ENERGY SAVINGS USING ADVANCED PROCESS CONTROL TECHNOLOGY

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ABSTRACT

This paper proposes a technological model that delivers both reduced energy costs and improved production management. Indeed, the present financial circumstances affecting the ceramic and frit industry in terms of gradually increasing energy costs and difficulties to acquire capital investment are similar to what occurred in other sectors, such as oil refining, pulp and paper, etc., which went through the same hardships at an earlier stage and where these models have been successfully implemented.

The model comprises programs to improve process control, instrumentation and software that enhance production process efficiency and are also capable of adapting to substantial changes in the manufacturing environment.

It is thus a great **novelty** to propose such a type of production control and management system in the ceramic sector as, up to now, technological development has consisted of switching from analogical instrumentation to digital instrumentation using PLCs that contain loops to control variables **individually**. The proposed model implies a very significant step forward in quality terms in that these control systems are interrelated and can be linked directly to financial and cost targets.

What **differentiates** this proposal from other energy improvement systems, audits, etc. is that it is not based on *a posteriori* monitoring or calculation of rates and indexes but rather on **real-time tools** that control the process by following energy guidelines while honouring the operating variables set in the planning stage and the equipment's inherent limitations.

As an added value, once this control technology is working, primarily on achieving energy savings, it can be extended to the host of opportunities so brilliantly set out in Jose Gustavo Mallol Gasch's paper "Automation in the Ceramic Industry, Evolution and Prospects. Qualicer 2006"

With this type of technology, savings of **between 3% and 8% in initial energy consumption** have already been achieved in sectors where they have been implemented, such as oil refining, pulp and paper, iron and steel, and in some cases **savings of up to 10%** have been recorded depending on the situation at the outset, all of which have been achieved with **low capital outlay**.

We believe that such savings are achievable in our ceramic and frit sectors. By way of an example, figures based on a real-life production plant indicate that in economic terms for a consumption rate of around **350,000 MWh/year**, savings of over **€300,000 per year** are possible when applied in medium and large enterprises.

1. INTRODUCTION

In today's business scenario, especially in the ceramic and frit sectors, two significant factors come together, namely:

- A steady increase in energy costs, and
- Difficulties to carry out capital investment due to a lack of finance.

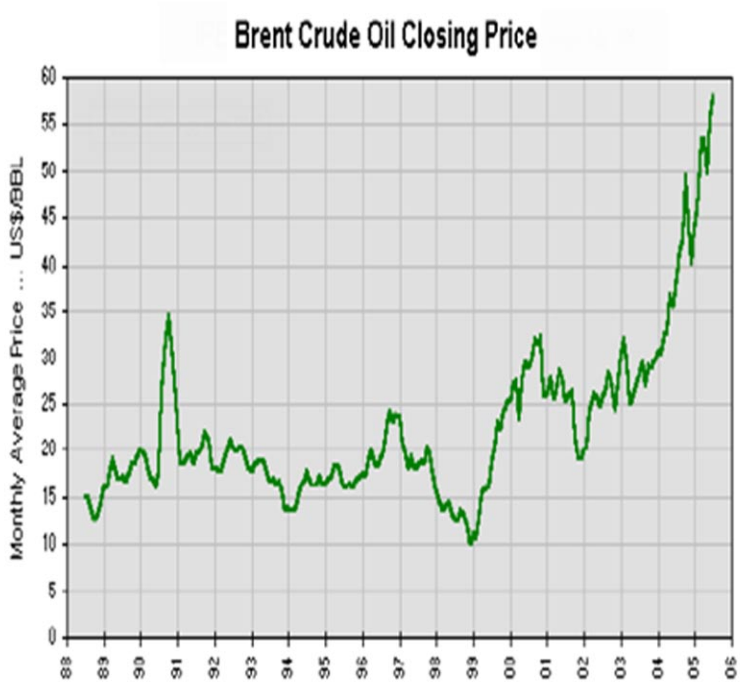
For these reasons, applying advanced technology that may provide a reduction in energy costs on the basis of moderate investment is of special relevance. Furthermore, in the present economic situation, new models of commercial contracting allow for framework agreements to be defined in which owners and technology providers can define ways of collaborating, in which they share the benefits of implementing energy efficiency solutions. Thus, a technology partner can become part of the project and the capital investment, which is moderate, becomes minimal for the sector, as it can be either partially or fully financed on the basis of the proven incentives achieved by executing the Project.

This technology and these models are already being successfully implemented across the globe in various types of industries, such as:

- Oil Refining and Petrochemicals.
- Pulp & Paper
- Iron & Steel

These industries successively found themselves facing circumstances that led to advanced technology being implemented as the best way of achieving cost savings, mainly in energy, as well as the added value of the resulting improved performance and enhanced production management.

