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Peculiarities of Greenhouse Gas Emission at Iron & Steel Plants of Ukraine

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The purpose of work is to develop carbon dioxide emission forecasting method. The object of investigation is mechanism of carbon dioxide formation at iron & steel plants. The mechanisms were analyzed via calculating procedure with the use of power capacity methodology. As a result of investigation, carbon dioxide formation model was developed in order to calculate changes of carbon dioxide emissions at changing output and range of commodity products, melting and casting technology, iron consumption, etc. The forecasting technique can be used when working out the projects of joint implementation.

Keywords: CARBON DIOXIDE, FORECASTING, PRODUCTION TECHNOLOGY, CALCULATION TECHNIQUE, COMMODITY PRODUCT, STEEL CASTING AND SMELTING

Introduction

Kyoto Protocol provides reduction of greenhouse gas emissions. Working out of joint implementation projects stipulates forecasting greenhouse gas emissions. So, it is necessary to consider both emissions on the plant where energy saving measure is being implemented and outside if technology or equipment change on the lead unit affects working conditions of auxiliary plants. These forecasts should consider the possible changes of production output at the operating enterprise, changes of final (commodity) products range, planned technical reconstruction of current equipment, advancement of current technique.

Each iron & steel plant represents a circuit of interdependent technological processes. And forecasting should be based on the model of greenhouse gas formation, which considers the features of greenhouse gas formation when producing each type of products and effect of production technology change on greenhouse gas amount.

Results and Discussion

Many mining and smelting plants have taken emission inventory measures for the last years [1, 2]. This inventory results are presented in the form of the following model:

$$W = \Sigma\, Q_i \times k_i + W_p, \qquad \text{(Eq. 1)}$$

where W – volume of greenhouse gas emission in the whole plant, t CO_2/year; Q_i - volume of i-product output, t/year; k_i - greenhouse gas emission factor when manufacturing i-products, t CO_2/t; W_p - volume of greenhouse gas emission as a result of other industrial activity (for example, repair, transport, etc.), t CO_2.

The scope of other operations (services) does not always correspond to amount of primary activity. The amount of formed greenhouse gas emissions is insignificant (usually not more than 1 %), and consequently it is possible to consider their amount as semi-fixed value. Model (1) records amount of greenhouse gas emission of the enterprise for inventory period. Absence of correlation between the volume of output of certain types of products does not allow defining the value of greenhouse gas emission as a result of modernization or at change of quantity of commodity (final) products.

At the same time each metallurgical plant produces not only commodity products (rolled metal) but also semi-finished materials (lime, sinter, cast iron, steel), which output volume is determined by amount of commercial rolled metal and consumption indexes of each semi-finished material on manufacture of products.

Steam produced by heat electric generation plant can be referred to semi-finished material for enterprises with complete production cycle. The most of this steam is used for blast furnace blowing, chemical water purification, electric-power production, etc.

Proceeding from these concepts, "Energostal" has developed a model of greenhouse gas emission calculation based on the principles of production planning: the volume of commercial output is forecasted first, then demand for each type of semi-finished material, replaceable equipment, power resources is considered on the basis of their consumption indexes. This model is as follows taking into account greenhouse gas emission (k_i):

$$W = \Sigma\ Q_{ic}\ (q_{ci}\times k_i + q_{si}\times k_s + e_p), \qquad \text{(Eq. 2)}$$

where Q_{ic} - volume of *i*-commercial output, t/year; q_{ci}, q_{si} - consumption index of each semi-finished material and steam respectively on manufacture of *i*-commercial product, t CO_2/t (t CO_2/ Gcal); k_s - greenhouse gas emission factor at steam generation, t CO_2/ Gcal; e_p - semi-fixed amount of greenhouse gas emission under other activity referred to unit of commercial product, t CO_2/t.

The main type of greenhouse gas formed as a result of industrial activity at iron & steel plants is carbon dioxide CO_2. Dependence between technological processes at iron & steel plants and amount of oxides of nitrogen and methane is not established yet, therefore their amount is accepted as fraction of emitting CO_2. Besides, methane formation in metallurgical and heat engineering aggregates is extremely doubtful, except for in case of incomplete burning of gas fuel. From these considerations, all further calculations are for CO_2 emission, and if necessary amount of NO_x and CH_4 should be accepted in fractions from amount of carbon dioxide.

