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MODEL OF TRULY CLOSED CIRCUIT OF WASTE STREAM FLOW IN METALLURGICAL ENTERPRISE

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The publication presents flows of metallurgical waste in manufacturing metallurgical enterprise. On the basis of analysis the structure of waste flows and the way of waste management within the enterprise or outside it were described. In the observation of the metallurgical waste flow a universal model of waste flow structure was created. It may be used in waste management of a metallurgical enterprise with full production cycle (from raw materials processes, through steel production up to final products).

Key words: metallurgical enterprise, metallurgical waste, analyse, waste management

INTRODUCTION

During conduction of manufacturing processes, starting from raw materials processing through different manufacturing stages up to final products with accompanying operations (transport, storage, sorting) certain amount of waste is being produced. In the analysis of the types of waste from the perspective of their reuse the enterprises alone make a decision how to recycle and reuse them. At present the priority of environmental management in manufacturing enterprises is the decrease of the amount of stored waste.

In this publication, on the basis of analysis of waste flow cycle in manufacturing processes of metallurgical enterprises, a model based on waste categorisation was created according to the place of waste creation and the possibilities of management of such waste. The interactions taking place between particular processes in metallurgical enterprise were shown in reference to waste management. A full production cycle steelworks was used as a case study.

ASSUMPTIONS FOR CONSTRUCTING THE MODEL OF WASTE STREAM FLOW IN STEELWORKS

For the purpose of this publication a model is understood as a simplified form of imaging a complex object [1]. Application of the model allows to transfer the results of conducted research on the scientific ground. Despite the fact that models simplify the object of research they also allow to order the results of analysis and their better understanding. In many cases the models have a universal character and can be applied in enterprises from a given industry branch. Assuming such understanding of the model the authors of the publication, on the basis of tests of waste stream flows in metallurgical enterprises, prepared the assumptions for the model of waste management. Waste flow in the model is treated as truly (partially) closed cycle waste management [2] because besides the recycled waste and such which return to the beginning of the production system (particular processes) there is also such waste which is not managed in a given enterprise [3]. It was assumed in construction of the model that waste can be divided into two categories: open waste and closed waste. The name of waste refers to the way it is managed. Open waste undergoes reuse only in small percent by the enterprise; usually it is sent to other external enterprises.

In the category of open waste there are also waste products which cannot at present be further used (waste temporarily stored). The waste in closed stream is managed on the premises of the steelworks. A partially closed industrial system was created during model formulation in which most waste is recycled and placed back at the beginning of another manufacturing process and/or sent to other external businesses for which the waste is a raw material for further processing [4].

During preparations of the waste stream flow cycle model in metallurgical enterprise there were three basic processes singled out: manufacturing of pig iron, manufacturing of steel and manufacturing of rolled products. The mentioned processes became key processes in the analysis of the waste flow. In each of those processes the structure of created waste was determined and the waste stream flow was observed within a given process and between the processes. A division was also made into waste that is recycled and sent back to production (closed waste) and such which is managed outside the enterprise or temporarily stored (open waste). In order

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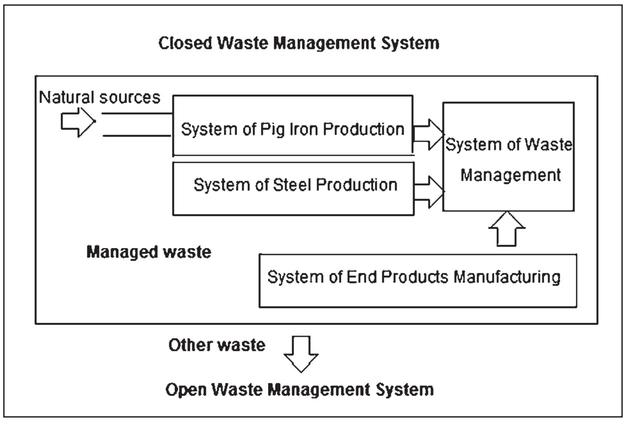

Figure 1 Model of waste management (essence)

to understand the essence of the model Figure 1 presents its simplified structure.

