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MATERIAL AND ENERGY FLOW ANALYSIS (MEFA) – FIRST STEP IN ECO-INNOVATION APPROACH TO ASSESSMENT OF STEEL PRODUCTION

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The main goal of the study was to evaluate material and energy flow analysis (MEFA) of steel production. The application of umberto universal software to devise MEFA for the steel production was presented. The material and energy flow analysis of steel production includes a range of technologies through each unit process in integrated steelmaking route in Poland. Modelling MEFA helps a high level of technology to be reached through the effective use of resources and energy.

Key words: steel production, material, energy, flow analyses, eco-innovation

INTRODUCTION

The acceleration of the process of globalization and the growth of economic activity influence the environment. It seems important to create synergies between the innovation and environmental policies by integrating the sustainability issues into the economic process.

Driven by increasing prices and scarcity of raw materials, the iron and steel industry has made significant progress in increasing its environmental performance through a number of eco-innovations which include energy-saving solutions and re-designs of various production processes.

ECO-INNOVATION APPROACH

Innovation has long been seen as central to economic performance and social welfare. Introduction of new solutions is increasingly recognized as a significant driver of economic growth [1], so they affect a variety of organizational and processual dimensions in various branches of industry. In such perspective eco-innovation has become a fundamental tool for exploring alternative routes to sustainable development, reducing the environmental impact and optimizing the use of natural resources. Eco-innovation includes cleaner technologies, products and services that reduce environmental risk and minimize pollution and use of resources [2, 3].

The introduction of eco-innovation in the steel industry calls for evaluation of its effectiveness. Such assessment should comprehensively reflect the effects of possible changes that cause eco-innovation in processes. The article presents the use of the MEFA method for the evaluation of resources and energy consumption in the steel industry.

MATERIAL AND ENERGY FLOW ANALYSIS (MEFA)

According to the paper [4] MEFA is a method to establish an inventory for a Life Cycle Assessment (LCA) [5, 6] and it is an element of multi-criteria decision analysis (MCDA) application in steel production for development of eco-efficiency evaluation [6]. Up to now, in domestic steel industry MEFA and LCA based on industry data and laboratory tests of raw materials have been focused on the preparation of raw materials for sintering [7].

In this paper, Umberto Universal software was used for MEFA of steel production [7]. The applied software for modelling material flow, enables not only the simulation of industrial processes, but also the simulation of any processes connected with material or energy flow. Through effective use of resources and energy or waste management, modelling a material flow helps a high level of efficiency of a given process or technology to be reached. It is important to determine the aim of the analyses and boundaries of the predefined system at the very beginning of building of a model [8].

Material flow networks are a special form of the Petri net and they may be used to model material and energy flow in processes consisting of a large number of unit processes, by considering their impact on the natural environment where the given process takes place [7]. Applying Sankey diagrams enables a visual analysis of a given system to be carried out. The thicker the arrow is, the bigger the flow is. In complex chains of technology, consisting of many unit processes, the anal-

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ysis of a material or energy flow network, in the form of Sankey diagrams, allows for the location of extreme flows. In this way, it is possible to modify a given unit process in order to limit its energy consumption, or reduce the emission of pollutants.

MATERIALS AND METHODS

The objective of this study was to carry out a material flow network of national integrated steel plants. The integrated steel plant system boundary included the whole chain of steel production, from iron ore sinter plant, to hot rolling plant. The selected functional unit (FU) of this study was one ton of rolled steel produced in the national steel plants. A data inventory was obtained from existing steel plants in Poland and used to assess the inventory for eco-innovation and pollution prevention in the Polish steel industry [5].

Conducting the analysis required the following stages:

1. Determining the system boundaries;
2. Determining unit processes (transitions) considered within the system;
3. Determining the input and output (places) considered within the system boundaries;
4. Building a material flow network - including transitions, places, connections, and arrows;
5. Data inventory Life Cycle Inventory;
6. Determining assumptions and the functional unit;
7. Calculating material and energy flow;
8. Modelling the flow;
9. Building a Sankey diagram.

Material and energy flow networks, consist of transitions, places and arrows (Figure 1).

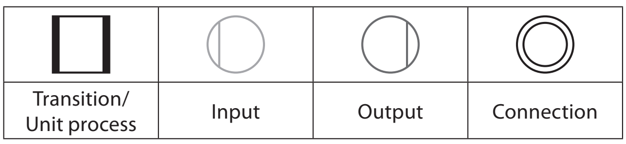

Figure 1 A graphic representation of flow network elements [7]

Each of the elements of a flow network plays a different role [7]:

- Transitions - unit processes, are presented in a flow network as squares; materials and energy are processed in transitions.
- Places - three types of places are distinguished: input, output, and connections.
- The Arrows connect places and transitions, building the structure of a material and energy flow network.

The system boundary included the following unit processes in the steel plant under analysis: the iron ore sinter plant (IOSP), blast furnace (BF), lime production plant (LPP), basic oxygen furnace (BOF), continuous casting plant (CCP) and hot rolling plant (HR).

RESULTS AND DISCUSSION

The main goal of the article was to present the material flow network across the chain of steel production.

In Figure 2 there is a model network of technology of steel production in the form of a Sankey diagram.

