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How Dense Slurry Fly Ash Disposal helped Europe's largest Brown Coal Power Station to reduce its Water Consumption by over 90%

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ABSTRACT

The Bełchatów power station in the Polish province of Lodz has a generating capacity of 5,420 MW, making it Europe's largest brown coal power station and third largest coal power station in the world. Some 28 TWh of electrical energy, equivalent to around 20% of Poland's entire power requirement, are produced every year. The vast amount of 420 tons of fly ash accumulated per hour is landfilled or used as backfilling material. The landfill site for the ash slurry is around 5 miles away from the power station itself. The former system with centrifugal pumps was overburdened with both the volume and the long pumping distance. The wear rate increased drastically. Failure of the pumps and thus the removal of the fly ash would have caused the power station to shut down. In 2013, a total of six high solids handling piston pumps, each driven by a 1,000 hp hydraulic unit, were installed for transporting the fly ash of the entire power station. Some 800 yd3 of fly ash slurry are pumped every hour. Because piston pumps are capable of conveying much dryer material, today's water consumption is not even 10% compared to the previous solution with the old centrifugal pumps. As a result, the required water quantity is reduced by around 3,800 tons per hour and the power consumption is around 50% compared to the old pump technology.

Figure 1: The Bełchatów Power Plant

TECHNICAL BACKGROUND AND STATE OF THE ART

After burning coal for electricity, various coal combustion residues (CCR's) such as Fly Ash, Bottom Ash, Boiler Slag and Flue Gas Desulfurization Material (United States Environmental Protection Agency, 2017), commonly referred as to coal ash[1], remains at the incineration facility. The percentage of the total waste mix depends on the coal grade and incineration process. However, in the power plants of the USA, fly ash is typically the largest component by volume which is approximately 70 to 80 percent of the ash and only 30 to 20 percent is bottom ash (Bassetti et al., 2015) (United States Environmental Protection Agency, 2015, p.4_19).

Fly Ash, which is separated from the exhaust by electrostatic precipitators (ESPs) or baghouse filters, is collected in big hoppers underneath the separation equipment. From there the ash is either transported with water to a settling pond or as dry ash to silos for temporary storage. (Westerling, 2015). If the fly ash is compliant with local regulations, the operator can utilize the dry fly ash and sell it as a resource to various customer groups such as producers of wall boards, ready-mix concrete, mineral fillers or other construction applications. The reason for utilizing fly ash is that Fly Ash is a pozzolan, meaning it is a siliceous and aluminous material that, in the presence of moisture, will […] form cementitious materials (CEMEX S.A.B. de C.V. , n.d.). In 2013 the USA produced approximately 53 million tons of coal ash, of which 23 million tons were utilized beneficiary. Of the unused portion, the EPA acknowledged that 36 per cent was stored in landfills, and 21 per cent in wet storage facilities such as ponds (Power Engineering International, 2015).

The approximate worldwide production of CCR was 780Mt tons in 2011. The effective beneficiary utilization according to Heidrich et al. was 53 percent which equals to 415Mt tons. However, the utilization rate varies very much from country to country and can reach from 10.6 percent in Middle East & Africa to 96.4 percent in Japan (Heidrich et al., 2013). This means on the other hand that globally 47 percent (which equals to 367Mt) of the CCR's are still pumped or hauled to landfills or ponds. The quality of the Ash (and therefore the possibility to sell it) as well as the actual quantity of Ash is related to the incineration process and to the type and quality of the burned coal. This leads for example to the circumstance that the ash content in the coal used for power generation in India is approximately 30–40 percent which is unlike higher than the ash content in most of the developed countries (Senapati, 2011). High ash coal means the generation of a large amount of fly ash which is according to Heidrich et al. mostly dumped to landfills as waste product since only 13.8 percent of the 105 Mt annually produced tons of CCR are beneficially reused in India (Heidrich et al., 2013).

The latest development of regulations on CCR disposal systems is focusing on environmental protection and asks for systems which are using minimum water content in order to minimize the risk of "leaking into ground water, air entrainment, and the catastrophic failure of coal ash surface impoundments" (Fiscor, 2015).

[1] The Term 'coal ash' is used interchangeable for all different ash types (Fly Ash, Bottom Ash, Boiler Slag and Flue Gas Desulfurization Material).

