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Influence on the Atmosphere of Production of Raw Materials for Metallurgy

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ABSTRACT

The concept of end-to-end energy-ecological assessment of the entire sequence of processes in the production of a product is known. A similar estimate was introduced for greenhouse gas emissions in the iron and steel industry. However, the contribution of the processes of extraction, enrichment and transportation of raw materials in the above estimates is given approximately. In this work, an attempt is made to clarify this contribution by determining emissions of harmful substances and greenhouse gases for a generalized technological scheme of an open pit. The calculations used the data of the main units on the assumption of their operation at maximum power. For this reason, auxiliary units were not considered.

Keywords: Quarry; Drilling Rig; Explosion; Excavator; Dump Truck; Traction Unit; Dump Car; Diesel Locomotive

Introduction

To Manage A Situation, You Need to Have Information

In [1], an end-to-end energy-ecological assessment of the entire sequence of processes in the production of a product is proposed. A similar estimate is given for greenhouse gas emissions in ferrous metallurgy [2,3]. The contribution of the processes of extraction, enrichment, and transportation of raw materials in the above estimates is taken at 10-20% of the parameters of the main technological processes. In this paper, an attempt is made to clarify this contribution by numerical assessment of emissions of harmful gases (WG) and Greenhouse Gases (GHG) for a generalized technological scheme of an open pit and a mining and processing plant (GOK).

The production of raw materials here includes the processes of ore mining, transportation, transshipment, and beneficiation. The features of these processes depend on the type of output product (ferrous or non-ferrous metals), however, general technological schemes can be distinguished. Crushing of the massif by drilling and blasting operations, loading and transporting from the bottom by road transport to the transshipment site, loading trains (turntables) with traction units (TA) and delivery of ore to the GOK, crushing and grinding ore, beneficiation, concentrate pelletizing, transportation of concentrate or pellets to a metallurgical plant (MK) - this is a possible general technological scheme for the production of raw materials. In specific conditions, there may be no transport by turntables, for example, vehicles deliver ore directly to the GOK. The calculations were made on the assumption that all units operate at full capacity for 24 hours. This will make it possible to indirectly estimate the emissions of auxiliary units, for example, the formation of roads by bulldozers, rearrangement of railway tracks in technological dead ends, etc. All of these processes generate emissions of dust, harmful gases, greenhouse gases into the atmosphere. Dust formation is not covered here. An attempt has been made to estimate emissions of harmful and greenhouse gases.

The method for estimating emissions (emissions) is based on the following formulas:

\[ E_{VH}^{PP} = q_{VH}^{PP} Q_{PP} n_{PP} \]  (1)

\[ E_{GH}^{PP} = q_{GH}^{PP} Q_{PP} n_{PP} \]  (2)

Where \( q_{VH}^{PP} \) - specific emission of VG or SG, kg / kW or kg / t; QPP is the energy parameter of the process indicated by the PP index, kWh or kg / product; t is the duration of the process, hours; nPP is the number of units in the PP process. Instead of the XX indices, the formula VH or GH should be inserted, the PP index denotes the process, IE - the energy source: electricity from a Thermal Power Plant (TPP) or a diesel engine (DD).
The volume of the exhaust gases of a diesel engine is determined by the formulas from [4]
\[
V = \frac{8.72 \times 10^{-6} P_0.5 t}{1.31(1 + 273/T_v)} M^3
\]
(3)
where the specific fuel consumption, g / kWh; \( P \) - engine power, kW; \( T_v \) - exhaust gas temperature, °C; \( t \) - engine running time, s. The greenhouse gas \( \text{CO}_2 \) is contained in waste gases up to 12% by volume [5,6]. Thus, the highest \( \text{CO}_2 \) gas emission from nPP units at a known volume \( \text{Vog} \) is determined
\[
E_{\text{Vog}} = 0.12 \cdot V_{\text{ax}} \cdot P_{\text{ax}} \cdot n_{\text{ini}}
\]
(4)
where \( \rho_{\text{DU}} = 1.977 \text{ kg } / \text{ m}^3 \) is the density of carbon dioxide.

The quaries have auxiliary vehicles with gasoline engines, but their share in emissions is much less than dump trucks and diesel locomotives. Specific emissions will be calculated by dividing total emissions by the mass of MPP products delivered to the consumer, kg/t. Drilling of the wells. Well drilling is performed by drilling rigs, for example, a rotary drilling machine SBSh-250 MNA-32, equipped with an electric motor \( Q = 500 \text{ kW} \). The depth of the wells is 10-20 m, the diameter is 250 mm [7]. We will neglect other electricity consumers of the drilling rig since our calculations are of an estimate nature. A well with a depth of 15m, such a drilling rig will, according to approximate calculations, be drilled for 2 hours, which will take 1000 kWh. From rough calculations it is necessary to drill \( n_{\text{BR}} = 72 \) wells (3 rows of 24). The distance between the wells in a row, between their rows and between the first row of wells and the edge will be taken as 8 m. Thus, the blasted block will be 83,000 m³, and the total mass of the MDBM chipping is 166000 t [8]. For these data, we will choose more equipment that can process the breakout in 24 hours.

