2011 International Conference on Biomedical Engineering and Technology
IPCBEE vol.11 (2011) © (2011) IACSIT Press, Singapore

Heavy metals dust from electric arc furnace

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Abstract. The dust collected in bag filters at the end of the EAF fume extraction system is teh final product of a series of phenomena, such as the emission of particles from the steel bath, the transport of these particles from the steel bath, the transport of of these paticles by the gas flow in the fume extraction system, the in-flight physico-chemial transformations they undergo, etc. The results of the morphological anaysis of the EAF dust show that the dust formation process takes place in two steps: first, the emission of dust " precursors", i.e. vapours, metal droplets, and solid particles, inside the furnace; second, the conversation of those precursors into dust by agglomeration and physico-chemical transformations.
This dust contains hazardous, leachable elements such as zinc, lead or cadmium which require EAF dust to be stored in specific landfills.

Keywords: EAF dust, gases emission, heavy metals, metal droplets, vapours

1. Introduction

Mechanism dust formation by bubble bursting

The Electric Arc Furnace (EAF), designed for steelmaking from recycled scrap iron (Figure 1), also co-produces between 15 to 25 kg of dust per ton of steel. Dust formation is strongly linked to the process which can be divided into five steps:

- furnace charging: the scrap and the additives (lime, coal, etc.) are loaded into special charging buckets which are then emptied into the furnace;
- melting: an electric arc is created between the graphite electroides and scrap which entails the charge melting and the formnation of a steel bath covered by a slag of layer, volatile solute species (e.g.) zinc begin to be removed;
- refining: in this step of the process, phosphorus is removed from the steel bath by interfacial reactions between the slag and liquid metal, injection of oxygen promotes the decarburization reaction with dissolved carbon and bubbles of carbon monoxide (CO) are formed, which helps to remove other dissolved gases;
- slag forming: the CO-bubbles crossing the slag layer make it foam, the foamning process being enhanced by the addition of coal powder;
- casting: after the composition and the temperature of the bath have been controlled, the liquid steel is cast.

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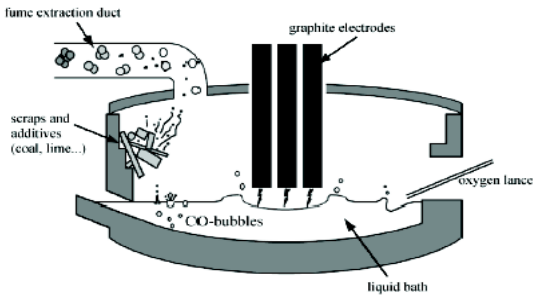

Figure 1 Shematic representation of an Electric Arc Furnace

The projection of liquid steel and slag droplets by bursting of CO bubble has been recognized as the principalk mechanism of dust emissuion in EAF. Very few studies about bubble-burst at the surface of liqud metal have been reported [1]. However, in order to uderstand the phenomenon, useful results and observations can be found in the abundant literature about the air-water system. From these studies, the bubble/burst process can be split up nto three steps which give rise to two types of droplets (Figure 2).

When emerging at the surface (Figure 2.a), a bubble lifts up a liquid that progresivelly gets thinner under the influence of drainage, when the bubble comes to rest. The shape of a bubble floating at the surface of a iquid can be determined by folowing the approach proposed by Unger *et.al.* [2]

As the film reaches a critial thickness, it breaks up and the bubble cap is disintegrated into fie droplets called film drops (Figure 2.b). Many authors [3, 4, 5, 6] studied the number and size of film drops as a function of the bubble size. The number is proportional to the surface of the film. The size distribution is wide: from 0.3 to 500μm.

After the disruption of the bubble cap, the cavity remaining at the liquid surface closes up, creating an upward Rayleigh jet that is unstable and can break up into droplets usually called jet drops (Figure 2.c). The number of jet drops never exceeds ten and and decreases when the bubble size increases [3, 6]. Their sizes have been found to rande between 0.1 and 0.18 times the diameter of their parent bubble for air-water system [7, 8].

