International Journal on Emerging Technologies **8**(1): 357-362(2017)

ISSN No. (Print) : 0975-8364
ISSN No. (Online) : 2249-3255

Input Output Mass Balance of Trace Elemental Species at a Typical Indian Coal Fired Power Plant

Nitin Goyal*, Anil Dutt Vyas** and Satendra Kumar Jain**
**Department of Civil Engineering, Manipal University Jaipur, Jaipur.*
***National Thermal Power Corporation, Noida*

(Corresponding author: Nitin Goyal)
(Received 28 December, 2016 accepted 18 January, 2017)
(Published by Research Trend, Website: www.researchtrend.net)

ABSTRACT: The element concentrations and distributions in coal, bottom ash, pulverized-fuel ash (PFA, ash collected in the ESPs) and fly ash (as present in the flue gases downstream of the ESP) of a typical coal-fired power plant of India were studied. The study was aimed to establish the relationship between the trace elemental concentrations in the different process streams. For this purpose mass balances were determined to obtain a good understanding of the accuracy of the measurements. A total of 9 test series were performed by way of carrying three tests on each of the three 500 MW units.

This paper reports the input output mass balance of elements (As, Se, Cd, Pb, Ni, Co, Cu, Cr, Mn, Zn, F, B, and S) during combustion of coal in generating electricity. This includes assessment of elements present in coals fed and their partitioning in bottom ash, fly ash and flue gas emissions. The input and output mass balance assessments are reported in terms of the unaccounted mass balance of each of the elements; the ratio of the elements in ash to fuel *i.e* coal and emission factors.

Keywords: Coal fired power plant; trace elements; input-output analysis; mass balance

I. INTRODUCTION

Coal based thermal power generation has always been a concern due to the enormous amounts of trace gas emissions in the atmosphere. The Central Pollution Control Board (CPCB) [a statutory organisation under the Ministry of Environment, Forest and Climate Change (MoEF & CC), Government of India], has recently introduced revised norms for the emissions from thermal power plants which include stringent emissions norms for particulates and oxides of sulphur and nitrogen along with the addition of limits for emissions of mercury (CPCB, 2015).

The present study quantifies emissions of several trace elements from a typical Indian coal fired power plant. The main objectives of this study were:

- To assess the level of trace elements (As, Se, Cd, Pb, Ni, Co, Cu, Cr, Mn, Zn, F, B, S) present in coals fed to the power plant.
- To assess the quantum of trace elements release through wastes in terms of gas and solid at different unit processes involved in the generation of electricity.
- Mass balance of the trace elements of three boilers in the plant, right from coal fed to emissions, particulate as well as gaseous phase. Determination of the ratio of trace element content in ash samples to the content in fuel and emission factor for each of the element monitored.

II. SAMPLING AND ANALYSIS

The study was carried out at three different units of a thermal power plant (each having 500 MW capacity). These pulverized coal boilers were equipped with Electrostatic precipitators (ESPs) of high efficiency (~99.9%) to arrest the particulate matters from the emitting flue gas.

To achieve the mass balance objectives, a sample collection scheme was followed as presented in Figure 1. The samples were collected from various points from the raw material to ultimate disposal as presented in Table 1.

Coal samples were collected from coal feeder in triplicate for each of the Boiler units. Pulverized coal samples (coal fines) were collected from the pipe lines. Grab Coal Reject samples were collected for each set of measurement from the respective boiler units. Grab Ash samples were collected for each set of measurement from the respective boiler units for Economiser, APH, ESP and Ash Silo. All samples were analysed as per applicable USEPA 3050B, 3051A, 3052 & 9214 analysis protocols.

