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Review Article

PROSPECTS OF THE ENVIRONMENTAL TECHNOLOGIES IMPLEMENTATION IN THE CEMENT INDUSTRY IN RUSSIA

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ABSTRACT

Russian cement industry is in decline. Enterprises operate on the basis of technologies developed in USSR. In this connection such fundamental issues of the enterprises functioning, as energy efficiency, environmental safety, resource-saving, resources provision and others, are overlooked. The paper attempts to define the priorities of the Russian cement industry development based on the experience of developed countries. The most promising technologies for the designated key areas were described and their benefits and drawbacks were identified. Due to the major role of the raw resources in Russian economy, the issues of increasing the efficiency of cement plants, should be discussed with considering the efficiency of mining enterprises extracting mineral raw materials needed for manufacturing process. Given the significant investments required to the industry modernization, which can not be achieved through government support, it is proposed to create conditions for the development of the integrated companies. In addition, a key factor that can ensure the sustainable development of the industry is a cross-sectoral co-operation, which will allow to organize a low-waste production cycle with a minimal costs of raw materials.

Keywords: cement industry, ecology, limestone, clay, Russia, cross-sectoral cooperation, environmental technologies

INTRODUCTION

Construction is one of the basic Russian industries, which plays a significant role in the economy (Table 1). Four key points can express its economic importance. Firstly, it provides a significant part of the country's population employment (more than 7% [FSS 2016]). Secondly, the quality of life in the country depends on the volume of construction (increasing the housing area per 1 person). Thirdly, construction industry forms the basis for the development of service sector and industries providing resources. Fourthly, the implementation of large construction projects, such as apartment complexes, could attract new residents in the region. Development of construction industry is connected with the increasing in number of companies involved in the industry (Figure 1).

The increase in the number of companies leads to increasing the number of ongoing projects what, on the one hand, is a factor of improving the quality of life, but, on the other hand, is direct and indirect factor of increasing anthropogenic impact on the environment.

The direct impact of construction industry is connected with the number of projects. Despite a trend of environmentally friendly technologies implementation [Didenko and Skripnuk 2014], it is ordinary in Russia that the regulatory authorities requirements performed only on paper. Many examples of such a situation could be found in mass media. The indirect impact includes the need of increasing raw building materials produc-

Table 1. Share of construction industry in GDP of the Russian Federation [FSS 2016]

Year	Share, %	Year	Share, %
2002	4.74	2008	5.39
2003	5.32	2009	5.42
2004	4.97	2010	5.59
2005	4.58	2011	7.04
2006	4.47	2012	6.40
2007	4.91	2013	6.08

tion volume, what as seen on the example of cement (Figure 2).

From 2000 to 2014 the volume of cement production in Russia doubled, and according to [Vysockiy 2013], in 2020 cement production will grow up to 90 million tons per year (in 1.5 times compared to 2014). At the same time, about 75–80% of the Russian cement industry capacities need to be modernized [Kasyanov 2009]. It will require more than 6.5 billion euros.

The major part of Russian cement plants operate with using equipment of the Soviet period (Table 2), so they have nothing in common with modern environmental technologies. Cement industry produces about 5% of total CO_2 emission, which could be used in other sectors of the economy due to implementation of the innovative CO2 capture technologies [Tcvetkov and Cherepovitsyn 2016] during the processes of fuel combustion and chemical reactions (about 83% of total CO_2 emission) [ClimaTechWiki 2010].

Such technologies are relevant to Russia, especially in a view of signing the Paris agreement on climate change in April 2016. Despite some criticizing against this agreement, it is an important step for Russia taking "environmental obligations" to the global community.

The increase in cement production determines the necessity of clay and limestone mining enlargement (the key components for its production in Russia). According to Russian government regulation, clay and limestone are common min-

