Cement production efficiency improving

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Abstract. The paper considers the issues of increasing the efficiency and environmental safety of cement production by using clinker dust in slurry preparation and replacing a certain part of clinker with mineral additives having pozzolanic activity. On the basis of research work carried out at the production site of the Baherden cement plant (Turkmenistan), the suitability of a Venturi scrubber to capture the dust generated in wet clinker kilns of cement plants has been established. The technological scheme for the use of the sludge generated in the scrubber in the preparation of clinker was developed. Based on the results of analyses of the main indicators of cement prepared with the addition of sludge the possibility of using the collected dust in the production of cement has been established. The optimal solution for three interrelated problems, such as increasing the efficiency of cement production, reducing the amount of harmful gases emitted into the atmosphere, and rational use of natural resources, is to reduce the specific consumption of clinker by compensating a certain part of it with mineral additives with pozzolanic activity. **Key words:** Clinker, dust, sludge, pozzolanic Portland cement, mineral additives, ecology.

1 Introduction

Cement production is a major consumer of energy and natural resources, as well as a source of anthropogenic pollution. The increase in the rate of construction work, hence the increase in cement production, requires an increase in the efficiency of cement production.

One way to increase the efficiency of cement production is to use the dust generated from the burning of clinker and replace a certain portion of the clinker consumed in cement production with mineral additives with pozzolanic activity. This would reduce the amount of dust and carbon dioxide emitted into the atmosphere, as well as the cost and amount of raw materials consumed for the preparation of clinker, which is the main component of the products.

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2 Materials and Methods

To improve the economic performance and environmental safety of cement production, it is recommended to recover the waste generated and use mineral additives (with pozzolanic ability) in the grinding of clinker, which will reduce energy and labour costs, as well as reduce the amount of feedstock consumed in cement production.

Dust in cement plants is generated in many manufacturing departments. The total amount of dust generated may be up to 30 % of the output. Of these, 80 % are related to clinker burning [13]. According to reports in the literature, production of 1 kg of clinker using the wet process [12] generates 3-5 m3 of dust with 40-50 grammes per cubic metre of clinker, which represents approximately 250 kg of dust per tonne of clinker fired.

The largest fraction of the gases from clinker kilns is carbon dioxide (CO2). Statistics show that 5% of carbon dioxide discharged into the atmosphere worldwide comes from the cement industry. In cement manufacturing, 60 % of CO2 is produced from the burning of clinker due to the decomposition of lime, 40 % from the burning fuel required for the burning of clinker [14].

In order to study the dust recovery technology the possibilities for dust collection by means of a Venturi scrubber and for using the sludge generated in the scrubber for clinker preparation were investigated. Research was carried out at the production site of the Baherden Cement Plant (Turkmenistan), which produces cement using the wet process.

To study the possibility of using the dust collected in the scrubber for preparing clinker, the chemical composition and loss on ignition of the raw mix and sludge generated in the scrubber were determined. The results of the analyses are shown in Table 1.

Table 1. Chemical composition of the raw mix used at the Baherden cement plant site and the sludge generated in the scrubber.

Materials	Chemical composition, %						Losses on ignition, %
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	
Raw mix	13.48	3.85	2.81	42.21	1.33	0.24	34.14
Sludge produced in the scrubber	17.64	4.37	2.54	45.67	1.90	0.95	20.64

As shown in Table 1, the chemical composition of the raw mix and the scrubber sludge and the loss during calcination differ slightly from each other, which at first glance rules out the possibility of adding the scrubber dust sludge to the raw mix. To investigate the possibility of reusing scrubber sludge for clinker preparation, the aforementioned materials were subjected to a calcination process. Chemical composition of the materials after calcination is given in Table 2.

Table 2. Chemical composition of raw mix used at Baherden Cement Plant site and sludge generated in scrubber after calcination.

Materials	Chemical composition, %					
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3
Raw mix	20.47	5.85	4.27	64.10	2.02	0.37
Sludge produced in the scrubber	22.22	5.51	3.2	57.54	2.39	1.19

The chemical values of the investigated materials after calcination are almost identical. This confirms the possibility to use the sludge produced from the collected dust in the scrubber for clinker preparation.

