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QUALITATIVE CHARACTERISTICS OF FOUNDRY DUSTS

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Recycling has become a top priority research task in highly developed countries, addressed from the perspective of environmental protection as well as cost-effectiveness of products. In many countries, including Poland, landfilling is still commonly accepted as a method of choice for waste neutralisation. This paper presents results of studies on the environmental impact of iron-bearing foundry waste in the event of its landfill disposal.

Key words: steel, foundry, dust, blasting, water extract

INTRODUCTION

For environmental and economic reasons, foundries are forced to pay more attention to waste management problems. This particularly applies to waste dust, since its form is particularly unfavourable and harmful to natural environment, while the related landfilling charges are high. Individual casting operations are characterised by considerable amounts of dust of diverse physical and chemical properties being produced. This is particularly noticeable in processes of smelting, liquid metal working, cleaning and fettling of castings [1-10]. Experiences of the countries most advanced in terms of environmental protection imply that minimisation of waste generation “at the source”, i.e. prevention of waste production, is indeed the most efficient waste management strategy. In metallurgy, however, consequences of the environmental protection oriented efforts, primarily focused on air protection, are quite the opposite. Although using more and more efficient filters does contribute to reduction of dust emission into the foundry’s internal and external environment, but at the same time, the quantity of dust accumulated in filters increases. Not only is that an issue typical of foundries, but the same challenge also faces steelmaking processes, particularly smelting in electric-arc furnaces (EAF). Therefore, with regard to this type of dust, several dedicated solutions were proposed to enable waste management by taking its diversified chemical composition into consideration [11]. The approximated ratios referred to in the literature of the subject, based on a proportion between the dust quantity and the mass of castings produced, make it easier to perform a preliminary assessment of dust emission depending on the given foundry’s efficiency. They also highlight they scale of issues that need to be tackled in the foundry dust management area. Some model values of these indicators are as follows [10-13]: cast iron melting in a cupola furnace – up to 30 kg/Mg of castings, charging and melting in an induction furnace – up to 20 kg/Mg of castings, moulding sand preparation processes – up to 6 kg/Mg of castings, knocking out castings from green-sand moulds – ca. 1 kg/Mg of castings, cleaning and fettling – up to 40 kg/Mg of castings. It has also been for the large variety of technological processes used in founding that properties (chemical, mineralogical or grain composition) of the emitted dust is significantly diversified. Therefore, the qualitative and quantitative characteristics depend on multiple technological factors, also conditioning the manner in which dust can be utilised.

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EXPERIMENTAL

In accordance with the applicable legal regulations in force, an owner of waste (also in the form of dust) is obliged to prevent the waste generation in the first instance, and secondly to prepare the waste for recycling where its generation could not have been successfully prevented. The least desirable method of waste handling is neutralisation at landfills. The most fundamental legal acts applicable in the European Union to which member states must adhere are directives. The directive which lays down the criteria and procedures for waste to be accepted at landfills is Directive 2003/33/EC [14]. In accordance with the guidelines implemented by the said directives, the metallurgical waste types subject to the study were assessed for their physical and chemical parameters. The waste types in question were analysed with reference to the conditions they must meet in the event that they are sources of effluents discharged into water or land as well as the content of substances particularly harmful to the aquatic environment [15]. The relevant tests were conducted at a laboratory certified by the Polish Centre for Accreditation for sampling and testing of waste specimens. The dust subject to examination was produced in steel and iron casting. The relevant production plants used either EAFs or the OTTO Junker induction furnaces for smelting. The metal was then subject to secondary metallurgy processes using argon and/or spheroidisation by application of the PE cored wire method. Casting moulds were made by either mechanical or manual means, and the moulding sand used was bentonite-based and chemically cured. Castings were cleaned by vapour blasting in tumbling shot-blasting machines of both hanger and continuous type The abrasives used for working of the castings removed from the blasting machines subject to tests contained steel/cast iron shot or quartz sand as the main