A study of how the price of Brent crude oil – to which most energy costs are index linked – has developed shows an initial peak in 1991 and a steady increase from 2000 onwards, especially sharp after 2004. For that reason, the decision to implement proven Advanced Control technology was unanimous and led to spectacular results. In fact, returns on capital expenditure were and in many cases continue to be achieved within the first year. Furthermore, as stated in the foregoing paragraph, the technology enabled these firms to organise their production processes more efficiently by providing them with real-time data on process variables, which meant they could adjust their machine settings more precisely according to instant or mean values instead of to programs and indexes taken at weekly and/or monthly intervals. Therefore, a significant increase in quality was afforded to them that has led to improved financial results and in some cases even survival, despite the extreme hardships they were facing.



The author of this paper has personally witnessed and collaborated widely in such implementation processes, specifically in the Oil Refining industry, where energy accounts for almost 50% of its variable costs and was set to reach almost unacceptable levels, had suitable measures, including energy cost savings, many of which are based on advanced control techniques, not been implemented.

1.1. Control Strategy

Energy improvement was based on the so-called Energy Intensity Index, **EII,** whose first step was to identify the process assets (facilities) that performed most intensely from an energy viewpoint, in terms of generation, consumption, and heat exchange. It thus became feasible to compare one plant with another, and then to evaluate the impact that an improvement, modification, new units, etc. had on the overall plant index.

In the production process study, the following were identified:

- **Those items that consume energy** – in this sector, that would mainly refer to **furnaces, turbines, etc.** This is where the main potential for energy cost-cutting lies, as they generally coincide with the main consumers in the production process.
- **Energy exchangers, pre-heaters, recovery systems.** By improving data collection and with a more complex control system, strategies to maximise heat production can be incorporated, as can systems to detect fouling with cleaning recommendations adjusted according to profitability criteria. It can also manage loading constraints applied for various reasons, including environmental restrictions.

- **Also, with regard to production strategies, load, hold-up, and residence time control**. Given that the information systems (Production Planning, Costing, etc.) can be linked to the control systems, the latter can be fed in directly with the production settings. Therefore, in many cases, this provides for real-time optimisation and includes not only the strategies but also more direct control of the loading to the different units, the so-called hold-ups or production charges, and for some items of equipment such as furnaces, on-line calculation of the hold-ups.

Once the greatest consumers had been identified, which in this industry are **in the first place processing furnaces**, the energy-efficiency enhancement actions were based on actions involving **high capital outlay**, namely:

- Introduction of possible improvements such as efficient burners, cleaning of convection areas, etc.

- Vapour economisers, flue gas preheating.

And actions requiring **very low capital outlay**, using the advanced control infrastructure, and in particular control strategies were designed and implemented for the furnaces, such as:

- **Furnace output temperature control**, combining the feedback from the deviation of furnace temperature with a feed-forward with regard to the variations in the feed and composition of the gas to be burned. With this scheme, control became possible with a reduction in variability of about 0.5 ºC, compared with 1 to 2 ºC or more in a classic control system.

- **Control of excess Oxygen**. The readings were combined of the oxygen analysers at the combustion gas outlet with those of the CO analysers and, if stack dampers were available, actions were performed on these in the case of natural draught or on the combustion air in the case of forced draught. This enabled continuous operation within the set operating limits.

- In addition, inside the furnaces, parameters were obtained through the control scheme that helped operate within the criteria set by production, while keeping within an optimum safety zone. In particular, it was possible to ascertain the following:

  - Tube temperature profiles.

  - Temperatures in the area where the radiative and the convective zones met.

  - Heat fluxes inside the furnace.

  - Burnt heats and efficiency calculations through the heat absorbed by the process.

