HOME

COMPARATIVE STUDIES ON BALLS VERSUS SPHEROIDAL TETRAHEDRONS WORKING MEDIA TO ORE GRINDING IN AN INDUSTRIAL DRUM MILL

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ABSTRACT

A new working media for drum mills has been tested, composed of spheroidal tetrahedrons. The mass of the spheroidal tetrahedrons grinding media was equal to the mass of spherical grinding media of Ø 80 mm. Because the working medium is a new one and it is a subject of patent, the authors will present only technological results of its action.

The experimental work took account of the influence of various technological and structural parameters and properties of the material being milled.

The most important of these are:

- Filling the mill with working media – 40 per cent;
- Uniform supply and maintaining a constant output consistent with the list data (specification) of the drum mill;
- The raw material for milling was copper porphyry ore from Assarel mine (Bulgaria), taken from the stream feeding the mills in the concentration plant;
- Density of the slurry in the mill was over 70 per cent;
- Milling was carried out in an open circuit (no circulating load);
- The grinding media of balls and spheroidal tetrahedrons were obtained by die forging (hot volume stamping);
- Elements in both grinding media differ in mass not exceeding one per cent;

Two series of five runs were done using each grinding media. Besides permanent monitoring of the technological parameters, representative samples were collected of the feeding ore and of the slurry flowing out of the mill. A sieve analysis was made of each survey sample. Results are averaged for each of the working media. Results were compared by:

- newly formed size fraction – 0.08 mm, which is the difference between the percentage of this fraction in the ore feed and the slurry;
- percentage of particles with a particle size suitable for flotation, size fraction – 0.2 mm, similarly defined as the difference between their contents in ore feed and slurry;
- degree of milling/crushing, which is recorded by formula:

  $$S = \frac{D_{av}}{d_{av}},$$

  where:

  S – degree of grinding;

  D_{av} is the average measured diameter of particles in the mill feed ore with particle size + 0,2 mm;

  d_{av} is the average measured diameter of particles in the slurry with particle size + 0.2 mm.

Experimental data show that under equal other conditions, grinding media composed of spheroidal tetrahedrons ensures higher technological performance in the milling process compared to grinding media composed of balls. The newly formed estimated size fraction – 0.08 mm is averagely higher by 2.32 per cent, and flotation size fraction – 0.2 mm is higher by 5.868 per cent. The extent of milling was higher by two units (milling with balls is 10.1, while milling with spheroidal tetrahedrons it is 12.1).

These positive results justify the extension of the research in view of optimising the technological parameters and increasing the efficiency of the working media of spheroidal tetrahedrons.

Keywords: spheroidal tetrahedrons, balls, grinding, drum mill

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INTRODUCTION

The process of grinding in drum mills with balls had been the subject of research and modeling for prolonged decades, despite the simplicity of design and principle of action. The balls are the traditional working media for grinding in industrial conditions. There are hardly any unexploited opportunities in a grinding balls media which to present a surprise or seriously affect onto technological process of grinding.

As a result of serious and sustained theoretical and laboratory research and industrial experience gained into grinding raw materials with various physical and mechanical properties a serious scientific basis was created. There is no doubt on the influence of various parameters onto grinding process. Their influence is interrelated and complex and their separate study is limited to a great extend.

The grinding process requires high energy consumption. It is a necessary process in mining activities, onto production of cement, etc. Hundreds millions of tons of raw materials are grinding every year, where the energy consumption on average is 20 - 30 kWh / t. The problem of reducing energy consumption per tone is a permanent task. It has economical, ecological and environmental dimensions.

The research directions about reduction of energy consumption onto comminution are:

1. Optimization of the common costs onto comminution including sieving, crushing, grinding and classification;
2. New design of machines: Grinding roll press, KID and so on.
3. Improving the effectiveness of classification;
4. Automation of the processes of grinding and classification, etc.

An option to reduce energy consumption in grinding in drum mills is the use of a new form of working elements comprising the grinding media, instead of the traditionally used balls working media. Such a form ware experimented by the authors of the report. The new form of the element of grinding media is close to the geometric figure spheroidal tetrahedron. Further in the text we will use the term “spheroidal tetrahedron”.

