Resource saving and energy saving at the simultaneous production of two types of cement

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Abstract. Modern trends in the development of the global cement industry are to reduce the energy intensity of production and reduce the environmental burden on the environment. These goals can be achieved by using fuel-containing man-made waste in place of natural raw materials and fuel. Great decrease of fuel costs by 20-40 % when making Portland cement is shown to be achieved by combining calcination of both Portland cement clinker and carbonate-silica mix in one heat and technological cycle to get cements with low-temperature calcination. Extra heat effect is achieved by adding combustible industrial wastes, like ashes from power plants or coal waste, to the raw mix to get cements with low-temperature calcination. Further modification of lime-silica cements obtained by Portland cement clinker within 20-40 % range by weights is shown to get mixed product with strength indices in sand mortar corresponding to 0,6-0,8 grade strength of original Portland cement. Combined method for making two kinds of binders is shown to reduce carbon dioxide by 22-60 % calculated as the final modified product as compared with traditional making of Portland cement clinker. When substituting 50 % of clinker part by cements with low temperature calcination with certain composition, grade strength of the mixed product is similar to Portland cement indicators.

1. Introduction
Currently production of Portland cement has exceeded 4bln tone per year and keeps growing. In the nearest future Portland cement remains the only binder due to wide occurrence of mineral resources on the Earth applied for making it and accessibility of technology. New trends for the development of the world cement industry are reduction of both the energy intensity of Portland cement production and environmental impact. Emission of greenhouse gases as carbon dioxide under dissociation of both calcium and magnesium carbonate inside the cement kiln thereby making about 500kg per 1 ton of clinker are considered to be the most negative side effects of production. It is not impossible to greatly reduce CO₂ emissions directly when producing Portland cement because raw material compositions applied for clinker making contain much carbonate. However, it may be done by adding various mineral admixtures at clinker grinding thereby reducing specific yield of carbon dioxide per unit of the final mixed product.
2. Combined method in producing Portland cement

2.1. Ways to reduce fuel costs

Energy consumption under production of Portland cement is 60-70% of cost thereof, with one part thereof being to electric energy, while the other three parts – to heat energy [1]. Potential ways to reduce energy costs under production of Portland clinker are:

- application of energy-efficient technologies and equipment;
- gas recovery and recirculation;
- application of material resources reducing heat loss affected by reactions;
- utilization of wastes containing fuel components in compositions thereof;
- reducing of heat loss in equipment.

The most efficient ways to save energy without reequipping cement plants are heat recovery of waste gases from kilns as well as utilization of wastes containing fuel components in compositions thereof [2]. Ashes from thermal power stations and coal beneficiation wastes are regarded as large wide-spread man-made fuel-containing mineral wastes. Large-scale utilization of such wastes may enable to solve serious environmental problems faced by many industrial regions of our planet [3, 4].

Direct application of fuel-containing wastes instead of part of argillous components for producing Portland clinker is not quite efficient, as it enables to substitute no more than 10-15% of natural argillous raw material that negligibly reducing fuel capacity of high-temperature process for clinker making [5].