In wet cement plants, the raw mix used to prepare clinker is a dispersed system in the form of a suspension (sludge). For the recovery of industrial waste from wet process cement plants, wet dust collection (scrubber) is technologically feasible. In the scrubber, the dust particles come into contact with the fine water droplets sprayed by the nozzle and sludge with high humidity is generated. This completely eliminates the loss of dust during bagging, transport and mixing with the raw material. The sludge generated in the scrubber can be routed to a sludge basin where the sludge composition can be adjusted.

A wet array, an improved version of the Venturi scrubber, has been chosen for scrubbing the gases generated in the clinker kilns of the Baherden cement plant. The principle of its operation is the following: the discharge gases from the confuser section enter the throat at a velocity of 50 - 100 m/s, where the degree of turbulence in the gas stream increases significantly. This results in an intensive mixing of dust particles and crushing of water droplets injected by the nozzle. As the degree of droplet fragmentation increases, the contact area between the two fine phases (water droplets and dust particles) increases. As a result of contact of the fine-dispersed phases, dust particles are wetted and deposited in the sludge trap, where a colloidal solution in the form of sludge is formed. The formed disperse system in the form of a suspension has the same composition as the sludge prepared from the feedstock. On the basis of studies carried out it has been established that a Venturi scrubber is a highly effective dust collector for wet cement production. It should be noted that the identity of the chemical composition of dust, captured in a colloidal solution in the wet scrubber and sludge, prepared from raw materials, increases the possibility of reuse production waste (dust) in the preparation of clinker.

The study resulted in a process flowchart for the treatment of dust generated in wet cement production and its use for clinker preparation (Fig. 1).

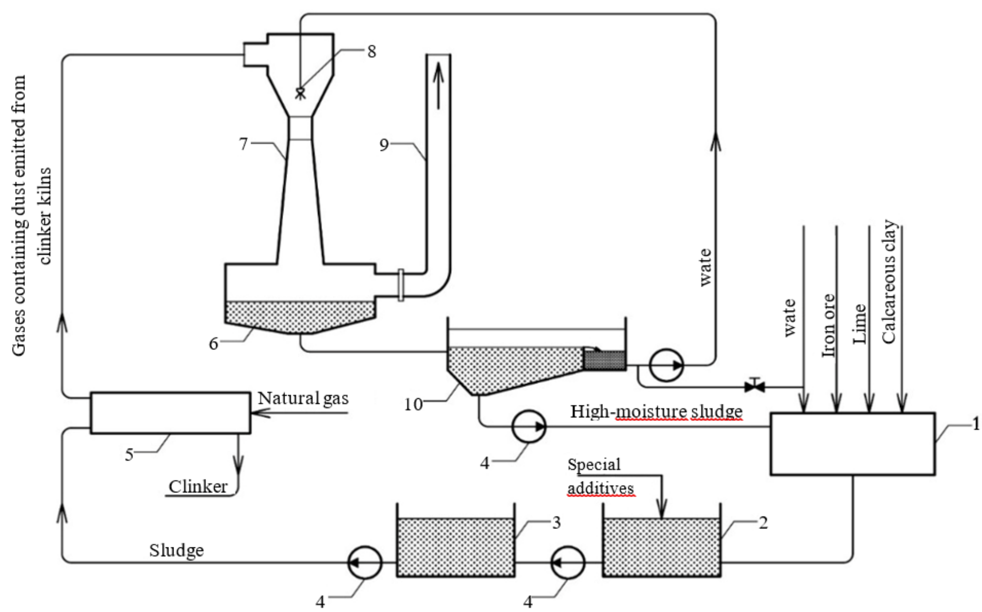

Fig. 1. Technological scheme for utilisation of dust generated during wet clinker preparation: 1-ball mill; 2-titration sludge basin; 3-pool for finished sludge; 4-sludge pump; 5-clinker kiln; 6-sludge collector; 7- Venturi tube; 8-nozzle; 9-gas-pipeline; 10-pool for thickening the sludge generated in the scrubber.

