# Heavy Metals in Coal Ash – A Brief Review of Global Trend

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**Abstract:** The development of heat power plant has been increasing steadily due to the global energy demand for industrialization. Coal ash, the main waste from power plant is, therefore, increasing during the continuous operation of power plant. The disposal of coal ash without a proper management has raised many environmental issues such as air, soil, and water pollution. One of the serious environmental problems regarding to coal ash is the mobilization of heavy metals containing in coal ash to surrounding environmental. This can cause various damages to the ecological system due to the toxicity of heavy metals. This paper aims to report the occurrence of heavy metals in coal ash and the current state of coal ash management in some countries. An overview on the global trend for coal ash management and subsequent utilization is also given briefly with the focus on removal or stabilization of heavy metals.

**Index Terms:** coal ash, heavy metals, toxicity, global production, management

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## I. INTRODUCTION

Coal ash is the term that was used to call the materials produced when the coal was combusted to produce electricity in a heat power plant. Sometimes, coal ash is also referred as "coal combustion products" to emphasize that it can be recycled and used as a material for other purposes [1]. The production of coal ash is continuously increasing due to the steady growth of energy demand for industry. Global estimation of coal production indicated that the total coal ash production will be excessed 2.3 billion tons in 2030 while this number is only around 0.25 billion tons in 1990 (Figure 1). The increase in coal ash production is nearly linearized with the time in the period of 1990 - 2030. Even though the amount of coal ash was utilized for other purposes also continuously increasing, the percentage of coal ash utilization is still lower than 50%. This indicates that more than 50% of coal ash production was and will be disposed as waste and may cause some environmental problems.

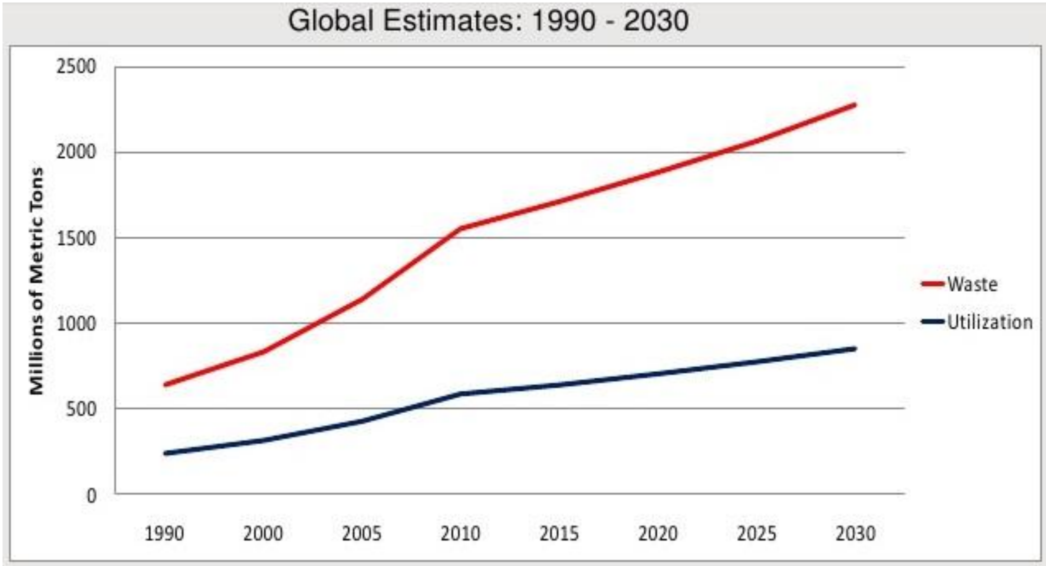


Figure 1. Global estimation of coal ash production and coal ash utilization till 2030 [2]