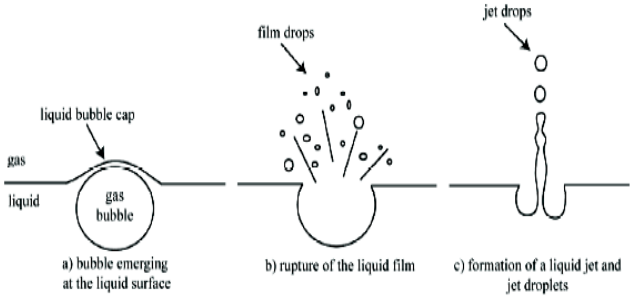

Figure 2 Schematic representation of the burst of a bubble o a lichid surface

Jet drop come from the desintegration of the upward jet created after the removal of the bubble cap. Their number increases when the bubble size decreases, and their size represents 12 to 18% of the parent bubble size. The siye of CO-bubbles formed in EAF remains little known. However, analysis of foaming slag samples and numerical calculations indiate that their sizes are probably between 2 and 20 mm [9]. According to our results, such bubbles are expected to produce jet drops whose sizes vary from 0.2 mm to almost 4 mm, which is much larger than most of the particles found in EAF dust samples. As observed in laboratory furnace, jet drops are not exhausted by fume extraction system and are likely to fall back into the steel bath. Jet drops can thus hardly contribute to dust formation from bubble burst in EAF.

Film drops are emitted during the disintegration of the liquid cap which covers the bubble at the surface of the bath. Their morphology and size range are very close to those of the partices contained in EAF dust. The amount of projections produced by bubble burst in EAF varies between 0.016 ad 0.028 kg m^{-3} [9]. These figures are close to those derived from laboratory experiments (Table 1). Further associated with the conclusion of jet drop size study, they show that, when a bubble bursts, it is mostly the film drops that conbtribute to dust formation. The resuts also reveal a significant derease of the amount of film drops

resulting from bubble burst when the bubble size decreases. Moreover it have been brought out the existence of a critical bubble size (around 4.5 mm) under which no film drop is detected. Whie this phenomenon was already evidenced by Spiel [6] for air – water systems, it had never been observed in the case of liquid steel.

The ayms of teh experiments are to clariy the way the bubble burst at a liquid steel bath surface and to quantity the resulting emissions, i.e. film drops and jet drops (Leybold) (Figure 3)

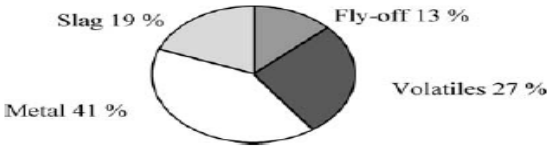

Figure 3 Part of metal and slag projection, volatilization and direct fly-off in final dust. [10]

According to the preceeding analysis and experimental quantifications of each mechanism made by Birat et al. [11], The prevailing mechanisms of dust precursor emssion appear to be the volatilization (27% of the dust) and the bursting of CO bubbles (60% of the dust). The direct flu-off of solid particles remains very limited if sufficient operating cautions are taken. As for the projections at the impact points ofthe arc or of the oxygen jet, most of them fail to be carried up by the fume extraction sysrtem, due to their size, and fall into the liquid bath.

2. The physical characterization of dust

The dust removal of gases from process does not influence the mercury concentration, while the improving of dust removal systems considerably reduces the cadmium emissions. More than 90% from these emissions result in the melting-refining.

Table 1 rest of 10% are secondary emissions resulted at charging, slag tapping and leaks (fugitive emissions) [12].

Table 1. Dust emissions from electric arc furnace

Emission type	Operation /Place	Scrap		Iron sponge	
		Dust emissions kg/t	% Total	Dust emissions, kg/t	% Total
Primary	Melting – refining	14	93	14	95,6
Secondary	Charging	0,4	2,75	0,05	0,33
	Off-gases	0,5	3,5	0,5	3,4
	Space from around of furnace	0,1	0,75	0,1	0,67
	TOTAL	15	100	14,65	100

The filters system with selenium allows the concentration reducing of mercury below 0.01 mg/Nm^3.

According to PARCOM – ATMOS requires the reduction of gaseous emissions of cadmium and mercury can be carried out by improving of sorting of the scrap and to forbid the reusing of scrap with cadmium and mercury [13].