The possibility of using a Venturi scrubber for collecting clinker dust and using it for clinker preparation according to the developed process flowchart was tested in an experimental plant with a capacity of 100 m3/h. The possibility of using the scrubber sludge in the preparation of clinker was determined by chemical analyses.

To check the possibility of using the dust collected in the scrubber for clinker preparation by adding it to the sludge prepared from the raw material, a series of experiments were carried out. The main indicators of experimental samples of sludge and clinker prepared with the addition of scrubber-generated sludge are shown in Table 3. Obtained data characterizing the quality of slime and clinker meet the requirements (TU 01855005-01-2016).

Table 3. Chemical composition and other characteristic values of the sludge and clinker prepared from the raw materials with the addition of the trapped dust in the form of sludge.

Samples	Chemical composition, %						ST	TM	SM	C_3S	C_2S	C_3A
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3						
Sludge	13.89	3.90	2.79	42.56	1.4	0.31	94.0	1.40	2.08	-	-	-
	14.08	3.84	2.80	42.93	1.43	0.32	93.0	1.37	2.12	-	-	-
	14.98	4.83	2.77	42.19	1.38	0.36	93.0	1.38	2.12	-	-	-
	14.13	3.93	2.82	42.38	1.34	0.34	92.0	1.39	2.10	-	-	-
Clinker	21.83	5.78	4.06	65.52	1.96	0.44	93.0	1.42	2.22	59.12	17.82	8.02
	22.16	5.62	4.19	66.12	1.86	0.45	95.0	1.34	2.00	58.26	16.35	7.91
	22.26	6.13	4.32	66.26	1.83	0.42	92.0	1.42	2.13	59.32	16.93	8.06
	22.08	6.04	4.26	66.19	1.92	0.46	92.0	1.42	2.14	58.91	16.81	7.88

Note: ST – saturation factor; TM - alumina ratio; SM – silica module; C_3S - tricalcium silicate; C_2S - bicalcium silicate; C_3A - tricalcium aluminate.

Table No. 4 shows the results of experiments carried out to check the quality of cement produced from sludge prepared with the addition of captured dust in the form of sludge. As can be seen from the data given in the table, the quality of cement meets the requirements (GOST 753-2015).

Table 4. Main indicators of cement produced from sludge prepared with the addition of captured dust in the form of sludge.

Samples	TM	SM	ST	Dispersity , % 45 µm	Maximum compressive strength MPa, at age		
					3 days	7 days	28 days
1	1.42	2.12	94.0	5.2	28.1	41.8	49.3
2	1.41	2.10	95.0	4.8	27.9	41.6	49.5
3	1.39	2.16	96.0	4.9	29.2	42.4	50.2
4	1.44	2.19	93.0	5.1	28.3	42.2	50.6

As a result of research, the applicability of the Venturi scrubber for capturing the dust generated in the clinker kiln of a wet process cement plant has been established. The capture of dust with wet dust collectors, particularly with the Venturi scrubber, allows the dust captured in the form of sludge to be used in the preparation of clinker by adding it to the raw sludge. Results of analyses of the main cement indicators obtained from the slurry prepared with the addition of the captured dust indicate the possibility of using this dust in cement production. With the implementation of the developed scheme in production, economic and environmental performance of cement plants will increase, as well as the consumption of raw materials will be reduced, which is important for future generations.

In cement production, the main material inputs, as well as energy and labour, are consumed in the clinker preparation process. In addition, the preparation of clinker generates a large number of harmful gases, of which carbon dioxide (CO_2) is the main pollutant. Today, the reduction of CO_2 emissions is a global challenge in order to tackle climate change on the planet [5, 6, 7, 9,11, 14].

The optimal solution for interrelated issues such as increasing the efficiency of cement production, reducing the amount of harmful gases emitted into the atmosphere and the rational use of natural resources is to reduce the specific consumption of clinker by compensating a certain portion of it with mineral additives.

