ENERGY EFFICIENCY IMPROVEMENT FOR ADVANCED CERAMICS PRODUCTION IN RUSSIA: CHALLENGES AND OPPORTUNITIES

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ABSTRACT

Presently, energy efficiency (EE) improvement is considered a part of the state environmental policy in Russian Federation, an instrument for modernization of national industry and a tool to enhance its environmental performance. This approach holds much promise regarding ceramics manufacturers, where industrial sites are most energy-intensive and are classified as category I objects in terms of negative environmental impact. Since 2010s Russian practitioners have tended to evaluate energy efficiency and environmental performance based on best available techniques (BATs), addressing these as stated in the EU Integrated Pollution Prevention and Control Directive.

With regard to existing industries an open information exchange performed via practitioners questioning and visits to production sites leads to two major conclusions. Firstly, EE-related initiatives in Russia are mostly considered as a way to improve economic, rather than environmental performance. Secondly, possible strategies in this area are determined by product characteristics.

Ceramics manufacturers for mass market (i.e. bricks, tiles, pottery, sanitaryware) are open towards Best Available Techniques (BATs) as process-integrated technical and technological measures, namely variation of raw materials, adjustment of firing regimes, deep modernization of dryers and furnaces, excessive heat regenerating schemes, etc. On the other hand, manufacturers of so-called advanced ceramics, which is under strict performance and reliability control, shift towards management solutions. These include quality management systems compliant with national and/or ISO 9001 standards and environment management systems compliant with ISO 14001. Recently, an integrated management system known as 'lean production' has been introduced, and practitioners explore both its financial and environmental benefits.

At the same time creation or deep modernization of a production site makes it possible to incorporate BATs in manufacturing process in a most balanced way. This requires an in-depth analysis of all technological stages; however, compared to non-BAT based approach, resulting solutions prove to be not only environmentally sound, but also ready-to-apply and economically viable.

Keywords: best available techniques, lean production, technology design

INTRODUCTION

Ceramics manufacturing falls into the category of highly energy-intensive industries and since 2014 when Integrated Pollution Prevention and Control was introduced in Russia

https://doi.org/10.5593/sgem2019V/6.3

as a part of national environmental legislation this sector has been closely monitored with regards to resource efficiency and environmental performance. Since 2010s a number of pilot projects on the subject have been carried out that formed a ground for considerable changes in both legislative acts and common perception. In 2014 the Russian government introduced the national 'BAT Act' [1] that linked together concepts of energy efficiency, environmental performance and Best Available Techniques and defined the latter as a combination of economically viable and technically feasible technological, technical and managerial decisions allowing to achieve high environmental performance and production efficiency and simultaneously ensure a reliable level of environmental protection [2, 3]. Baseline for BAT-related assessment was drawn in an open information exchange that involved questioning the operators and visits to the production sites. Based on the results of pilot projects BATs for ceramics manufacturing have been identified and the national Information and Technical Reference Book (ITRB) [4] developed, but in manufacturing technical ceramics, a comprehensive study is yet to be done.

IMPLEMENTATION OF BATs IN MASS-MARKET CERAMICS PRODUCTION: EMPIRICAL EVIDENCE

Traditional sub-sectors including tile and brick manufacturing in 2003 – 2013 participated in pilot projects intended to evaluate possibilities of implementing BATs in Russian industries. A sound example of such projects was reported by a manufacturer of wall and floor ceramic tiles, who in 2006 – 2011 initiated a deep modernization of the production site. In that period of time national BAT-related documents were still widely discussed and most initiatives corresponded to the European Reference Document on Best Available Techniques in the Ceramic Manufacturing Industry [5].

The information exchange allowed to identify, as suggested by BREF, key stages of production process, raw materials, energy and material flows as well as energy consumption and pollutants emission levels. The implemented technological process was typical for the sector and included raw materials processing, batch production by joint ball-milling and spray drying, green bodies shaping by uniaxial semi-dry hydraulic pressing, glazing and firing in roller-hearth kilns. Raw materials comprised of local and commercially available clays and feldspar concentrates. As a part of an energy-saving scheme the operator in 2009 discontinued its own glaze-making, shut down the fritting chamber and shifted towards commercially available glaze batches.

Energy consumption covered thermal energy and electricity, where thermal energy is used for high-temperature firing (numerous in certain cases), spray drying and heating the production site, and electricity empowers kiln ventilation systems, dryers, milling and shaping equipment, transportation systems, decoration and sorting units. Typically over 50 % of energy was consumed in drying and firing, therefore possibilities for energy saving were connected to the heating equipment performance.