2.2. Binders after low-temperature calcination

Production of mixed binders made from energy-intensive local cements modified by clinker adding under grinding may prove to be viable solution in the current conditions. This category includes binders for calcination obtained by heat treatment before sinte ring of the raw charge consisting of carbonate rock and argillous component [6-11]. The calcination temperature therewith is 900-1100 °C while the final product after fine grinding is a hydraulic binder identical to roman cement by its main properties and compound composition obtained from natural carbonate raw materials with argillous admixtures of 20-25% by weight [12]. Natural carbonate-argillous mixture ratio as well as hydraulic activity of such binder is defined by hydraulic index value m to be within 1.1-1.7 range [13]. However, CaCO3 in the mixture before calcination will be 70-75% by weight. Therefore, carbon dioxide yield will also be similar to values of Portland cement production. Lower energy intensity will be the technological advantage therewith due to reducing the calcination temperature by 350-550 °C. Such binders alone have relatively weak ultimate strength to be 5-15 MPa in sand mortar, and are differed by deferred kinetics of setting and hardening under normal conditions. However, if modified by active mineral admixtures under grinding their strength becomes 25 MPa and approaches the values of average grade cement. Significant effect (up to 35 MPa) is achieved under integrated application of both mineral and chemical admixtures [14]. The idea itself for reasonable receiving of both intermediate product as clinker and final product as modified (mixed) binder is to be changed if simultaneously try to significantly reduce energy intensity of Portland cement and carbon dioxide yield at clinker calcination. We may consider therewith both Portland cement modification by adding the binder that is less energy-intensive and more eco-friendly by CO2 emissions, and vice versa, modification of more energy-efficient lime-silica cement obtained at low temperature calcination by adding Portland cement clinker at grinding. There are several ways to increase energy efficiency, with the first one being the reduction of clinker share in the mixed binder and increase of clinkerless share therein. Energy intensity of the clinkerless share may be decreased by reducing carbonate content in the mixture. However, it is not possible for roman cement made from natural mix by availability of the hydraulic index in the permissible range. Application of binders for low temperature calcination with far less carbonate content in the raw mix is considered to be effective. A V Volzhensky et al [15,16] have proposed the way to get low-temperature cement by simultaneous calcination at 900-1100 °C of either limestone or dolomite with fly ash of thermal power stations or waste coal. Full spectrum of binders after low temperature calcination with strength of compression of 5-20 MPa in sand mortar and mechanism of hardening...
typical to lime-pozzolanic cement of mixed grinding is supposed to be obtained by this technology. Principal technological advantage of the indicated cements is that the most energy-consuming dissociation process of CaCO\textsubscript{3} and MgCO\textsubscript{3} is actually provided by the heat generated at simultaneous calcination of fly ash or waste coal. Carbonate content in the mix is much lower that with Portland cement and is 25-50 \%. Therewith ash or waste coal content in the mix is 50-75 \% by weight thereby providing quite high heat capacity of the raw mix in the indicated range of initial components ratio that made 3245-6160 kJ/kg for the mixes being analyzed. Lime-ash, lime-glynite, dolomite-glynite and dolomite-ash cements obtained after calcination refer to hydraulic binders. Their modification by adding Portland cement clinker enables to regulate strength properties in wide range ‘Figure 1’ thereby greatly widening areas for applying modified cement [17]. Besides, carbon dioxide yield expressed as final mixed product is reduced by 22-60 \% per 1 ton of modified cement depending on components ratio in the raw mix and in the final product ‘Figure 3’.

![Figure 1. Relation between average relative strength of modified binder samples and Portland cement clinker content](image)

- \( R_1 \) – compression strength of samples with modified binder;
- \( R_2 \) – compression strength of samples with Portland cement.

Energy efficiency ratio \( K_e \) ‘equation 1’ is proposed to be used for evaluation of heating properties of two-component fuel-containing mixture and calculation of components ratio therein:

\[
K_e = \frac{m^w \cdot Q^w}{Q^0} \quad (1)
\]

where, \( Q^0 \) - required specific fuel costs for calcination the raw mix, kJ/kg; \( Q^w \) - heat capacity of combustible waste, kJ/kg; \( m^w \) - specific content of combustible waste in the raw mix, kg/kg.

To burn the raw mix without process fuel (\( K_e = 1 \)), specific content of waste in 1 kg of two-component raw mix will be ‘equation 2’:

\[
m^w = \frac{Q^0}{Q^w} \quad (2)
\]

The required reference fuel consumption (kg) for calcination of 1 t of raw mix (at \( K_e < 1 \)) will be ‘equation 3’:

\[
B_f = \frac{1000 \cdot Q^0}{29308} (1 - K_e) \quad (3)
\]

therewith, decrease in process fuel consumption for calcination 1t of raw mix will be:
\[ E_f = K_e \cdot 100 \] (4)

Figure 2. Energy cost for calcinations of fuel-consuming raw mixes at production of low-temperature cements