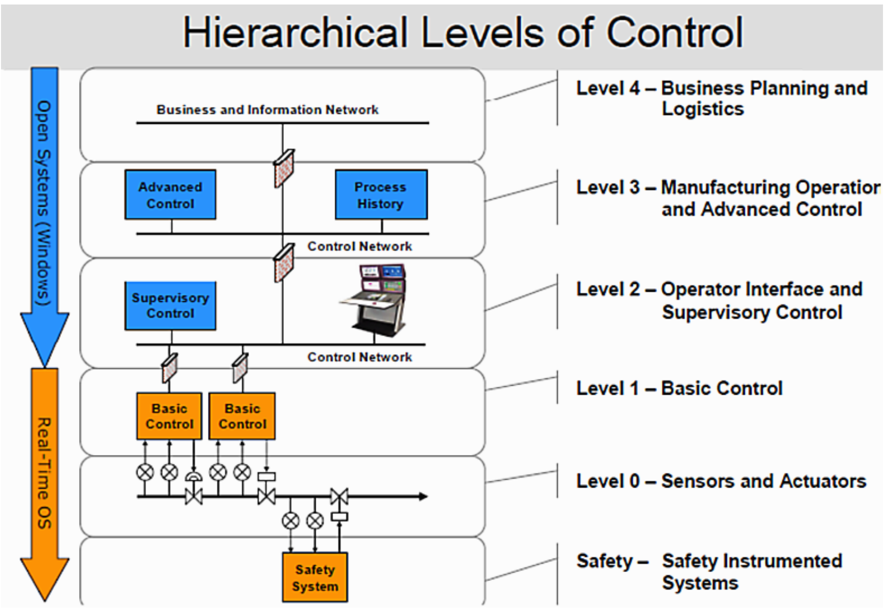
In other consumers within this refining process, the low-investment action was also based on the design and implementation of advanced control applications, namely:

- Minimising the operating pressure of the distillation towers, enabling hydrocarbon separation to occur with lower energy consumption
- Maximising feed preheating to the towers and in particular to the furnaces.
- Optimising the furnace feed, deviating the maximum possible feed to those with the greatest energy efficiency.

These improvement strategies and programmes in process control, instruments, and software, which fundamentally allowed the industry to go from a continuous process industry that controlled one variable after another, and only in few cases positioned a more important variable above a less important one (cascade), to controls in which as indicated previously (quality and gas) analysers acted and variables were interrelated (Multivariable Control), thus developing control schemes, were driven by economic and cost parameters.

The improvements were implemented step by step, and they led to enhanced efficiency of a production process capable of adapting to substantial changes in the environment. The experience is perfectly extrapolable to the ceramic and glaze sectors, and this is the author's aim.

The figure below shows the levels that can be attained starting from the current ones numbered 0, 1 and 2.

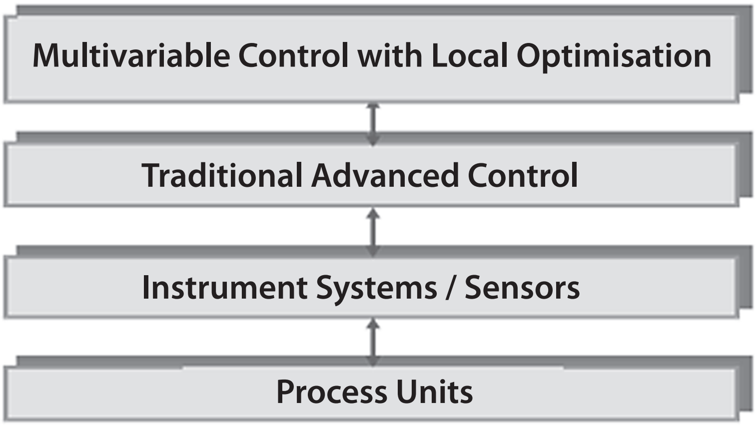


This technology allows the following features to be built into the production process:

- Restriction to pre-set operating and/or environmental limits

- Maximum feed and performance rates
- Minimum energy and auxiliary material consumption
- Protection of both the plant and personnel from changes in process conditions.

A diagram of the hierarchy involved is given in the following figure:



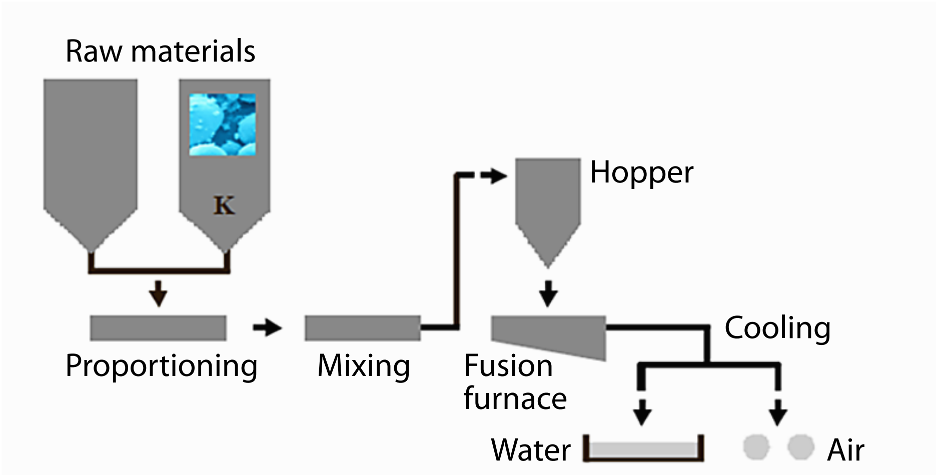
That means that the process is controlled by means of traditional loops, basically PID controllers, which operate at second intervals. Some items in cascade and with modified feed-forward operate at slightly longer time intervals and form part of the Traditional Advanced Control. Then comes Multivariable Control, which combines data from sensors and analysers to establish local optimisation settings. These controls operate at minute intervals.

