



A COMPARATIVE RISK ASSESSMENT OF HAZARDOUS TOXIC AND POTENTIALLY TOXIC ELEMENTS GENERATING FROM COAL FIRED POWER PLANT AND WASTE WATER TREATMENT PLANT, THAILAND

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Abstract: Fly ash from Mae Moh power plant in Lampang province, northern Thailand (unit 6, 8, 10 and 11) was investigated to find out the heavy metals (As, Cd, Hg, Pb and Zn) content of fly ash. Every metal content except mercury is at higher level than the background soil. The average arsenic content was two times higher than the background soil and unit 11 contains the largest amount of arsenic (148.5 mg kg^{-1}). Mercury content of fly ash in the dumping site was not detectable. Sludge, end product of wastewater treatment plant, from Nong Kaem wastewater treatment plant was also investigated. The average arsenic content was higher in fly ash (89.56 mg kg^{-1}) than sludge (22.01 mg kg^{-1}) whereas cadmium, lead, zinc and mercury content was higher in sludge ($0.56, 306.07, 1963.23$ and 3.97 mg kg^{-1} respectively) than fly ash ($0.46, 10.07, 90.73$ and 0 mg kg^{-1}).

Keywords: Fly ash, sludge, heavy metal, coal, power plant, Thailand

Introduction

Coal is the most carbon intensive among fossil fuels, emitting 80% more carbon per unit of energy than gas and 29% more than oil. Over the next 15 years, world coal use is expected to increase more than 2% annually. Besides energy, varieties of by-products are also obtained from the combustion of coal, such as fly ash (about 80%), bottom ash (about 20%), flue gas desulfurisation sludge and so on. Coal power plant wastes contain concentrated levels of arsenic, cadmium, chromium, lead, selenium, sulfates, boron and other contaminants. According to a crude estimation, more than 300 billion tons per year of fly ash are produced in the world of which 95.4 millions metric tons are from USA (Stewart and Kayoncu, 1999).

Mae Moh power plant is the largest electricity generation plant in Thailand. This plant is using 40,000 tons of lignite per day available in the nearest mining area. Around 30% of this lignite is converted into ash of which 80% is fly ash and 20% is bottom ash. This fly ash is contaminated with higher amount of toxic and potentially toxic elements like over three times higher content of arsenic, fourteen times higher of mercury, etc than the background soil (Brigden *et al.*, 2002). The fine particles in fly ash are small enough to be inhaled into the extremities of the lung airways, and as a result it can lead to adverse human health effects (Dudka and Adriano 1997; Brigden *et al.*, 2002).

Sewage sludge is the end product from wastewater treatment plant, which is generally called sludge. Sludge may contain both heavy metals and pathogenic microbes, which restricts its beneficial use. Nongkaem wastewater treatment plant, Thailand is using the wastes from Bangkok Metropolitans and produce huge amount of sludge.

Presently, fly ash is used mainly for land filling and in cement industries thus they are releasing huge amount of heavy metals into the immediate environment by leaching and making the environment contaminated. The sludge from that wastewater treatment plant is used mainly in the agricultural field which also liberating huge

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amount of heavy metals. These heavy metals are finally deposited in human body through plants/animals and are the cause of different types of deformities/diseases. The study was conducted to determine the heavy metals contents in fly ash from Mae Moh Power Plant and sewage sludge from Nongkaem wastewater treatment plant, which deteriorate the environment.

Materials and Methods

Collection of fly ash and sewage sludge: Fly ash samples were collected from unit 6, 8, 10 and 11 of the Mae Moh coal fired power plant in Lampang, Thailand. The samples were crushed until homogenous and sieved through a 2-mm mesh. The dewatered sludge samples were collected from Nong Kaem central wastewater treatment plant immediately after coming out from the plant. Care was taken during sludge collection to avoid moisture loss by evaporation from the sludge. The collected fly ash and sludge were stored in the cold room (<5 °C) in sealed plastic containers.

Characterization of fly ash and sewage sludge: Fly ash and sewage sludge were analyzed mainly for heavy metals. The analysis was done in the laboratory of Chulabhorn Research Institute (CRI), Bangkok, Thailand. Prior to this analysis some parameters like moisture content, TKN, etc were measured in the laboratory of Environmental Engineering and Management program, AIT (Table 1).

Table 1. Parameters with analyzing methods of fly ash and sludge.