THEORETICAL – ECONOMIC NOTES

In the fifties of last century Fairchild and Warneke suggested that grinding with cubic bodies would work more efficiently than the spherical grinding media. They supposed balls make only point contacts with each other, while cubes can have point contacts and contacts in line also. Contacts between the surfaces of cubic elements are also possible. They also suggested that at a low peripheral speed of the drum / about 60 per cent of critical speed / it would be possible to limit over grinding.

In 1954 Chuck Norris published comparative results of grinding in several, different in size laboratory models drum mills with different shapes of working elements. Experiments were carried out with: balls, cubes, cylinders, discs, cubes with cut tops, balls with six flat walls. Experiments have shown advantages of balls resulting in:

- Minimum energy consumption per unit of grinded material;
- Minimum wear of the working media.

Grinding in drum mills happened by impact energy of the falling grinding elements. It should be sufficient to destroy the biggest particles of the grinded material. There is a surplus of energy during the grinding of smaller particles apparently and it creates over grinding of ore.

Highest productivity and efficiency in grinding, in terms of newly formed surface or a controlled estimated class are reached when the coefficient of filling of the mill with working media is between 40 per cent and 50 per cent.

Productivity and efficiency of a drum mill strongly depend on:

- Constructive parameters of the mill;
- Rotation speed of the drum /percentage of critical speed /;
- Degree of drum filling with the working media;
- Mass of the working element onto the working media;
- Solid-liquid ratio T_s: T_w / pulp density/;

- Physical and mechanical properties of grinding material;
- Sieve characteristic on grinded material, etc.

Efficiency of grinding is defined as the ratio of the productivity of the mill, under certain conditions of grinding, to energy consumed. A large number of laboratory studies and industrial surveys have been done, designed to establish the relationship between the energy input for grinding and the useful work which in fine grinding is expressed by the newly formed surface in a unit volume of drum. It was found that the percentage of useful work of grinding is low, and gets even lower as fineness decreases. For example the grinding of apatite ore showed the following values for consumption of electricity:

from maximum particle size 1 mm below 0.2 mm – 8.5 kWh / t

from maximum particle size 1 mm below 0.15 mm – 12.5 kWh / t

from maximum particle size 1 mm below 0.1 mm - 23.5 kWh / t

Defining the efficiency of grinding is done by determining the differences of sieve characteristics of the raw material before and after the grinding process. From them one could define the newly formed surface which is the result of grinding process, using the formula / 1 /

$$q = \frac{Q(\beta - \alpha).60}{V.t}, \quad (1)$$

here:
q - relative productivity of a newly formed controllable class, t/m^3.h ;
α - content of a controllable class in the feeding material, part of one;;
β - content of a controllable class in the pulp, part of one ;
V - volume of the mill, m^3 ;
t - duration of grinding, h ;

Another parameter taking into account the efficiency of grinding is the degree of grinding. It is calculated by the formula / 2 /. That is the ratio between the average size of the feeding material according to classes of sieve analysis and the average size of the same class of sieve analysis in the pulp.

$$S = \frac{D_{av}}{d_{av}}, \quad (2)$$

where:
S - degree of grinding;
D_{av} - average diameter of feeding material, mm;
d_{av} - average diameter of pulp, mm;

Reducing energy consumption for the grinding process is of great importance for reducing the cost of processing the ore at the ore dressing plant. That fact is much more meaningful for ore dressing factories processing low content useful components ores. Reducing the high cost of energy for grinding by a few per cent will significantly improve the economics of processing the ore. As far as the energy for grinding is obtained from burning of organic fuels such as low quality coal, gas, petrol, etc., the reduction of energy consumed in grinding will indirectly affect the reduction of harmful discharges into the atmosphere and greenhouse gases.

METHODOLOGY

A methodology was created for conducting comparative experiments to examine the influence of the shape of the elements of two grinding media to grind one the same raw material (copper porphyry ore) using industrial model drum mill sized 900 x 900 mm (Figure 1).The mill is in serial production.

Grinding media are represented by balls and spheroidal tetrahedrons.