The analysis of the obtained calculated relations indicated in ‘Figure 2 (a, b)’ has revealed that \( K_e = 0.55-1.37 \) for the laboratory compositions at heat capacity of fly ash at 3860-5070 kJ/kg and its composition in two-component mixture amounting to 50-75 %. We have \( K_t = 0.69-1.2 \) for raw mixes with waste coal at their heat capacity of 6490-8580 kJ/kg. The process fuel therewith under the established heating process for calcinating raw mixes with values of \( K_t \geq 1 \) is not required.
Possibility of self-calcination of two-component carbonate-ash mixture at 1100 °C was confirmed by production of pilot batch of 60 tons of lime-ash cement by Voroshilovgrad Cellular-Concrete Plant in 1989 (now, Ukraine). The 30m rotary lime kiln was used for calcination of carbonate-ash mixture. Fly ash content in the mixture was 66 % by weight. The pilot batch of autoclave gas-concrete items was made from lime-ash cement obtained with no process fuel. Later this plant released the pilot batch of lime-brick cement made from gravitational waste coal.

2.3. Combined heating process
The authors calculated the combined method for producing modified Portland cement while simultaneously firing two raw mixes in two rotary kilns. In a low-temperature furnace, the heat of the gases that leave the high-temperature furnace is utilized. In a high temperature furnace, the firing temperature is 1300-1500 °C. And in a low-temperature furnace, the firing temperature is 1000-1100°C.

Firing products are Portland cement clinker (high temperature furnace) and calcareous or dolomite clinker (low temperature furnace). In the future, two types of clinker are crushed together.

The heat gas flow of the high temperature furnace is directed to a low temperature furnace, where the final product, for example, is dolomite clinker. Thermal power represents the difference between the required thermal power for firing dolomite clinker and the thermal power of the gas stream that leaves the high temperature furnace.

Thermal power is the amount of heat that must be supplied to the furnace per unit time to ensure the quality of the final product.

Thermal power is defined by equation (5):

\[ N = P \cdot q \]  

where, \( P \) - kiln capacity, kg of clinker per sec., \( q \) – specific consumption of heat energy for making 1kg of clinker, kJ/kg.

The energy indices of combined firing are calculated for the Kramatorsk cement plant. The furnace produces clinker by wet production method. The furnace capacity is 16 tons of clinker per hour. The temperature of the gases leaving the Portland cement kiln is 500 °C.

Capacity of heat flow of gases is defined by equation (6):

\[ N_d = V \cdot c \cdot t \]  

Figure 3. Properties of modified cements by specific yield of CO₂
where, $V$ – gas volume exhausted from dolomite kiln, m$^3$/s, $c$ – gas heat capacity, kJ/m$^3$ K, $t$ – gas temperature.

Decrease of specific fuel consumption will be ‘as in equation (7)’:

$$B_f = \frac{N_d}{Q} \tag{7}$$

where, $Q$ – calorific value of standard fuel - 29 308 kJ / kg.

Costs for process fuel in the dolomite furnace can also be reduced through organ-containing waste. In Ukraine, one of the variants of such waste is coal enrichment waste.

The thermal capacity of the dolomite furnace is calculated for the variant: gases from the Portland cement kiln are sent to the furnace and there are wastes containing organic matter in the feed mix. Calculation results are given in the table 1.

Table 1. Energy indicators of cement rotating kiln at combined procedure for making two kinds of binders

| The thermal energy that a dolomite furnace, kW | Thermal energy of gases Portland cement kiln, kW | Thermal energy released by waste combustion, kW | Thermal energy of combustion of high-quality fuel, kW |
|---------------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| 8932                                        | 4652                                          | 4280                                          | -                                             |

More efficiency in the combined production of binders by extra reducing heat loss may be achieved at simultaneous calcination of two raw mixes in two-section rotary kiln.

3. Conclusions

Combined method for making two kinds of binders is shown to reduce carbon dioxide by 22-60 % calculated as the final modified product as compared with traditional making of Portland cement clinker.

The proposed combined procedure for making Portland cement clinker and cements with low-temperature calcination will enable to greatly expand possibilities to utilize large volumes of industrial wastes, like ashes from power plants and coal waste.

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