More precisely, the EPA requests in operative power plants the “dry ash handling with no liquid discharge […] for fly ash transport for both existing and new power plants” (United States Environmental Protection Agency, 2015) in the USA.
As previously outlined, most plants are using specific control technologies such as electrostatic precipitators (ESPs) or baghouse filters to remove fly ash particles from the flue gas. After the fly ash particles are captured, they are dropped into the collection hoppers. From the hoppers, the plants transport the fly ash via wet-sluicing (for a simplified schematic see Figure 7), dry handling, or a combination of both to its next destination (United States Environmental Protection Agency, 2015). Around 76 percent of the US based 708 coal- and petroleum coke- fired generating units currently transport their fly ash using “dry handling systems” or other processes that do not require wet-sluicing. However, the Term ‘Dry Ash Handling’ is misleading in this example, as around 20 – 25 percent water plus chemical additives are needed to suppress dust before transportation. Once the wetted ash material is hauled to the landfill, additional water is commonly used to improve the compacting and control the dust emissions of the landfill (Timmons, 2015) (United States Environmental Protection Agency, 2015).
The other 24 percent of the existing US based plants are using wet-sluicing technologies and combine fly ash handling systems to transport their fly ash. Those plants need to “convert from wet to all dry handling operations no later than December 31, 2023” (United States Environmental Protection Agency, 2015, p.7_26).

A great and proven possibility to fulfil the latest EPA Regulation is to convert the plant from wet-sluicing technologies into a Dense Slurry- or even into a Paste System, which was already confirmed in 2015 by Dale Timmons who clearly stated that “from the perspectives of environmental protection , operational safety and financial risk, DSS has proven itself altogether superior to “dry ash” management” (Timmons, 2015, p.12) and “the zero discharge requirements would apply to this system” (United States Environmental Protection Agency, 2015, p.7_29).

Dense Slurry System (DSS)
The term “dense slurry” refers to a mixture of CCR’s with plant waste water according to a defined recipe, where the solid-to-water ratio is approximately 1:1 (see Figure 2).
The solid-to-water ratio for the DSS is considerably higher than the ratio used in the wet-sluicing system, where the typical solid-to-water ratio varies from 1:10 to 1:15.

Figure 2: Disposal of Fly- and Bottom Ash of a DSS (solid-to-water ratio ≈ 1:1)

The DSS’s are typically using a dry vacuum or pressure system to convey the dry fly ash from the ESP to a silo, but instead of using trucks to transport the fly ash to a landfill, the fly ash is mixed with plant waste water according to a specific recipe and pumped to the landfill with hydraulic driven piston pumps (or equivalent other equipment) where “pozzolanic reactions occur to form a low hydraulic conductivity, high-compressible-strength solid product within 24 to 72 hours” (United States Environmental Protection Agency, 2015, p.7_29).
This provides the possibility to cultivate the landfill as parklands or wildlife habitats after closure. However, the chemical and physical properties of CCR’s and wastewater are changing from plant to plant (Longo, 2015). Consequently it is essential to carry out tests on site to create the right recipe for stabilizing CCR’s (Timmons, 2015) prior to the final design of the plant. This leads to another great advantage of the DSS System. It is a solution to minimize one of the greatest concerns which is fugitive dust of landfills and dried ponds (Longo, 2016) (Timmons, 2015) (United States Environmental Protection Agency, 2015). The dried, stabilized CCR’s reduce the fugitive dust of the landfill considerably. In addition to this benefit, the S- Tube piston pump gives the plant operator the possibility to not only mix the plant waste water but also the bottom ash to the fly ash (means the entire CCR) and transport it in one closed system to the landfill.

Transportation of the dense slurry in a DSS is done via pipelines with small diameters (compared to those of conventional slurry pumps), in which erosion is minimized because the particles are kept in suspension in the viscous slurry (Kranitz, 2014).
As the solid-to-water ratio is multiple times higher than with wet sluicing systems, the quantity of installed pipelines is reduced significantly as well.
For the distance of the Bełchatów project, the client changed the design from 12 pipelines with 450mm diameter to only 6 pipelines with 200mm diameter. Just the change of the pipeline design is saving a new plant of this size around 7.500 tons of steel for the pipeline (Assuming that the standard EN 1092-1 DN450 PN25 and DN200 PN63 is used). Taking the actual steel price of 300 US$/ton (London Metal Exchange, 2017) into account, this leads to capital savings of at least 2.5M US$ without related instruments and accessories as well as labor and installation costs.