By implementing this type of technology, savings have been achieved in these industries ranging from **3% to 8% in initial energy consumption**, and in some cases of over **10%** depending on the situation at the outset. Furthermore, these savings can be achieved with a low capital outlay as they really only involve software items, servers that are added to the basic controls (PIDs) that already exist in these types of industries. The most costly package may be the continuous oxygen, CO, and density analysers, etc., this nevertheless being significantly lower than capital expenditure for new facilities and equipment.

2. BASIC PRINCIPLES OF FRIT AND CERAMIC TILE OPERATIONS

2.1. Frits

As is well known, the frit manufacturing process, commonly known as fritting, aims to produce a glassy, water-insoluble material by fusion and subsequent cooling of the mixes of various materials, as illustrated in the following figure:



The process starts when previously selected and measured raw materials are fed in pre-determined proportions. They are transferred on a pneumatic conveyor to a mixer and from there are fed into the melting furnace, where the actual fritting process takes place.

The furnace is kept at a temperature of about 1400 ºC for certain types of frit. The time the material remains inside the furnace is defined by how long the raw materials take to fuse and the flowability of the melt.

The furnace is fitted with natural gas-fired burners, using air as oxidiser, and a heat recuperator is installed at the combustion gas outlet, with a downstream baghouse to filter the gases released into the atmosphere. At present, the standard control consists of pressure regulation at the stack outlet and furnace temperature control by means of a closed loop with the fuel input.

A brief analysis of the process, based on criteria similar to those mentioned in the Oil Refining industry, shows that the variables to be monitored in the fritting process include the following:

- Temperature inside the furnace
- Oxygen percentage
- Feed temperature into the bag filter
- Furnace loading
- Furnace hold-up

- Maximum NOx and CO emissions.

Advanced control technology is, therefore, perfectly applicable and it would lead us to design similar schemes, though obviously adapted to this process, which differs in certain ways from oil refining. However, here also the units with the greatest energy consumption are **the array of fusion furnaces** and it is these that are consequently the principal candidates. The proposed schemes are as follows:

- Keep chamber temperature control in feedback but combined with a feed forward with regard to the variations in gas feed and heating power, if the measurement is available. This scheme may be expected to provide a significant decrease in temperature variability, which does not just affect consumption but also product quality.
- Control of surplus Oxygen. To the classical scheme of the output oxygen loop on the handled combustion air variable one can add burnt heat constraints, chamber draw, etc., which allow:
  - Continuous operation at constant surplus air, not subject to charge variations or influence of day and night, etc.
  - Due to the control of other variable and the lower expected variability, settings with lower values can be used than those allowed with a simple control scheme.
- The transitory processes of compositional change in the feed with a product switchover also offer many possibilities for optimisation in order to reduce these process periods both in the start-up and on ending the manufacture of a product. This would also have a significant effect, not just on energy consumption, but also on reducing manufacturing costs.
- Frit furnace efficiency is affected by the degree of efficiency of the installed economisers. The control and monitoring system in a scheme such as the one proposed would enable continuous monitoring of furnace efficiency, providing an exchange factor, on-line cleaning recommendation and, where appropriate, deviation of the feed to a more efficient furnace.
- The furnace hold-up or production charge seems to be a further significant variable that, with the control and monitoring items, can be arranged on-line with relation to indirect extrapolations or measurements. This also affects energy consumption, in addition to manufacturing optimisation.
- Depending on the types and capacities involved, the fabrication of these processes requires a certain number of furnaces, about 10 to 20, which are fed the different raw materials mixtures. Particularly significant is the potential of the feed optimisation to the furnaces, routing the maximum possible feed to those that exhibit the greatest energy efficiency, which can be determined on-line.

Thus, with these optimisation and control scheme proposals it may be inferred that significant savings can be achieved in energy consumption and that, in addition, the proposals could very significantly impact the optimisation of the manufacturing process, whose order of magnitude on cost savings may have a much greater effect.

