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CEMENT PRODUCTION IN RUSSIA: BEST AVAILABLE TECHNIQUES AND OPPORTINITIES FOR USING ALTERNATIVE FUEL

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ABSTRACT

Cement is the second most-consumed resource in the world, with more than 4 billion tonnes of the material produced globally every year. The cement production is considered to be one of major polluters regulated by Best Available Techniques (BAT) both in Europe and the Russian Federation. At the same time, cement industry generates greenhouse gases (GHG) emissions both of the 'energy' and 'process' origin. In Russia, climate legislation is just being formed, but operators of cement installations have already begun looking for economically feasible solutions for reducing CO_2 emissions.

In Europe, conventional fuels are often replaced by waste fuels, derived from pre-treated and sorted waste fractions including solid and liquid recovered fuels, and/or biomass. The use of waste (to partially substitute raw materials as well as conventional fuels) is considered to be BAT for the cement manufacturing process. For Russian cement plants, this fact opens economic advantages as well as opportunities for greening production, though practitioners are concerned about the possible growth in emissions of 'ordinary' pollutants such as sulphur and nitrogen oxides as well as dust.

The article describes results of quantitative estimation of emissions (CO_2, SO_2, NO_x) after the partial replacement of the natural gas with wood chips, wood powder and sunflower pellets (burnt exclusively in the calciner). The calculations were made under the assumption that the specific heat consumption (heat rate) does not change while obtaining 7 – 15% of heat needed by burning the alternative fuel.

The estimated data show that the replacement of natural gas with 7.5 – 15% of alternative fuel leads to a decrease in the total end-of-pipe gas emissions by 0 – 0.56% (mass) and 0.09 – 1.04% (volume release).

The use of wood chips in 7.5 to 15% amount out of the total heat rate for firing 1 kg of clinker leads to the decrease in total gas emissions (by mass) from the kiln system by 0 –0.49%, SO_2 emissions: by 0.16 – 0.27%, NO_2 emissions: by 0.29 – 0.67% and NO emissions: by 0.25 – 1.24%. Emissions of CO_2 will reduce by 0 – 0.52 % physically and 7.5 – 15.5 % reporting wise. The use of sunflower pellets in 7.5 to 15% amount out of the total heat rate for burning 1 kg of clinker leads to a decrease in total gas emissions (by mass) from the kiln system by 0.28 – 0.56%, SO_2 emissions: by 0.55 – 0.97%, NO_2 emissions: by 0.48 – 1.06, and NO emissions: by 0.43 –1.54%. Emissions of CO_2 will

decrease by 0 – 0.26%; for reporting purposes, the decrease will reach 7.5 – 15.76 %. The use of wood powder in 5 to 15 % amount out of the total heat rate for firing 1 kg of clinker leads to the decrease in total gas emissions (by mass) from the kiln system by 0.23-0.68 %, CO_2 emissions: by 0.25 – 0.76 % while simultaneously increasing SO_2 emissions by 0.23 – 0.68 %. NO_x emissions decrease in proportion to the amount of main process fuel burned in the nozzle of a rotary kiln.

Since alternative fuels will be supplied to the rotary kiln zone with a temperature of 1100–1200 °C and excess air (oxygen) content in a vaporous phase, the phenol-formaldehyde resins within wood fuel additives will undergo the process of complete oxidative decomposition and combustion. No additional emissions of organic substances (phenol-formaldehyde resins decomposition products) are expected. Kiln dust emissions depend primarily on the efficiency of end-of-pipe techniques used to treat stack gases, and will not change when replacing natural gas with fuel additives. At the same time, using fuel additives will contribute towards reducing GHG emissions of cement production and meet requirements of the emerging GHG legislation (regulation system) to be introduced in 2019-2020.

Keywords: greenhouse gases, alternative fuel, wood chips, sunflower pellets, emission reduction.

INTRODUCTION: OPPORTNUNITIES FOR USING WASTE TO REDUCE EMISSIONS OF GREENHOUSE GASES

Since 2014, Russia is in the transition process to a fundamentally new waste management system: production waste is considered not as undesirable residues, but rather as secondary resources in a circular economy. According to the Russian Development Strategy for the Industry for Treatment, Disposal and Decontamination of Production and Consumption Waste for the Period up to 2030 [1], the share of recycled and decontaminated waste in the total waste generated should increase from 59.6% in 2016 up to 86% by 2030. Current dynamics for waste disposal and decontamination are shown in Fig. 1.