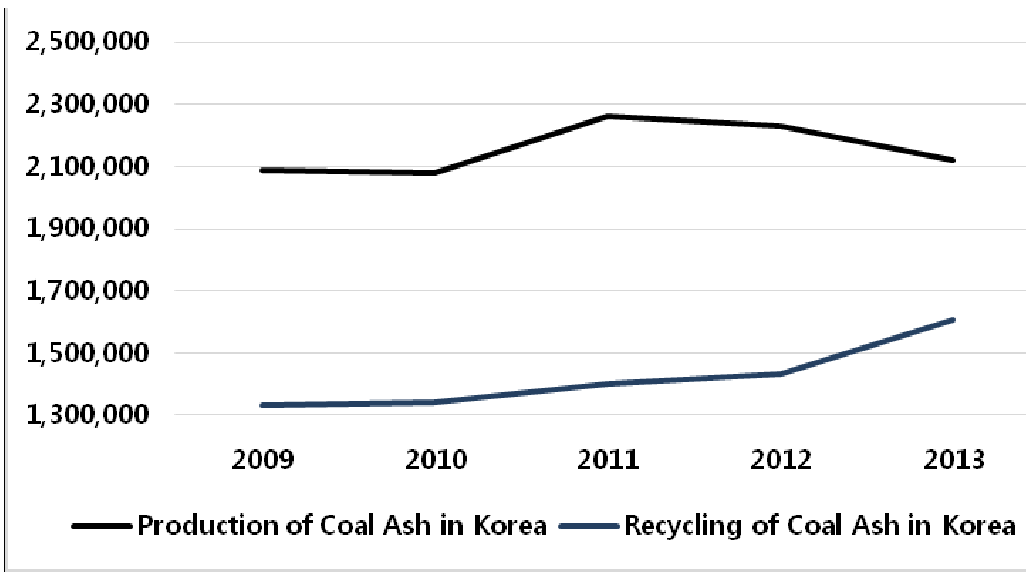


Figure 2. Production and recycling of coal ash in Korea during period of 2009 – 2013 [3]

The pattern of coal ash production and utilization in Korea during the period of 2009 -2013 was slightly different with the global trend (Figure 2). The data reported by South Korea Power Plant including 4 big plants (Samcheonpo, Yeongheung, Yeongdong and Yeosu) indicated that the total coal ash production in 2013 was not significantly increased compared to the number in 2009. In contrary, the amount of coal ash which was recycled to use in other purposes of industry was continuously increasing during 4 years. Especially, it was significantly increased in the stage from 2012 to 2013. However, the amount of coal ash disposed as waste to landfilling was still very high (up to 500,000 tons in 2013). This problem created the driving forces for the research and development in coal ash recycling technologies.

**II. HEAVY METALS CONTAINING IN COAL ASH**

The main elemental compositions of coal ash are Si, Al, Fe, Ca, Mg, K, and Na. However, it has been indicated that coal ash from power plant also contain various heavy metals and metalloids at trace level such as As, Cd, Cr, Co, Cu, Pb, Mn, Hg, Ni, Zn, Sb, and Se [4]–[6]. Even though these metals occur in coal ash as trace level, it has raised many serious environmental problems when they are mobilized and migrated to surrounding environment due to its high toxicity. The mobilization of these metals can lead to ground water pollution, soil pollution and ecosystem destruction. The common agent which leads to the mobilization of heavy metals from coal ash is the low pH water from acid rain. Therefore, coal ash should be managed in an appropriate way to prevent these problems.

The concentration and type of heavy metal are various with the type of coal ash. Concentrations of common heavy metals and metalloids in some coal ash samples are listed in Table 1. It was noted that the concentration of most heavy metals including Co, Cu, Mn, Ni, and Zn in Spain coal ash is the highest compared to that from other countries. The uncommon metalloid like Sb was also detected at 3.8 mg/kg in the coal ash sample from Spain. The highest concentration of As, the most toxic metalloids, was detected in the coal ash sample from UK. Among the heavy metal concentrations listed Table 1, the highest concentration was 847 mg/kg (Pb) detected in the China coal ash sample. In the most coal ash samples, Mn and Zn were always observed with a higher concentration compared to other metals while Cd and Hg were usually detected with a lower concentration among analyzed heavy metals. Se and Sb were rarely investigated in the coal ash samples. They were only reported in the coal ash from Spain. Korean coal ash sample contains heavy metals with the concentrations equivalent or lower than that in the coal ash from other countries.