Figure 3: Slurry Pipelines Ø 450

Figure 4: DSS Pipelines Ø 200

Paste System
A Paste System is on the machine side basically designed like a DSS where a pasty material is created out of the CCR's and waste water and pumped to a landfill. The solid-to-water ratio is even higher than the one of a DSS, containing only an absolute minimum of water to create a material which looks and behaves like toothpaste.
The solid-to-water ratio can reach up to approximately 3:1 (cp. Figure 5).
The major difference of the DSS slurry and paste is that the Slurry of a DSS can be understood as Newtonian fluid type slurry whereas paste is understood as a non-Newtonian fluid (Housley & Johnson, 2015).

Practically, this means that a Paste is not flowing like water but has a yield stress and can be surface stacked (see Figure 6) or even sub-aqueous deposed. The reason is that paste has a network of fine packed ultra-fine particles "which act like a net to hold coarser particles [such as bottom ash] in suspension" (Housley & Johnson, 2015, p.2).

Figure 5: Paste material Sample

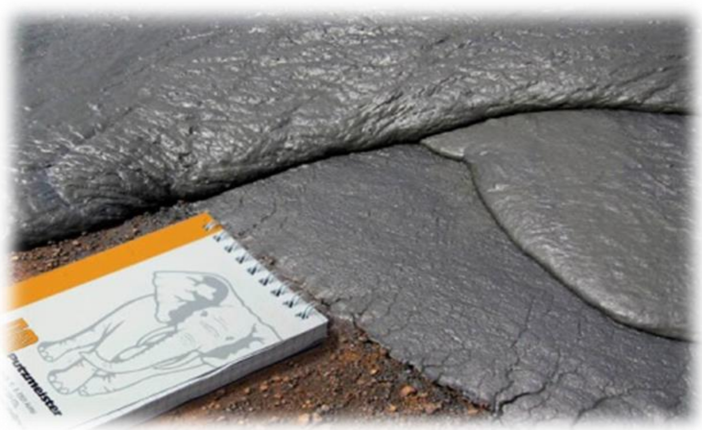

Figure 6: Paste Stacking Layers on a Landfill

This technology is not really new, paste systems are a mature technology and proven in various hard rock mines, where the waste material is coming from the milled tailings which need to be stored in landfills or backfilled into the old stopes. Just like CCR's the mine tailings "may contain other metals and constituents of concern that have potential for harmful impacts to surface and groundwater. Tailings also have the potential to generate and leach acids into the water" (Longo, 2016, p.38). However, according to her Paper the Paste System immobilizes the metals in the tailings, and can help prevent acid generation. This is confirmed by Housley & Johnson who are stating that paste Systems are reducing the ground water contamination as "paste has very low permeability, making it an ideal barrier to fluid migration into the ground" (Housley & Johnson, 2015, p.3). After hardening of the paste the "surface may be available for other uses, such as parklands, wildlife habitats or re-use as industrial or housing property" (Longo, 2016, p.40). Furthermore it is not only beneficial for the fly ash portion of the CCR disposal. Proper designed recipes for paste allow to apply water which otherwise would need to be treated in a Waste Water Treatment Plant. The aim is to use as much as possible waste water in a paste because through the paste process "even the most problematic constituents […] can be encapsulated" (Longo, 2016, p.39).

This even includes big particles of bottom ash as coarse material in order to improve the physical strength of the material on the landfill as those can be pumped with nowadays piston pumps. However, a pumpable paste requires sensitive process control systems because paste is very sensitive to water addition as “the slump moves from a 7” to a 10” in only a 2% change in solids content” (Longo, 2015, p.4).

The following Case Study of the Bełchatów plant is an example how a plant transformed their Fly Ash Transportation from a Wet Sluicing system to a DSS with zero liquid discharge and consequently reduced its water consumption enormously.

OLD WET SLUICING ASH DISPOSAL SYSTEM IN BEŁCHATÓW

The Bełchatów plant is using multiple electrostatic precipitators (ESPs) to remove their fly ash particles from the flue gas.
After the fly ash particles were captured by the ESP, they were dropped into various collection hoppers where big water powered vacuums pulled out the ash of the hoppers. Once the ash is out of the hopper it combined itself with the transport water which is flowing through the sluice pipes. From this stage on the ash was pumped with centrifugal slurry pumps and a solid-to-water ratio between 1:10 and 1:15 to the landfill pond (see Figure 7). The free surface water of the pond was afterwards pumped backwards to the large surface impoundment where the Fly Ash water was treated with other waste waters of the plant.

