Nanostructures based on carbon and silicon dioxide to improve the properties of building and structural materials

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Abstract. The article presents hardware and technological solutions for obtaining a product containing silicon dioxide from nanodispersed dust of gas cleaning of silicon production, intended to improve the properties of building and structural materials. To obtain nanostructures of carbon and silicon dioxide of the required quality, allowing to improve the properties of building and structural materials, a complex resource-saving technology of their high-tech production was developed. The necessary characteristics of nanodispersed modifying additives have been determined. A technological scheme has been developed; technological operations of thermal vortex enrichment are described. The material balance of thermal vortex enrichment is given.

1. Introduction
Development of technologies at present are energy and resource conservation [1-3], green technologies [4]. Development of technologies allowing to improve the quality of associated mineral raw materials without prejudice to the main technological process of silicon production [5-8] makes it possible to obtain nanodispersed dust (ND) containing carbon in the form of carbon nanotubes (CNTs), fullerene and silicon dioxide. The modifying effect of CNTs [9-10] and silicon dioxide [11-14] is becoming increasingly popular in various industries, including construction. One of the promising directions for the development of the use of these nanoparticles is road construction.

2. Developed product
This product was developed as part of a project to create a high-tech production of nanostructures based on carbon and silicon dioxide.

2.1. Characteristic of output product
The output product described in this article is a powdery concentrate of nanostructures containing silicon dioxide.
Table 1. Characteristics of the output product containing silicon dioxide.

| Indicator name | Indicator values | Method of measurement |
|----------------|------------------|-----------------------|
| Mass fraction, %: |                  |                       |
| SiO$_2$         | not less than 98 | EN 196-2              |
| CaO            | no more than 0.3 | EN 451-1              |
| SO$_3$         | -                | EN 196-2              |
| K$_2$O         | no more than 0.3 | EN 196-2              |
| Na$_2$O        | no more than 0.1 | EN 196-2              |
| Fe$_2$O$_3$    | no more than 0.1 | GOST 2642.5-97        |
| Al$_2$O$_3$    | no more than 0.3 | GOST 2642.4-86        |
| MgO            | no more than 0.2 | GOST 2642.8-97        |
| P$_2$O$_5$     | -                | GOST 2642.10-86       |
| Cl             | -                | EN 196-2              |
| H$_2$O         | no more than 0.3 | GOST 2642.1-86        |
| SiC            | -                | GOST 26564.1-85       |
| С-free         | -                | GOST 2642.15-97       |
| pH             | 7.5±0.5          | GOST 2642              |
| Mass fraction of losses on ignition at 950 °C, % | no more than 0.8 | EN 196-2 |
| Specific surface (according to BET), m$^2$/g | not less than 16 | ISO 9277 |
| Bulk density, kg/m$^3$ | to 360 | GOST R 54246-2010 |
| Granulometric composition of the packaged product (after long-term storage and self-coagulation processes), % | not less than 63.5 | GOST R 8.755-2011 |

Individual nanoparticles: GOST R 8.755-2011

Agglomerates:
- small, more than 1 micron; no more than 30.0
- medium, more than 10 microns; no more than 5.0
- large, more than 45 microns; no more than 1.5

2.2. Technological scheme of thermal vortex enrichment
The general process flow diagram is shown in Figure 1.

![Figure 1. Technological scheme of thermal vortex enrichment.](image-url)
2.3. Characteristic of raw materials
Nanodispersed dust for performing thermal vortex enrichment is a product of collection in the gas cleaning system of silicon production.

| Parameter                        | Content, % |
|----------------------------------|------------|
| Dust chemical composition        |            |
| - SiO$_2$, not less than         | 84.3       |
| - Fe$_2$O$_3$, no more than      | 1.0        |
| - Al$_2$O$_3$, no more than      | 2.1        |
| - CaO, no more than              | 11.5       |
| - C, no more than                |            |

To perform thermal vortex enrichment, materials with the characteristics presented in Table 3 are used.

| No P/p. | Name of raw materials, materials, intermediate products | GOST, OST, STP, TU, regulations or methods for the preparation of raw materials |
|---------|---------------------------------------------------------|------------------------------------------------------------------------------|
| 1       | Natural gas                                             | GOST 5542-2014                                                              |

2.4. Description of the thermal vortex enrichment
The process is a thermal vortex enrichment of nanodispersed dust. The dust is fed tangentially to the bottom of the furnace. Burning gas is also tangentially fed through the second inlet pipe. Due to tangential input and natural convection, an upward vortex with a temperature of 700-850 °C is formed in the working chamber of the furnace. At a given temperature, the carbon contained in the initial nanodispersed dust is oxidized to carbon dioxide. Decarbonized nanodispersed dust together with carbon dioxide is taken from the upper part of the furnace. Decarburized nanodispersed dust is a product of MD 1. A description of the implementation of thermal vortex enrichment is given in Table 4.

| No P/p. | Action                                                                 | Result                                                         |
|---------|------------------------------------------------------------------------|                                                               |
| 1       | Check the serviceability of the equipment, the integrity of the connections and branch pipes | Thermal vortex enrichment equipment is ready for operation |
| 2       | Switch on the supply of burning gas to the working chamber of the furnace | The supply of burning gas to the working chamber of the furnace is switched on |
| 3       | Wait until the working chamber warms up to operating temperature, determined with a thermometer | Working chamber is ready for thermal enrichment of nanodispersed dust |
| 4       | Switch on the supply of nanodispersed dust to the working chamber of the furnace | The supply of nanodispersed dust to the working chamber of the furnace will turn on |
| 5       | Wait until the end of thermal enrichment of the required amount of nanodispersed dust, determined visually by the amount of the output product | The process of thermal enrichment of nanodispersed dust is completed |
| 6       | Turn off the gas supply                                                | Thermal vortex enrichment completed                             |
2.5. Standardized technological parameters
Standardized technological parameters of thermal vortex enrichment are shown in Table 5. Control of parameters is carried out using the measuring equipment of the experimental stand. The layout of the technological equipment is shown in Figure 2.

Table 5. Parameters of the thermal vortex enrichment process.

| No | Parameter                  | Working value | Limit values |
|----|----------------------------|---------------|--------------|
| 1  | Temperature, °C            | 700 – 850     | 650 – 900    |

![Diagram of technological equipment]

Figure 2. Layout of technological equipment.

2.6. Material balance
The material balance of thermal vortex enrichment is shown in Table 6.

Table 6. Material balance of thermal vortex enrichment.

| Parish                   | Consumption          |
|--------------------------|----------------------|
| Nanodispersed dust, kg   | 1                    |
| Natural gas, kg          | 1                    |
| Concentrate MD1, kg      | 0.85                 |
| Carbon dioxide*, kg      | 1.15                 |

* Carbon dioxide consumption is based on pure carbon.

The technological process, which is the implementation of thermal vortex enrichment, does not produce waste that requires neutralization.

3. Conclusion
The developed technology of thermal vortex enrichment of dust from gas cleaning of silicon production allows not only to improve the ecological situation, to increase the profitability of the main production, but also to obtain innovative nanostructures for modifying road materials, concrete and asphalt concrete. The requirements for the quality of the produced modifying nanoparticles and the
quality of the feedstock and materials used for their production from the waste gases of an ore-thermal furnace for silicon production have been established.

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