To obtain the most accurate and reliable results, despite the stochastic model of solid-liquid ratio T_s: T_w / pulp density/, parameters affecting the grinding process are retained unchanged and are distributed into three groups:

- Parameters related to the grinded material: physical-mechanical characteristics of grinding material, sieve characteristic and mineral composition of ore;

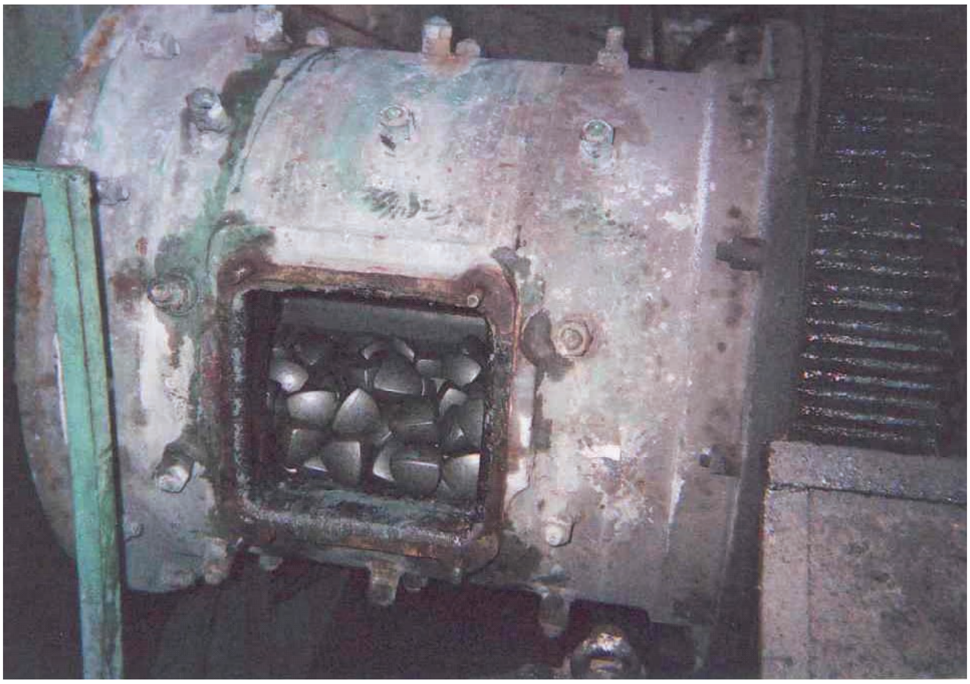

FIG 1 - Photo of the mill used to conduct comparative experiments with open hatch showing spheroidal tetrahedrons type of working media.

- Parameters related to the mill: external dimensions of the drum, the character of the lining, design of the mill;
- Parameters related to technological conditions: open or closed circuit of grinding, classification efficiency, degree of filling of the mill with grinding media, speed of rotation of the mill /percentage of critical speed / , quantity of circulating load, size or mass of working elements, composition and surface treatment of the elements of grinding media, solid-liquid ratio T_s: T_w / pulp density/ etc.

The methodology retains all the parameters for both types of working media with exception the shape of media and the percentage of filling the drum with the grinding media due to the shape of the elements. We point out the most important parameters:

- Consistent grinding in series with the grinding media balls and spheroidal tetrahedrons in the same mill;
- Controlled ore dosage , according to catalog productivity of the mill, t / h;
- Maintaining constant pulp density of 70 per cent solid;
- Filling the mill with the grinding media 40 per cent;
- The mass of grinding media is an equal;
- Diameter of the balls φ 80 mm;
- Balls and spheroidal tetrahedrons were made by the method of die forging (hot stamping) by one the same manufacture of steel, with one the same metal composition;
- the grinding is in open circuit / without classification /;
- Deviation in the working elements by mass is up to 1.0 per cent ;
- Grinding ore is 80 per cent below 10 mm with a maximum particle size 16 mm;
- Grinding ore is copper porphyry from deposit of Assarel, Bulgaria, taken by conveyor belt connected the disintegration department and Grinding department into Assarel ore dressing plant.

Prior to each series of experiments with the balls and spheroidal tetrahedrons we carried out a control test to establish:

5. Time to reach discharging pulp with content of 70 per cent solid;
6. Constant amount of pulp.

After finishing of each experiment grinding media is discharge and the mill is washed.

Controllable parameters in grinding process are:

- quantity of feeding ore;
- Water dosage to keep pulp density;
- moisture content of the ore;
- environment temperature;
- sieve characteristic of feeding ore;
- sieve characteristic of pulp;
- permanent control of grinding process by determining the liter weight of pulp;
- permanent control of class -0.08 mm content in the pulp.