Technological process involved negative impact on all components of the environment. Gaseous pollutants (mainly NO_2, NO, CO), traces of heavy metals and dust from stationary and non-stationary sources were emitted into air. Process waste water formed during cleaning operations in batch preparation and glazing units, as well as in batch dehydration in screen-presses. Solid waste appeared as dust residues in environment protection units and tile scrap. The environment was also affected by noise.

Taking into consideration a significant environmental impact, the operator opted for a combination of process-integrated technological solutions and managerial approaches that correlated well with relevant BREF and later formed a ground for the national ITRB. These suggested:

- a comprehensive technological process design that included deep modernization of key units, automatisation; continuous equipment charge;

- energy-saving scheme, that covered automated regime control, optimization of green bodies shape and size, heat recuperation, installation of energy-efficient mills and two-tier firing kilns;

- process-integrated technological measures aimed at energy efficiency improvement, pollution prevention and control that included, among others, automated technological monitoring and use of high-grade raw materials to reduce the amount of admixtures.

As a part of the operator's business strategy, process-based management systems were also introduced, that included local energy management and environment management systems compliant with ISO 50001 and ISO 14001 standards respectively, both of which were undergoing certification procedures at the time.

Specific energy consumption as well as production output during the pilot project are presented in Table 1. The operator succeeded in continuous energy efficiency improvement despite notable changes in production output (from 6.9 bil m^2 in 2007 and down to 5.7 bil m^2 in the economical breakdown of 2009).

Table 1. Specific energy consumption and production output of a tile manufacturer

Year	2006	2007	2008	2009	2010	2011
Electricity, GJ/tonne	0.74	0.64	0.75	0.91	0.77	0.75
Natural gas, GJ/tonne	8.23	7.61	6.90	6.49	6.13	6.14
Output, tsd m^2	5736.4	7166.8	6880.8	5709.2	6483.4	7204.9

Highest energy consumption values are associated with high-temperature firing in roller-hearth kilns. Installation of new kilns in 2007 and in 2008 allowed to reduce thermal energy consumption by 7 and 9 % respectively; shutting down of the fritting chamber in 2009 further decreased thermal energy consumption by 9 %.

BAT OPPORTUNITIES IN MANUFACTURING OF SPECIAL-PURPOSE CERAMICS

Technical ceramics manufacturing is without any doubt the most energy- and resource-intensive sub-sector in ceramics production. This sector embraces a broad range of materials with tailored properties for advanced applications in the aerospace and automotive industries (engine parts, catalyst carriers), electronics (substrates, active and reactive units), environment protection (filters) and many others, and requires the largest variety of raw materials, from high grade clays to rare-earth elements oxides and non-oxide compounds, the highest firing temperatures (i.e., energy consumption), and the most sophisticated processing techniques. The picture is aggravated by a typically poor resource efficiency arising from small-scale production output and a substantial percent defective allowable. For example, product yield for low-temperature co-fired ceramics (which includes most commercially available microwave devices) does not exceed 85 % [6], and the rest forms a 'hard-to-recycle' industrial waste, comprising densely sintered bodies of non-ferrous metals, titanium dioxide, alumina, complex rare-earth oxides, boron glasses. Important input and output flows of technical ceramics manufacturing processes, as suggested by the relevant BREF, are presented in the following figure (Fig. 1).

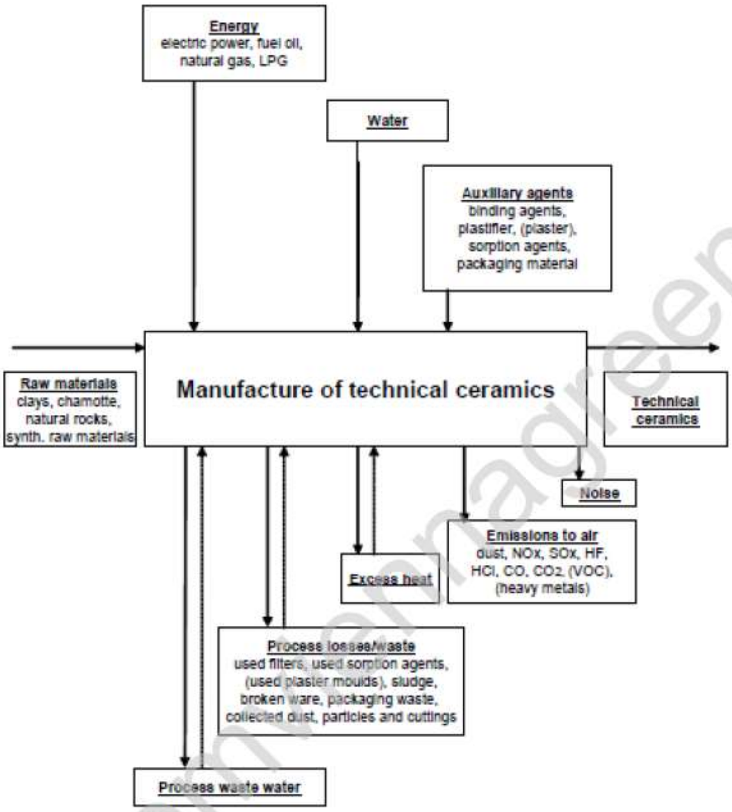

Figure 1. Input and output flows in the manufacture of technical ceramics [5]

