

Secondary energy component in energy-saving processes of cement production

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Abstract. Problems of energy saving in the firing of raw sludge is an important factor in the long-term development of cement production. An integrated approach to the study of the properties of raw materials and additives makes it possible to find ways to save fuel and energy resources. Reducing the moisture content in the sludge by the use of plasticizing reagents is one way to solve the problem of reducing energy consumption during firing of sludge. Reducing the moisture content of raw sludge from 41% to 35.5% makes it possible to reduce energy consumption by 23.3 kilograms of equivalent fuel per ton of clinker. The most effective type and concentration of plasticizing reagent was selected. A decrease in the moisture content and an increase in flowability were studied on a model raw sludge based on kaolinite-montmorillonite clay, chalk and pyrite cinder – a coal -alkaline reagent (0.1 wt.%). The studied reagents were arranged in the following sequence according to the effectiveness of increasing the flowability of sludge: coal-alkaline reagent, Polyplast SP-1, calcium lignosulfonate (LST), Viscrete20HE, Linamix PK.

1. Introduction

In the technology of cement production there are methods that make it possible to significantly reduce energy consumption: reducing costs by changes in the composition of the raw mix; fuel and electricity savings by changes in the composition of cement [1]. Reducing the moisture content in the sludge by the use of plasticizing reagents is one way to solve the problem of reducing energy consumption during firing of sludge. It has been repeatedly proved by scientific research that by introducing special additives into the mixture, the moisture content of the sludge is reduced. Currently, preference is given to super - and hyperplasticizers [2-7].

The introduction of plasticizing reagents into the raw material mixture makes it possible to reduce the viscosity of the sludge, increase its fluidity, and also lower the calcite decarbonization temperature (CaCO_3), which subsequently will shift the processes of interaction of substances in the solid phase to lower temperatures 1250–1270°C [8].



Cement industry seek to improve the thermotechnical characteristics during firing of raw cement slurry [9, 10].

Rheology methods are used to study the structure and description of the viscous flow properties of disperse systems [11, 12]. Understanding the ongoing changes in these properties makes it possible to optimize the technological process of obtaining materials with the necessary properties, at the minimum cost of energy resources.

The aim of the study was a comparative assessment of the effect of plasticizing reagents on the possibility of energy saving during firing of cement clinker.

2. Materials and Methods

Superplasticizers Polyplast SP-1 (mixture of sodium salts polimetilennaftalinsulfo acids) Linamix PK (based of polyoxyethylene derivatives of polymethacrylic acid) the hyper plasticizer Viscocrete 20HE (based on polycarboxylate ethers), coal-alkaline reagent (CAR), calcium lignosulfonate (LST) were used in the work.

The minimum possible dosages of plasticizing reagent were determined while maintaining the flowability of the sludge samples, according to the technological regulations, at a level of 54 ± 2 mm on the MKHTI TN-2 device.

The study of the structural and mechanical properties of cement raw sludge was performed on a rotational viscometer Brookfield DV-II+.

The mineralogical composition of the initial raw materials according to x-ray phase analysis performed on an ARL X'TRA diffractometer is shown in the Table 1.

Table 1. The mineralogical composition of the initial raw material components, wt. %.

Component names	Calcite	Montmorillonite	Kaolinite	The feldspars	Quartz
Chalk	96.1	—	—	—	3.4
Clay 1	—	14.1	82.2	3.7	—
Clay 2	5.4	15.9	13.7	17.0	45.6

The processes occurring during heating and cooling of the samples were studied on a synchronous thermal analysis device STA 449 F3 Jupiter – combined TG-DSC that allows measurements of mass changes and thermal effects. The DSC-TG measurement process was carried out in an atmosphere simulating an air environment with a heating rate of $10^\circ\text{C}/\text{min}$, while the sample was heated to 1450°C .

3. Results

Raw mix composition for preparing a raw cement slurry is, wt. %: clay 1-2.00; clay 2-14.98; iron supplementation – 2.54; chalk – 80.67. Raw cement slurry was obtained by co-grinding with water in a ball mill of initial raw materials to a residue on sieve No. 008 of 6-8 wt. %. The content of plasticizer in the raw sludge was varied from 0.1 to 1.0 wt. % on a dry matter basis.