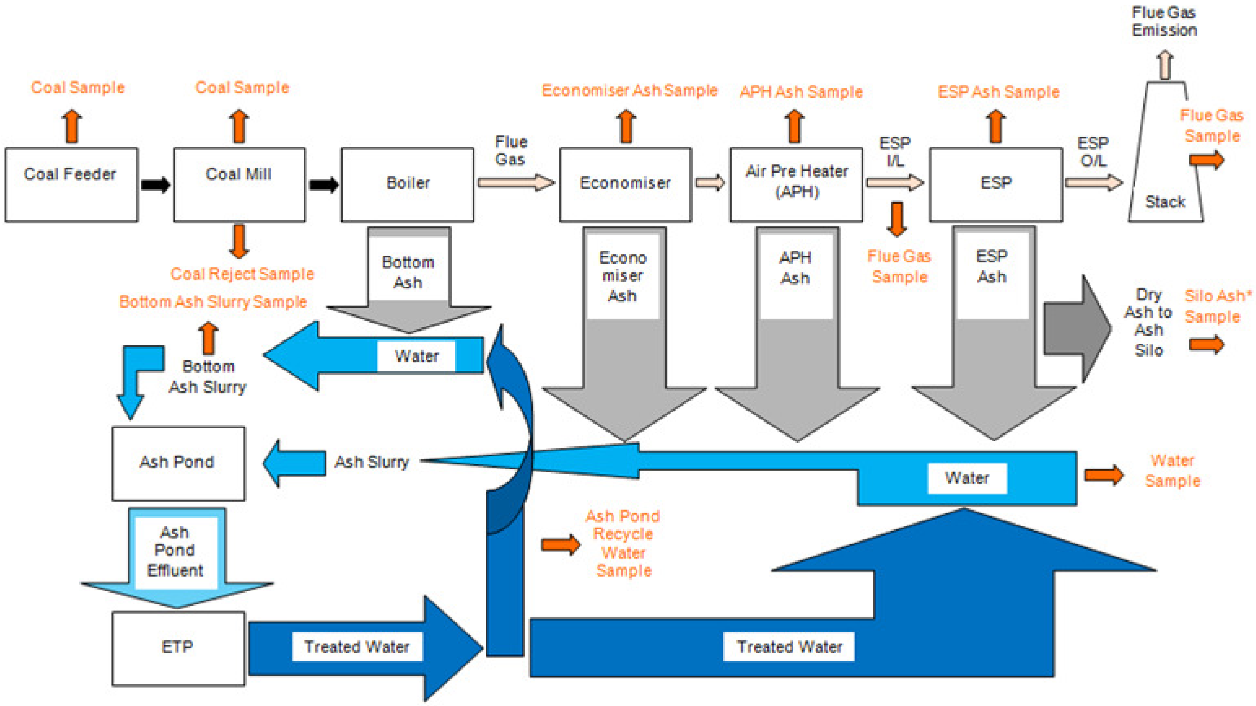

Fig. 1. Sampling Scheme for Mass Balance Study.

Table 1: Emissions Monitoring Scheme.

S. No.	Sampling	Sample / Material	Numbers of samples from each of boiler units	Total number of samples
1	Coal	Coal Samples from Feeder	3	9
		Coal Fines after mill	3	9
2	Coal Reject	Coal Reject Samples from Coal Mill	3	9
3	Ash	Economiser Hopper Ash Samples	3	9
		APH Hopper Ash Samples	3	9
		ESP Hopper Ash Samples	3	9
		Ash from Silo (only available for unit no. 4)	3	3
		Bottom Ash (In the form of Bottom Ash Slurry)	3	9
4	Water	Raw Water	3	9
		Ash Pond Recycle Water	3	9
5	Flue Gas	ESP Inlet	3	9
		Stack	3	9

Grab Bottom Ash Slurry samples were collected for each set of measurement from the respective boiler units. Grab Raw Water and Ash Pond Recycle Water samples were collected for each set of measurement from the respective boiler units.

Water and Bottom Ash Slurry samples were analysed as per applicable APHA 22nd Edn. 2012 - 3120B & 2005 – 4500C analysis protocols. Flue gas sampling was carried out at ESP Inlet and Stack for each set of measurement for the respective boiler units, as shown in Fig. 2.

Fig. 2. Flue Gas Monitoring ESP Inlet.