For an average-sized frit company with a consumption of about **350,000 MWh/year**, we can conservatively estimate a saving of about 3 to 5%, basically for energy consumption in the furnaces, involving an estimated saving of **300,000 €/year**.

If one further adds the energy optimisation applications:

- Reduction of transitory periods.
- Hold-ups.
- Feed as a function of efficiency.
- Feed as a function of facility and pollution constraints.

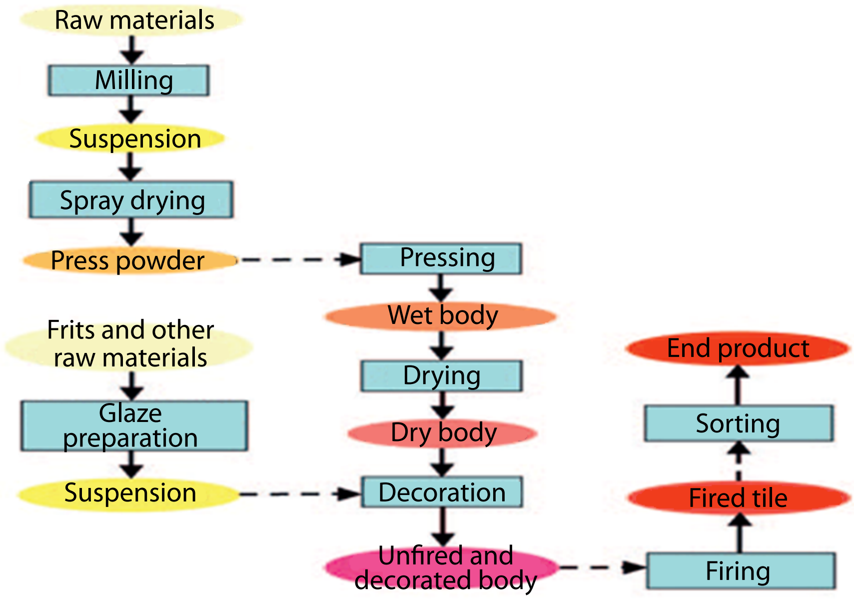
the figure would increase significantly.

This without considering the added value that could be contributed to process optimisation by providing real-time information and continuously applying economic and facility constraints criteria.

If finally, we should wish to extrapolate, there remains a field for optimisation in raw materials, in which we consider that Oil Refining technology could also be applied to the selection of crudes and manufacture of mixtures. As is well known, refineries process appropriate mixtures of crudes as a function of availability and cost, in which there are very significant variations. Furthermore, product fabrication, fundamentally petrols, is based on the optimisation of product mixtures that conform to certain specifications, but which are mixed according to criteria of minimum cost or maximum profit.

2.2. Tiles

We turn now to the **ceramic tile** manufacturing process, the main stages of which are illustrated in the figure below.



Unlike the previous process, there are more interrelated stages where one stage exercises unquestionable influence over another and affects the quality of the end product to be sold. However, they have common features in that they are enormous energy consumers, which is one of the main items in manufacturing variable costs. **Firing and Drying** are, therefore, worthy candidates for such energy and fabrication optimisation.

Without such a detailed analysis as in frit manufacture, furnaces or kilns and dryers are also candidates for the application of similar control schemes to those indicated in the previous section.

In addition, this type of manufacture, which is more complex than in the foregoing process, offers additional opportunities since, as noted above:

- There are many interrelations between the variables to be controlled and this is where the application of control by multivariable models is particularly appropriate.
- There are properties whose continuous analysis is difficult, but which are essential to quality. The development of inferential models would help provide better control and cut costs.

Therefore, albeit without such a detailed analysis, tile manufacture is also a good candidate for the application of the proven Oil Refining technology, which could enable plants to operate continuously within the physical constraints of the facilities and the quality requirements, with the ensuing enhancement of quality and reduction in costs, including energy costs.

3. IMPLEMENTATION OF SOLUTIONS

In common to both processes, prior analysis and assessment are required of:

- The currently installed control system, PLC's, Control Networks, etc.
- Currently installed sensors and analysers
- Method of collecting both historical and real-time process data.

With that infrastructure available, the technical solution based on applying advanced control technology is structured into the following stages:

- Study, improvement and tuning of basic loops, mainly PIDs. The basic loop infrastructure (PIDs) can normally be improved, which leads to greater stability, prevents excursions and helps speed up adaptation to change, etc.
- Analysis of the process with special emphasis on the afore-mentioned improvement areas and the availability of analysers, sensors, inference models, when required.
- Application of Multivariable Control.
- Connectivity, process data storage and historical archives.
- Where applicable, second-level applications based on economic algorithms.

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