The dependence shown in Fig. 1 shows that the required flowability of 54 ± 2 mm is achieved at a moisture content of about 41%. Further research will present the results of reducing moisture to 35.5% with the same flowability. Reducing moisture will reduce the cost of heat for evaporation of moisture from raw sludge for cement production.

The fundamental component that affects the rheo-technological properties of raw sludge is the clay component. Mineral kaolinite practically does not absorb water and does not swell in it, as a result of this raw material sludge has lower water demand. Due to the content of bentonite mineral in natural clay, the moisture demand of raw sludge increases. The adsorption capacity of a clay mineral largely depends on the nature of hydrophobic compounds; therefore, the concentration of surfactants introduced affects the sorption capacity of a clay mineral [13].

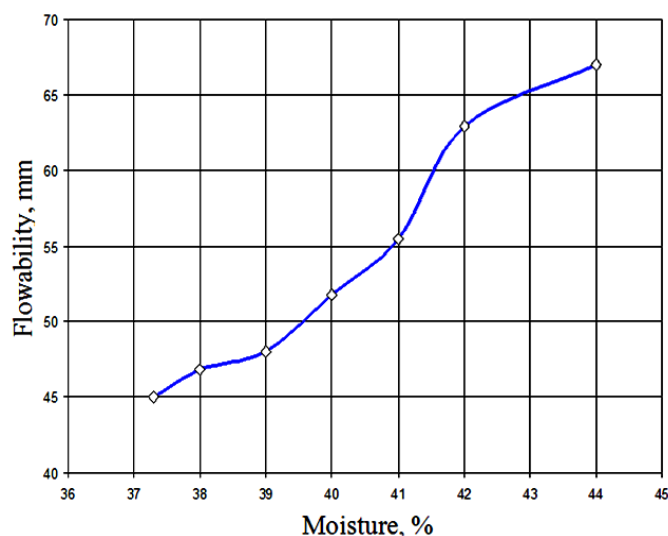


Figure 1. The dependence of moisture to raw cement slurry on flowability.

The results of the studies, which are shown in Figures 2-4, show that there is no clear advantage between superplasticizers and plasticizers. The introduction of 0.1 wt. % LST and Polyplast SP-1 in the composition of the raw material mixture equally increase the flowability to 57.0 and 64.8 mm, respectively. The introduction of Viscocrete hyperplasticizer into the raw mix (Figure 2, curve 3) showed that this reagent exerts its plasticizing effects at a concentration of more than 0.3 wt. %. At low concentrations, clay is adsorbed with respect to the polycarboxylate superplasticizer and its own swelling with water, which leads to a decrease in sludge flow [14]. With the introduction of this reagent, foaming was observed, which occurs due to the air-entraining action on the sludge suspension. This factor is a disadvantage of this plasticizer.

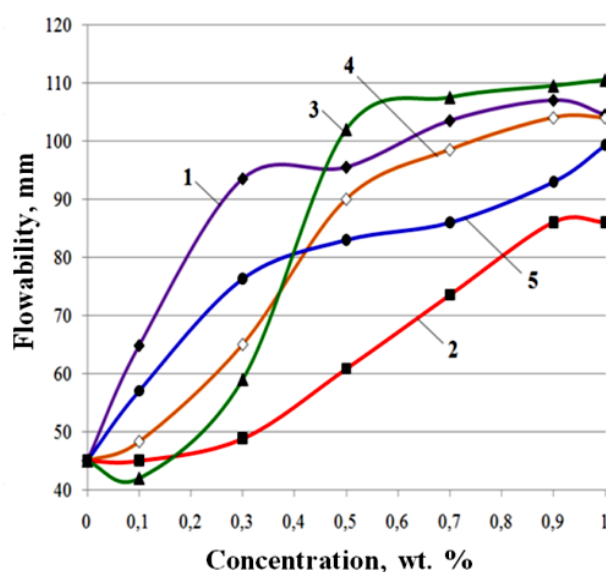


Figure 2. Influence of reagents on flowability of the model slurry: 1 – Polyplast SP-1; 2 – Linamix PK; 3 – Viscocrete; 4 – CAR; 5 – LST.

