Coal Ash Disposal Facilities: We have Come a Long Ways

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ABSTRACT

Coal has been used for electrical power generation for decades. While the use of coal as a fuel for power generation has decreased in the U.S., it is growing in India and globally. There are several hundred unlined coal ash ponds and landfills in the U.S. due to the old regulations that had coal ash exempt from regulations which other streams of waste had to comply. However, coal ash spills from unlined ponds have had profound impact on the regulations in the U.S. While most developing countries currently do not have enforced regulations on air and water pollution from coal combustion plants, the case studies presented in this paper show that the human health and ecological cost is orders of magnitude greater after a spill compared to the cost of enforcing preventive measures. The new regulations in the U.S. have resulted in excavation and removal of unlined coal ash or in-situ capping. These heavy earth work activities have provided opportunities for research related to wet ash that has low strength to improve the strength and dewater or stabilize the moisture using innovative technics such as moisture absorbing polymers or electro-osmotically enhanced dewatering.

INTRODUCTION

Coal and oil lead the global sources of fuel used for energy production (at about 30% each). Coal while considered a "dirty" fuel due to the greenhouse gas (GHG) emissions and trace metals that it leaves behind in the combustion residue, it is the cheapest and easier to transport. Hence it is a popular fuel in China, U.S., and India, the three largest consumers of coal. The growth in the consumption of coal in China is tapering off as the country invests in alternative forms of energy. The consumption of coal in the U.S. has declined significantly in the last few years primarily due to relatively cheap natural gas from the fracking technology and stringent regulations for managing coal energy plants driving the cost up for energy from coal.

While China's consumption of coal grew only by 17% from 2009 to 2014, due to strong economic growth, India's consumption of coal increased by 44% to reach 360 million tons of oil equivalent. In addition to India, countries in the Asian continent are also increasing coal consumption, offsetting declines in Europe and USA. During the period 2009-2014, coal consumption rose by 83.3% in Indonesia, 75.4% in the Philippines and 78.5% in Vietnam (Euro monitor 2015).

Coal combustion is on a steady rise across the globe. Hence, it is vital to put in perspective the lessons learned from air and surface water and ground water pollution disasters. The developed countries made significant changes in the flue gas scrubbing system in the last few decades, which has significantly cleaned up the air emissions. However, the flue gas constituents those have been removed have moved to the fly ash and bottom ash depending on the air cleaning technology used by the plant. Hence, in the developed countries, the challenges lie in protecting surface and ground waters. In the developing countries including South Africa, not all coal energy plants use state-of-the-art scrubbing system to clean the flue gas and coal ash is seldom landfilled in lined facilities. In U.S., the new regulations came in effect in 2015 that will gradually move coal ash disposal from unlined ponds to lined landfills to protect the surface and ground waters. Developing countries, while behind on that front, will need to take actions to protect the air and waters.

This paper will focus on the two most recent key environmental disasters that changed the coal combustion product (CCP) regulations in the U.S. In addition, this paper will discuss the new CCP regulations and technological challenges and what research is in progress to make the transition to implementing new regulations cost effective and implementable on the tight schedule.

CCP GENERATION AND UTILIZATION

While CCP composition varies across coal power plants depending on the mineralogical composition of the coal, and the flue gas cleaning technology used, in the U.S., CCP contains the following fractions:

1. Fly ash: 80%;
2. Bottom ash: 15%; and
3. Boiler slag and flue gas desulfurization (FGD) residues such as gypsum: 5%

Figure 1 shows the global CCP production based on Heidrich et al. (2013). China, U.S., and India lead the production at approximately 300, 120, and 110 million metric tons, respectively. Figure 2, shows the percent of the produced CCP that is beneficially utilized. The percent utilizations in the U.S. and India are about 40% and 15%, respectively. Thus, remaining unutilized CCPs have been disposed in mostly unlined wet ponds or dry basins. These unlined facilities impose a long-term threat to the surface and ground waters. The risk is compounded due to oversight in routine inspections, structural and hydraulic maintenance of levees and storm water management system, and threat from natural hazards such as earthquakes.