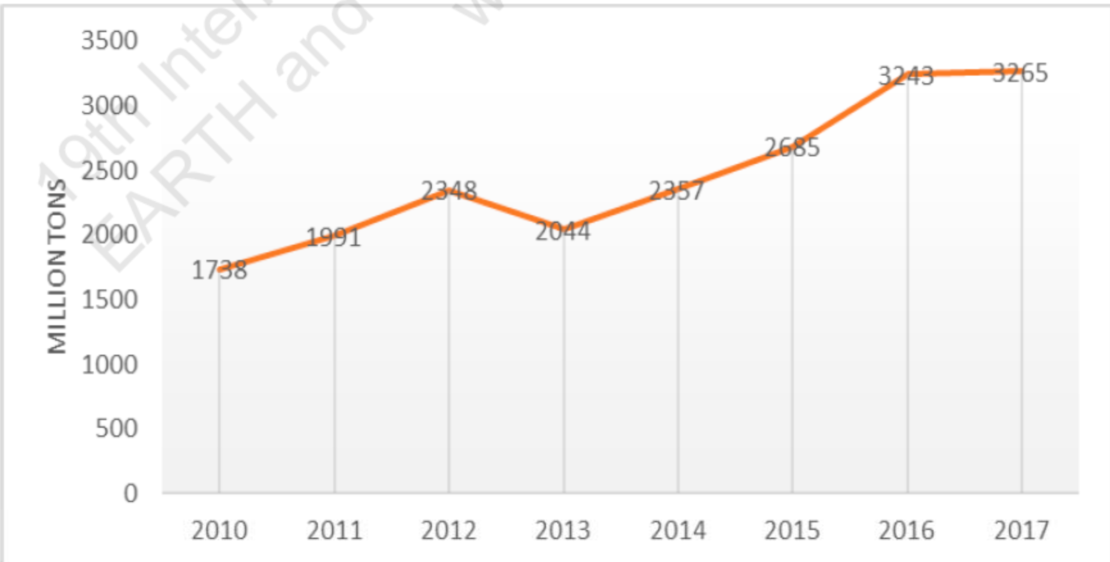

Figure 1. Dynamics for disposal and decontamination of industrial and consumption waste in the Russian Federation, 2010-2017 [2]

Russia is actively moving towards the environmental reform (modernisation); in others words, to the prevention of environmental pollution through the introduction of environmentally friendly production technologies in all economic sectors. The new system of environmental regulation based on the application and implementation of Best Available Techniques (BAT) stimulates larger industrial enterprises to choose more environmentally friendly technologies and methods and use effective stack gas treatment equipment. At the same time, Russia is working out a new system for regulating (reducing) GHG emissions. Regulators consider applying such approaches as GHG emissions trading system, support to energy efficiency enhancement and to the use of renewable energy sources (such as wind, solar and biomass).

Cement production is an energy and carbon-intensive process; this industrial sector has always been among the greatest CO_2 emission sources with about 750-900 kg CO_2 released with each production tonne of cement [3, 4]. These derive from the physicochemical reactions involving the raw materials and the combustion of fuels.

About 60-63 % of CO_2 emissions result from the calcination of $CaCO_3$, and remaining 37-40 % – from the combustion of fuel [3]. The technological characteristics of cement production form prerequisites for the use of waste fuel in cement kilns: high temperatures in the kiln (material temperature is > 1450 ° C, and the temperature of gaseous environment in the baking zone is ~ 2000 °C) will allow to treat toxic substances over period of 7 seconds with no additional (secondary) waste generated.

In theory, cement kilns can operate on 100% biomass, but there are certain limitations such as the calorific and moisture content but also the content in trace compounds (i.e. chlorine) of the specific fuel. Most organic materials have low calorific values of about 9.5 – 17 GJ/tonne. Cement kilns require fuels with high calorific values (20 – 22 GJ/tonne), thus the use of biomass should be in combination with other fuels. Up to 60% of the precalciner fuel can be of low calorific value [4, 5, 6]. When low calorific value fuels with high chlorine compounds (requiring chlorine by-pass system) are used in a kiln, the fuel energy consumption will increase. When utilising high waste fuel rates, clinker capacity may be reduced, as cement kiln operation with a 60-80% waste substitution rate differs drastically from the operation with 100% fossil fuels. Fuel use for using biomass may increase by 0 – 275 MJ/tonne clinker while electricity use may also increase by 0 – 2.7 kWh/tonne clinker [6]. Russia has massive amount of biogenic wastes that can be used as fuel additives providing for (1) the reduction of waste and (2) decrease of GHG emissions in cement production. Such solutions are particularly effective for production and consumption waste with the calorific value of 11 GJ/tonne and more (still, 2-3 times lower that calorific values of coal and natural gas).