A decrease in the viscosity of the suspension occurs due to the fact [15] that the surface of the solid phase of the suspension becomes rough, and the adsorbed layer of reagent molecules smoothes it, reducing the coefficient of friction between the particles, and an electric charge of the same name is cre-

ated on the surface of the particles of the solid phase, which subsequently due to electrostatic forces excludes the possibility of their adhesion.

Coal-alkaline reagent, having an alkali in its composition, peptizes clay particles, thereby contributing to an increase in flowability and a decrease in the plastic viscosity of the slurry suspension (Figures 2, 3, curve 4).

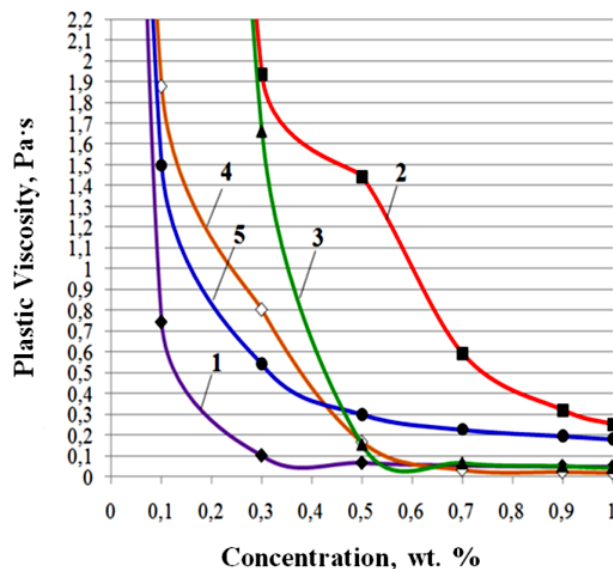


Figure 3. Influence of reagents on plastic viscosity of the model slurry: 1 – Polyplast SP-1; 2 – Linamix PK; 3 – Viscocrete; 4 – CAR; 5 – LST.

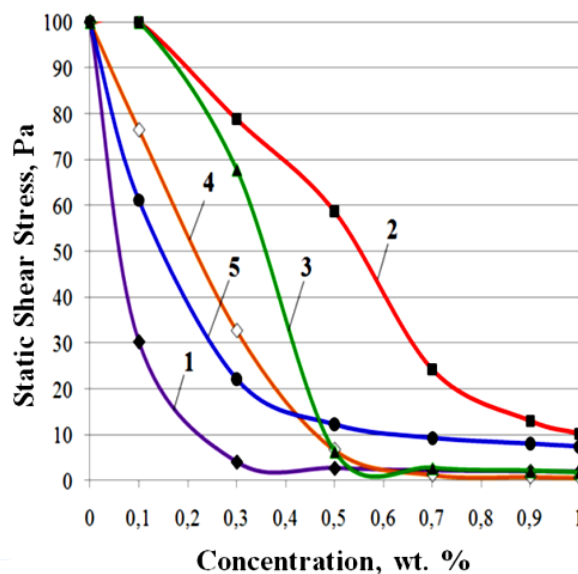


Figure 4. Influence of reagents on static shear stress of the model slurry: 1 – Polyplast SP-1; 2 – Linamix PK; 3 – Viscocrete; 4 – CAR; 5 – LST.

At a minimum concentration (0.1 wt.%), the LST reagent changes the potential of the particles to the negative region and dispersion of the suspension to the smallest particles begins, which prevents the adhesion of individual particles, slows down the coagulation of neoplasms, thereby leading to the release of water. So the mechanism of dilution of the raw mix is manifested. In this regard, the required flowability (Figures 2-4, curve 5) is achieved with less water consumption.

Based on the experimental data, the optimal concentrations of the studied plasticizing reagents were determined (Table 2).

Table 2. Optimal concentrations of plasticizing reagents for the model raw slurry.