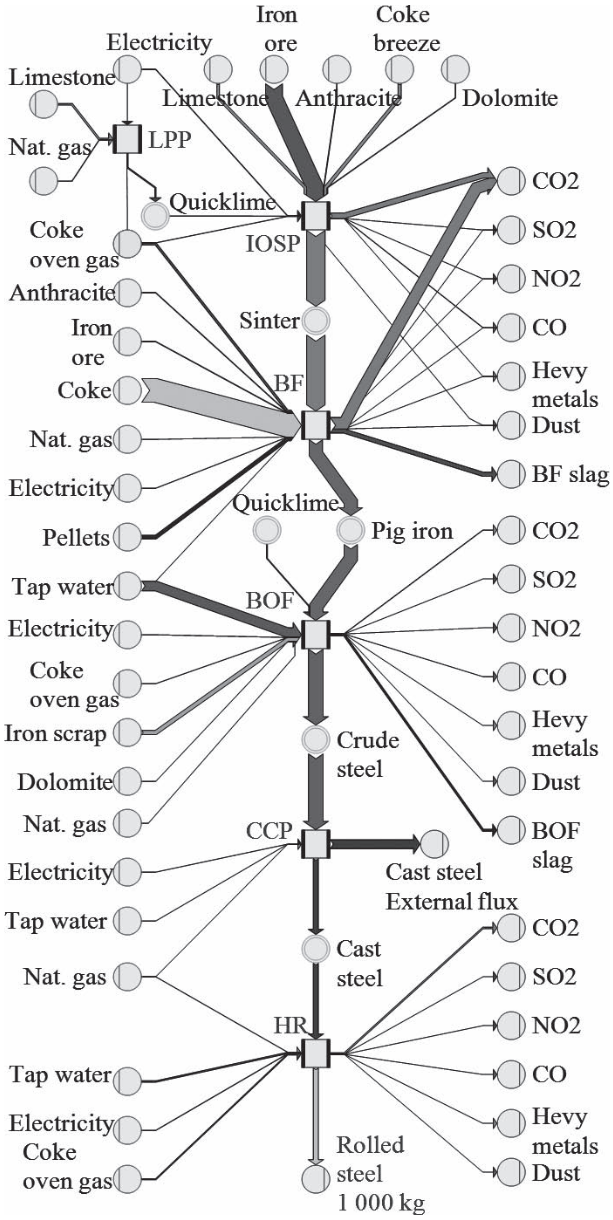

Figure 2 Material and energy flow network of steel production

Based on the input (Table 1) and output (Table 2) data inventory and taking into consideration the functional unit in the calculations, MEFA network was devised.

Sankey diagrams enabled the visualization of material flow between unit processes of the technology of steel production. An analysis of the material and energy flows for the technology of rolled steel production in the form of Sankey diagram showed that for the production of 1 Mg of rolled steel (FU), BF consume the greatest amount of energy (in the form of coke), while BOF consume the greatest amount of tap water. A significantly greater amount of emissions of CO_2 was from BF and IOSP.

Table 1 **Inventory of input data into the analyzed system**

Input			
Process	Material	Quantity	Unit
LPP	Electricity	7,03	kWh
	Natural gas	555,68	MJ
	Limestone	343,70	kg
	Coke oven gas	25,40	MJ
IOSP	Coke breeze	4 937,78	MJ
	Iron ore	3 356,7	kg
	Anthracite	897,73	MJ
	Dolomite	95,60	kg
	Electricity	221,05	kWh
	Coke oven gas	225,51	MJ
	Limestone	502,8	kg
BF	Tap water	0,98	m^3
	Anthracite	907,95	MJ
	Iron ore	102,60	kg
	Electricity	71,23	kWh
	Natural gas	39,19	MJ
	Coke oven gas	3 411,65	MJ
	Pellets	697,80	kg
	Coke	36 480,81	MJ
BOF	Coke oven gas	180,52	MJ
	Iron scrap	824,80	kg
	Electricity	77,59	kWh
	Tap water	252,86	m^3
	Dolomite	14,90	kg
	Natural gas	41,19	MJ
CCP	Tap water	1,51	m^3
	Natural gas	10,05	MJ
	Electricity	29,64	kWh
HR	Natural gas	272,29	MJ
	Electricity	113,01	kWh
	Tap water	37,04	m^3
	Coke oven gas	1 817,38	MJ

Table 2 **Inventory of output data into the environment**

Output			
Process	Material	Quantity	Unit
IOSP	CO_2	1 052,4	kg
	SO_2	2 830,0	g
	NO_2	2 157,0	g
	CO	72 145,0	g
	Hevy metals	381,0	g
	Dust	1 280,0	g
BF	Dust	245,0	g
	Hevy metals	175,0	g
	CO	2 688,0	g
	NO_2	50,0	g
	SO_2	28,0	g
	CO_2	2 256,4	kg
	BF slag	846,3	kg
BOF	BOF slag	393,8	kg
	Dust	527,0	g
	Hevy metals	211,0	g
	CO	13,4	kg
	NO_2	11,0	g
	SO_2	17,0	g
	CO_2	82,3	kg
CCP	Cast steel ext.	1 7910,0	kg
HR	Rolled steel	1 000,0	kg
	Dust	3,0	g
	Hevy metals	1,0	g
	CO	53,0	g
	NO_2	59,0	g
	SO_2	11,0	g
	CO_2	298,0	kg

According to obtained MEFA results and modification of the production process it is possible to reduce energy consumption and environmental impact by modification of chosen unit processes.

CONCLUSIONS

This is the first approach which contains a whole chain of steel production, taking into account all the inputs and outputs of the mentioned unit processes.

The Sankey diagram enabled the identification of unit processes with the biggest consumption of raw materials and energy. and the greatest amount of emissions to the environment.

Next stages of this research will be material flow cost accounting (MFCA) and holistic evaluation of eco-efficiency of steel production. based on MEFA, MFCA and LCA, which will allow the assessment and selection of the most eco-innovative method of steel production.

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Note: The responsible translator for the English language is M. Sokolowska, Gliwice, Poland