WASTE STREAM FLOWS IN METALLURGICAL ENTERPRISE

Numeric data used in further part of the analysis refer to an annual activity of a given steelworks. In that given year the total mass of all transported waste was 2 725 678 Mg. The biggest mass out of transported waste was the mass of slag – 1 861 529 Mg (over 68 % of mass of waste streams out of all waste). The amount of produced slag per every tonne of steel products varied from 0,6 to 0,8 Mg depending on the quality of charge materials and the type of produced metallurgical products. The remaining parts of the mass of waste were: scrap metal, slag from scrap metal, sculls, ingot ends, slurry , mesh fractions of coke, mesh fractions of sintered products, scissel, dust from iron blast furnace duster, used fireproof materials, debris and other leftovers including rubbish. The share of such waste in overall mass was 32 %. Table 1 presents the structure of waste categories produced in analysed metallurgical enterprise.

In the observation of the course of metallur gical waste stream flows in each of the processes of production a classifi cation of waste was made and it was divided into open and closed waste. In the category of open waste there were: slag and granulated slag (excluding converter slag), scrap metal slag and some of scrap metal as such, used fireproof materials, debris and other waste including municipal rubbish. Other kinds of waste were placed in the category of closed waste. Moreover, each category of waste was further segregated according to place of creation and the processes of further processing (Table 2).

System of waste fl ow S_{HT} consists of: real structure of steelworks S_H and flows F between objects O_{SH} of the structure.

$S_{HT} = <S_H, F> ; F \subset O_{SH} \times O_{SH}$

where: S_H = {SPP, SSP, SEM}, that is

SPP - System of Pig Iron Production, ***SSP*** – System of Steel Production, ***SEM*** – System of End Products Manufacturing – Rolling Mills (small, medium, large).

Table 1 **Structure of waste in steelworks [5]**

Type of waste	Amount / Mg	In waste (total) / %
Slag	1 119 706	41,080
Granulated slag	235 884	8,654
Converter slag	505 939	18,562
Compacted steel scrap	694	0,025
Steel scrap	514	0,019
Steel pit scrap	4 816	0,177
Scrap + skulls	3 588	0,132
Scrap	465 703	17,085
Ingot scraps+returns	520	0,019
Scissels	235 019	8,622
Skulls	47 586	1,746
Dust from blast - furnace dust catcher	8 050	0,295
Sinter screenings	41 700	1,530
Coke screenings	160	0,006
Sludge	17 547	0,644
Used refractory materials	1 530	0,056
Debris	25 760	0,945
Other waste + garbage	10 962	0,402
Total all	2 725 678	100,000

Table 2 **Types of metallurgical waste streams [5]**

Type of waste	Source node	Sink node	Type of stream
Converter slag	SSP-CH	SSP-SSB	C
Steel scrap	SSP-S	SPP	C
Steel scrap	SPP	SSP-SA	C
Steel scrap	SSP-O	SSP-SA	C
Scrap + skulls	SSP	SSP-SA	C
Scrap	SSP-SA	SSP-SCTA	C
Scrap	SSP	SSP-SCTA	C
Scrap	SSP-COS	SSP-SCTA	C
Ingot scraps+returns	SSP	SSP-IS	C
Scissels	SEM	SSP-SCTA	C
Skulls	SSP-COS	SSP-SA	C
Skulls	SSP-CH	SSP-SA	C
Skulls	SSP-SSB	SSP-SA	C
Skulls	SPP	SSP-SA	C
Dust from blast - furnace dust catcher	SPP	SPP-S 0-1	C
Sinter screenings	SPP	SPP-S 0-1	C
Coke screenings	SPP	SPP-S 0-1	C
Sludge	IBST	SPP-S 0-1	C
Compacted steel scrap	INPUT	SSP-SA	O
Steel scrap	INPUT	SSP-S	O
Slag	SPP	OUTPUT	O
Granulated slag	SPP	OUTPUT	O
Used refractory materials	SPP	SSP-GA	O
Debris	SSP	SSP-GA	O
Other waste + garbage	SSP	SSP-GA	O

Objects $\mathbf{F_{SH}}$ of structure $\mathbf{S_{HT}}$ include, among other: ***SPP-S 0-1*** – System of Pig Iron Production – Storage Space, ***IBST*** – Iron-Bearing Sludge Tank, ***SSP-COS*** – System of Steel Production – COS, ***SSP-CH*** – System of Steel Production – Casthouse, ***SSP-F*** – System of Steel Production – Foundry, ***SSP-SA*** – System of Steel Production– Scrap Aisle, ***SSP-SSB*** –System of Steel