RESULTS

The use of waste as an alternative fuel is included in the European list of Best Available Techniques (BAT) for cement industry (BAT 4.2.4 Use of waste) [3]; this fact bears great economic advantages for cement plants and makes the application of this technology attractive. However, there are no technical requirements and criteria for the use of waste fuel in the Russian cement industry presently (technological parameters of emissions (the Russian version of BAT-associated Emission Levels), fuel substitution percent as the BAT parameter, etc.). The development of these documents requires testing this alternative fuel technology at the pilot sites. But before that there is a need to evaluate (calculate) priority pollutant emissions (CO, NOx, SO_2, dust) which will result from substituting a portion of conventional process fuel (natural gas) with alternative fuel (biomass).

From the international cement production practice and a number of publications, it is known that biomass fuel does not affect dust emissions from a rotary kiln [7, 8, 9]. The ash residue generated during the combustion of fuel additives almost completely precipitates to the clinker. Dust emissions depend solely on the type of dust-treatment equipment and do not change when adding fuel substitutes to conventional fuel.

Thus, a calculation and analytical methods can be used to estimate the change in total gas emissions from the kiln and CO_2 and SO_2 emissions after replacing part of the process fuel with fuel additives. It should be expected that while the amount of dust, CO, organic substances and polycyclic aromatic hydrocarbons (PAH) emissions does not really change NO_x emissions will decrease by the proportional amount to the share of the substituted main process fuel.

Before the start of calculations, it is necessary to choose the type of waste that we are going to use as waste fuel and its economic and environmental benefits or negative impacts. The simplest and easiest solution is using such common renewable resources as wood chips, wood dust and pellets.

The paper estimates emissions of several priority pollutants (CO, SO_2, NO_x) as well as emissions of CO_2 as the result of the replacing part of the main process fuel with fuel additives. In Russia, CO, SO_2, NO_X and dust are included in the list of so-called marker parameters (Russian BAT-AELs), most significant air pollutants of the cement production sector to be self-monitored and reported by operators and checked by the environmental authorities [10, 11]. Some stakeholders argue that burning biomass could lead to failing to meet sector BAT-AELs set for dust, CO, SO_2, and NO_X. This is why it is important to consider constrains and demonstrate opportunities for the partial replacement of conventional fuel by the renewable biomass.

In cases, where the main process fuel is natural gas, a partial substitution is planned for wood chips and sunflower pellets, burned only in the calciner. The calculated amount of fuel additives contributes to 7-15% of the specific heat consumption for clinker burning.

The wood powder is used as a fuel additive in the scenarios with a coal as main process fuel. The calculated amount of fuel additives contributes to 5-15% of the specific heat consumption for clinker burning. The kiln capacity and specific heat consumption for clinker burning (q = 3200 kJ/kg clinker) remain unchanged for both variants.

The average composition of dry natural gas used as primary process fuel in technological process on Russian cement plant can be described as follows: CH_4 – 95.88%; C_2H_6 – 2.06%; C_3H_8 – 0.585%; C_4H_{10} – 0.173%; C_2H_{12} – 0.0336%; CO_2 – 0.237%; N_2 – 1.04%. The composition of fuel additives is shown below in Table 1.

Table 1 – The composition of fuel additives

Recalculation of the composition of fuel additives as found basis	Percentage, %		
	wood chips	sunflower pellets	wood powder
Moisture content, W^p	24.49	8.9	2.39
Ash value $A^p = A^c \cdot (100 - W^p)/100$	2.107	2.733	25.086
$S^p = S^g\,(100 - (A^p + W^p))/100$	0.022	0.177	0.261
$C^p = C^g\,(100 - (A^p + W^p))/100$	32.665	39.147	39.453
$H^p = H^g\,(100 - (A^p + W^p))/100$	4.823	5.037	4.446
$N^p = N^g\,(100 - (A^p + W^p))/100$	0.403	0.530	0.732

The percent change in the total gas emissions as the result of the partial substitution of natural gas and coal as a main process fuel by fuel additives will comprise:

- for 7.5 % of wood chips: 0 by mass and – 0.09 by gas volume release;
- for 15 % of wood chips: – 0.49 by mass and – 0.17 by gas volume release;
- for 7.5% of sunflower pellets: – 0.28 by mass and – 0.52 by gas volume release;
- for 15% of sunflower pellets: –0.56 by mass and –1.04 by gas volume release;
- for 7.5% of wood powder: – 0.27 by mass and – 0.23 by gas volume release;
- for 15% of wood powder: – 0.80 by mass and – 0,68 by gas volume release.