The machine tool with an electric drive does not have its own emissions of harmful substances and greenhouse gases, but such emissions do occur in the production of electricity. Let’s call these emissions transit. Energy from coal-fired power plants has the highest emissions of HH and GHG and for rough calculations is suitable for determining the upper limit. A coal-fired Thermal Power Plant (TPP) has specific gas emissions in kg / kWh: \( E_{\text{NOx}}^{\text{so}} = 0.56 \), \( E_{\text{CO}}^{\text{so}} = 0.014 \), \( E_{\text{CH}_4}^{\text{so}} = 0.004 \) [9]. From (2) at \( t = 2 \) hours and \( n_{\text{BR}} = 72 \) we obtain, kg: \( E_{\text{NOx}}^{\text{co}} = 40320 \), \( E_{\text{CO}}^{\text{co}} = 1008 \), \( E_{\text{CH}_4}^{\text{co}} = 288 \). Imploding works. Based on approximate calculations, QBP = 18 tons of explosive (BB) - grammonite 30/70 (250 kg per well) is laid in all wells. After the block is blown up, a dust and gas cloud is formed. Dust emissions are not considered here. For 1 ton of grammonite 30/70 is formed during explosion, kg / t of explosives: \( E_{\text{so}}^{\text{so}} = 0.03 \), \( E_{\text{co}}^{\text{co}} = 0.012 \), \( E_{\text{CH}_4}^{\text{co}} = 0.008 \), \( E_{\text{CH}_4}^{\text{co}} = 0.0025 \). For the calculations, the maximum values of specific emissions from the table were taken. 1. This data is used unchanged for all emissions calculations for diesel vehicles. The power of diesel engines of open pit excavators is assumed to be equal to QDE = 800 kW [12, 13] bucket capacity MDE = 20 t. During \( t = 24 \) h, three excavators from (1) form VG, kg: \( E_{\text{NOx}}^{\text{co}} = 1728 \), \( E_{\text{CO}}^{\text{co}} = 691 \), \( E_{\text{CH}_4}^{\text{co}} = 461 \). Other harmful gases listed in (Table 1), are not considered due to the insignificance of their emissions and the approximations of the estimated calculations in this work.

### Table 1: Composition of the exhaust gases of diesel internal combustion engines at full load.

| Exhaust gas component | Exhaust gas concentration, % | Concentration, g / m³ | Specific emission g / (kWh) |
|-----------------------|-------------------------------|-----------------------|-----------------------------|
| **Nitrogen oxides NOₓ** | 1.0...8                        | 0.25...2.5            | 1.5...12.0                  |
| **Carbon monoxide, CO** | 0.005...0.4                   | 0.25...2.5            | 1.5...12.0                  |
| **Hydrocarbons, C₇H₁₈** | 0.009...0.3                   | 0.25...2.0            | 1.5...8.0                   |
| **Sulfur dioxide, SO₂** | 0.02                          | 0.1...0.5             | 1.0...4.25                  |
| **Benzo (a) pyrene, C₇H₈** | 0.05...1                      | 0.25-10⁻⁶            | 1.10-6...2.10⁻⁶             |
| **ALDEGIDY RCHO** | 0.002                         | 1.0...10.0           | -                           |
| **INCLUDING:** |                               |                      |                             |
| **formaldehyde, HCHO** | 0.0001...0.0019               | 0.001...0.04         | 0.06...0.2                  |

The diesel engine of the calculated excavator has a specific fuel consumption \( = 210 \text{ g } / \text{ kWh} [13,14] \), power = 800 kW, exhaust gas temperature \( = 500 \text{ °C} \). For these data, the volume of exhaust gases for \( t = 86400 \text{ s} \) from (3) will be 62497 m³. Consequently, from (4), the emission of three diesel excavators will be, kg \( E_{\text{CO}}^{\text{co}} = 44480 \). Let’s say the excavator cycle is 0.5 minutes. Then, three excavators will load 28800 tons of rock per day. Transportation from the face. Excavators load crushed ore into dump trucks. For example, in the body “BelAZ-7517”, which can transport MTZ = 160 tons [15] and

