, E.,GARCÍA-TEM, J., SANZ, V. Y MONZÓ, M. *Manual para el control de la calidad de materias primas arcillosas*. Instituto de Tecnología Cerámica – AICE, Castellón, España, 1998.

[6] AMORÓS, J.L., FELIÚ, C., LLORENS, D., CANTAVELLA, V., y MEZQUITA, A. *Medida no destructiva de la densidad aparente de piezas en crudo mediante absorción de rayos X*. Qualicer 2006. IX Congreso Mundial

de la Calidad del Azulejo y el Pavimento Cerámico. Castellón: Cámara Oficial de Comercio, Industria y Navegación, 2006. vol 2 pp PBC 69-82.

[7] CANTAVELLA, V., LLORENS, D., MEZQUITA, A., MOLTÓ, C., BHARDWAJ, M.C., VILANOVA, P., FERRANDO, J. y MALDONADO-ZAGAL, S. *Uso de la técnica de ultrasonidos para medir la densidad aparente de las baldosas en crudo y optimizar el proceso de prensado*. Qualicer 2006. IX Congreso Mundial de la Calidad del Azulejo y el Pavimento Cerámico. Castellón: Cámara Oficial de Comercio, Industria y Navegación, 2006. vol 2 pp PBC 165-178.

[8] AMORÓS, J.L., BELTRAN, V., BLASCO, A., ENRIQUE, J.E., ESCARDINO, A., NEGRE, F. *Defectos de fabricación de pavimentos y revestimientos cerámicos.* Asociación de Investigación de las Industrias Cerámicas e Instituto de Tecnología Cerámica, Universitat de València, 1991.

[9] LUCAS, F. *Processos produtivos em revestimentos cerâmicos: variáveis de processo e possíveis causas de defeitos*. Cerâmica Industrial, 9(5/6),pp7-20, 2004.

[10] JARQUE, J.C., CANTAVELLA, V., DAROCA, M.J., GÓMEZ, P., ARRÉBOLA, C. y CARCELLER, A. *Influencia de las condiciones de operación del horno de rodillos sobre la curvatura de las piezas*. Qualicer 2002. VII Congreso Mundial de la Calidad del Azulejo y el Pavimento Cerámico. Castellón: Cámara Oficial de Comercio, Industria y Navegación, 2002. vol 3 pp Pos 149-152.

[11] OGUNAIKE, B.A., RAY, W.H. *Process dynamics, modeling, and control*, Oxford University Press, 1994.

[12] DESPHANDE, P.B., *Multivariable process control.* ISA, 1989.

[13] HENSON, M.A., SEBORG, D.E., *Nonlinear process control*. Prentice hall, New Jersey, 1997.

[14] SLOTINE, J.E. *Applied nonlinear control*. Prentice hall, New Jersey, 1991.

[15] LUYBEN, W.L., BJORN D.T. and LUYBEN, M.L. *Plantwide process control*. McGraw-Hill, Nueva York, 1998.

[16] KOSKO, B. *Neural networks and fuzzy systems*. Prentice Hall, Nueva York, 1992.

[17] HAYKIN, S. *Neural networks*. Prentice Hall, Nueva York, 1999.