In Tables 2 and 3 the dust quantities in grams in screen sizing and percent from total weight resulted from samplings of tests made at the out from furnace and at chimney are listed. It is noted that fractions ≤ 50 μm have performed the highest catching ratio on the filters used at the samplings from chimney.

For one in the measures stages a chemical analysis on one dust sample from the workshop atmosphere on the filter of cellulose - ester with 0.81 μm dimension during the melting of the first bucket and the chemical analysis of metallic bath at melting and refining have been made.

In Table 4, the results of chemical analysis on the dust samples taken during the steel elaboration in EAF are shown.

Table 2 Granulation composition of dust

Sampling Place	**Dimensions μm**	**Sampling quantities, g**

		Melting				Refining	
		Bucket I		Bucket II			
		G	%	G	%	G	%
Out from furnace	500	0.0695	30.27	0.0197	10.10	0.1137	38.15
	200	0.1278	56.66	0.0304	15.53	0.0462	15.5
	80	0.0238	10.36	0.0394	20.13	0.0372	12.48
	20	0.0061	2.22	0.0384	19.62	0.0619	20.77
	0.8	0.00339	1.47	0.0678	34.62	0.0390	13.08
Total		0.22959	100	0.1957	100	0.298	100
Chimney	200	0.0066	49.25	0.0053	53.53	0.0559	65.53
	80	0.0014	10.44	0.0024	24.24	0.0101	11.84
	50	0.0005	3.73	0.0012	12.12	0.0025	2.93
	0.8	0.0049	36.56	0.0011	10.10	0.0168	19.69
TOTAL		0.0134	100	0.0099	100	0.0853	100

Table 3 Granulation composition of dust

Sampling place	Dim. μm	Sampling quantities, g											
		Melting										Refining	
		Bucket I		Bucket II		Bucket III		Bucket IV		Bucket V			
		kg/t	%	kg/t	%	kg/t	%	kg/t	%	kg/t	%	kg/t	%
Out of furnace	500	0.399	55.45	0.245	51.42	0.067	10.50	0.054	11.53	0.007	4.22	0.109	19.11
	200	0.180	25.0	0.074	15.53	0.18	28.23	0.151	3224	0.136	82.17	0.108	18.94
	80	0.056	7.78	0.096	20.57	0.365	55.66	0.256	54.66	-	-	0.331	58.04
	10	0.057	7.92	0.0344	7.22	0.0302	47.4	0.002	0.42	0.0055	3.32	0.0127	2.22
	0.8	0.0273	3.79	0.0246	5.16	0.005	0.78	0.0053	1.13	0.017	10.27	0.0095	1.66
Total		0.7195	100	0.4764	100	0.6375	100	0.4683	100	0.1655	100	0.5702	100
Chimney	150	0.005	18.52	0.001	5.84	-	-	-	-	-	-	0.003	17.65
	85	0.008	29.63	0.002	11.69	0.002	14.81	0.001	12.66	0.001	16.13	0.006	35.29
	50	0.014	51.85	0.011	64.33	0.009	66.66	0.006	75.95	0.005	80.64	0.008	47.05
	0.8	-	-	0.031	18.13	0.0025	18.2	0.0009	11.39	0.0002	3.22	-	-
Total		0.027	100	0.0171	100	0.0135	100	0.0079	100	0.0062	100	0.017	100

Table 4 Chemical analysis of filters dust and workshop atmosphere at elaboration in EAF