Table 1 **Chemical composition of the foundry dusts examined / %wt**

No	C_{LECO}	O_{LECO}	Mg	Al	Si	S	K	Ca	Mn	Fe	Zn	Cr	Cu
1	0,8	22,73	5,97	0,4	2,97	0,5	1,2	7,83	23,7	30,93	1,47	0,53	0,15
2	5,36	23,63	-	2,7	14,7	1,27	0,93	1,17	6,9	38,73	3,1	0,2	-
3	3,32	6,39	-	0,23	1,77	-	-	0,1	0,53	87,77	-	0,05	0,13
4	4,17	3,68	0,07	1,87	3,23	0,07	0,1	0,47	1,03	86,0	-	0,07	0,2
5	2,91	2,22	-	1,47	2,83	0,13	-	0,07	0,58	89,57	-	-	-
6	3,35	12,63	-	6,43	5,7	0,37	0,2	0,23	0,63	69,87	-	0,13	-
7	0,46	6,92	0,17	1,0	2,47	-	-	0,13	1,37	86,4	-	1,07	-
8	0,99	10,53	0,12	0,91	16,82	0,18	0,14	0,17	0,63	68,73	-	0,27	-
9	2,64	39,17	0,43	1,63	28,33	-	0,13	0,53	0,47	26,4	-	-	0,32
10	1,23	30,5	-	2,37	38,7	-	0,17	0,73	0,37	24,83	-	-	0,07
11	14,37	20,33	1,67	7,43	28,83	0,43	0,9	17,57	0,23	7,83	-	-	0,35

Table 2 **a), b). Values of contamination ratios for substances classified as particularly harmful to aquatic environment based on tests of water extracts of the waste types studied (values obtained for industrial waste, according to Directive 91/271/EEC (as amended) [15] / mg/l**

a)

No	Pollution								
	Arsenic	Barium	Cadmium	Chromium total	Copper	Mercury	Molybdenum	Nickel	Lead
1	< 0,001	0,021	< 0,0005	0,029	0,0040	0,0040	0,0120	< 0,0040	< 0,010
2	< 0,001	0,060	0,005	0,020	< 0,0040	0,0040	0,020	0,0071	0,019
3	< 0,001	0,285	< 0,0005	< 0,003	0,0046	0,00055	0,0338	0,0054	0,0105
4	< 0,001	0,694	< 0,0005	< 0,003	0,0069	0,0029	0,0377	0,0195	< 0,010
5	< 0,001	0,568	< 0,0005	0,004	< 0,0040	0,00065	0,0176	0,0049	0,013
6	< 0,010	2,32	< 0,0005	0,0036	< 0,0040	< 0,0005	0,0116	0,0144	0,022
7	< 0,001	0,063	< 0,0005	< 0,003	< 0,0040	0,0034	0,0653	0,0043	< 0,010
8	< 0,001	0,161	< 0,0005	< 0,003	< 0,0040	< 0,0005	0,1490	0,0075	0,0103
9	< 0,001	0,090	< 0,0005	< 0,003	0,0188	< 0,0005	0,0238	< 0,0040	< 0,010
10	< 0,010	0,110	< 0,0005	< 0,003	0,0052	< 0,0005	0,0130	< 0,0040	< 0,010
11	0,0047	0,072	< 0,0005	< 0,003	0,0244	< 0,0005	0,0151	0,0124	0,018
Limits*	0,1	2	0,4	0,5	0,5	0,06	1	0,5	0,5
Stand.*	8	9	9	9	9	10	9	9	9

b)

	Pollution							
No	Antimony	Selenium	Zinc	Chloride	Fluoride	Sulfate	Dissolved organic carbon	pH
1	< 0,050	< 0,001	1,46	750	1,2	230	3,38	8,1
2	0,020	0,018	1,98	500	0,76	330	5,4	5,87
3	< 0,050	< 0,001	0,069	< 2	2	12	10,3	7,6
4	< 0,050	< 0,010	0,068	4,1	43	1,3	19,4	7,8
5	< 0,050	< 0,001	0,031	< 2,0	22	6	2,4	7,4
6	< 0,050	< 0,001	0,069	4,1	67	3	146	7,8
7	< 0,050	< 0,001	0,023	< 2,0	0,23	2,2	4,67	7,2
8	< 0,050	< 0,001	0,030	4,6	13	21	6,13	7,5
9	< 0,050	< 0,010	0,135	3,5	0,98	4,40	16,6	9,3
10	< 0,050	< 0,010	0,110	3,3	1,2	5,2	17,2	8,9
11	< 0,050	< 0,001	0,102	12,0	0,51	48,0	48,2	8,9
Limits*	0,3	1	2	1000	25	500	30	6,5-9,0
Stand.*	9	11	9	12	12	12	12	14

Additional information: **Limit*** −the highest limit; **Stand*** − designation according to the standard
The values which exceeded the highest permissible contamination ratios have been marked in bold.

component. The following dust types were tested (sample number provided in parentheses):

- dust produced in smelting in an EAF (samples 1,2) and in the OTTO Junker crucible furnace (samples 3, 4)
- dust from a tumbling shot-blasting machine produced in shot blasting of castings (samples 5, 6, 7, 8),
- dust from a blasting machine using quartz sand-based abrasive (samples 9,10),
- dust from bentonite-based moulding sand preparation stations (sample 11).