Possible measures for energy efficiency enhancement are limited by strict requirements set both for technological process and products control. While for new and deeply modernized installations there exists a choice of process-integrated measures and techniques [7], practitioners in the field of advanced structural ceramics seek possible response to these challenges by employing holistic management systems. Below is a case study based on open information exchange of a Russian industry that has successfully introduced 'lean production' system as a tool to improve both its economical and energy efficiency [8, 9] by increasing the product output without any alterations of technological parameters available.

Dominant manufacturing process features, as described by site operator [8, 9], are as follows:

1) an extremely specified manufacturing process and as a result – a great number of unique production tools, facilities, equipment and machinery. In production cycle 25 different types of equipment and 100 types of various facilities are used, and over 70 technological operations are performed;

2) a complicated process management and control system, which is formed by incoherent work schedules, a large variety of technological operations and rigid quality control demands. Each unit is subjected to testing, and the protocol covers over 50 positions.

Possible negative environmental impacts at the production site are typical for the industry and comprise dust emissions from stationary sources, emissions of NOx and HCl during firing, and solid waste formation in the form of gypsum molds and defective items. No sources of carbon (i.e. fossil fuel or organic binders) are used in manufacturing process, so emissions of carbon monoxide are not registered. Water is also fully evaporated, so no industrial wastewater is generated.

The adjusted 'lean production' programme has been introduced at the production site in 2014, and the first step to be taken comprised drafting a Value Stream Mapping to analyse manufacturing process and determine possible sources of losses. As a numerical value to describe energy and resource efficiency enhancement a startup coefficient Ks is used, which equals started green bodies to product yield ratio. In 2015 [Lean_2] this parameter comprised about 1.6, i.e. to obtain 100 non-defective items not less than 160 green bodies were necessary.

A detailed study of all technological stages and determination of operational Ks proved that most crucial stages to increase product yield were shaping and drying of green bodies. Thus, several process-integrated measures were suggested that included changing a slurry preparation technique; altering molds construction and methods of their use; and most importantly – re-design of dryers to provide uniform heating and avoid temperature gradients. Another important action taken towards Ks increase was aimed at better management of the most energy-intense stage, i.e. high-temperature firing. Since 2015 the operator has initiated a deep modernisation of existing kilns and installed a number of newer ones, with improved heat insulation and automated firing regime controls.

Energy efficiency and environmental performance enhancement is achieved by reducing the number of defective items entering heat treatment stages (drying and firing), this allows to reduce specific energy consumption and decrease specific gaseous emissions. Moreover, due to quality concerns no backward material flow is possible, and lower number of defective items at all technological stages means less solid waste generation.

CONCLUSION

The comprehensive analysis of Russian sectoral activities in energy efficiency improvement in ceramics production leads to two major conclusions. Firstly, such activities are regarded as an instrument to improve economic performance of the installation, while environmental benefits and possibilities for process renovation are often neglected. Secondly, applicability of various approaches towards energy efficiency improvement is determined by strictness of product characteristics.

Manufacturers of mass-market ceramic ware (bricks, tiles, sanitaryware, etc.) are able and demonstrate willingness to implement process-integrated measures and techniques. These include variation of raw materials, adjustment of firing regimes, modernization of heat-intensive units, implementation of heat recuperation and backward material flow schemes. On the contrary, in advanced ceramics manufacturing that should comply with pre-set specifications on product features levels and repeatability, practitioners opt for managerial approaches and solutions.

Implementation of process-integrated (primary) and end-of pipe BATs at the production site is a challenging issue and the operators may have focus mainly on management solutions that allow reducing environmental load. The integrated process-based 'lean production' system holds much promise as an environmentally sound, ready-to-apply and economically viable option. This system generally complies with best available techniques (BATs) for ceramics manufacturing described in the relevant national Reference document [4] and might be considered as a 'candidate BAT'.

ACKNOWLEDGEMENTS

This research was carried out under financial support from the Ministry of Education and Science of the Russian Federation within the framework of State order, contract No. 10.6309.2017/BCh.

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