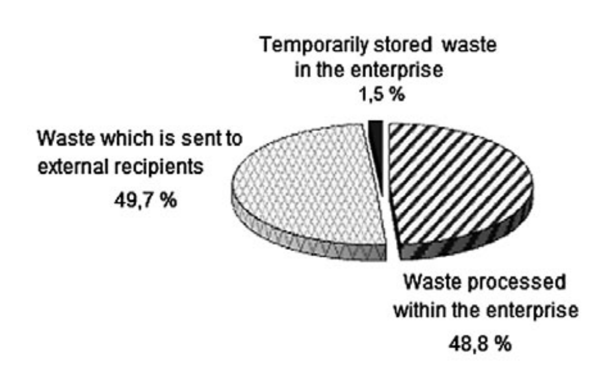

Figure 2 Waste management in steelworks

Production – Slag Storage Bay, ***SSP-SCTA*** – System of Steel Production – Scrap Cars Transfer Area, ***SSP-IS*** –System of Steel Production – Ingots Storage, ***SSP-GA*** – System of Steel Production – Grading Area, ***SSP-SY*** – System of Steel Production – Storage Yard.

Another step was to determine the amount of waste processed within the enterprise and temporarily stored as well as the amount of waste which is sent to external recipients. Figure 2 presents the percentage share of waste managed in a given calendar year in steelworks.

The conducted analysis shows that almost half of waste, 1 331 012 Mg, is processed in next manufacturing processes. The biggest amount processed is the converter slag 505 939 Mg and scrap metal 365 384 Mg. Third position on the list is scissel (235 019 Mg). Among the waste sent to external recipients in overall mass the slag dominates (1 1 19 706 Mg). Slag is 82,6 % of all waste purchased by external companies. Debris dominates among waste which is temporarily stored (25 760 Mg) and is 65,9 % of waste which is not managed by the steelworks. Details concerning the amount of produced waste with division into ways of management are presented in Table 3.

The analysis of the waste stream flow used in manufacturing processes in steelworks allowed for ordering them according to categories: waste managed in the same process in which they were created and waste which can be managed by being used in other production processes.

The Table shows that 80,5 % of waste is managed within the same production processes in which it was created and only 19,5 % is managed by the use in processes which precede or come after the process where waste was created. Waste such as: converter slag, sculls, ingot ends – and returns are processed again in the process of steel production (76,76 % of all metallurgical waste). The mesh fractions of sintered products and dust from iron blast furnace duster are used in process of pig iron production (3,75 %). Among 19,5 % of waste used in other processes than those in which it was created the biggest amount is scissel (17,66 %) which is sent from the rolling process directly to the process of steel production.

Table 3 Management **of metallurgical waste [5]**

Type of waste	Source node	Sink node	Amount / Mg
Slag	SPP	OUTPUT	1 119 706
Granulated slag	SPP	OUTPUT	235 884
TOTAL waste sent outside the enterprise			**1 355 590**
Compacted steel scrap	INPUT	SSP-SA	694
Steel scrap	INPUT	SSP-SY	130
Used refractory materials	SPP	SSP-GA	1 530
Debris	SSP	SSP-GA	25 760
Other waste + garbage	SSP	SSP-GA	10 962
TOTAL waste temporarily stored in steelworks			**39 076**
Converter slag	SSP-CH	SSP-HS	505 939
Steel scrap	SSP-SY	SPP	384
Steel pit scrap	SPP	SSP-SA	4 490
Steel pit scrap	SSP-O	SSP-SA	326
Scrap + skulls	SSP	SSP-SA	3 588
Scrap	SSP-SA	SSP-SCTA	365 384
Scrap	SPP	SSP-SCTA	43 621
Scrap	SSP-COS	SSP-SCTA	56 698
Ingot scraps+returns	SSP	SSP -IS	520
Scissels	SEM	SSP-SCTA	235 019
Skulls	SSP-COS	SSP-SA	23 954
Skulls	SSP-CH	SSP-SA	366
Skulls	SSP-SSB	SSP-SA	21 849
Skulls	SPP	SSP-SA	1 417
Dust from blast - furnace dust catcher	SPP	SPP-S 0-1	8 050
Sinter screenings	SPP	SPP-S 0-1	41 700
Coke screenings	SPP	SPP-S 0-1	160
Sludge	IBST	SPP-S 0-1	17 547
TOTAL waste managed in the steelworks			**1 331 012**
TOTAL ALL			**2 725 678**