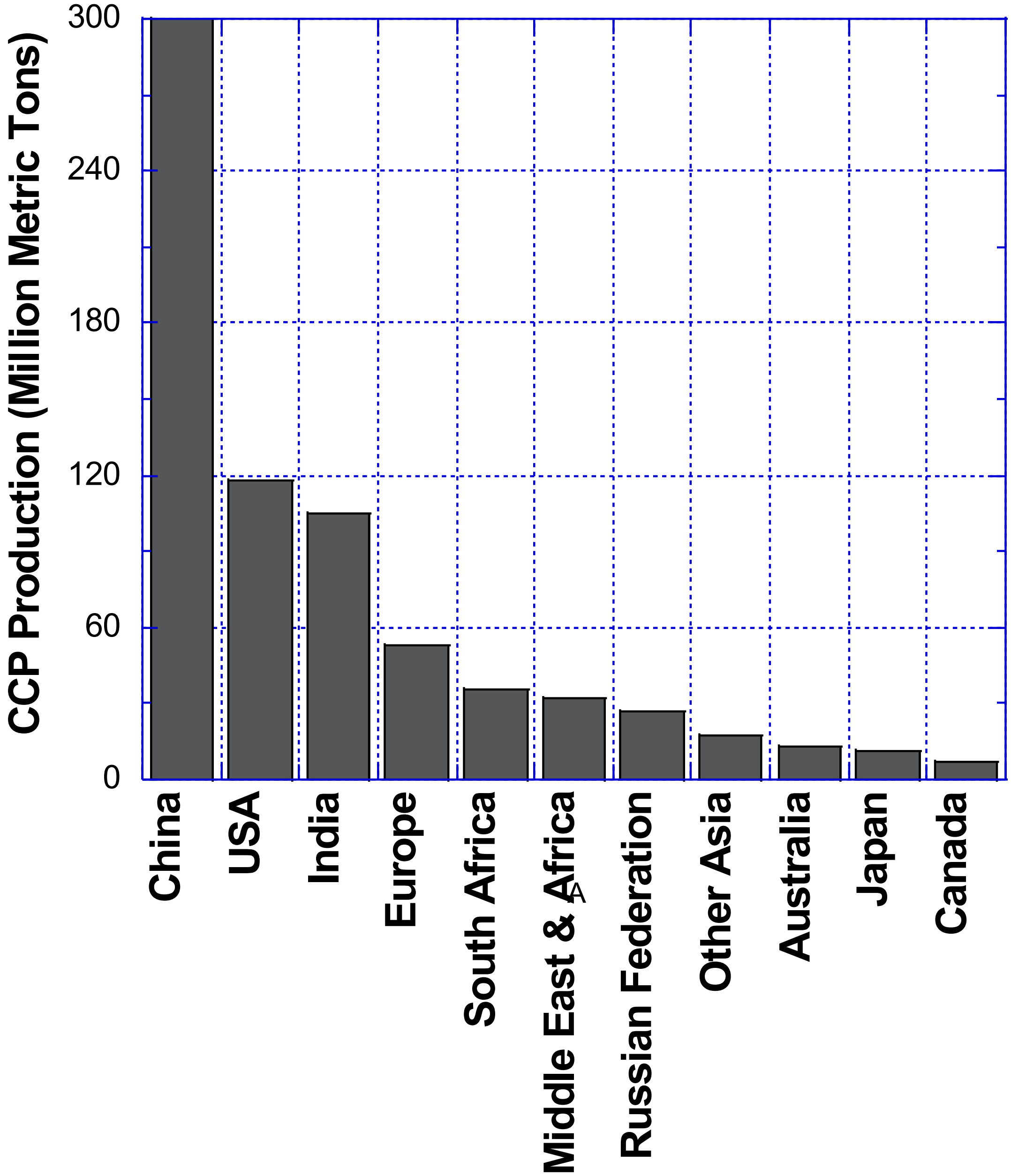

Figure 1. Global CCP Production

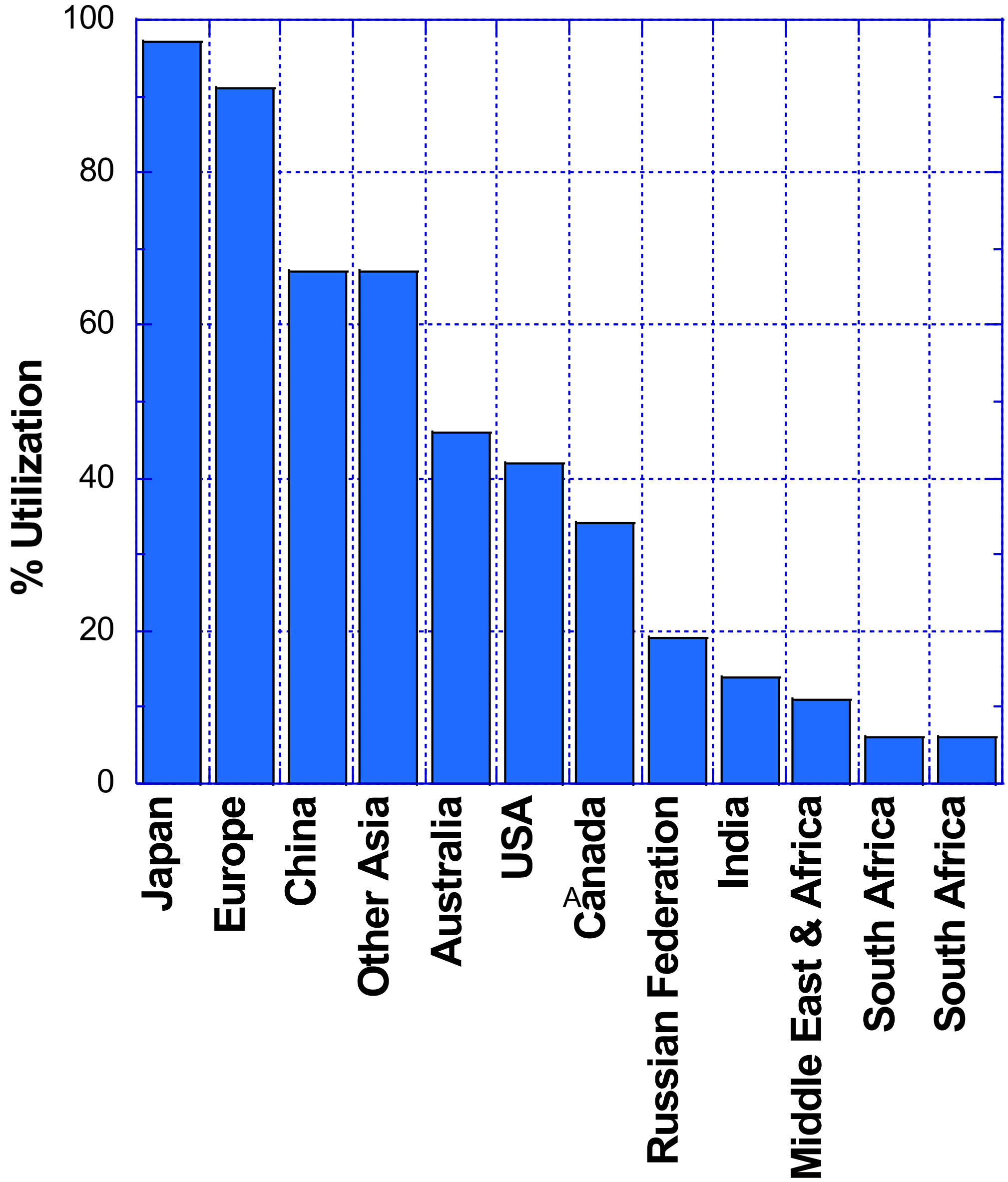

Figure 2. Global CCP utilization

CCP ENVIRONMENTAL ACCIDENTS

In the U.S. history, there have been three major reported accidents:

1. 2005: Pennsylvania Power & Light, Martins Creek Station, 380,000 m^3 of fly ash leaked into Delaware River;
2. 2008: Tennessee Valley Authority (TVA), Kingston Plant, 4 million m^3 of ash leaked into Emory and Clinch Rivers; and
3. 2014: Duke Energy, Dan River Steam Station, 35,000 metric tons of ash spilled into the Dan River.

In response to the TVA spill, the U.S. Environmental Protection Agency proposed final CCR rules in 2010 which impact surface impoundments at 480 coal-fired power plants in the U.S. (Daniels 2016). Similarly, the 2014 Dan River spill prompted the State of North Carolina (where Dan River Plant is located) to pass the Coal Ash Management Act (CAMA) in 2014. This is a unique situation where the state regulatory agency to initiate such counter measures to make sure this does not happen again within the state of North Carolina. Similar to EPA's CCR rules, CAMA sets out comprehensive requirements that dictate ash disposal, beneficial utilization, to happen in time frames that are shorter than EPA's CCR rules (Daniels 2016).