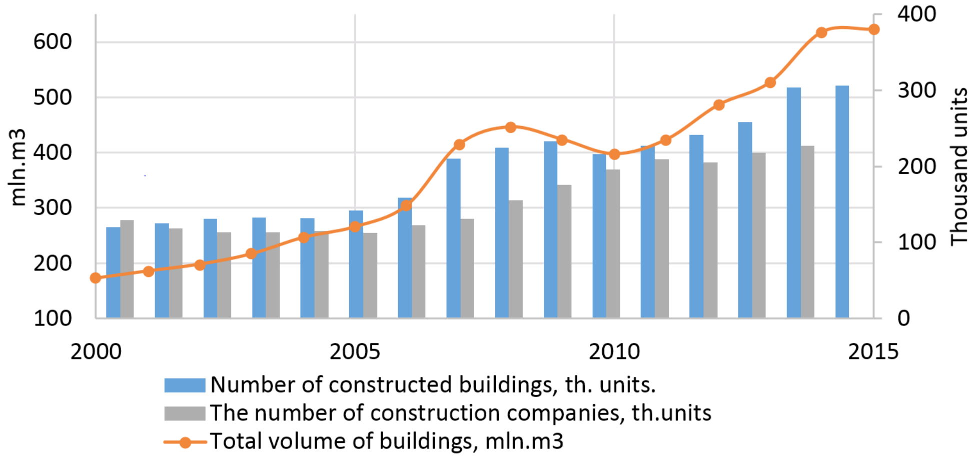

Figure 1. Relation between total volume of constructed buildings and number of construction companies in Russia

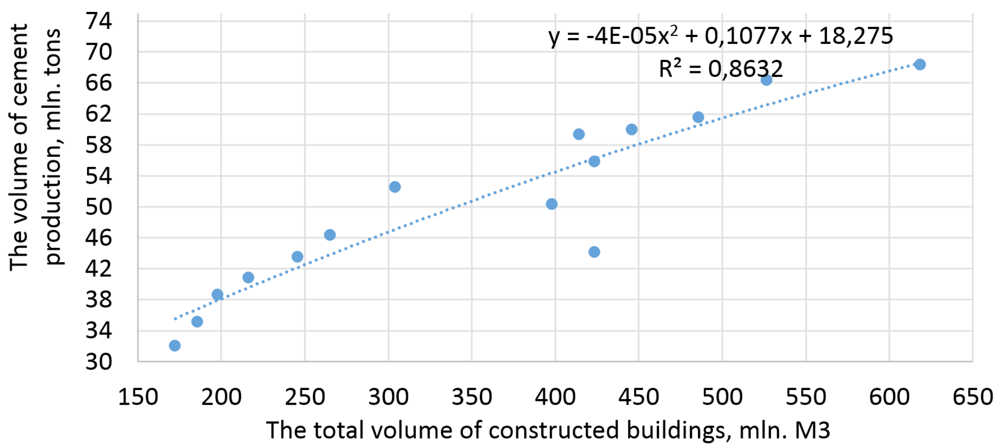

Figure 2. Relation between volume of constructed buildings and volume of cement production in Russia

Table 2. Depreciation of cement factories fixed assets [Vysotsky 2014, Guz 2015]

Total production capacity, mln. tons	Distribution of fixed assets by functioning time, mln. tons			
	>55 years	55–35	35–25	<25 years
100.1	25.8	43.5	5.4	25.4

erals, the extraction of which is considered to be relatively safe for the environment. However, the increase in production volumes and exploitation of new fields lead to increasing of disturbed areas and contaminated lands. In addition, due to high rate of transport costs in price of the building materials, the fields usually located near the areas with intensive construction, which are densely populated [Pivovarova 2015].

In this paper we attempt to summarize the information about the innovative technologies used in the processing chain of cement production and to determine the prospects of their implementation in Russia.

MATERIALS DESCRIPTION

Mining

Extraction of clay and limestone is carried out, as a rule, in quarry, which has a significant negative impact on the environment in the surrounding areas: pollution of air, soil, sediment, water, the formation of large depression cones, etc. Given the extremely lenient mechanism of emissions state regulation and imperfect tax system, the only significant obstacle to the development of deposits of non-metallic minerals is the process of withdrawal of land for industrial purposes.

The main impact of quarry is the destruction of natural objects within the quarry and on the territory of overburden dumps. Beyond the quarry, main environmental impact caused by dusting of overburden dumps, and pollutant emissions from blasting and the engines of road-construction equipment and vehicles. There is also a risk of pollution and changes in the chemical composition of groundwater [Tazhetdinova 2012].

Limestone

As a possible compromise could be the implementation of production technology without blasting and tightening ecological requirements for the equipment. In [Volkov et al. 2013, Kurchin et al. 2013] the proposed room-and-pillar mining method for limestone. The authors argue that it is possible without losses of production efficiency, especially in the northern regions with severe climatic conditions [Kozlov et al. 2015].

There are some examples of the limestone deposits underground mining in the world practice: in Korea [Yung et al. 2007], in some regions of the United States [Esterhuizen et al. 2008], and in European countries [Daniel and Careddu 2011]. In support of transition to underground mining, in addition to reduce dependence on climatic conditions, we would also like to point two essential arguments discussed by Parker [1996]:

1) stripping and restoration requirements are eliminated;
2) additional reserves are often available beneath the quarry floor, under pit slopes, or under adjoining property.