	Dust – filter sample							Aspirated dust	Metal sample analysis		
Element %	P1 a)	P2 a)	P3 b)	P4 b)	P5 c)	P6 c)	P7 c)	P8 d)	Element %	P 8.1 e)	P 8.2 e)
Fe tot	32.7	32.72	41.37	47.92	29.0	35.0	23.4	38	C	0.1	0.44
Ni	0.1	0.08	0.10	0.09	0.073	0.015	0.1	0.07	Ni	0.21	0.2
Co	0.005	0.005	0.005	0.007	0.005	0.005	0.004	0.007	Co	0.04	
Cr	0.276	0.28	0.37	0.28	0.27	0.13	0.16	0.24	Cr	0.25	0.25
Zn	10.75	10.80	1.47	0.90	14.5	6.6	20.9	1.62	Zn	<0.005	<0.005
Pb	0.22	0.27	0.17	0.20	4.1	2.64	3.96	1.29	Pb	<0.005	<0.005
Cu	0.35	0.35	0.29	0.15	0.204	0.240	0.245	0.64	Cu	0.52	0.26
As	0.012	0.011	0.041	0.039	0.030	0.05	0.021	0.025	As		0.003
Mn	3.33	3.23	4.18	1.78	3.28	2.85	3.04	2.49	Mn		0.13
V	Traces	Traces	No detected	No detected	0.004	0.004	0.003	Traces	V		
Cd	0.10	0.11	0.006	0.006	0.35	1.181	0.07	0.012	Cd		
P_2O_5	0.36	0.50	0.17	0.11				0.22	P	0.013	0.034
Al_2O_3	12.0	10.5	5.75	5.3				11.9	Al	0.37	0.25
SiO_2	6.4	5.85	7.88	3.9				8.4	Si	0.002	0.012
MgO	2.85	4.2	7.55	4.5				2.43	Mg	0.003	0.003
CaO	5.2	6.4	7.55	7.74				2.9	Sb	0.005	0.003
PC	10.5	10.5	3.55	5.34				10.3	Sr	0.008	0.006
									S	0.031	0.036
									W	0.02	0.904
									Sn	0.012	0.011
									Mo	0.06	0.06

Obs.: a) P1, P2 – dust samples from bags filters that supply furnace of 100 t

b) P3, P4 – dust samples from bags filters that supply 2 furnaces of 10 t

c) P5, P6, P7 – from literature

d) P8 – dust sample aspirated from workshop of furnace of 100 t

e) P8.1, P82 – samples of metal elaborated in the furnace of 100 t to which correspond the dust sample no. 8

3. Determination of emission level of heavy metals contained in dust

In Table 5, the emission level for the heavy metals performed in the dust caught from the space around the electric arc furnace have been calculated when the cleaning unit has not operated.

Table 5 Emissions level of dust at the electric arc furnace

Elem.	Emissions level at melting, g/t				PARCOM – ATMOS
	Bucket I	Bucket II	Bucket III	Bucket IV	
Dust	2883	243	108	109	60 – 200
As	0.59	0.06	0.027	0.027	0.06-14
Cd	0.29	0.029	0.013	0.013	0.03-1.5
Cr	9.53	0.97	0.43	0.44	0.3-2.0
Cu	15.25	1.56	0.69	0.7	0.3-1.0
Ni	1.66	0.17	0.076	0.076	0.1-0.6
Pb	30.75	3.13	1.39	1.41	5-20
Zn	38.6	3.94	1.75	1.77	20-90
Mn	59	6.05	2.69	2.71	-
Co	0.16	0.017	0.008	0.008	-

According to recommendations **PARCOM-ATMOS,** the dust emissions with content of heavy metals (As, Cd, Cr, Cu, Hg, Ni, Pb, Zn, Se) are covered in the range of 60 – 200 g/t for the elaboration of carbon steel. In the case of the aggregate protecting shell and usage a cleaning plant as bags filter, the dust removal level gets to 5 – 10 mg/Nm^3 [13].

4. Conclusion

Granulation and chemical analyses of dust samples has pointed out the following properties:

-the dust granulation emitted at chimney is prevalent < 50 μm (in 18–36% out of all below 0.8 μm);
-contents of heavy metals such as:
Mn, Zn, Pb, Cu, Cr, Ni in dust are high.

The values of heavy metals emissions in some samples exceed the required ones by PARCOM – ATMOS (for Europe)**,** such as: Cr, Cu, Ni, Pb.

Thus, from the output values measured it has been shown that only 15% of gases volume that comes out of the furnace are taken over by the catching system through the 4the hole, the rest ones being scattered in shed and exhausted in atmosphere through skylights.

The main causes of inefficient catching system are:

- the operating of exhauster below the nominal capacity (110,000 Nm^3/h as against 180,000 Nm^3/h);
- the leakinesses the door, arched roof – hearth, the ringed space around the electrodes that allow to enter uncontrolled of air into furnace;
- the exhaust of false air on the line of exhausted gases mainly between penstock and combustion chamber.

As a result it should be taken into account that the fine fractions adhere to the heavy metals, some of them being carcinogen.

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