Consumption index of semi-finished material (q_{ci}) is amount of semi-finished material (replaceable equipment, etc.) necessary for manufacture of *i*-commercial product taking into account all previous metallurgical processes. For example, consumption index of sinter for iron smelting is 1.75 t/t, consumption index of pig-iron on steel smelting – 0.88 t/t, therefore consumption index of sintered ore for steel is $1.75\times0.88 = 1.54$ t/t. The information about consumption indexes is available in technical reports of each department.

Values k_i and k_s are defined primarily by amount and quality of usable fuel. So, CO_2 evolution occurs usually at fuel combustion: for blast-furnace gas 6.65-7.0 t CO_2/t coal equivalent; for coke gas 1.25-1.40 t CO_2/t coal equivalent; for natural gas 1.6-1.8 t CO_2/t coal equivalent.

Consumption index of thermal power station steam on manufacture of each type of commodity output is difficult to calculate by-hand as steam is used for production of both commodity output and each semi-finished material, and in the form of blowing, electric power, chemical water, heat power. It is easier to calculate this value on PC using the program developed by "Energostal" [3, 4]. Calculation of CO_2 emission for three principal types of commodity output at JSC “ArselorMittal Kryvyy Rih” according to results of emission inventory for 2006 [1] is presented in **Table 1**.

Total emission of CO_2 was 16534.5 thousand tons taking into account operation of three sintering plants. Operation of coke-chemical and ore-mining industries was not considered for correct comparison to other integrated works. It follows from **Table 1** that manufacture of rolled sections, rolled blooms and ironmaking are accompanied by CO_2 emission 16 512.4 thousand tons. Other 22.1 thousand tons of CO_2 (0.13 %) emit at the expense of energy resources and slag.

It is obvious from **Table 1** that amount of CO_2 emission is defined by volume of commodity output and value of emission factors ($k_c = \Sigma\ q_{ci}\times k_i + q_{si}\times k_s$). In turn, emission factor (k_c) depends on values of consumption indexes and emission factors in each metallurgical process (k_i). Consequently, the most radical method to decrease CO_2 emission is reduction of both semi-finished materials and fuel consumption at each stage of manufacturing process. In this respect, measures related to decrease of CO_2 emission and reduction of energy intensity production are identical.

Also it follows from **Table 1** that CO_2 emission is the most important in total value k_c for each type of products when ironmaking and steam generation. Therefore decrease of pig-iron consumption on steel smelting is the most effective way to reduce CO_2 emission.

The most effective measure to reduce greenhouse gas is adoption of continuous steel casting. Calculation of CO_2 emission for converter steel teeming on continuous casting machine is given in **Table 2**.

Table 1. Effect of commodity output volume (Q_c, thousand tons) and consumption indexes of semi-finished materials (q_c, t/t) on carbon dioxide emission at JSC "ArselorMittal Kryvyy Rih"

Semi-finished materials, products	Emission factor (k_i), t CO_2/t	Section Q_c = 6223 thousand tons		Blooms Q_c = 889.5 thousand tons		Pig-iron Q_c = 241.5 thousand tons	
		q_c, t/t	$q_c \times k_i$, t CO_2/t	q_c, t/t	$q_c \times k_i$, t CO_2/t	q_c, t/t	$q_c \times k_i$, t CO_2/t
Rolled section	0.1071	1.0000	0.1071				
Rolled blooms	0.0876	1.0347	0.0906	1.0000	0.0876		
Steel, ingots	0.0964	1.1410	0.1100	1.1028	0.1063		
Cast-iron *	0.5668	0.9804	0.5557	0.9475	0.5370	1.0000	0.5668
Sintered ore	0.2340	1.6259	0.3805	1.5714	0.3677	1.6584	0.3881
Lime carbonate	1.2460	0.0802	0.0999	0.0775	0.0966	0.0114	0.0142
Steam from thermal power station, Gkal	1.0216	0.7943	0.8115	0.7645	0.7810	0.6570	0.6712
Other			0.1334		0.1259		0.0160
Total, k_c **			2.2887		2.1021		1.6563
$k_c \times Q_c$, thousand tons of CO_2			14242.6		1869.8		400.0
Total without sintered ore and steam from thermal power station			1.0967		0.9534		0.5970

Notes: * – taking into account cast iron consumption for mold manufacture;
** – without considering coke-chemical and ore-mining production

Table 2. Carbon dioxide emission at JSC "ArselorMittal Kryvyy Rih" when converter steel continuous casting

