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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, 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:

$$E_{XX}^{\text{пп}} = q_{XX}^{\pi\pi} \cdot Q_{\text{пп}} \cdot n_{\text{пп}} \quad (1)$$

$$E_{XX}^{\text{пп}} = q_{XX}^{\pi\pi} \cdot Q_{\text{пп}} \cdot t \cdot n_{\text{пп}} \quad (2)$$

Where $q_{XX}^{\pi\text{з}}$ - 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]

$$v_{or} = \frac{8,72.10^{-6}.b_{з} \cdot p_{з}.t}{1,31(1+273/T_{or})}, M3 \quad (3)$$

where is the specific fuel consumption, g / kWh; - engine power, kW; - exhaust gas temperature, ° C; t - engine running time, s. The greenhouse gas CO2 is contained in waste gases up to 12% by volume [5,6]. Thus, the highest CO2 gas emission from nPP units at a known volume Vog is determined

$$E_{XX}^{ПП} = 0,12.v_{XX}^{пз} \cdot p_{зY} . n_{ПП} \quad (4)$$

where ρDU = 1.977 kg / m^3 is the density of carbon dioxide.

The quarries 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 QB = 500 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 nBR = 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 m^3, and chipping - 124,500m^3, the total mass of the MDBM chipping = 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: $q_{CO2}^{TЭ}$ - 0.56, $q_{SO2}^{TЭC}$ - 0.014, $q_{NO_x}^{TЭC}$ - 0.004 [9]. From (2) at t = 2 hours and nBR = 72 we obtain, kg: $E_{CO2}^{TЭ}$ - 40320, $E_{SO2}^{TЭC}$ - 1008, $E_{NO_X}^{TЭC}$ - 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: $q_{NPO_x}^{BP}$ - 30, $q_{NO_x}^{BP}$ - 2 [6,7]. From the explosion QBP = 18 tons of grammonite 30/70 at nBP = 1 is formed according to the formula (1), kg: E_{CO}^{BP} - 540, $E_{NO_x}^{BP}$ - 36.

Loading in the face by electric excavators. The crushed ore is loaded onto dump trucks with diesel or electric excavators. For example, the electric EKG-10 has a bucket with a volume of 10 m^3, which includes 15–20 tons, let us take MEE = 20 tons. The main drive with a power of QEE = 800 kW [10-12]. Let us assume that the cycle of picking-loading-turning of the excavator is 0.5 minutes. Then the excavator will load 28800 tons of rock per day. Six excavators, consisting of three electric and three diesel, will be required to load the entire deflector.

Fort=24hoursnEE=3excavatorsduringloadingoperationsinthe face form transit emissions from (2), $E_{CO_2}^{ЭЭ}$ - 32256, $E_{SO_2}^{ЭЭ}$ - 806, $E_{NO_x}^{ЭЭ}$ - 230 . Downhole loading with diesel excavators. The exhaust gases of a diesel engine are listed in table. 1 [4-6]. Approximately, from the operation of a diesel engine, gases are formed, kg / kWh: $q_{NO_x}^{ДД}$ - 0.03, $q_{CO}^{ДД}$ - 0.012, $q_{C_xH_y}^{ДД}$ - 0.008, $q_{SO_2}^{ДД}$ - 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: $E_{NO_x}^{ДЭ}$ - 1728, $E_{CO}^{ДЭ}$ - 691, $E_{C_xH_y}^{ДЭ}$ - 461, $E_{SO_2}^{ДЭ}$ -144. 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 / m^3,	Specific emission g / (kWh)
Nitrogen oxides NOx,		1,0...8	10...30
Carbon monoxide, CO	0,005...0,4	0,25...2,5	1,5...12,0
Hydrocarbons, C_xH_y	0,009...0,3	0,25...2,0	1,5...8,0
Sulfur dioxide, SO_2	0,02	0,1...0,5	0,4...2,5
Benz (a) pyrene, C_20H_{12}	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	-	-
acrolein, CH_3CHO	0,0001...0,00013	0,001...0,04	0,06...0,2

The diesel engine of the calculated excavator has a specific fuel consumption = 210 g / kWh [13,14], power = 800, kW, exhaust gas temperature = 500 °C. For these data, the volume of exhaust gases for t = 86400 s from (3) will be 62497 m^3. Consequently, from (4), the emission of three diesel excavators will be, kg $E_{CO_2}^{ДЭ}$ = 44480. Let's say the excavator cycle is 0.5 minutes. Then, three excavators will load 28,800 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 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 the chipping 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: $E^{ТЗ}_{NO_x}$ - 43344, $E^{ТЗ}_{CO}$ - 17338, $E^{ТЗ}_{C_xH_y}$ - 11558, $E^{ТЗ}_{SO_2}$ - 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: $E^{ТЗ}_{CO_2}$ = 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 QTК = 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 tТКЭ = 16 hours a TA works as an electric locomotive and tТКД = 8 hours - as a diesel locomotive.