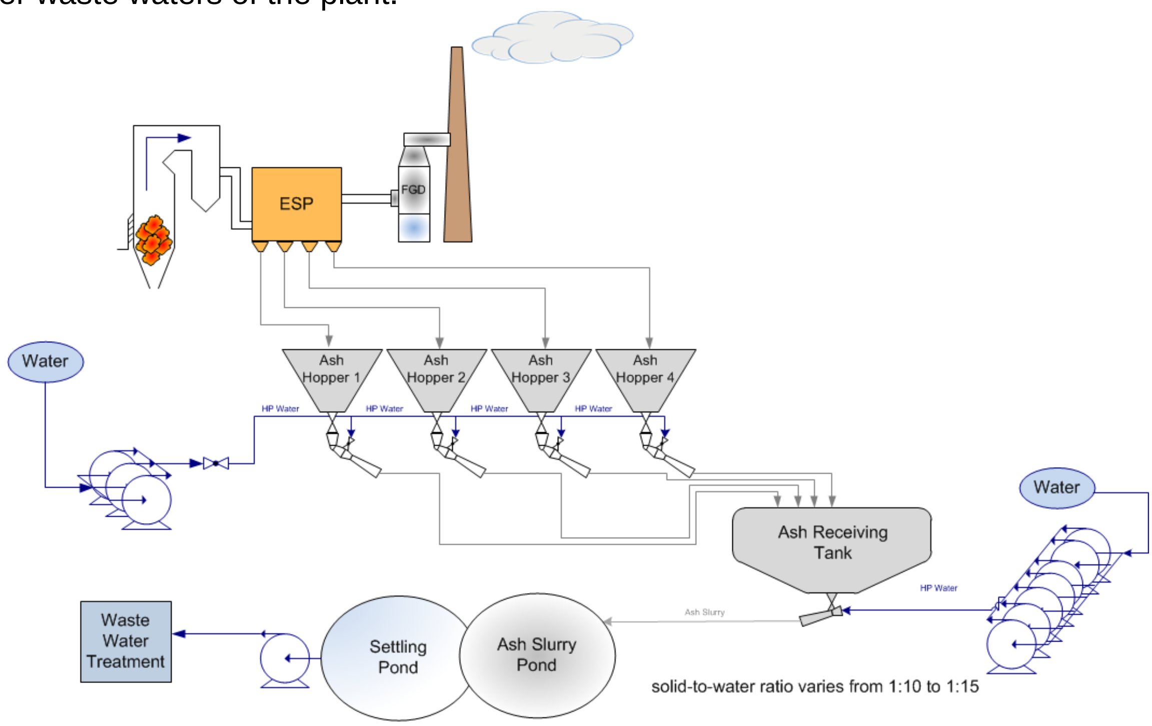

Figure 7: Simplified Schematic of a Hydro Ejector of a Wet Sluicing Ash Disposal System

This old wet sluicing system with centrifugal pumps was overburdened by both, the increasing delivery volume and also the long pumping distance. The wear rate increased significantly over the years and the availability of the pumping system decreased continuously.

NEW ZERO LIQUID DISCHARGE DENSE SLURRY SYSTEM IN BEŁCHATÓW

In 2013, a total of six piston pumps, each driven by a 1000 hp hydraulic power unit, were installed for transporting the fly ash of the entire power station and replaced the old centrifugal slurry system. The pumps of the Bełchatów plants are all equipped with a Pulsation preventing Constant Flow Technology (PCF) which is one of the “most innovative systems […] that provides a constant pump discharge with little interruption in flow between discharge cycles of the two cylinders” (Pierre Mainville, 2017).
Currently, there are three pump lines in operation and three on stand-by to achieve a total redundancy for continuous availability of the system.
Nowadays approximately 600 m3 of dense fly ash slurry are pumped every hour to the landfill area. This landfill replaced the old slurry pond as the DSS does not require a pond with active recirculation of surface water or surface impoundments.