Chemical composition of the dusts subject to testing has been provided in Table 1.

In accordance with domestic legal regulations implementing the relevant European Union directives, hazardous waste may include waste containing compounds of such elements as vanadium, chromium, nickel, copper, zinc, arsenic, tin, barium and mercury. The dusts assumed to be examined were sampled from EAFs, OTTO Junker induction furnaces and a tumbling shot-blasting machine (samples 6,7,8), and they contained at least one of the foregoing compounds, which may be decisive of their classification as hazardous waste. The samples subject to the study were water extracts of foundry dust tested for the content of the following components: arsenic, barium, cadmium, chromium, copper, molybdenum, nickel, lead, antimony, zinc, mercury, selenium, bromide, chloride, fluoride, sulfate, total and dissolved organic carbon, total dissolved solid, alkalinity. The results thus obtained were compared with the highest permissible levels of pollutants which may be discharged into aquatic environment

Table 3 **a), b). Acceptable limits of leaching: A - for inert waste; B - for waste other than inert and hazardous; C - for hazardous waste; D - for solid not included in the reactions of hazardous waste, (liquid/solid phase = 10 l/kg (mg/kg dry mass) – according to the requirements of the EU [14] / l/kg**

a)

No	Pollution								
	Arsenic	Barium	Cadmium	Chromium total	Copper	Mercury	Molybdenum	Nickel	Lead
1	<0,01	0,21	<0,005	0,29	0,040	0,040	0,120	<0,040	<0,10
2	<0,2	0,60	0,05	0,20	<0,040	0,040	0,20	0,071	0,19
3	<0,01	2,85	<0,005	<0,03	0,046	0,006	0,338	0,054	0,105
4	<0,01	6,94	<0,005	<0,03	0,069	0,029	0,377	0,195	0,105
5	<0,01	5,68	<0,005	0,04	<0,040	0,0065	0,176	0,049	0,129
6	<0,01	23,2	<0,005	0,036	<0,040	<0,005	0,116	0,144	0,222
7	<0,01	0,625	<0,005	<0,03	<0,040	0,034	0,653	0,043	<0,10
8	<0,01	1,61	<0,005	<0,03	<0,04	<0,005	1,49	0,075	0,103
9	<0,01	0,901	<0,005	<0,03	0,188	<0,005	0,238	<0,04	<0,10
10	<0,10	1,10	<0,005	<0,03	0,052	<0,005	0,130	<0,04	<0,10
11	0,047	0,717	<0,005	<0,03	0,244	<0,005	0,151	0,124	0,176
A	0,5	20	0,04	0,5	2	0,01	0,5	0,4	0,5
B	2	100	1	10	50	0,2	10	10	10
C	25	300	5	70	100	2	30	40	50
D	2	100	1	10	50	0,2	10	10	10

b)

	Pollution								
No	Antimony	Selenium	Zinc	Chloride	Fluoride	Sulfate	Dissolved organic carbon	Total dissolved solid	pH
1	<0,50	<0,01	14,6	7500	12	2300	33,8	170	8,1
2	0,20	0,18	19,8	5000	7,6	3300	54	27398	5,87
3	<0,50	<0,01	0,69	<20	20	120	103	960	7,6
4	<0,50	<0,01	0,680	41	430	130	194	2600	7,8
5	<050	<0,01	0,314	<20	220	60	24	1230	7,4
6	<0,50	<0,010	0,692	41	670	30	1460	7290	7,8
7	<0,50	<0,01	0,231	<20	2,3	22	46,7	310	7,2
8	<0,50	<0,01	0,303	46	130	210	61,3	1100	7,5
9	<0,50	<0,01	1,35	35	9,8	44	166	1730	9,3
10	<0,50	<0,10	1,10	33	12	52	172	1560	8,9
11	<0,50	<0,10	1,02	120	5,1	480	482	6380	8,9
A	0,06	0,1	4	800	10	1000	500	4000	8,1
B	0,7	0,5	50	15000	150	20000	800	60000	5,87
C	5	7	200	25000	500	50000	1000	100000	nonst.*
D	0,7	0,5	50	15000	150	20000	800	60000	min. 6

* parameter nonstandard.

The values which exceeded the highest permissible contamination ratios have been marked in bold

(Table 2a,b) and analysed from the perspective of the facility type where individual waste types may be landfilled (Table 3a,b).

RESULTS AND DISCUSSION

In accordance with the applicable European Union requirements [15], substances classified as particularly harmful to aquatic environment and causing pollution of waters have been divided into two categories: substances which should be eliminated and substances the generation of which should be restricted.