**Table 1.** Comparison of metal contents in various coal ash samples (the unit in mg/kg)

| **Sample** | **Philippines** [5] | **Greece** [7] | **Spain** [8] | **UK** [9] | **Poland** [10] | **India** [4] | **China** [11] | **Korea** [12] |
|---|---|---|---|---|---|---|---|---|
| **As** | 8.4 - 41.8 | - | 60 | 40 - 205 | - | - | - | 2.5 - 4.7 |
| **Cd** | <1 | 11.6 - 14.4 | 1.3 | 0.13 - 0.82 | 3 | - | 315 | 0.2 – 0.4 |
| **Cr** | 6 - 49 | 110 - 160 | 134.2 | - | 64 | 87 - 103 | - | - |
| **Co** | 6 - 25 | - | 29.2 | - | - | 8 - 18 | - | - |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Cu** | 22 - 34 | 31.8 – 62.8 | 71.8 | - | 38 | 56 - 83 | - | 25 - 59 |
| **Pb** | 8 - 22 | 123 - 143 | 52.0 | 17 - 176 | 44 | 20 - 56 | 847 | 14 - 43 |
| **Mn** | 122 - 308 | 213 - 330 | 324.6 | - | - | 47 - 139 | - | 73 -179 |
| **Hg** | 1.2 - 1.9 | - | 0.01 | - | - | - | 8.3 | - |
| **Ni** | 6 - 50 | - | 87.9 | - | 41 | 28 - 63 | - | 13 - 24 |
| **Zn** | 23 - 138 | 59.6 - 86.9 | 221.3 | - | 120 | 60 - 124 | - | 40 - 81 |
| **Sb** | - | - | 3.8 | - | - | - | - | - |
| **Se** | - | - | 1.6 | - | - | - | - | - |

Most of heavy metals and metalloids in coal ash sample can be analyzed using Inductively Coupled Plasma (ICP) or Atomic Absorption Spectroscopy (AAS) instruments after the sample was digested in aqua-regia (concentrated HCl : concentrated $HNO_3$ = 3: 1, v/v) [5]. For an accurate value of metal concentration, coal ash sample is air-dried until the weight becomes constantly. In addition, in order to evaluate the mobility of heavy metals in coal ash, various studies on leachability and speciation have been conducted [7], [12]–[15]. Most of studies performed a sequential extraction experimental procedure proposed by the Community Bureau of Reference (BCR) to study the partitioning of heavy metal in coal ash. For this, the total heavy metals and metalloids in coal ash would be divided into 4 fractions including exchangeable, easily reducible, organic bound, and residual [13]. More recently, another study has divided total heavy metal partitioning in coal ash into 6 fractions including water soluble fraction, exchangeable fraction, carbonate fraction, iron and manganese fraction, organic fraction, and residual fraction [15]. The mobility and bioavailability of each metal will be evaluated based on the distribution of the metals in each fraction. The metals bound to exchangeable and carbonate fraction are said to be more mobile and bioavailable while the metal bound to residual fraction are said to be more stable and non-bioavailable. The analysis results indicated that most of heavy metal in Indian coal ash existed as residual fraction (>60%) [13]. In another study [15], Cd, Cu, Mn, Pb, and Zn were observed to be mainly present in Fe–Mn oxides, organics and residual fractions, therefore, their leachability could be well controlled. In the leaching and mobility test, Cd was found to be the most easily extractable elements in coal ash whereas Co, Cu, Sb, and Zn have low mobility potentials [14]. The leachability of heavy metals in a Greek coal ash sample in the decreasing order is as follow Cd > Cr > Pb > Zn > Cu > Mn [7].

The toxicity and effect of heavy metals on human health vary with the metal species, the exposure duration, and the age, gender, and nutritional status of exposed individuals [16]. With metalloids like Sb and As, $As^{3+}$ and $Sb^{3+}$ were considered to be more toxic than $As^{5+}$, and $Sb^{5+}$. Even at a very low level of exposure, As can cause nerve damages and increase cancer risks in human skin, liver, lung, kidney, and bladder in human. Most heavy metals are known to induce the damage of multiple human organs and human cancer according to the United States Environmental Protection Agency (US EPA), the International Agency for Research on Cancer (IARC), and the World Health Organization (WHO).