During the grinding every 15 minutes is sampling, after the establishment of a constant mode of operation. One experiment samples are united in common sample. It is accomplished by sieve analysis in a set of sieves, equal to both products: feeding ore and pulp. Used sieves are knitted size of holes: 16,00 mm, 12.50 mm; 10.00 mm, 7.10 mm, 5.00 mm, 3.00 mm, 2.00 mm, 1.00 mm, 0, 40 mm, 0.20 mm, 0.10 mm, 0.08 mm and 0.063 mm. The obtained results are statistically processed and average values were obtained for each class of sieve analysis with balls grinding media and with the spheroidal tetrahedrons media for all series. Each series includes five experiments of grinding.

EXPERIMENTAL RESULTS

The experimental results obtained in one series are presented in tabular or graphical form. Table 1 gives the summary results for the content of a class of -0.2 mm in the ore fed in the mill and in the pulp after media by using the balls grinding media and the spheroidal tetrahedron media. Particles of such sizes are suitable for the flotation.

TABLE 1

Average experimental results of parallel grinding with balls grinding media and with spheroidal tetrahedrons grinding mediafor class -0.2 mm.

Content - 0.2 mm, per cent			
Attempt	**Feed Mill**	**Pulp**	**Newly Formed Surface**
Grinding medium – Spheroidal Tetrahedrons			
1	1.81	60.43	58.62
2	2.33	63.65	61.32
3	2.46	61.55	59.09
4	2.73	64.31	61.58
5	2.20	65.71	63.51
Average	**2.306**	**63.13**	**60.824**
Grinding medium – balls			
1	2.39	55.50	53.11
2	2.35	54.11	51.76
3	1.57	55.52	53.95
4	2.46	60.51	58.05
5	2.03	59.94	57.91
Average	**2.160**	**57.116**	**54.956**

The newly formed surface in class - 0.2 mm by using spheroidal tetrahedron grinding media is 5.868 per cent more than the average obtained class - 0.2 mm when a grinding media is balls. Table 2 contains summarized results for class -0.1 mm.

Newly formed surface in class - 0.1 mm by using the grinding media spheroidal tetrahedrons is 4.19 per cent more than the average obtained class – 0,1 mm by the grinding media balls.

Table 3 reflects the average experimental results for the same series of experiments in class -0.08 mm, but these values are illustrated graphically in Figure 2.

The average rise of newly formed surface in class - 0.08 mm using spheroidal tetrahedrons grinding media is 2,32 %.

TABLE 2

Average experimental results of parallel grinding with balls grinding media and with spheroidal tetrahedrons grinding media for class -0.1 mm.

Content - 0.1 mm, per cent			
Attempt	**Feed Mill**	**Pulp**	**Newly Formed Surface**
Grinding medium – Spheroidal Tetrahedrons			
1	1.54	45.80	44.26
2	2.08	47.68	45.60
3	2.18	46.65	44.47
4	2.43	48.49	46.06
5	1.99	49.30	47.31
Average	**2.044**	**47.584**	**45.54**
Grinding medium – balls			
1	2.06	42.31	40.25
2	2.06	41.44	39.38
3	1.40	42.85	41.45
4	2.17	45.16	42.99
5	1.77	44.45	42.68
Average	**1.892**	**43.242**	**41.35**

TABLE 3

Average experimental results of parallel grinding with balls grinding media and with spheroidal tetrahedrons grinding mediafor class -0.08 mm.

Content - 0.08 mm, per cent			
Attempt	**Feed Mill**	**Pulp**	**Newly Formed Surface**
Grinding medium – Spheroidal Tetrahedrons			
1	1.27	31.04	29.77
2	1.79	31.23	29.44
3	1.81	31.12	29.31
4	2.06	31.93	28.97
5	1.72	31.99	28.77
Average	**1.73**	**31.46**	**29.73**
Grinding medium – balls			
1	1.71	28.53	26.82
2	1.75	28.63	26.88
3	1.19	29.47	28.28
4	1.79	29.57	27.78
5	1.45	28.77	27.32
Average	**1.58**	**28.99**	**27.42**

Shown on Table 4 are the average experimental results for the same series of experiments in class -0.063 mm.