The emissions of trace elements were determined by the EPA method 29. The method included seven ice-bath-chilled impingers connected in a series with leak-free ground glass fittings for collecting gaseous emissions. The first impinger was empty and was used as a moisture trap. The second and third impingers, which contained 100 ml of 5% (v/v) HNO_3/ 10% (v/v) H_2O_2, absorbed and retained trace elements in the gaseous phase. The fourth and fifth impingers contained $KMnO_4$ for elemental Hg capture. The seventh impinge contained 200-300 g of dried and pre-weighed silica gel, which was employed to determine the moisture gain and prevent moisture condensation in the pump and the metering device.After each sampling, solution samples recovered from the back-half of the sampling trains were analyzed using inductively coupled plasma optical emission spectrometry (ICP-OES). Detailed sampling procedures for halogen measurements applied in this study can be seen in EPA Method 26A. After particulates were removed by filtering, the flue gas sample was extracted and pulled through a series of glass impingers containing dilute sulfuric acid and dilute sodium hydroxide solutions. The hydrogen fluoride was dissolved in the acidic solution and formed fluoride (F^-) ions. Fluorine has a very low solubility in the acidic solution and passed through to the alkaline solution where they are hydrolyzed to form a proton, the halide ion, and the hypohalous acid. Sodium thiosulfate was also added in excess to the alkaline solution. The halide ions in the separate solutions were measured by ion chromatography (IC) system.

III. RESULTS AND DISCUSSION

The mass balance calculations were done using the following formula:

Input concentrations of trace Element (TE) in grams per hour (g/h)

=Coal Flow rate (kg/h) * Concentration of TE in Coal (g/kg)

Output concentrations of Trace Element (TE) in grams per hour

=Economiser Hopper Ash deposition rate (kg/h) * Concentration of TE in Economiser Hopper Ash (g/kg)

+Air Pre Heater Hopper Ash deposition rate (kg/h) * Concentration of TE in APH Hopper Ash (g/kg)

+ESP Hopper Ash deposition rate (kg/h) * Concentration of TE in ESP Hopper Ash (g/kg)

+Stack Emission gas flow rate (Nm^3/h)* Concentration of TE (gaseous) in Stack Emission (g/Nm^3)

+Stack Emission gas flow rate (Nm^3/h) * Concentration of TE (particulate phase) in Stack Emission (g/Nm^3)

Table 2 presents the coal flow rates in various unit operations that were used for calculations in this study. Tables 3, 4 and 5 present the partitioning of trace elements at various unit operations in Unit 2, Unit 4 and Unit 5, respectively.

Table 2: Coal Flow Rates in Various Unit Operations.

Parameter	Unit	Unit A	Unit B	Unit C
Coal Flow	Kg/h	267000.0	322000.0	325000.0
Water Flow (to form Bottom Ash Slurry)	Kg/h	164728.3	198661.1	200512.0
Bottom Ash Slurry Flow (20% of total ash + water in proportion 1:8)	Kg/h	185319.4	223493.8	225576.0
APH Hopper Ash Flow (3% of total ash)	Kg/h	3088.7	3724.9	3759.6
Economiser Hopper Ash Flow (7% of total ash)	Kg/h	7206.9	8691.4	8772.4
ESP Hopper Ash Flow (70% of total ash)	Kg/h	72068.6	86914.2	87724.0
Flue Gas Flow at ESP Outlet	Nm^3/h	2615112.5	2700511.0	2633866.6
Total Ash Flow (Ash Percentage in Coal x Coal Flow)	Kg/h	102955.2	124163.2	125320.0
Bottom Ash	Kg/h	20591.0	24832.6	25064.0

Table 3: Input - output mass balance of elements at UNIT A.

All units in g per hour			
Specie	Input	Output	% Unaccounted
As	243.0	214.1	11.9
B	2865.4	2388.3	16.6
Cd	272.8	226.3	17.0
Co	1472.5	1383.9	6.0
Cr	4837.6	3850.6	20.4
Cu	3541.8	2980.8	15.8
F	2563.2	2132.0	16.8
Mn	28490.2	24277.2	14.8
Ni	3991.7	3322.1	16.8
Pb	2744.3	2506.7	8.7
S	394839.6	366826.6	7.1
Se	271.5	218.9	19.3
Zn	6879.7	5969.1	13.2

Table 4: Input - output mass balance of elements at UNIT B.

all units in g per hour			
Specie	Input	Output	% Unaccounted
As	190.9	166.5	12.8
B	2330.9	2067.5	11.3
Cd	291.0	238.6	18.0
Co	1504.1	1246.8	17.1
Cr	5806.4	4568.7	21.3
Cu	3866.6	3158.8	18.3
F	2799.1	2138.9	23.6
Mn	31694.2	28248.3	10.9
Ni	4057.5	3453.9	14.9
Pb	2885.8	2794.1	3.2
S	377395.6	306506.3	18.8
Se	272.8	230.8	15.4
Zn	6467.6	5917.1	8.5

Table 5: Input - output mass balance of elements at UNIT C.