Dan River Coal Ash Spill (2014)

A 1.2 m diameter reinforced concrete pipe underlying a coal ash disposal impoundment at Duke Energy's Dan River Plant collapsed in February 2014. This pipe was there to carry the storm water up gradient of the impoundment to the Dan River located downgradient. When the pipe collapsed, the wet ash entered the pipe and resulted in a massive spill of approximately 35,000 metric tons of coal ash into the Dan River at Eden, North Carolina, U.S.A. Fig. 3 shows a schematic of the coal ash impoundment, the location of the broken pipe, and the river.

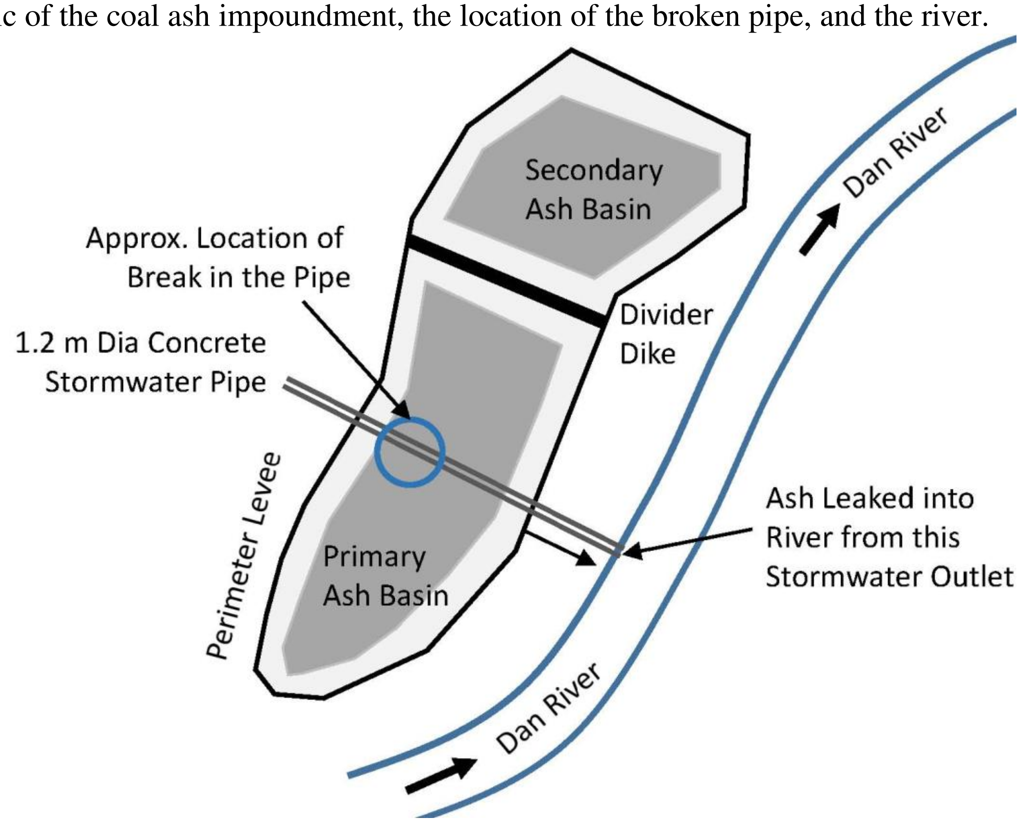

Figure 3. Schematic of Dan River CCP Spill in North Carolina, USA (modified version of schematic obtained from Duke Energy)

The spill coated the beds and the sides of the river channel with several-meter-thick ash deposits (Lemly 2015). It changed the water chemistry of the downstream segment of the river due to the release of heavy metals such as arsenic, selenium, manganese, chromium, and copper.

Lemly (2015) estimates about $300 million (U.S.) for short term impacts from this spill based on many factors including esthetics, ecological, recreational, and human health, and consumptive use. The author postulates that the costs will only increase due to the long-term nature of cleanup to bring the environment back to where it was before the spill. While the estimated damage amount may not be accurate because of the assumptions built in the analysis, it is clear than the cost to fix the environment after the spill is many orders more than the cost of preventive measures.

The volume of ash and porewater, and its rapid release, overwhelmed the river's natural flow and changed the chemistry of the entire flow of the river (Lemly 2015). Duke Energy temporarily fixed the leak by filling the leaky pipe with sand bags and rock and pumping water out of the pipe. The long-term solution implemented was to excavate the coal ash from the fill area and remove the pipe permanently and re-route the storm water. While much of the coal ash that went into the river was not captured due to the relatively high flow rates in the river transporting the ash over 110 km distance, hydraulic dredging was used to remove some of the ash that went into the river.