The spinner transports the MTK = 1500 tons from the transfer point to the GOK during the trip. To remove the entire mass of 166,000 tons of chipping per day, 111 trips of five (nTKV = 5) turntables will be required. Considering the specific formation of gases at TPPs kg / kWh (see above), according to formula (2), we find transit emissions of gases, kg: $E^{ТКЭ}_{CO_2}$ - 161280, $E^{ТКЭ}_{SO_2}$ - 4032, $E^{ТКЭ}_{NO_x}$ - 1152. When using diesel traction for tТКД = 8 hours with a diesel power QTК = 1470 kW, emissions are formed from five diesel locomotives TA, kg: $E^{ТКД}_{NO_x}$ - 1059, $E^{ТКД}_{CO}$ - 424, $E^{ТКД}_{C_xH_y}$ - 282, $E^{ТКД}_{SO_2}$ - 88. From (3) at = 210 g / kWh, = 1470, kW, = 500 ° C for t = 28800 s, we find the volume of exhaust gases - 38305 m^3. Consequently, from (4), the emission of five diesel sections of TA will be, kg $E^{ТКД}_{CO_2}$ = 45438. Splitting up. A variety of equipment is used to crush ore, in particular cone crushers. Usually, ore crushing is carried out in three stages: coarse, medium and fine crushing [20]. These processes use screens operating in a closed cycle with crushers, conveyors and other units. Let us analyze only the emissions from the cone crushers. Table 2 shows the parameters of such crushers selected for analysis [21]. The capacities are selected from the ranges given in [21]. With this choice, one KKD requires two KSD and ten KMD. If at the inlet of KKD 1500 m^3, then at the outlet of all KMD 1500 m^3 is formed (we neglect losses). In this case, 400 + 2 · 500 + 10 · 250 = 3900 kWh of electricity is consumed.

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
	Receptionist	Rated unloading			
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 kWh / 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 QДР = 1.3 kWh / t. There is no intrinsic emission from the crushing process. Transit specific emission during crushing will be, kg / t $E^{ДР}_{CO_2}$ - 0.73, $E^{ДР}_{SO_2}$ - 0.02, $E^{ДР}_{NO_x}$ - 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: $E^{ДР}_{CO_2}$ - 121180, $E^{ДР}_{SO_2}$ - 3320, $E^{ДР}_{NO_x}$ - 863. Shredding. It is carried out by various types of mills, including ball mills. Ball mill MShR-3600x5000 with a capacity of up to 190 t / h has an engine power of 1250 kW [22]. Specific power consumption will be 1250/190 = 6.58 kWh / t. There is no intrinsic emission from the grinding process. Transit specific emission during grinding will be, kg / t $E^{ЭЭ}_{CO_2}$ - 3.68, $E^{ЭЭ}_{SO_2}$ - 0.118, $E^{ЭЭ}_{NO_x}$ - 0.033. When crushing 166000 t is formed, kg: $E^{ДР}_{CO_2}$ - 61088, $E^{ДР}_{SO_2}$ - 19588, $E^{ДР}_{NO_x}$ - 5478. Flotation 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.

	CO_2 кг	Вредные газы, кг			
Technological processes		CO	NO_x	C_xH_y	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	144
Transportation from the face	1115715	17338	43344	11558	3612
Electric transport from the quarry	161280	-	1152	-	4032
Diesel-powered transportation from the quarry	45438	424	1059	282	88

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Splitting up	121180	-	863	-	3320
Shredding	61088	-	5478	-	19588
Outcome	1621757	18993	54178	12301	32598
Specific emission, kg / t	9,770	0,114	0,326	0,074	0,196

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 QFS = 1470 kW [17]. Let him form the composition in t = 2 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, kg: $E^{ФС}_{NO_x}$ - 88, $E^{ФС}_{CO}$ - 35, $E^{ФС}_{C_xH_y}$ - 24, $E^{ФС}_{SO_2}$ - 7.

From (3) at = 210 g / kWh, = 1470, kW, = 500 °C for t = 86400 seconds, 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, which was considered when compiling tables. Delivery to the consumer. Performed by mainline diesel locomotives or electric locomotives. Let us consider the emissions of WG when using a diesel locomotive [18,19]. The two-section diesel locomotive 2TE10M has a 2206 kW diesel engine in each section, i.e., the total power is 4412 kW. For example, let's choose the distance from Olenegorsk to the Cherepovets MK - 1800 km, which the train travels in three days. When using diesel traction during tДП = 72 hours of the voyage with the power of two diesel engines QTK = 4412 kW, considering the specific engine emissions from Table. 1 let us find the emissions of the diesel locomotive, kg: $E^{ДП}_{NO_x}$ - 9530, $E^{ДП}_{CO}$ - 3812, $E^{ДП}_{C_xH_y}$ - 2541, $E^{ДП}_{SO_2}$ - 794.

From (3) at = 210 g / kWh, = 4412, kW, = 500 °C for t = 259200 seconds, we find the volume of exhaust gases - 1034012 m^3. Therefore, from (4), the CO_2 emission will be, kg $E^{ДП}_{CO_2}$ = 245309. Non-ferrous metallurgy enterprises are located close to raw material bases. Non-ferrous ores are poor because they contain less than 3% of the required metal. Consequently, it is advisable to reduce the found indicators of VG and GHG emissions by three, since in previous calculations it was assumed that the composition with the concentrate goes to MC for three days. The calculation results for the entire technological chain in the development of poor and rich ores are summarized in (Tables 4 & 5). Data in the line "Previous processes" in (Table 5) are obtained from the same line of (Table 4) by multiplying its data by the quotient 4080/166000, i.e., assuming that a ton of ore is mined per ton of concentrate.

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

Technological processes	CO_2	Harmful gases			
		CO	NO_x	C_xH_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	Harmful gases			
		CO	NO_x	C_xH_y	SO_2
Previous processes, kg	39860,05	466,8159	1331,604	302,3378	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

$$[0,9\cdot1,057+0,3\cdot(1,4\cdot1,057+5,5)+14]\cdot1,3+0,3\cdot(1,4\cdot1,057+5,5)\cdot0,5+5=28,21.$$

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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