Name of the parameter	Extraction method	Method/Reference
Moisture content (%)	-	Oven dry method
pH	1:1 (Raw material: Distilled water)	pH Meter
Total Kjeldahl Nitrogen (TKN %)	Digestion reagent Conc. H ₂ SO ₄	Standard Methods (4500/APHA, 1995)
Total Phosphorus (%)	Perchloric acid digestion	Colorimetric method using UV spectrophotometer, (O'Halloran, 1993)

Analysis of heavy metals

Sample preparation: Samples (both fly ash and sewage sludge) were oven dried overnight. The dried sludge samples were then sieved through 100-mesh size. Since atomic absorption spectrometer deals with the liquid form of samples, microwave (CEM, MARS) acid digestion was done for all the samples by following the standard of the machine.

Sample analysis: The digested samples were filtered by filter paper (Whatman # 47) and were analyzed by Atomic Absorption Spectroscopy (AAS) for heavy metals. Trace metals in solution such as Zinc (Zn), and mercury (Hg) was analyzed by adding cold vapor generator with Flame Atomic Absorption Spectroscopy (FAAS, Varian). Graphite Furnace Atomic Absorption Spectroscopy (GAAS, Varian: model 220Z) was used for analyzing As, Cd and Pb. For the analysis in GAAS, some chemical modifier was co-injected with the samples in the graphite tube. Calibration curves for different metals were prepared by using the calibration standard prepared instantly from different reagent stocks (1000 ppm, Merck) along with one blank sample. In case of Hg, standard was prepared in 5% HNO₃ (69%) + 5% HCl (37%). Twenty-five per cent SnCl₂ in 20% HCl was used as a reducing agent in case of mercury analysis. Calibration curves were prepared in the range of 0-50 ppb for As, 0-30 ppb for Pb, 0-2.0 ppb for Cd, 0-15 ppb for Hg and 0-0.6 ppm for Zn. Any sample exceeded the calibration range was diluted accordingly and reanalyzed.

Results

Characterization of fly ash and sludge: The collected fly ash from unit 11 and sludge were characterized (Table 2). There was no moisture in the fly ash but the moisture content of sludge was 73.58%. Sludge had higher TKN and phosphorus content than fly ash whereas the pH of fly ash was higher than sludge.

Table 2. Characterization of fly ash and sludge.

Name of the properties	Fly ash	Sludge
Moisture content (%)	0	73.58
PH	12.03	6.93
TKN (%)	0.051	2.23
Phosphorus (%)	0.082	1.88

Concentration of heavy metals in fly ash and sludge: It was observed that heavy metal contents varied between different units of the power plant and also varied significantly between fly ash and sludge (Table 3). The fly ash was collected from four different units of the power plant, i.e. unit 6, 8, 10 and 11. The arsenic

content of fly ash varied remarkably among different units. These differences are due to different in lignite coal compositions. The highest arsenic content was found in unit 11 followed by unit 6, unit 10 and unit 8.

Table 3. Concentration of heavy metals in fly ash and sludge.

Sample name	Amount of heavy metal (mg kg ⁻¹)				
	As	Cd	Pb	Zn	Hg
Fly ash (unit 6)	82.97 ± 0.24	0.56 ± 0.03	8.88 ± 1.46	99.87 ± 0.003	0
Fly ash (unit 8)	59.57 ± 0.27	0.34 ± 0.02	8.43 ± 0.10	88.41 ± 0.004	0
Fly ash (unit 10)	67.18 ± 0.95	0.30 ± 0.01	8.02 ± 0.21	84.12 ± 0.004	0
Fly ash (unit 11)	148.50 ± 2.12	0.62 ± 0.01	14.93 ± 1.11	90.51 ± 0.09	0
Sludge	22.01 ± 2.18	0.56 ± 0.92	306.07 ± 15.07	1963.23 ± 0.07	3.97 ± 0.28

The average cadmium (Cd) content of fly ash and sludge was 0.454 and 0.56 mg kg⁻¹, respectively. The cadmium content of fly ash varied significantly in different units of the power plant. It was the highest in unit 11 and trailed by unit 6, unit 8 and unit 10. The cadmium content of unit 11 was higher than that of sludge.

Lead (Pb) content is extremely high in sludge than fly ash, i.e. 306.066 and 10.063 mg kg⁻¹ for sludge and fly ash, respectively. Among different units of the power plant, unit 11 had the highest amount of lead followed by unit 6, unit 8 and unit 10. However, unit 6, 8 and 10 had similar amount of lead.

Zinc (Zn) content of sludge and fly ash followed the similar trend like lead, i.e. extremely higher content of zinc in sludge (1960 mg kg⁻¹) than fly ash (90.73 mg kg⁻¹). There was almost same amount of zinc in different units of the power plant.

There was no mercury (Hg) in fly ash but the amount was very high in sludge. Fly ash may contain mercury but it can evaporate easily to the atmosphere and starts to evaporate from the Electrostatic Precipitator (ESP) where it is deposited. It has the potentiality to become zero when it is dumped to the dumping site.