The average rise of newly formed surface in class - 0,063 mm using spheroidal tetrahedrons grinding media is 1,904 per cent.

Figure 3 shows the degree of grinding when using spheroidal tetrahedrons as a grinding media – 12.1, and the degree of grinding when using balls as a grinding media – 10,1. The degree of grinding is defined by formula /2/ and covers class +0.2 mm.

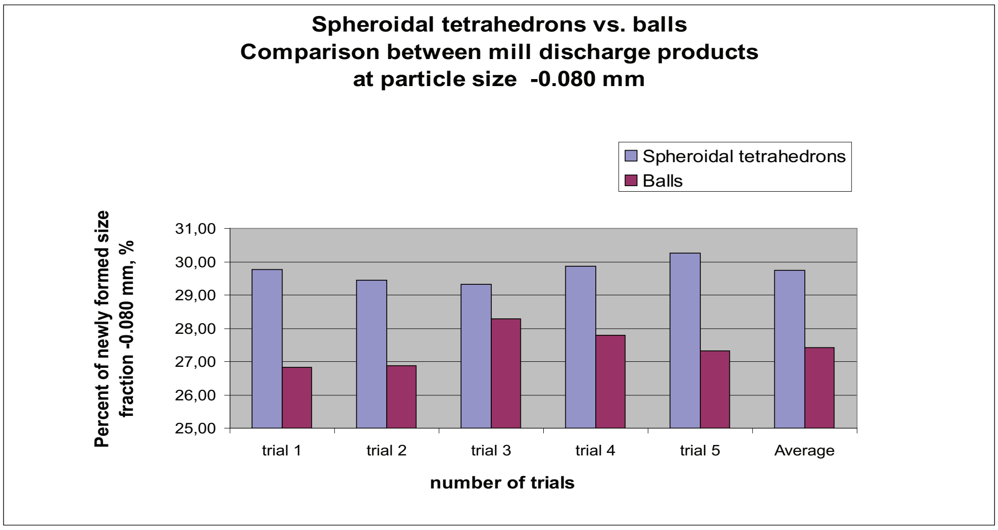

FIG 2 - A Diagram displaying the data in Table 3 for the content of -0.08 mm estimated class after grinding with balls and spheroidal tetrahedrons.

TABLE 4

Average experimental results of parallel grinding with balls grinding media and with spheroidal tetrahedrons grinding media for class -0.063 mm.

Content class - 0.063 mm, per cent			
Attempt	**Feed Mill**	**Pulp**	**Newly Formed Surface**
Grinding medium – Spheroidal Tetrahedrons			
1	1,20	28,21	27,01
2	1,71	28,31	26,60
3	1,76	28,03	26,27
4	1,96	28,62	26,66
5	1,69	28,58	26,89
Average	**1,664**	**28,350**	**26,686**
Grinding medium – balls			
1	1,64	26,02	24,38
2	1,68	26,16	24,48
3	1,13	26,81	25,68
4	1,69	26,65	24,96
5	1,39	25,80	24,41
Average	**1,506**	**26,288**	**24,482**

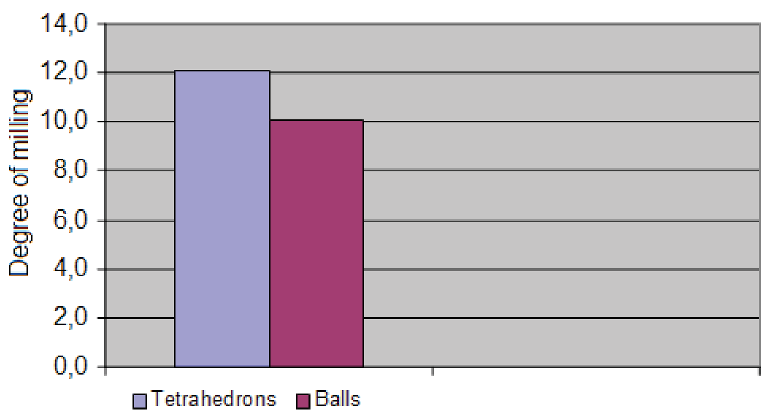

FIG 3 - Diagram showing the degree of grinding when using balls and tetrahedrons as grinding media.