Based on the contamination ratios obtained from the tests of water extracts of the dust types studied, it was established that (Table 2a,b):

- water extracts of all the dust types studied did not contain substances considered as particularly harmful to aquatic environment and causing contamination of water, which should be eliminated; the mercury content in the extracts tested was also below the permissible threshold which is 0,06 mg/l;
- the permissible levels of contamination ratios established for water extracts of the EAF dust (2) and the OTTO induction furnace dust (4) were found to be exceeded for the following substances particularly harmful to aquatic environment:
- the pH value of the EAF dust (2) was lower than required, implying a pollutant whose production should be restricted;
- the fluoride content in the induction furnace dust (4) was exceeded; fluoride causes water contamination, and so its production should be restricted;
- based on tests of water extracts of dust from blasting machines using steel/cast iron shot as the abrasive, there was one case (6) when the permissible value of the barium, fluoride and dissolved organic carbon (DOC) ratios was found to be exceeded, and all these substances are classified as water contaminants whose production should be restricted;
- based on tests of water extracts of dust from blasting machines using quartz sand as the abrasive, there was one case (9) when the permissible pH value was found to be exceeded, implying that this substance is a contaminant whose production should be restricted;
- in the water extract of dust from moulding sand preparation stations (11), the limit value was found to be exceeded for dissolved organic carbon (DOC), implying that this substance is a water contaminant whose production should be restricted.

According to the requirements of the European Union [14] establishing criteria and procedures for the acceptance of waste at landfills, one of the relevant criteria taken into consideration is the waste assessment against the permissible values. The waste sorts subject to the assessment are classified as waste regularly produced in a single process or as waste generated on an irregular basis. The waste types discussed in this article, namely different types of dust, are regularly produced in a single process. Both the facility and the waste generation process were thoroughly investigated, the raw materials and the process itself were properly identified, and the facility operator provided all the required information, particularly concerning any changes in raw materials.

The waste assessment is conducted with reference to the permissible values established for the EU member states [14], and these values along with the values obtained for the waste (dust) types studied, have been collated in table 6 in a breakdown into individual types of landfill sites. 3.

Based on tests of water extracts of all the waste dust types studied (Table 3a,b), it was found that the limit value was exceeded for antimony, for both landfilled and inert waste types.

Furthermore, in water extracts of EAF dusts (1,2) the permissible content of mercury, zinc, chloride and sulphate was exceeded, while the water extract of EAF dust (2) additionally showed the permissible contents of cadmium, selenium and total dissolved solid (TDS) to be exceeded. Permissible content thresholds analysed in water extracts of induction furnace dusts (3,4) were found to be exceeded for fluoride, while water extract (4) contained excessive amount of mercury. Water extracts of dust from blasting machines using steel/cast iron shot as the abrasive were found to have exceeded the permissible threshold values for fluoride (5,6), barium (6), mercury (7), molybdenum (7,8), dissolved organic carbon DOC (6) and total dissolved solids (6). The permissible content of fluoride was found to be exceeded in one of water extracts (10) of dust from blasting machines using quartz sand as the abrasive. In the water extract of dust from moulding sand preparation stations (11), the permissible threshold content values were exceeded for total dissolved solids (TDS).

Figure 1 shows the elements (except for antimony) for which the permissible levels were exceeded in water extracts of the dust types studied against the limits established for inert waste.

Based on the results thus obtained, one may conclude that none of the dust types studied may be classified as inert, and consequently admitted to being dumped at inert waste landfill sites.

The conclusion which may be formulated with reference to tests of water extracts and based on a compari-

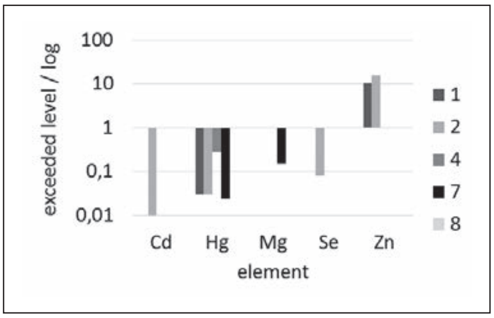

Figure 1 Permissible levels exceeded for inert waste based on water extracts of the dust types subject to tests

son of permissible values for waste other than inert and hazardous is that induction furnace dust (4) and blasting machine dust (5) contained excessive amounts of fluoride, while blasting machine dust (6) was characterised by exceeded values of ratios for fluoride and dissolved organic carbon, and even for hazardous waste.