Name of the additive	The optimum concentration of additive, wt. %	Flowability, mm
Without addition	0	45.0
Polyplast SP-1	0.1	64.8
LST	0.1	57.0
CAR	0.3	65.0
Viscocrete20HE	0.3	59.0
Linamix-PK	0.5	60.8

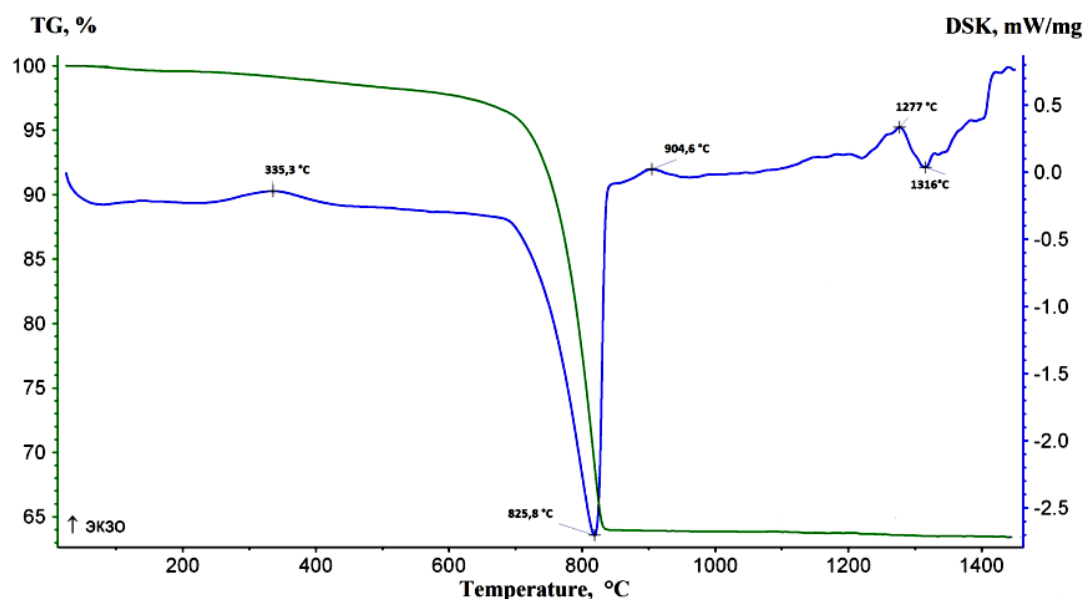
4. Discussion

Works [9, 16] confirmed the theoretical and experimental fact of the efficiency of using a coal-alkali additive, not only as a reagent that improves the rheo-technological properties of sludge, but also as a source of additional heat in the temperature range 200–450 °C, which in turn leads to savings thermal energy.

Analysis of changes in energy consumption at the stage of endo- and exothermic reactions of the raw mixture with the introduction of plasticizing reagents into it, allows us to solve the problems of reducing the moisture content of raw cement slurry and energy saving during clinker firing. On the thermogram (Figure 5) there are no endothermic effects of dehydration of clay minerals, the endothermic effect of decarbonization occurs at 825.8°C.

For example, when added to raw sludge 0.9 wt. % of the additive containing carbon and sodium hydroxide, the process of dehydration of clay minerals is intensified and the process of decarbonization (803.8°C) is shifted to lower temperatures and the processes of interaction of substances in the solid phase are accelerated. This fact is confirmed by the differential thermal analysis data (Figure 6). When heating samples containing a plasticizer, there is a tendency for the peak of the decarbonization temperature to shift by 22°C.

A decrease in sludge moisture by 1% increases the kiln productivity by 1.5% and gives a saving of 2–2.5% fuel or 5.3 kg of equivalent fuel per ton of clinker, the specific fuel consumption during the wet production method is reached 170 kg of equivalent fuel per ton of clinker [17].