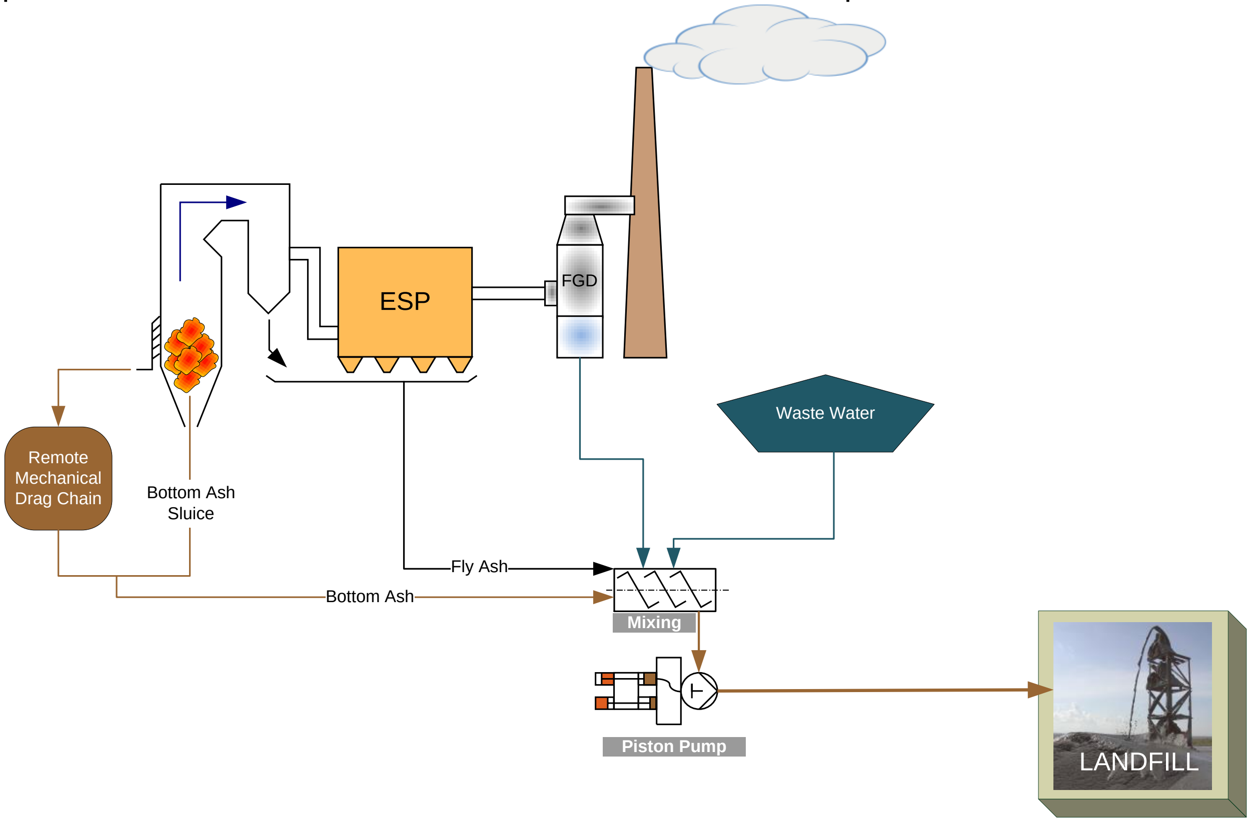

Figure 8: Simplified Schematic of the DSS Ash Disposal Process

As mentioned in the introduction part, CCR’s from brown coal combustion are lower graded than the ones from hard coal. Thus, the vast majority of CCR’s of the Bełchatów plant is not utilized but needs to be landfilled or used as backfilling material in the hard coal mine next to the power plant.
The landfill site for the ash slurry is approximately 4 -8 km away (depending on the injection point) from the power station itself.
The operation of the Bełchatów plant is producing approximately 600 m³/h of dense fly ash slurry as well as an annual production of 341.000 tons of gypsum out of the desulphurization process.

All Gypsum is used as raw material for building material manufacturing, and the ash is collected at a new specifically designed landfill, […] which has been appropriately designed to prevent any impact on soil or groundwater environments. Consequently Wastewater discharges will be completely eliminated (EBRD, 2005)

Reduction of Water- and power consumption

Because the new DSS is transporting the fly as at 58 percent dry solids concentration, the water consumption is considerably less, compared to 10 percent solids concentration of the old wet sluicing technology.