Semi-finished materials, products	Emission factor (k_i), t CO_2/t	Section Q_c = 6223 thousand tons		Cast sections Q_c = 889.5 thousand tons	
		q_c, t/t	$q_c \times k_i$, t CO_2/t	q_c, t/t	$q_c \times k_i$, t CO_2/t
Rolled section	0.1071	1.0000	0.1071		
Steel, cast sections	0.0859	1.0347	0.0889	1.0000	0.0859
Pig-iron	0.5668	0.8877	0.5031	0.8579	0.4863
Sintered ore	0.2340	1.4722	0.3445	1.4226	0.3329
Lime carbonate	1.2460	0.0832	0.1037	0.0798	0.0994
Steam from thermal power station, Gkal	1.0216	0.8099	0.8274	0.7827	0.7996
Other			0.0313		0.0237
Total, k_c			2.0060		1.8278
$k_c \times Q_c$, thousand tons CO_2			12483.3		1625.8

As a result, CO_2 emission will decrease by 16112.4 - 14109.2=2003.2 thousand tons CO_2 or by 2.2887-2.0060 = 0.2827 tons CO_2/t when producing rolled section.

The more amount of killed and low-alloy steel grades (the more steel cutoff pieces in blooming department), the more benefit from steel continuous casting.

Almost each paper about measures directed on reduction of greenhouse gas emission in atmosphere pronounces substitution of open-hearth steelmaking method by converter method. There is no doubt that open-hearth process has many disadvantages as compared to converter and not only in view of CO_2 emission.

Firstly, it is difficult and sometimes

impossible to install continuous casting machines in open-hearth plants because of the fact that steel tapping is not synchronized with operation of continuous casting machines.

Secondly, open-hearth furnaces in general require a lot of repair and heavy expenses, which is especially important for the developed countries.

As for CO_2 emission and energy intensity of steelmaking, very often these issues are considered not enough, and attention is paid only to operation of steelmaking plants. But iron smelting, production of coke, sinter and lime, iron-ore extraction and dressing are necessary for steelmaking. And all these processes are accompanied by both greenhouse gas emission and power resources input, which is not considered when comparing converter and open-hearth steel.

Calculation of CO_2 emission for production of one ton of converter and open-hearth steel at JSC "Iron & Steel Works "Azovstal" is presented in **Table 3**. CO_2 emission factor (k_i) is much higher for open-hearth steel (0.4599 t CO_2/t) than for converter steel (0.1737 t CO_2/t) in steel melting shops. But in converter plants, one ton of steel needs 907.8 kg/t of pig-iron and in open-hearth plant – 626.3 kg/t. Increase of pig-iron consumption means higher consumption of steam, sintered ore, lime carbonate per ton of steel. As a result, it appears that CO_2 emission is 1.6099 t CO_2 when making 1 ton of converter steel and open-hearth steel – 1.4461 t CO_2 at JSC "Iron & Steel Works "Azovstal". This calculation does not include coke production and almost 75 % of sintered ore used at the integrated works and produced beyond JSC "Iron & Steel Works "Azovstal".

Three methods of steel smelting are applied at JSC "Iron & Steel Works "Azovstal": in converters, two-bath and one-bath open-hearth furnaces. CO_2 emission factors are 0.0837; 0.1013 and 0.2517 t CO_2/t respectively, and pig-iron consumption on steel smelting – 868.8; 811.4 and 584.3 kg/t. Factory power capacity is 784.1; 683.5 and 627.0 kg of equivalent fuel/t respectively.

Method worked out by Ukrainian State Scientific & Engineering Center "Energostal" (sample (2) of CO_2 emission calculation) allows evaluating effect of open-hearth plants substitution by converter ones with simultaneous implementation of steel continuous casting.

Calculation of CO_2 emission when producing hot-rolled sheet (3682.9 thousand t/year) at JSC "Iron & Steel Works "Zaporizhstal" is presented in **Table 4**. These data are applied to open-hearth steel casting and converter steel casting in two ways: with pig-iron consumption 868.8 kg/t of steel (approximately, as at JSC "Iron & Steel Works "Azovstal"); with pig-iron consumption by 100 kg/t less (768.8 kg/t), that is at the level reached in 80-s by metallurgy of USSR. CO_2 emission factor for converter plant with continuous casting is accepted at the level of JSC "Iron & Steel Works "Azovstal" (0.1737 t CO_2/t).