\[ E_{\text{Vog}} = \frac{8.72 \times 10^{-6} P_0.5 t}{1.31(1 + 273/T_v)} M^3 \]
has an engine with a capacity of \( QTZ = 1400\ kW \). In 24 trips a day, a dump truck will take out 3840 tons of bumps from the quarry. The total weight of thechipping 166, 000 tons per day can be removed by 43 dump trucks. From (2) we will determine that 43 dump trucks for \( t = 24\ h \) form VG, kg: \( E_{CO_2}^{30} \cdot 43344, E_{CO}^{31} \cdot 17338, E_{CO_2}^{32} \cdot 11558, E_{CO_2}^{33} \cdot 3612 \). Let us assume the cycle time of loading-unloading of a dump truck is 30 minutes. In 24 hours, it will complete 44 cycles and transport 7040 tons of ore. From (3) at \( = 210\ g / kWh, = 3430, kW, = 500 °C \) for \( t = 86400\ s, \) we find the volume of exhaust gases - 109370 m\(^3\). Therefore, from (4), the emission of forty-three dump trucks will be, kg: \( E_{CO_2} = 1115715\).

Dump trucks carry ore to a transfer point or to a processing plant if it is located nearby (Sorsky GOK). Transportation from the quarry. At the transshipment point, excavators load trains of dump cars (turntables). The formed masses of VG in the process of loading by diesel excavators are close to the previously found masses when analyzing the loading of dump trucks. The turntables are driven by traction units (TA). Used TA, consisting of an electric locomotive and two motor dump cars or an electric locomotive, a diesel locomotive and one motor dump car, an example of OPE-1 [16]. Power of traction electric motors \( QTK = 6000\ kW \). The OPE-1 goes from the power grid in places where there is a contact wire (central or side). Suppose that per day \( tTIG = 16\ h \) a TA works as an electric locomotive and \( tTK = 8\ h \) as a diesel locomotive.

### Table 2: Cone Crusher Parameters

| Type of cone crusher | Slit width, mm | Productivity at nominal discharge gap, m\(^3\)/h | Main drive power, kW | Specific power consumption, kWh/m\(^3\) |
|----------------------|---------------|---------------------------------|------------------|------------------|
| KKD-1500/180         | 1500          | 180                             | 1500             | 400              | 0.27             |
| KSD-3000-T           | 380           | 25-50                           | 750              | 500              | 0.67             |
| KMD-2200-T1          | 110           | 8-12                            | 150              | 250              | 1.67             |

The specific consumption will be \( 3900/1500 = 2.6\ kW / m^3 \). The same result can be found by adding the numbers in the last column of the (Table 2). The density of ores of different metals has different meanings. If we take an average density of 2.0 t / m\(^3\), then for all crushing operations, the specific power consumption will be \( QDP = 1.3\ kW / t \). There is no intrinsic emission from the crushing process. Transit specific emission during crushing will be, kg / t \( E_{CO_2}^{30} \cdot 0.73, E_{CO_2}^{31} \cdot 0.02, E_{CO_2}^{32} \cdot 0.0052 \). For crushing 166,000 tons per day, five KKD are needed with the corresponding amount of KSD and KMD. With such crushing, it is formed, kg: \( E_{CO_2}^{30} \cdot 121180, E_{CO_2}^{31} \cdot 3320, E_{CO_2}^{32} \cdot 863\). Shredding. It is difficult to collect data on this process for some middle process. For this reason, the emissions of this process are assumed to be zero. This process is characterized by large masses of crushed rock and small masses of the resulting concentrate.

### Table 3: Emissions of gases into the atmosphere during various opencast mining processes.

| Technological processes          | CO, kg | Вредные газы, кг |
|----------------------------------|--------|-----------------|
| Drilling downhole processes      | 40320  | 288             |
| Imploding works                  | -      | 540             |
| Downhole loading with electric excavators | 32256  | 230             |
| Downhole loading with diesel excavators | 44480  | 691             |
| Transportation from the face      | 1115715 | 17338          |
| Electric transport from the quarry | 161280 | 1152             |
| Diesel-powered transportation from the quarry | 45438  | 424             |