Table 4 **Management of metallurgical waste – process approach**

Type of waste	Source node	Sink node	Amount / Mg
Converter slag	SSP-CH	SSP-HS	505 939
Steel pit scrap	SSP-O	SSP-SA	326
Scrap + skulls	SSP	SSP-SA	3 588
Scrap	SSP-SA	SSP -SCTA	365 384
Scrap	SSP	SSP-SCTA	43 621
Scrap	SSP-COS	SSP -SCTA	56 698
Ingot scraps+returns	SSP	SSP -IS	520
Skulls	SSP-COS	SSP-SA	23 954
Skulls	SSP-CH	SSP-SA	366
Skulls	SSP-HS	SSP-SA	21 849
Dust from blast - furnace dust catcher	SPP	SPP-S 0-1	8 050
Sinter screenings	SPP	SPP-S 0-1	41 700
Coke screenings	SPP	SPP-S 0-1	160
TOTAL amount of waste managed in steel production			**1 072 155**
Steel scrap	SSP -SY	SPP	384
Steel pit scrap	SPP	SSP-SA	4 490
Scissels	SEM	SSP -SCTA	235 019
Skulls	SPP	SSP-SA	1 417
Sludge	IBST	SPP-S 0-1	17 547
TOTAL amount of waste managed outside the manufacturing process			**258 857**

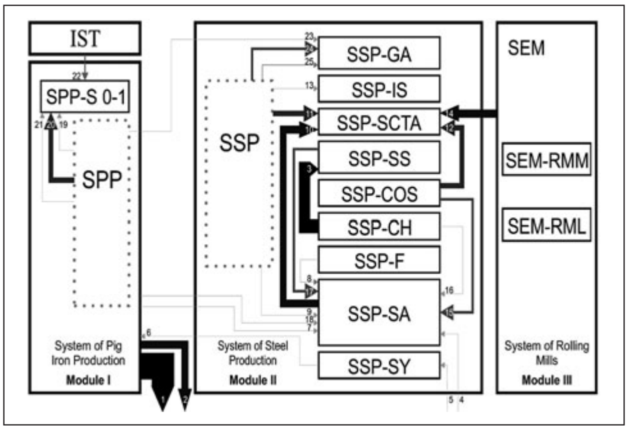

Figure 3 Model of waste stream flow in metallurgical enterprise
Legend:
1. Slag; **2**. Granulated slag; **3**. Converter slag; **4**. Compacted steel scrap; **5**, **6**. Steel scrap; **7**, **8**. Steel pit scrap; **9**. Scrap + skulls; **10**, **11**, **12**. Scrap; **13**. Ingot scraps + returns; **14**. Scissels; **15**, **16**, **17**, **18**. Skulls; **19**. Dust from blast - furnace dust catcher; **20**. Sinter screenings; **21**. Coke screenings; **22**. Sludge; **23**. Used refractory materials; **24**. Debris; **25**. Other waste + garbage

HOLISTIC APPROACH OF WASTE FLOW IN STEELWORKS – MODEL OF METALLURGICAL WASTE MANAGEMENT

In order to prepare the final model of metallurgical waste management a structure of Sankey's diagram was used to show interactions between process of waste creation and the places of their management [6] Structure of the model is presented in figure 3.

CONCLUSIONS

The aim of this publication was understanding dynamics system of feedback between the place of waste creation and the place of their management in process approach in metallurgical enterprise. The construction of research methodology may serve as a sort of pattern for analysis of waste stream flows in metallurgical enterprises with full production cycle. In most recent models of business the manufacturing enterprises are elements of supply chains and are the components of surrounding [7]. Truly closed waste management is in accordance with the assumptions of sustainable development.

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Note: The responsible translator for English language is D. Grochal, Katowice, Poland