The solid-to-water ratio changed accordingly to 1.4:1. In regards of water consumption, this means that the old wet sluicing ash disposal system transported 420 tons of fly ash per hour with 4.200 tons of water. Today, not even 10 % of this water quantity is required which reduces the total volume flow rate drastically (see Figure 9). As a result of that reduction, the power consumption is around half as much as required for the wet sluicing system based on the following equation:

$$P = p \times Q$$

Whereas *P* is the required power, *p* the required pressure in the pipeline and *Q* the total volume of transported material. The reason is, that by increasing the solids-to-water ration from 1:10 to 1:1, the total volume of transported material (*Q*) decreases by 90% whereas the required pressure in the pipeline (*p*) increases only slightly. Reducing the required power by increasing the solids-to-water ratio is true as long as the pumped material is slurry (Newtonian Fluid) and not a paste (Non- Newtonian Fluid).

Consequently the process control requirements for the solid-to-water-ratio can be kept at a minimum.

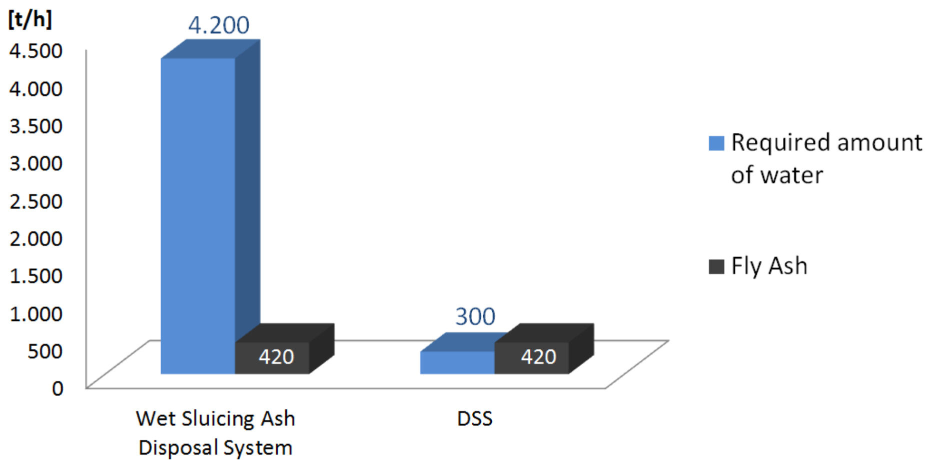

Figure 9: Wet Sluicing- vs. Dense Slurry System (DSS) in Bełchatów

The DSS in Bełchatów is successfully in operation since 2014 in a 24/7 operation mode. As the pumping system is equipped with special wear resistant wear parts, the DSS changed the maintenance intervals for replacing wear parts from multiple times per year to once a year. This reduces the maintenance costs significantly compared to using conventional wear parts and increases the availability of the plant in total.

To prevent unforeseen pulsation in the delivery pipeline the pumps are all equipped with the well proven Putzmeister constant flow technology (PCF) which is proven in world wide applications since decades.

CONCLUSION

Benefits of a DSS- or Paste System

- Compliant to the Zero Discharge Requirements of the EPA for Fly Ash transportation.
- 90 percent reduction of the water consumption compared to Wet Sluicing Technologies.
- Power consumption can be reduced by 50% compared to conventional wet sluicing systems.
- Improved use of the land fill due to surface stacking methods
- Possibility to cultivate the landfill as parklands or wildlife habitats after closure.
- 50 percent less maintenance of the pipelines and pipeline routes as only 50 percent of the pipelines are required.
- S- Tube Piston Pumps can combine the landfill of Fly- and Bottom Ash without the need of additional crushers or shredding devices.
- Elimination of booster pump stations for long distance pumping due to high pressure Piston Pumps.
- Fully redundant system for maximum availability of the plant.
- As the pumped volume is reduced, the installed pipeline material wall thickness can be reduced at 80% (capex saving of at least 2.5M US$ for pipeline design similar to Bełchatów).
- Reduction of the wear and maintenance costs of the pumping.
- Paste can be used effectively to reclaim existing ponds as it can be deposited sub-aqueously.
- DSS and Paste help to minimize the problems of fugitive dust of the landfill.
- Lower operation costs and risk evaluation of the landfill compared to dams and dikes (see Figure 10):

Figure 10: Geyser Placing Tower for Surface Stacking of Paste

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