**III. GLOBAL TREND IN COAL ASH MANAGEMENT**

Many technologies have been developed to utilize coal ash instead of disposal until now. Even though heavy metal contents in some coal ash samples are relatively high, coal ash was considered to be not a hazardous waste but a valuable resource according to American Coal Ash Association Educational Foundation and can be used as a material to produce other products [1]. Coal ash utilization technologies have been studied for decades by both universities and governmental agencies. Global coal ash utilization was increased more than 20% from 1990 to 2010 (Figure 1). The recycling of coal ash can result in many societal and environmental benefits, especially in reducing greenhouse gas emission, which was said to have an intimate connection to climate change and global warming.

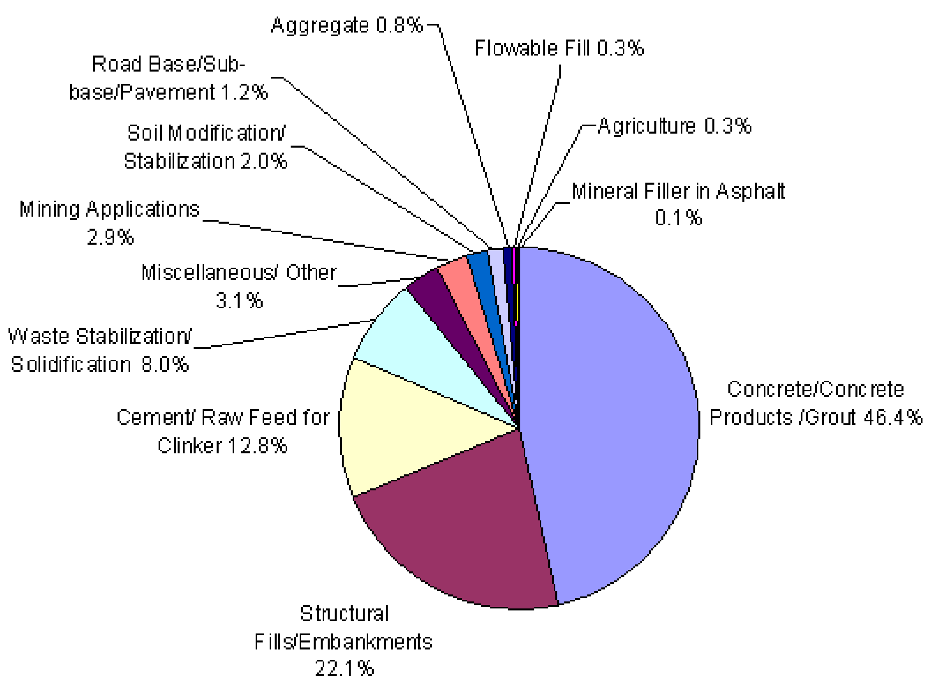

Figure 3. Current status of coal ash utilization (source: American Coal Ash Association) [17]

Coal ash was utilized in many fields as raw materials for various products (Figure 3). Currently, coal ash was mainly used in production of concrete, cement, and structural fills. More than 46% of coal ash utilization was for concrete production and the percentage of coal ash utilization for cement and structural fills were more than 34%. Each application of coal ash exhibits different benefits to our environment and social economic development. Using coal ash as a material for concrete production is a sustainable construction practices. When a ton of coal ash is applied to produce concrete, up to a ton of cement can be saved. This application consequently results in a prevention of almost a ton of carbon dioxide emitted from cement production. Besides, this process can help saving the energy demand to extract and process other materials for concrete production. When coal ash is utilized as raw materials for other products, the new landfill space or expanded disposal facilities are no more required. This approach, thus, results in conserving natural resources for other usages.

**IV. CONCLUSION**

Various heavy metals and metalloids were detected in coal ash produced by heat power plant. Some metals occur with high concentration and may damage to ecological system and human health in the case these heavy metals and metalloids are mobilized from disposal landfill due to external weather factor. In order to eliminate the environmental risks causing by coal ash disposal, many studies have been conducted to utilize the coal ash as raw materials for construction and other purposes. This global trend for managing and recycling coal ash is continuously increasing. The applications of coal ash in various fields have shown many benefits to economy, society, and environment such as reduction in utilization of virgin materials, land disposal, and greenhouse gas emission that are globally concerned problems.

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