In cement industry natural and artificial substances with pozzolanic activity are used as mineral additives [2, 3, 8,10, 16, 15]. These include natural minerals (pozzolans) containing in their composition the following oxides:

- mass fraction of silicon oxide SiO_2 ~ 40-70 %;
- mass fraction of aluminium oxide Al_2O_3 ~ 12-22 %;
- mass fraction of iron oxide Fe_2O_3 ~ 3-15 %;
- mass fraction of calcium oxide CaO ~ 2-12 %;
- mass fraction of alkali oxides R_2O ~ 2-12 %;
- mass fraction of magnesium oxide MgO ~ 1-8 %.

As a result of research into the composition of local raw minerals, basalt with the following chemical composition: SiO_2 – 57.62 %, Al_2O_3 – 14.80 %, Fe_2O_3 – 6.67 %, CaO – 5.09 %, MgO – 1.22 %, SO_3 – 0.02 %, K_2O – 2.18 %, Na_2O – 2.79 % and other components – 9.61%.

To evaluate the effect of the mineral additive on cement quality, test cement samples consisting of clinker, gypsum and basalt were prepared. The chemical composition and quality characteristics of the cement samples are given in Table No. 5.

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Table 5. Chemical composition and main characteristic indexes of cement with mineral additives.

Cement composition	Chemical composition , %						Dispersity		Compressive strength MPa, at age		
	SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO	SO_3	45 µm %	90 µm %	3 days	7 days	28 days
Clinker – 90%, Basalt – 5%, Gypsum – 5%	23.72	60.41	4.29	3.60	1.46	2.12	17.2	6.1	27.1	39.0	44.8
	23.34	61.47	4.42	4.13	2.75	1.23	12.1	4.0	32.8	41.7	50.0
Clinker – 85%, Basalt – 10%, Gypsum – 5%	24.58	57.03	5.18	3.94	3.07	2.3	16.0	8.0	23.6	37.4	47.9
	29.7	61.76	4.29	3.84	3.88	0.86	21.1	10.4	24.9	34.5	42.6
Clinker – 80%, Basalt – 15%, Gypsum – 5%	31.29	54.17	4.14	3.60	3.29	9.31	16.8	6.9	25.0	34.1	40.9
	27.6	55.5	4.19	3.76	3.14	1.1	15.6	6.3	27.0	35.0	41.7
Clinker – 75%, Basalt – 20%, Gypsum – 5%	30.09	52.65	4.29	3.72	2.79	2.09	16.7	5.6	21.2	34.3	38.7
	31.26	54.3	4.58	4.01	2.9	0.74	17.9	6.5	25.0	30.8	37.2
Clinker –65% Basalt – 30%, Gypsum – 5%	36.37	47.19	4.65	4.25	2.61	2.61	15.0	4.3	35.0	28.3	37.1
	34.24	48.66	4.26	4.25	2.73	2.08	17.4	6.8	26.0	31.5	33.2

According to Table No. 5, the performance of cement at Basalt concentration up to 15% is good, but with exceeding the percentage optimum the strength of cement decreases. It was assumed that this is due to the fact that the cement composition of $CaO/SiO_2 < 2.0$. To increase the above ratio, limestone was added to the cement as an auxiliary mineral component. The results are shown in Table 6.

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Table 6. Chemical composition and main characteristic indicators of cement, obtained with the addition of mineral additives in various weight ratios.

Cement composition	**Chemical composition, %**						**Dispersity**		**Compressive strength MPa, at age**		
	SiO_2	**CaO**	**Al_2O_3**	**Fe_2O_3**	**MgO**	**SO_3**	**45 µm %**	**90 µm %**	**3 days**	**7 days**	**28 days**
1	2	3	4	5	6	7	8	9	10	11	12
Clinker-75%, Basalt-15%, Limestone -5%, Gypsum-5%	27.2	53.79	4.50	4.10	1.84	2.67	16.2	6.7	25.6	36.5	44.4
Clinker-70%, Basalt-15%, Limestone -10%, Gypsum-5%	26.78	53.28	4.42	4.10	1.60	2.80	16.8	7.2	24.2	32.0	38.9
Clinker-65%, Basalt-15%, Limestone -15%, Gypsum–5%	28.34	50.62	3.98	3.12	1.33	2.84	14.6	5.9	18.3	26.0	34.4
Clinker-60%, Basalt-15%, Limestone -20%, Gypsum-5%	24.21	51.79	4.04	3.58	1.81	2.93	18.6	6.7	18.6	26.1	31.5

As a result of experiments carried out, the maximum allowable amount of mineral additives as well as their optimum quantitative ratio was established: the concentration of mineral additives can be increased up to 20%, and the ratio of basalt ore to limestone in this case should be 3:1 respectively. The data obtained were supported by the results of the production experiments (Table No. 7).