**Figure 5.** Thermogram of the raw material mixture without the introduction of additives.

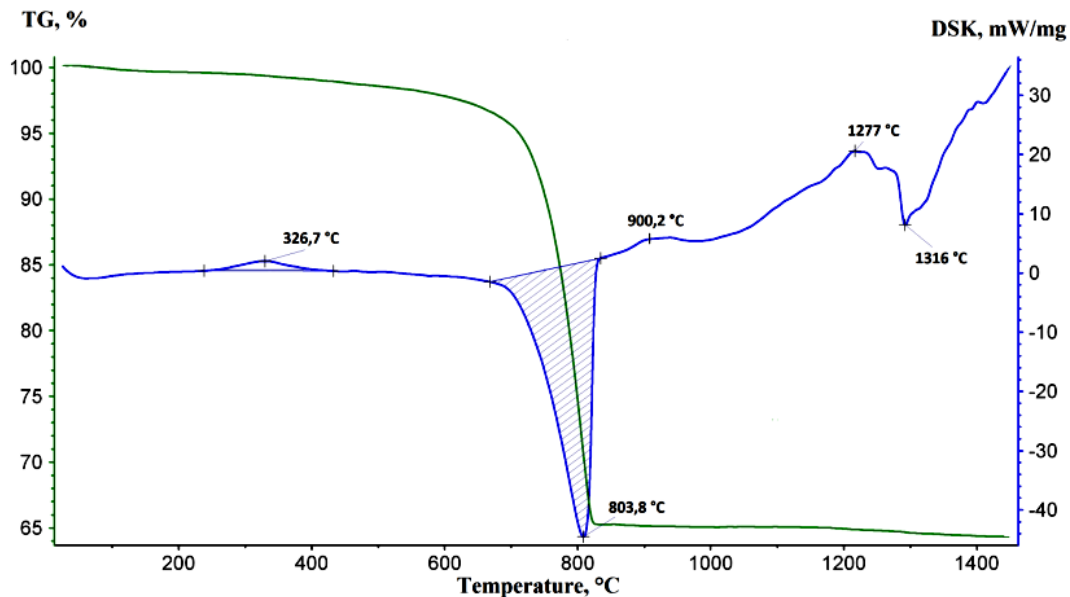


Figure 6. Thermogram of the raw mix with the addition of 0.9 wt. % coal-alkaline reagent.

According to the basic rules for compiling the heat balance [18], we calculated the characteristics of the rotary kiln by the average parameters of the kiln, as well as by the parameters obtained after reducing the moisture content of the raw cement slurry, while maintaining the temperature of the clinker at the outlet of the kiln (Table 3).

Table 3. The heat balance of cement rotary kiln.

Coming of heat	Amount kJ/kg clinker		Consumption of heat	Amount kJ/kg clinker	
Moisture, %	41	35.5	Moisture, %	41	35.5
1. From fuel combustion	6500	5818	1. Thermal Effect of clinker	1841	
2. With raw mix	62	53	2. On evaporation of water	2687	2129
3. Secondary air	1070	997	3. Losses of clinker	1296	
4. With dust return	37	34	4. Losses with the off-gas	1151	998
			5. Losses with the dust off	79	73
			6. Losses to the environment through the enclosure	623	575
Sum total	7668	6902	Sum total	7678	6912

The following technological characteristics were used in the calculations: coefficient of excess air – 1.1; the temperature of the exhaust gases is 210 °C with a change in the kiln productivity from 70 t/h when firing sludge with a humidity of 41% and 75.8 t/h with a moisture content of sludge of 35.5%. According to the methodology [18], the calculation of losses to the environment was performed. From the heat balance equations, the specific fuel consumption for firing 1 kg of clinker (X_t) was determined. With a raw material cement slurry moisture content of 41%, X_t amounted to 221.8 kg of equivalent fuel per ton of clinker; for a sludge with a moisture content of 35.5% X_t , it was 198.5 kg of equivalent fuel per ton of clinker. The obtained values were substituted into the input and account items of the thermal balances of a rotary kiln. The results are presented in table 3.

5. Conclusion

1. The results presented in this study are valid for the proposed model raw sludge and specific additives used in the experimental methodology. Other combinations of initial raw materials and additives will have different final characteristics (rheological, technological and thermal) of raw sludge for cement production.

2. When reducing the moisture content of raw sludge by 5.5% while maintaining normal fluidity 54 ± 2 mm, due to the introduction of plasticizing additives in an amount of 0.1-0.4 wt. %, provides a reduction in specific fuel consumption in the production of cement by the wet method by 23.3 kg of equivalent fuel per ton of clinker.

3. Calculations of heat balances showed that the main decrease in fuel consumption occurs due to a decrease in heat loss due to moisture evaporation from 2687 to 2129 kJ / kg, with exhaust gases from 1151 to 998 kJ / kg, with the fuel and energy sector remaining unchanged. Losses of heat with exhaust gases decreased by 13%, due to a decrease in the volume of emitted gases, which will reduce the load on smoke exhausters.

4. A decrease in the amount of exhaust gases from the kiln leads to a decrease in dust extraction due to a decrease in the gas flow rate. Reducing the load on the exhaust fan will save energy.

Acknowledgments

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