In [Bliss et al. 2008] it was also noted that underground limestone mining has some advantages, in comparison with the quarrying, especially if the field is located near populated areas, where there are special requirements for noise, vibration and emissions.

Returning to the question of blasting operations rejection, it should be noted that there is a successful practice of rock excavation by heavy rippers [Aggregates Business Europe 2007] or milling combines [Ermakov and Hosoev 2013]. These machines are used when limestone deposits are located in areas with high population density. This quarrying method is also preferable due to lower environmental impact (decrease the emissions into the atmosphere [Bratchikov et al. 2012]).

Another significant advantage of this method is increasing the production process flexibility. It is especially important when the selective quarrying is needed. Studies show [Safronov et al. 2015] that the most effective is the use of modern hydraulic excavators, although, it depends on the specifics of the field, of course.

Clay

Typically, clay is quarrying with the use of excavators. The process of clay extraction is almost completely automated. Significant fact is that clay refers to soft mineral resources. In low (negative) temperature conditions it solidifies, so the use of different techniques and methods of insulation is necessary.

One of the main problems of clay quarrying, in addition to general Russian quarry problems, is inefficient use of industrial areas after the exhaustion of the deposit resources. There are many examples of illegal dumps formation in such places [Nazarenko 2011]. Similar problems occur not only in Russia. For example, one of the main problems connected with clay harvesting in Ghana is the lack of post-production land reclamation, according to [Sarkodie et al. 2014].

Note that the problem of improving the clay extraction technologies is not enough discussed in scientific literature, despite the lack of a real alternative to quarrying, unlike most other non-metallic minerals. In our opinion, it is connected with a minor role of the clay industry in national economies (excluding the effect in related industry branches).

CEMENT PRODUCTION

Cement production technologies

Raw materials for cement production are carbonate rocks (limestone, chalk, marl, marble), clay rocks (clay, loam, clay shale) and various additives (diatomite, tripoli).

Cement production consists of two main stages: clinker production and clinker grinding. Depending on the method of the raw materials compound preparation, there are dry, wet and combined methods of clinker production. In the first method, the initial mixture is obtained as a powder, in the second as a slurry. The third method is an "intermediate process chain", which may be based on one of two previous methods. The largest share in the Russian cement industry takes a wet method of production (Table 3).

If we compare their effectiveness, the most preferred is a dry method, the share of which in total cement production reaches in Japan 100%, in India – 93% in Europe – 90% (average), in the USA – 82% [Potapov 2013]. In this regard, the strive of Russia to increase the share of dry cement production looks very reasonable.

Table 3. Types of furnaces in Russian cement industry [Kasyanov and Han 2009]

Type	Share, %	% of total capacity
"Wet"	85	83
"Dry"	9	17
Shaft	6	0

Many Russian scientists consider "dry method" as a panacea for national cement industry. However, we would like to underline that there are also alternative aspects of the industry development. Moreover, dry cement production could be relatively ineffective, what we can see on the example of China industry [Lu 2009]. So, the implementation of such projects should be based not only on the desire to adapt successful foreign practice, but also on a careful study of the environmental and economic situation in the region [Teslya et al. 2015].

Clinker substitutes

Up to 80% of the cement production costs are the expenses for clinker. They partly include the cost of fuel (20% of total cement cost). At the same time, about 40% of the energy is consumed in the process of clinker grinding [Dvorkin and Dvorkin 2011]. It opens wide perspectives for the development and implementation of clinkerless cement manufacturing technologies [Brito and Saikia 2013], which reduce the emissions of harmful substances and the amount of used mineral raw resources [NCA 2016].

In the USSR part of waste in cement production reached 26% (1980), i.e. from 137 million tonnes of raw materials, 36 million tons were the wastes of mining and processing industries (for example, blast furnace slag). Currently, this share dropped to 15–17% due to various reasons [Zarko et al. 2011].

Energy efficiency of the cement factories

Another direction of the cement industry development is increasing energy efficiency [Worrell et al. 2013]. [Imbabi et al. 2012] showed that economic efficiency of cement factories depends significantly on the availability of energy-saving technologies.

Besides the fact that the wet method is energy-intensive [CM Pro 2010], in Russian cement industry used such fuels as natural gas (88%), coal (11%) and shale (1%) [Nikolaichuk and Diakonova 2016], whose prices are characterized by annual stable growth [Nikolaichuk and Tsvetkov 2016]. Energy consumption of Russian cement plants is shown in Table 4.