Table 3. Carbon dioxide emission at "Iron & Steel Works "Azovstal" when steelmaking

Semi-finished materials, products	CO_2 emission factor (k_i), t CO_2/t	Open-hearth steel		Converter steel	
		q_c, t/t	$q_c \times k_i$, t CO_2/t	q_c, t/t	$q_c \times k_i$, t CO_2/t
Open-hearth steel	0.4599	1.0000	0.4599		
Converter steel	0.1737			1.0000	0.1737
Pig-iron	0.8102	0.6263	0.5074	0.9078	0.7355
Sintered ore	0.1164	0.2724	0.0317	0.3852	0.0448
Lime carbonate S *	0.8200	0.0283	0.0232		
Lime carbonate R **	1.1620			0.0859	0.0998
Steam from heat electric generation plant, Gkal	0.9011	0.4402	0.3967	0.5903	0.5319
Other			0.0272		0.0242
Total, k_c			1.4461		1.6099

Notes: * – lime production in shaft furnaces;
** – lime production in rotating furnaces

Table 4. Effect of consumption indexes of semi-finished materials (q_c) on carbon dioxide emission when steelmaking at JSC "Iron & Steel Works "Zaporizhstal"

Semi-finished materials, products	Open-hearth steel, ingot pouring			Converter steel, pouring on continuous casting machines *				
					method 1		method 2	
	k_i, t CO_2/t	q_c, t/t	$q_c \times k_i$, t CO_2/t	k_i, t/t	q_c, t/t	$q_c \times k_i$, t CO_2/t	q_c, t/t	$q_c \times k_i$, t CO_2/t
Hot-rolled sheet	0.0829	1.0000	0.0829	0.0829	1.0000	0.0829	1.0000	0.0829
Rolled slabs	0.1351	1.0253	0.1385	-	-	-	-	-
Steel	0.2758	1.1567	0.3190	0.1737	1.0458	0.1817	1.0458	0.1817
Pig-iron **	0.7036	0.8500	0.5981	0.7036	0.9086	0.6393	0.8040	0.5657
Moulds	0.1543	0.0137	0.0021	-	-	-	-	-
Sintered ore	0.1798	1.3354	0.2401	0.1798	1.4275	0.2567	1.2632	0.2271
Lime carbonate	0.8070	0.0748	0.0604	1.1620	0.1166	0.1355	0.1150	0.1336
Steam from heat electric generation plant, Gkal	0.9532	0.5098	0.4859	0.9532	0.5452	0.5197	0.4855	0.4628
Other			0.0127			0.0127		0.0127
Total, k_c			1.9397			1.8285		1.6665
Total ($k_c \times Q$). thousand tons CO_2			7144			6734		6138
Q – hot-rolled sheet annual output – 3682.9 thousand tons								

Notes: * - pig-iron consumption on steel smelting for converter steel (method 1) – 0.8688 t/t; method 2 – 0.7688; for open-hearth steel – 0.7172;
** – taking into account pig-iron consumption on mold manufacture

When open-hearth steel casting, CO_2 emission factor per 1 ton of rolled sheet is 1.9397 t CO_2/t, atmospheric emission will make 7144 thousand tons of CO_2. Certainly, efficiency of open-hearth plant substitution by converter shop will depend on amount of metal cutoff pieces in blooming department, values of CO_2 emission factors in departments of previous metallurgical processes and especially in thermal power station on planned consumption of pig-iron for steelmaking and other factors for each enterprise.

Conclusions

Calculation procedure of carbon dioxide emission on manufacture of unit of product was developed for iron & steel plants. This technique allows forecasting changes of carbon dioxide emissions depending on the volume and range of commodity output, steelmaking practice and pouring, range of steel grades, consumption index of pig-iron and other factors.

It is shown that converter steelmaking taking into account all previous metallurgical processes without decrease of consumption index of pig-iron causes higher power consumption of steel and carbon dioxide emission in comparison with open-hearth smelting. These parameters can be decreased only at the expense of implementation of steel continuous casting.

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Особенности эмиссии парниковых газов на металлургических предприятиях Украины

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Цель – разработка методики прогнозирования эмиссии диоксида углерода. Предмет исследования – закономерности образования диоксида углерода на металлургических предприятиях. Анализ закономерностей исследовался расчетным путем с использованием методологии сквозной энергоемкости. В результате исследований разработана модель формирования диоксида углерода для расчета изменений объемов его эмиссии при изменении количества и сортамента товарной продукции, технологии выплавки и разливки, расхода чугуна и т.п. Методика прогнозирования может быть использована при разработке проектов совместного осуществления.