Table 7. Chemical composition and characteristic values of cement produced under production conditions with the use of various mineral additives.

Cement composition		Clinker-75% Basalt - 15% Limestone - 5% Gypsum - 5%	Clinker - 80% Basalt - 12% Limestone- 3% Gypsum - 5%	Clinker - 80% Basalt -15% Gypsum - 5%	Clinker - 85% Basalt - 10% Gypsum - 5%
Chemical composition. %	**SiO_2**	23.88	28.51	28.82	26.32
	CaO	6.39	7.29	7.39	6.89
	Al_2O_3	4.50	4.85	4.86	4.74
	Fe_2O_3	57.81	53.10	53.59	56.77
	MgO	1.45	1.59	1.59	1.54
	SO_3	2.61	2.63	2.42	2.51
	Na_2O	0.35	0.43	0.44	0.39
	K_2O	0.99	1.14	1.09	0.01
Losses on ignition. %		0.07	0.07	0.00	0.00
Free calcium oxide (CaO)		0.48	0.48	0.54	0.58
Dispersit y	**45 µm %**	5.2	3.7	4.1	3.9
	90 µm %	0.1	0.3	0.2	0.1
Compressive strength MPa. at age	**3 days**	29.2	26.8	24.9	28.7
	7 days	40.9	38.6	36.6	39.4
	28days	47.6	45.1	46.0	50.3

Based on the data obtained from experiments on cement prepared with mineral additive (20 per cent of the total mass) and cement without additive, a cement production flow chart has been drawn up (Fig. 2).

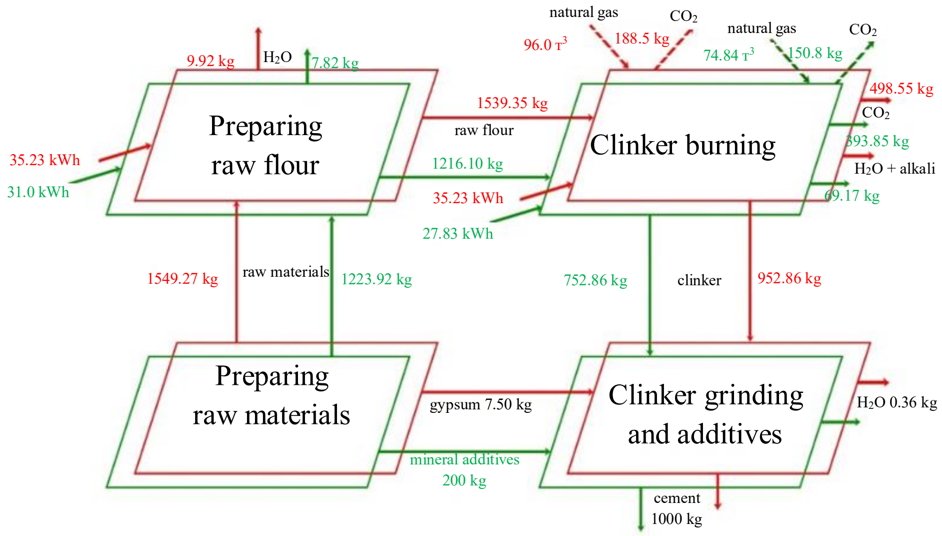

Fig. 2. Process map for cement production. (- no additive, - with additive).

The data presented show that in cement production with 20 % mineral additives the material, energy and carbon dioxide emissions are reduced in proportion to the percentage of mineral additives. Thus, the use of mineral additives can significantly increase the efficiency of cement production.