DISCUSSION

The newly created grinding media for drum mills provisionally called 'spheroidal tetrahedrons' is being produced and experimented in near to industrial conditions according to the methodology of the experiment, for the first time. As the shape of the spheroidal tetrahedron is different from the sphere, one cannot accept, that the existing theory for grinding and principle of action for a spherical grinding elements /balls/ is optimal also for grinding elements from spheroidal tetrahedrons. There are no proven and investigated optimal intervals of parameters, influencing the grinding with spheroidal tetrahedrons grinding media.

Comparative experiments were conducted keeping and preserving:

- Design parameters of the mill /rotation speed, lining of drum, method of discharging pulp/;
- Technological parameters in the optimal interval of grinding with balls grinding media like pulp density / solid-liquid ratio /, mass of the grinding media, mass of a single element from the grinding media.
- Quality and quantity composition of the ore crashed for grinding in industrial conditions.

To avoid differences regarding the composition of the metal, surface processing, way of production, the both grinding media – balls and spheroidal tetrahedrons were manufactured by the same factory, from the same brand steel by the method hot volume stamping. The masses of the elements of both grinding media differ up to ± 2 per cent. Two series of 5 attempts each were conducted with both grinding media. We present here the results, obtained in one of the series The results are averaged values based on the sieves' characteristics according to methodology.

Several facts were established:

- The degree of grinding was defined as the ratio between the average size of the ore particles feed the mill and the average size of particles in the pulp at the same classes. The degree of grinding by spheriodal tetrahedrons grinding media is 12.1, while the degree of grinding by balls grinding media is 10.1 (according Figure 3).

The spheroidal tetrahedron grinding media ensures a 5,868 per cent more pulp ready to flotation / grain size below 200 microns/ (according according table 1);

- All controllable classis included in flotation suitable class -200 microns / class -100 microns, class – 80 microns, class – 63 microns/ have better value when is grinded by spheriodal tetrahedrons. The absolute values of the newly formed class are accordingly 4,19 per cent, 2,32 per cent and 1,904 per cent - tables 2, 3 and 4 . These data show a normal grinding without over grinding which is very essential in flotation ore dressing;
- The obtained absolute values of technological results are higher than the statistical error. In no experiments on grinding by spheroidal tetrahedron media was the efficiency lower than grinding by balls grinding media;

From the comparative research study and the obtained technological results concerning the newly obtained class and degree of grinding we have grounds to suppose that in the conditions of a waterfall regime of grinding by spheroidal tetrahedron grinding elements show differences, due to the shape of the grinding element. The differences are mainly in the concentration of the energy of the shock: in a point, in line and on an area. The most often shocks are between:

- A top onto oval surface;
- An edge onto oval surface;
- An oval surface onto an oval surface.

Less probable shocks are between:

- Top onto top;
- Top onto edge;
- Edge onto edge.

Obviously there are shock load with varying intensity.

There is a significant difference between the coefficients of alignment of grinding media. The number of spheroidal tetrahedrons in a unit volume is 12 – 15 per cent more than the number of the same by mass balls. The surface of a spheroidal tetrahedron grinding element is 8,4 per cent greater than the surface of an 80 mm grinding ball element which is equal by mass to spheroidal tetrahedron grinding element.

CONCLUSION

The tested new shape of grinding element represented by spheroidal tetrahedrons media onto drum mills ensures a higher percentage of newly formed surface, which increases the productivity of drum mills at same quantity of energy spent. The decrease of energy consumption in such a highly energetic process as drum mill grinding with several per cent will provoke a better economic result. The expected positive results of implementing the new grinding media will perform into economic and ecological plan.

Economic priority

- An energy spent to obtain a given quantity of newly formed surface is decreased when we use spheroidal tetrahedrons grinding media;
- We expect to realize a waterfall regime at a lower per cent of the drum rotation speed, because of the increase of friction coefficient between the oval parts of the spheroidal tetrahedrons and the drum lining, which will decrease energy spent even further.
- The drum mill productivity when using spheroidal tetrahedrons grinding media will increase additionally because of the higher degree of grinding up to 10-15 per cent onto closed circuit grinding with classification.

Ecological plan

- The decrease of energy consumption for grinding will be accompanied by the decrease of quantity fuels burnt, which are the main source of electric energy production, and also the quantities of sulfur compound, nitrogen and carbon oxide detached into atmosphere and so on.

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