The estimated data show that the substitution of natural gas with 7.5-15% of alternative fuel leads to a decrease in the total end-of-pipe gas emissions by 0–0.56% (mass) and 0.09–1.04% (volume release). Total gas emission reduction as the result replacing a portion of natural gas with fuel additives is shown in Fig. 2.

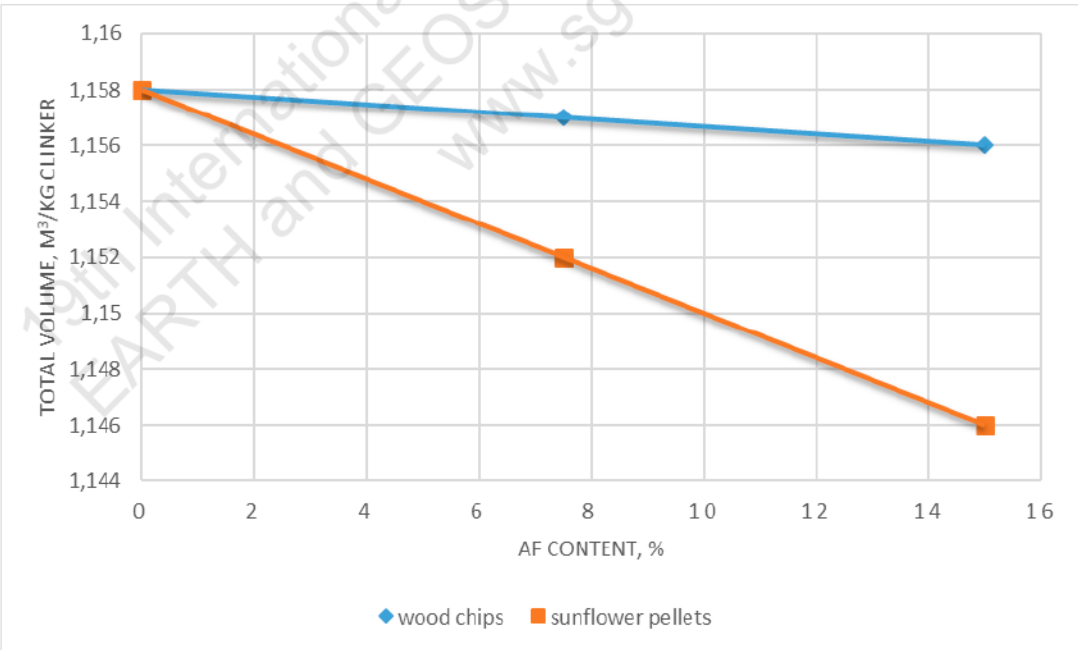

Figure 2. Total gas emission reduction as the result replacing a portion of natural gas with fuel additives

The percent change in SO_2 emissions as the result of the partial substitution of main process fuel by fuel additives will comprise:

- for 7.5 % of wood chips: – 0.16 by mass and – 0.13 by gas volume release;
- for 15 % of wood chips: – 0.27 by mass and – 0.24 by gas volume release;
- for 7.5% of sunflower pellets: – 0.55 by mass and – 0.12 by gas volume release;
- for 15% of sunflower pellets: – 0.97 by mass and – 0.81 by gas volume release;
- for 7,5% of wood powder: **+ 0.23** by mass and **+ 0.23** by gas volume release;
- for 15% of wood powder: **+ 0.68** by mass and **+ 0.68** by gas volume release.

The slight increase in SO_2 emissions for wood powder can be explained by the chemical composition of the raw material itself. Similar results were obtained for the ceramic production industry [12, 13]. Since cement installations have to meet sector-related BAT-AELs for SO_2, it is necessary to consider the increase assessed and make sure that the use of biomass energy additives is still desirable.

The percent change in NO_2 emissions after partial replacement of main process fuel by fuel additives will comprise:

- for 7.5 % of wood chips: – 0.29 by mass and – 0.41 by gas volume release;
- for 15 % of wood chips: – 0.67 by mass and – 0,81 by gas volume release;
- for 7,5% of sunflower pellets: – 0.48 by mass and – 0.54 by gas volume release;
- for 15% of sunflower pellets: – 1.06 by mass and – 1.22 by gas volume release;
- for 7,5% of wood powder: – 1.28 by mass and – 1.54 by gas volume release;
- for 15% of wood powder: – 2.06 by mass and – 2.78 by gas volume release.