3 Methods

The applicability of the Venturi scrubber for cleaning clinker dust was established as a result of experimental studies carried out in a plant with a capacity of 100 m3/h;

The feasibility of using the captured dust in the preparation of clinker was determined by comparing the chemical composition of the sludge generated in the scrubber with the chemical composition of the sludge prepared from the raw materials after the calcination process;

The influence of mineral additives on cement quality was established by testing the strength of samples of different compositions carried out in accordance with GOST 310.4-81 (methods for determination of flexural and compressive strength).

4 Research results

The possibility of using a Venturi scrubber to capture the dust generated in clinker kilns of wet cement plants producing cement using natural gas has been established.

The technological scheme of purification of gases, formed in clinker kilns of the plants on manufacture of cement by the wet method, working with natural gas, with use of the slime generated in a scrubber at preparation of clinker is developed.

The possibility of adding scrubber sludge directly into the sludge basin to adjust the composition of sludge for the preparation of clinker has been established.

The optimum quantity ratio and maximum allowable volume of mineral additives has been determined. The concentration of mineral additives can be increased up to 20 %, provided the Basalt/limestone ratio is 3:1.

5 Conclusions

For capturing the dust generated in clinker kilns of natural gas fired wet process cement plants it is advisable to use a Venturi scrubber, which is a perfect type of wet dust collector.

The analyses performed confirm the possibility to add sludge generated from the dust collected in the scrubber to the sludge prepared from the raw materials.

On the basis of calculations carried out according to aggregate indicators, it has been established that the use of collected dust during clinker preparation and the use of mineral additives will reduce the cost of production of pozzolanic Portland cement by about 15 - 18%, as well as exclude the emission of dust into the atmosphere and reduce the amount of carbon dioxide emitted into the atmosphere up to 20%.

References

1. *TU 01855005-01-2016 Clinker for cement production. Technical conditions* (Main State Service "Turkmenstandartlari", Ashgabat, 2016)
2. M.Y. Bikbau, Journal Time of Innovation (2017) www.time-innov.ru
3. M.Y. Bikbau, U.Y. Bikbau, *Method of nanocement production and nanocement. Patent RU 2544355C2* (2015)
4. *GOST 753-2015 Portland and slag-portland cement. Technical specifications* (Main State Service "Turkmenstandartlari", Ashgabat, 2015)
5. V.Sh. Isabekova, A.K. Bekbolotova, G.A. Mambetova, Proceedings of KSTU named after I. Razzakov **33**, 485-488 (2014)
6. *Kyoto Protocol to the UN Framework Convention on Climate Change* (1998) URL: https://www.un.org/ru/documents/decl_conv/conventions/kyoto.shtml
7. Glasgow Climate Pact (2021) https://ukcop26.org/wp-content/uploads/2021/12/Outcomes-Russia-RUS-COP26-Presidency-Outcomes-The-Climate-Pact.pdf
8. A.V. Kornilov, E.N. Permyanov, T.Z. Lygyina, A.A. Panina, D.S. Tsyplakov, *Portland cement mix with mineral additive. Patent RU 2476391* (2013)
9. O.S. Korobova, A.S. Tkacheva, Mining Information and Analytical Bulletin **7**, 42-46 (2016)
10. L.K. Nabiullina, E.N. Potapova, Achievements in chemistry and chemical technology **23(7)**, 30 - 34 (2009)
11. Paris Climate Agreement (2016) DOI: 10.24411/2500-1000-2019-10522
12. *Collection of methods for calculating atmospheric emissions of pollutants by various industries* (Gidrometozdat, L., 1986)
13. *Reference book on cement production* (State Publishing House of Building, Architecture and Construction Materials, Moscow, 1963)
14. M.N. Chomaeva, International Journal of Humanities and Natural Sciences **2-1**, 8-10 (2019) DOI: 10.24411/2500-1000-2019-10522
15. E.A. Shlyakhova, Internet-journal "Naukovovedenie» **4**, 1-5 (2012)
16. A.Y. Shodmonov, Scientific journal "Science and Education" **2(5)**, 250 – 256 (2021)