CONCLUSIONS

The waste generated in production processes, provided that they could not be prevented or recycled, must be landfilled in a manner which does not pose a threat to natural environment. For that purpose, a special procedure was developed, aimed at simplification of appropriate classification of waste [6]. What is required in the first instance is defining whether the given waste is hazardous. In this respect, considerable aid is provided by the list of waste types referred to in article 7 of Directive 2008/98/EC [8], since all waste types marked with an asterisk (*) in the list are considered hazardous. According to the said list, the hazardous waste generated in the iron and steel industry include:

- solid wastes from gas treatment containing hazardous substances (code 10 02 07*),
- flue-gas dust containing dangerous substances (code 10 09 09*),
- spent grinding bodies and grinding materials containing dangerous substances (code 12 01 20*).

With reference to the analysis of the water extracts, it should be highlighted that none of the dust types subject to the study can be dumped at inert waste landfills. Bearing in mind the costs related to the landfill storage of waste other than inert as well as the EU recommendations on utilisation of the waste being produced, the following should be undertaken:

- EAF dusts containing less than 4 % of Zn should be recycled to the furnace as iron-bearing material which additionally enhances the slag expanding process,
- induction furnace dusts containing more than 80 % of Fe should be consumed in production of briquettes and used as feedstock for electric arc or induction furnaces,
- dusts from blasting machines where steel/cast iron shot is used as the abrasive, once this material is relieved of its abrasive properties, should be used as feedstock for smelting furnaces of either EAF or induction type,
- on account of minimum content of substances harmful to the aquatic environment, dusts from blasting machines using quartz sand as the abrasive and dusts from moulding sand preparation stations should be utilised in the road building industry.

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REFERENCES

[1] Davis J. et al. Time-dependent material flow analysis of iron and steel in the UK. Part 2. Scrap generation and recycling. Resources, Conservation and Recycling 51 (2007), 118–140

[2] Yellishetty M. et al: Environmental life-cycle comparisons of steel production andrecycling: sustainability issues, problems and prospects. Environmental science & policy 14 (2011), 650–663

[3] Kaur G., Siddique R., Rajor A.: Micro-structural and metal leachate analysis of concrete made with fungal treated waste foundry sand. Construction and Building Materials 38 (2013), 94–100

[4] Mitterpach J. et al.: Environmental evaluation of grey cast iron via life cycle assessment. Journal of Cleaner Production 148 (2017), 324-335

[5] Olmez G. M. et al.: The environmental impacts of iron and steel industry: a life cycle assessment study. Journal of Cleaner Production 130 (2016), 195-201

[6] Tongpool R. et al.: Analysis of steel production in Thailand: Environmental impacts and solutions. Energy 35 (2010), 4192-4200

[7] Hassan M. et al.: Influence of iron species on integrated microbial fuel cell and electro-Fenton process treating landfill leachate. Chemical Engineering Journal 328 (2017), 57-59

[8] Van der Sloot H.A., Kosson D.S., van Zomeren A.: Leaching, geochemical modelling and field verification of a municipal solid waste and a predominantly non-degradable waste landfill. Waste Management 63 (2017), 74–95

[9] Holtzer M.: Porównanie procesu wytapiania żeliwa w żeliwiaku, piecu indukcyjnym i piecu obrotowym. Odlewnictwo – Nauka i Praktyka 5 (2005), 41-49

[10] Holtzer M.; Niesler M.; Podrzucki C.; Rupniewski M.: Wykorzystanie żeliwiaka do recyklingu pyłów odlewniczych. Archives of Foundry 20 (2006) 6, 111-121

[11] Lis T.; Nowacki K.: Determination of physical and chemical properties of electric arc furnace dusts for the purposes of their utilization. Steel Research 83 (2012) 9, 842-851.

[12] Zych J.; Smyksy K.; Postuła J.: Rydziński R. Recykling pyłów w odlewni żeliwnej średniej wielkości. Przegląd Odlewnictwa 12 (2009), 626-628.

[13] CAEF-BAT for the Abatement of Atmospheric Pollution in the Ferrous Feundry Industry, Raport European Commission – DG XI.E.I 1977.

[14] Directive 2003/33/EC: Council Decision of 19 December 2002 establishing criteria and procedures for the acceptance of waste at landfills pursuant to Article 16 of and Annex II to Directive 1999/31/EC

[15] Council Directive 91/271/EEC of 21 May 1991 concerning urban waste-water treatment and Directive 2010/75/eu of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control).

[16] Commission Decision of 18 December 2014 amending Decision 2000/532/EC on the list of waste pursuant to Directive 2008/98/EC of the European Parliament and of the Council.

Note: The responsible for English language is Franspol, Katowice, Poland