All units in g per hour			
Specie	Input	Output	% Unaccounted
As	222.9	190.9	14.4
B	2570.5	2268.4	11.8
Cd	267.0	219.4	17.8
Co	1566.8	1408.7	10.1
Cr	6326.1	4832.1	23.6
Cu	4873.2	4053.1	16.8
F	2727.9	2109.6	22.7
Mn	32113.9	28712.1	10.6
Ni	4016.6	3691.7	8.1
Pb	2808.4	2686.3	4.3
S	503579.8	435957.2	13.4
Se	277.2	206.3	25.6
Zn	6895.3	5749.2	16.6

This table displays total input and output concentrations of various trace elements and presents the percentage of unexplained mass that could not be accounted during the present mass balance study. The reasons for unaccounted mass may be:

- Volatility of the monitored species
- Uncertainty associated with laboratory analyses
- Representativeness of the samples collected from various unit operations

Ratio of Trace Elements and Emission Factors

The ratio of trace elements with respect to the amount of elements in ash samples to the fuel were computed and are presented in Table 6.

Table 6: Ratio of Trace Elements in Ash Samples versus Fuel (Coal).

Specie	Unit 2	Unit 4	Unit 5
As	0.88	0.87	0.86
B	0.83	0.89	0.88
Cd	0.83	0.82	0.82
Co	0.94	0.83	0.90
Cr	0.80	0.79	0.76
Cu	0.84	0.82	0.83
F	0.83	0.76	0.77
Mn	0.85	0.89	0.89
Ni	0.83	0.85	0.92
Pb	0.91	0.97	0.96
S	0.93	0.81	0.87
Se	0.81	0.85	0.74
Zn	0.87	0.91	0.83

IV. CONCLUSIONS

This study on mass balance of trace elements of a STPS comprised of several components *viz.* flue gas monitoring from three stacks of different capacities of the power plant, ash effluent sampling (Bottom Ash, Economizer Ash, APH Hoppers, ESP Inlet, ESP Outlet, ESP Hoppers) and liquid effluent amongst others.

The application of mass balance approach resulted in a satisfactory account for all the monitored species. The unaccounted mass varied from 3% to 25% of the overall input mass for different species.

REFERENCES

[1]. CPCB (2015). New Emission Standards vide Notification No. S.O. 3305(E) dated 07.12.2015. *Environmental Regulations for Coal Based Thermal Power Plants*.

[2]. Goodarzi F, Huggins FE and Sanei H (2008). Assessment of elements, speciation of As, Cr, Ni and emitted Hg for a Canadian power plant burning bituminous coal. *International Journal of Coal Geology*, **74** (1): 1–12.

[3]. Klein DH,Andren AW, Carter JA, Emery JF, Feldman C, Fulkerson W, Lyon WS, Ogle JC and Talmi Y, (1975). Pathways of thirty-seven trace elements through coal-fired power plant. *Environment Science and Technology*, **9**(1): 973–979.

[4]. Quispe D, Perez-Lopeza R, Silvac LFO and Nietoa JM(2012). Changes in mobility of hazardous elements during coal combustion in Santa Catarina power plant (Brazil). *Fuel*, **94**(1): 495–503.

[5]. Reddy MS, Basha S, Joshi HV and Jha B (2005). Evaluation of the emission characteristics of trace metals from coal and fuel oil fired power plants and their fate during combustion.*Journal of Hazardous Materials*, **123**(1): 242–249.

[6]. Senior CL, Helble JJ and Sarofim AF (2000). Emissions of mercury, trace elements, and fine particles from stationary combustion sources. *Fuel Processing Technology*, **65** (1): 263–288.

[7]. Yi H, Hao J, Duan L, Tang X, Ning P and Li X (2008). Fine particle and trace element emissions from an anthracite coal-fired power plant equipped with a bag-house in China. *Fuel*, **87**(10): 2050–2057.