Quantification of heavy metals from fly ash: Very large quantities of fly ash are produced by this power plant. The total quantities of toxic and potentially toxic elements contained in the fly ashes produced by this plant can be estimated from the total quantities of fly ashes produced and the elemental composition of the fly ashes (Table 4).

Table 4. Release of heavy metals from different units of the power plant *

Unit No.	Fly ash production (tons/day) **	Release of heavy metals (kg/day)				
		As	Cd	Pb	Zn	Hg
6	600	45.15 ± 0.13	0.31 ± 0.02	4.83 ± 0.79	54.35 ± 0.59	0
8	1100	59.43 ± 0.27	0.34 ± 0.02	8.41 ± 0.09	88.21 ± 1.15	0
10	1100	67.03 ± 0.86	0.30 ± 0.01	8.00 ± 0.21	83.93 ± 1.27	0
11	1100	148.16 ± 2.12	0.62 ± 0.01	14.89 ± 1.11	90.30 ± 1.51	0

* Calculation was based on the concentration of this study, ** Source: Viriyavejakul (2003)

Discussion

The concentration of TKN and phosphorus in sludge was 2.23% and 1.88% respectively, which was lower than Poonpolwatanaporn's (2000) study where sludge was collected from Si-Phraya CWTP but source was the same (BMA). This may be due to the variation in process or technology.

Arsenic is typically found in uncontaminated soils at concentrations up to 50 mg kg⁻¹ (Alloway 1990; WHO, 1989). The concentration of arsenic in fly ash sample from the Mae Moh plant was two times higher than background soil level. On the other hand, fly ash contained higher amount of arsenic (As) than sludge. The average arsenic content of fly ash was 89.55 mg kg⁻¹ whereas in sludge it was only 22.01 mg kg⁻¹. Nongkhaem wastewater treatment plant, Thailand uses the wastewater of Bangkok Metropolitan Area (BMA) and has less chance to be contaminated by arsenic because these come mostly from domestic sources. But the source of fly ash is lignite coalmine, which has higher content of arsenic. The fly ash samples of this experiment were collected from the dumping site and were analyzed after few days of collection, which may be the cause of this. But Brigden *et al.* (2002) got significant amount of mercury in fly ash from this plant where they collected the sample from the hopper used to deposit and transportation of fly ash. The samples were collected from different places for these two studies, which may lead to this variation of mercury. The concentration of mercury in typically uncontaminated soil is 0.625 mg kg⁻¹ (Alloway 1990; WHO, 1989). In sludge, it was 6 times higher than the normal soil level but fly ash was free from mercury. So, if fly ash is

dumped in that area, there is no probability for the contamination of soil and water by mercury because of its nature of evaporation. The concentration of heavy metals present in sludge was lower than the previous study of BMA (1998). This may be due to the change of processing technology in wastewater treatment plant and change in using pattern of materials by BMA inhabitants for strict environmental rules and regulations.

The variation in heavy metals concentrations between the samples is likely to be mainly due to the type of coal burned, the technology employed for combustion and the pollution control devices working at the units. The trace element composition of fly ash from a single facility has, however, been reported to vary measurably on a daily basis (Egeman and Coskun, 1996). The location of lignite mine extraction is not same for all the units. Due to the variation of mine extraction location the quality of mine can be varied which may lead to this variation of elements in different units. Different units of the power plant were installed in different time period that might be the cause of trace elements content variation is due to technological variation in different units. Brigden *et al.* (2002) were also studied the fly ash of Mae Moh power plant where concentration of heavy metals were higher than the present study. This variation of heavy metals contents may be due to the change of coal extraction location and the technological change within this period both in coal pretreatment and in firing. The values in Table 4 are only the approximated values as they are based upon the composition of a very small fraction of the total fly ashes produced. The variation of composition in different units of the power plant indicates that variability can occur in the elemental composition of fly ashes within the same plant depending on the raw materials and technological inputs. These data, however, give an indication of the large quantities of elements produced in one of the waste streams as a result of coal burning at the Mae Moh.

Conclusion

The production of power through the combustion of coal at the Mae Moh power plants in Thailand produces fly ash contaminated with a range of toxic and potentially toxic elements. Due to the very large quantities of coal burned and fly ash produced, each plant liberates many tons of these elements each year. Also, sludge from BMA contains high amount of toxic metals. These materials may release heavy metals into the environment and increase the risk of bioaccumulation and environmental pollution. Due to the very large quantities of fly ash and sludge produced by each plant very high amount of heavy metals release into the environment every year. Heavy metals content varies due to the technological change and variation in the source of raw materials. Dumping of fly ash can eliminate at least reduce mercury content in fly ash due to its evaporation potential. To reduce the environmental risk efficient management of these waste products is a pressing demand.

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