The key lessons learned from this spill are that any pipes that penetrate through a waste fill are pathways to carry the waste and pore fluids and it is just a matter of time when the physical integrity of these pipes is threatened. Hence, plugging or removal of the pipes and rerouting them around the waste is a better practice. If it is not possible to do that, routine inspections (using a video cam depending on the access) are critical to assess changes in the physical integrity of the pipe. However, it is often not possible to predict the rupture of an aging below grade pipe.

TVA Coal Ash Spill (2008)

A dike supporting a coal ash dredge fill of Tennessee Valley Authority's (TVA) coal fired power plant located in Kingston, Tennessee ruptured in 2008. It contained stored wet coal ash in an 84-acre containment area which leaked 4.2 million cubic meters of wet ash into the Emory river. This wet coal ash spill covered about 300 acres downstream and damaged waterways and personal property. This spill to date is considered the largest ash disaster in the U.S. history. The containment area has an average height of 20 m and is surrounded by a perimeter levee having an average height of 20 m. Leaks were detected in the levee few years prior to the rupture in 2008. The spill emptied 66% of the wet ash from the containment area. While the location of the spill is in a rural area, it damaged about 40 homes, power lines, water main, gas main, and downed many trees.

Ruhl et al. (2009) sampled the ash, sediments, and water from the upstream and downstream locations of the river and compared the concentrations to the background levels. The coal ash contained many heavy metals that were at higher concentrations than the background soil. However, strontium and arsenic levels in the ash were far great compared to the background soil. The authors also found a two-fold increase in mercury levels in the sediments downstream from the spill. River water samples had elevated heavy metal concentrations, especially arsenic. Shallow groundwater did not show any impacts in 2009. Thus, most impacts were confined to sediments and surface waters. All aquatic life near the plant downstream from the spill was buried and killed. Over a two-year period after the spill, almost 90% of the washed ash was dredged and removed from the river.

Regulatory Shift

Daniels (2016) point out that CCPs were regulated as per resource conservation and recovery act (RCRA) of 1976 in the U.S. However, CCPs were exempted as a special waste by amendment. Such amendments were possible when there was no history of major environmental disasters. Often the purpose of such exemptions was to reduce operational cost to the industry and consumers. However, in light of the coal ash disasters, to minimize the potential for such catastrophic environmental failures, the U.S. Environmental Protection Agency (EPA) approved final rules that establish a comprehensive set of requirements for the disposal of CCPs or coal ash in landfills and surface impoundments. These requirements have been finalized under the solid waste provisions, subtitle D, of the Resource Conservation and Recovery Act (RCRA). These regulations protect air and water. The rule establishes requirements for existing and new CCR landfills, surface impoundments and lateral expansion of an existing unit. The key requirements are focused on: (1) structural integrity; and (2) groundwater monitoring and corrective action. Because unlined CCP ponds or CCP disposal facilities leach CCP constituents to groundwater, the CCP Rules require comprehensive groundwater risk and hazard analysis. This requires simulating percolation of CCP leachate into the groundwater and predicting concentrations of CCP leachate constituents at the property boundary. If these concentrations exceed the maximum contaminant levels (MCLs) established for groundwater, corrective action is required.

RESEARCH NEEDS

The reported coal ash spills in the U.S. have triggered a strict schedule for coal energy plants to close the unlined ash ponds. Often these ash ponds contain saturated coal ash and handling the ash during excavation or grading is a challenge. The ash usually falls in the gradation of a silty soil. It has a much lower specific gravity than inorganic natural soils and relatively low strength when saturated. Often it weakens due to liquefaction when heavy equipment creates vibrations. Sinking of heavy equipment due to low strength is a real concern and often requires special technologies to dewater the ash in relatively short periods of time to allow the heavy equipment to move on the ash. It is also a need to classify the ash to predict at what water content it acts like a liquid. Traditional Atterberg limits tests used for natural soils do not seem to work well in predicting the behavior of coal fly ash. Thus, developing new dewatering technologies that would efficiently dewater the finer matrix of coal ash impoundments will be a valuable contribution. Alternatively, technologies that use moisture absorbing polymers which solidify the water fraction by reaction could be used to reduce the effect of moisture on the strength and handling of the ash in the field and eliminate the need to treat the pore water if dewatered. Thus, while the coal ash accidents had local environmental impacts, these disasters have resulted in good regulations and opportunities to do research so the industry can effectively implement the regulations.

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