Now let us turn to GHGs. The reduction of CO_2 emissions as the result of the partial replacement of main process fuel by fuel additives will comprise:

- for 7.5 % of wood chips: 0 by mass and – 0.04 by gas volume release;
- for 15 % of wood chips: – 0.52 by mass and – 0.25 by gas volume release;
- for 7.5% of sunflower pellets: 0 by mass and 0 by gas volume release;
- for 15% of sunflower pellets: – 0.26 by mass and – 0.04 by gas volume release;
- for 7.5% of wood powder: – 0.25 by mass and – 0.25 by gas volume release;
- for 15% of wood powder: – 0.76 by mass and – 0.76 by gas volume release.

On the other hand, for the reporting purposes, GHG emissions resulting from burning biomass, are not included in the total amount of CO_2 emitted by the installation [14, 15]. Thus, emissions of CO_2 will reduce by 0 – 0.76 % physically and by 7.5 – 15.76 % reporting wise which is important to meet national GHG emission reduction objectives to be set for the cement manufacturing sector in Russia.

The use of wood chips in 7.5 to 15% amount out of the total heat rate for firing 1 kg of clinker leads to the decrease in total gas emissions (by mass) from the kiln system by 0 – 0.49%, CO_2 emissions: by 0 – 0.52 %, SO_2 emissions: by 0.16 – 0.27%, NO_2 emissions: by 0.29 – 0.67% and NO emissions: by 0.25 – 1.24%.

The use of sunflower pellets in 7.5 to 15% amount out of the total heat rate for burning 1 kg of clinker leads to a decrease in total gas emissions (by mass) from the kiln system by 0.28-0.56%, CO_2 emissions: by 0 – 0.26%, SO_2 emissions: by 0.55 – 0.97%, NO_2 emissions: by 0.48 – 1.06, and NO emissions: by 0.43 – 1.54%.

The use of wood powder in 5 to 15 % amount out of the total heat rate for firing 1 kg of clinker leads to the decrease in total gas emissions (by mass) from the kiln system by 0.23-0.68 %, CO_2 emissions: by 0.25 – 0.76 % while simultaneously increasing SO_2 emissions by 0.23 – 0.68 %. NO_x emissions decrease in proportion to the amount of main process fuel burned in the nozzle of a rotary kiln.

CO emissions do not depend on the type of fuel used and will not change when replacing part of the process fuel with fuel additives. PAH emissions (incl. benzapyrene) will not change when replacing part of the process fuel to fuel additives.

Since alternative fuels will be supplied to the rotary kiln zone with a temperature of 1100–1200 °C and excess air (oxygen) is in a vaporous phase, the phenol-formaldehyde resins contained within wood fuel additives will undergo the process of complete oxidative decomposition and combustion. No additional emissions of phenol-formaldehyde resins decomposition products are expected. Kiln dust emissions depend primarily on the efficiency of end-of-pipe techniques used to treat stack gases, and will not change when replacing of natural gas with fuel additives.

Dust emissions from the kiln system depend only on the efficiency of the equipment used to treat stack gases, and will not change when replacing part of the process fuel to fuel additives.

CONCLUSION

Operators of Russian cement installations being interested in partially substituting conventional fuels by the renewables (such as biomass) are concerned about the possible increase of stack gases emissions. They suspect that burning biomass could lead to the growth of emissions of the most typical contaminants, such as SO_2, NOx, CO or dust. BAT-associated Emission Limit Values (technological parameters) set for these contaminants have to be met by all cement producers no later than in 2024. Results obtained in this research prove that the introduction of such fuel additives as wood chips, sunflower pellets, wood powder) in technological process of cement production in an amount lesser than 15 % will lead to decrease in total gas emissions by mass and by volume released. Moreover, most emissions show tendency to decrease.

NO_2 emissions are reduced more while using sunflower pellets (– 1.06% by mass). SO_2 emissions might increase, and operators of cement installations can choose fuel additive based on the sector BAT-associated emission levels of priority pollutants established by the Russian supervisory agencies.

As far as GHG emissions are concerned, the amount of CO_2 is reduced more significantly while using wood powder (– 0.76% by mass) and wood chips (– 0.52% by mass). It is important that GHG emissions resulting from burning biomass, are not included in the total amount of CO_2 emitted by the installation.

Thus, emissions of CO_2 while will reduce by 0 – 0.76 % physically and by 7.5 – 15.76 % reporting wise which is important to meet national GHG emission reduction objectives to be set for the cement manufacturing sector in Russia.

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