| CO, kg | Вредные газы, кг |
|--------|-----------------|
|        | CO  NO\(_x\) \( C_{H_2} \) SO\(_2\) |
| Drilling downhole processes      | 40320  | 288             | 1008            |
| Imploding works                  | -      | 540             | 36               | - |
| Downhole loading with electric excavators | 32256  | 230             | 806             |
| Downhole loading with diesel excavators | 44480  | 691             | 1728            | 461  |
| Transportation from the face      | 1115715 | 17338          | 43344           | 11558  |
| Electric transport from the quarry | 161280 | 1152             | 11558           | 3612    |
| Diesel-powered transportation from the quarry | 45438  | 424             | 1059            | 282  | 88 |
During flotation, a small mass of concentrate is obtained from a large mass of crushed ore. Moreover, the lower the content of the required metal in the ore, the greater the number of crushed ore processed. Let the ore contain 0.983% metal, for example copper. The concentrate contains 40% metal. Obviously, 1 ton of concentrate will require 40.69 ton of crushed rock. The iron content in magnetite ores and concentrates is comparable. In this case, approximately one ton of ore is mined per ton of concentrate. Formation of the composition. Produced by a shunting diesel locomotive, for example TEM7. The diesel power of such a locomotive is \( Q_{FS} = 1470 \text{ kW} \) [17]. Let him form the composition in \( t = 2 \text{ hours} \). In the composition of 60 cars in each of 68 tons of ore, total MFS = 4080 tons. The emission of a shunting locomotive from (2) will be: \( E_{CO} = 88 \), \( E_{NO} = 35 \), \( E_{H_2} = 24 \), \( E_{SO_2} = 7 \).

From (3) at \( = 210 \text{ g / kWh} \), \( = 1470, \text{ kW} \), \( = 500 \degree \text{ C} \) for \( t = 86400 \), we find the volume of exhaust gases - 114,916 m\(^3\). Consequently, from (4) the emission of the locomotive will be, kg: \( 27263 \).

In our calculations, the rock / concentrate ratio is assumed to be 166000/4080 = 40.686. In this case, the summary data of the table. 3 in the final calculations can be used without changes.

### Table 4: Emissions to the atmosphere from various processes of mining and concentration of low-grade ores.

| Technological processes | \( CO_2 \) | \( CO \) | \( NO_x \) | \( C_H_y \) | \( SO_2 \) |
|------------------------|------------|---------|------------|------------|--------|
| Previous processes, kg | 1621757    | 18993   | 54178      | 12301      | 32598  |
| Formation of the composition, kg | 27263 | 35 | 88 | 24 | 7 |
| Delivery to the consumer, kg | 81770 | 1271 | 3177 | 847 | 265 |
| Total, kg | 1730790 | 20299 | 57443 | 13172 | 32870 |
| Specific emission with delivery, kg/t | 424,21 | 4,98 | 14,08 | 3,23 | 8,06 |

### Table 5: Emissions into the atmosphere from various processes of mining and concentration of high-grade ores.

| Technological processes | \( CO_2 \) | \( CO \) | \( NO_x \) | \( C_H_y \) | \( SO_2 \) |
|------------------------|------------|---------|------------|------------|--------|
| Previous processes, kg | 39860,05   | 466,815 | 1331,604  | 302,373   | 801,2039 |
| Formation of the composition, kg | 27263 | 35 | 88 | 24 | 7 |
| Delivery to the consumer, kg | 245309 | 3812 | 9530 | 2541 | 794 |
| Total, kg | 312432,1 | 4313,816 | 10949,6 | 2867,338 | 1602,204 |
| Specific emission with delivery, kg/t | 76,576 | 1,057 | 2,684 | 0,703 | 0,393 |

Example. In work [3] the values of own emissions of \( CO \) are given, kg: sintering machine (AM) - 14; coke oven battery (KB) - 5.5; blast furnace (BF) - 5. Given the resource consumption, t: pellets from GOK to AM - 0.9; from a coal mine to KB - 1.4; from KB to AM - 0.3; from AM to DP - 1.3; from KB to DP - 0.5. Through emission of cast iron is determined by the formula from [3] on the assumption that the data obtained for ore materials are valid for coal mines

\[
[0.9\cdot 1.057+0.3\cdot (1.4\cdot 1.057+5.5)+14]\cdot 1.3+0.3\cdot (1.4\cdot 1.057+5.5)-0, 5+5=28.21.
\]
The emission of CO resources is equal to $1.057 + 1.057 = 2.114$ kg, i.e., about 10% of the through emission of pig iron. For non-ferrous metallurgy, the contribution of resources to the emission of products will be more than 10-20%.

**Conclusion**

The assessment of end-to-end emissions of harmful and greenhouse gases in the processes:

1. Open pit ore mining
2. Enrichment
3. Transport

Ancillary processes, such as the formation of quarry roads, the transfer of the rail track, the transfer of the contact network, charging and stemming, etc. were not considered. However, for the main equipment, parameters were chosen without considering their use at small capacities. This circumstance to some extent compensates for the exclusion from the consideration of emissions of auxiliary equipment. End-to-end emissions of harmful and greenhouse gases generated during open-pit mining, crushing and delivery of poor ores (non-ferrous metals) make a significant contribution to the total end-to-end emissions of the main products.

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