Table 4. Energy intensity of cement production methods [BBT 2015]

Method	Year of launch	Annual average fuel consumption, kg.OE./ton of clinker	Annual average electricity consumption, kw-hr/ ton of cement	Average energy consumption, kg.OE./ton of cement
Dry	before 1989	146.6	154.6	198.2
	after 2008	106.4	122.5	147.4
Wet	after 2008	189.2	121.9	229.6
Combine	–	147.2	99.6	180.6

It should be noted that the transition to dry cement production method, the development of clinker substitutes and implementation of energy saving strategies are caused by a desire to reduce environmental impact [Imbabi et al. 2012, Habert et al. 2010], in addition to producing tangible economic effect. In this connection, the sustainable development of the Russian cement industry should be based on inter-industrial collaboration. Significant perspective in this matter has the development of small bioenergy enterprises, based on peat and wood processing [Cherepovitsyn and Tsvetkov 2016], which could be cooperated with cement factories.

Advanced technologies in public documents

In [BBT 2015] 16 "best available technologies" are marked whose implementation can increase the sustainability of the cement industry of Russia. The main ones are listed below (some of them have already been mentioned):

- development of clinker substitutes;
- development of dry cement production method based on modern scientific and technological base;
- using of waste as energy resource;
- cooperation between cement factories and heat generating companies to generate additional heat;
- development, implementation, maintenance of operational and continuous requirements of the energy and environmental management systems;
- using of modern filtration systems, and implementing measures to reduce dust emissions;
- reduction of gaseous emissions: NO_x, SO_2, CO_2, etc.;
- decreasing the noise from the production process;
- creating the decree and implementation of the regular monitoring and measurement of the emissions parameters.

This document is comprehensive and detailed, as evidenced by the presence of large list of particular measures, based on extensive statistical analysis. However, the implementation of all proposed measures in each new / modernized enterprise is questionable in the absence of free access of Russia to foreign technologies. However, we tend to agree that the sustainable development of the cement industry requires new regulation system, which should describe the process of Russian cement plants functioning in details.

Similar ideas, but in a more limited form set out in the source [IEA and WBCSD 2009], where advanced technologies are divided into four segments: thermal and electric efficiency, alternative fuel use, clinker substitution, carbon capture and storage.

DEVELOPMENT OF INDUSTRY

Mining

The analysis of cement industry promising technologies showed that, even with the mass implementation of clinker substitutes, the demand for limestone and clay in the coming years will slightly decrease. This is confirmed by the experience of the USSR, where only one third of the raw material was provided by the waste.

The development of limestone underground mining can be promising for widespread implementation. However, despite the potentially equal cost of production (in comparison with quarrying), the practice of mining shows a much higher capital expenditures, for example, for realization of room-and-pillar mining method. In Russian conditions, such projects could be implemented in the northern regions.

Promising and feasible in the current situation are non-blasting methods of limestone quarrying, taking into account the successful experience of their implementation, as well as the availability of the necessary technologies in Russia.

Akey step for solving the problem of low efficiency of clay and limestone quarry is the improvement of legal documents in the field of environmental management. It is necessary to develop a development strategy for the industry, which will give an opportunity to implement the capital-intensive environmental projects (including measures for land reclamation) without loss of enterprises competitiveness in regional and international markets [Didenko et al. 2015].

Cement production

Russian cement industry, mainly operates using wet process. Despite the presence of a trend for the transition to more efficient technologies (production of dry and combined), the required investment, predicted in [Kasyanov 2009] are a significant deterrent to the development of the industry.

Improving the energy efficiency of cement factories is one of the key trends of the industry development. The possible way, offered in [BBT 2015], is the union of plants with energy companies. Moreover, Russia's scientific and technological base makes possible to reduce the cost of energy by realization of the local energy resources potential [Tcvetkov and Strizhenok 2016].

Given the capital and energy intensity of clinker production process, as well as significant amount of accumulated waste from processing facilities [Pushkin and Wiseman 2013], with high probability the possibility of clinkerless technologies development can be predicted.

CONCLUSION

The basis for the development of cement production technologies, as well as necessary resource for their functioning is capital – and knowledge-intensive process. In developed countries, this process is supported by the state regulation system in the field of environmental protection [Cherepovitsyn and Ilinova 2016]. These conditions have not been established in Russia yet. Moreover, in the current difficult economic situation, the possibility of state support for industry is very limited. In this regard, the introduction of such measures as mandatory environmental audit and certification according to ISO 14000 [Lashina and Petrov 2013] standards can lead to bankruptcy of most enterprises.

Despite the promising and proven by the international experience cost-effectiveness of innovative projects implementation in the cement industry, the implementation of all "best available technologies", proposed in [BBT 2015], is unrealizable to date.

As an intermediate solution could be vertical and cross-industry cooperation based on resource-saving technologies, which will subsequently liberate some financial resources for the modernization of the existing and the creation of new high-tech facilities.

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