Indian Geotechnical Journal, 30 (3), 2000

Environmental Impact of Fly Ash Pollution on Aquatic Life

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Introduction

Rapid industrialization and urbanization in recent times is posing a serious environmental problem. In particular, environmental pollution due to generation and management of waste materials has emerged as a serious problem to which an immediate solution is urgently required. A wide spectrum of materials, regarded as waste, are being discharged in large quantities throughout the world. The disposal and dumping of such waste causes the geo-environmental contamination of both soil and ground and surface water. Furthermore, the amount of space available for waste disposal is limited.

The President of the Indian Geotechnical Society, Prof. Sridharan (1997) recently made a nation wide pledge in the News Bulletin, which reads as follows:

"Accumulation of fly ash has reached alarmingly high levels requiring immediate attention for its disposal. Geotechnical Engineering activity is a primary mechanism of its bulk utilization and disposal. This requires a certain amount of basic and applied research both in the field and laboratories. I would urge members to contribute in this emerging area."

Fly ash is a waste product of coal burning in the thermal power stations. Several millions of tons of fly ash are produced globally every day. Only a small portion of this waste is utilized and the rest is dumped on land as a waste product.

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In many countries, considerable quantities of fly ash are already being used in the construction of roads and embankments, nevertheless bulk of it is still being dumped as a waste product and globally the engineers are facing it as a challenge to find solution for its consumption. This problem is critical to the countries like Japan, with scarce land for the fly ash disposal.

There is a general belief amongst the geotechnical engineers that fly ash is a non-hazardous waste material. However it contains quite a *significant quantity* of soluble salts which get dissolved in water when the fly ash comes in contact with it. Although the chemical composition of fly ash varies from place to place and time to time depending upon the quality of coal and the burning of coal in the thermal power plants, the salts present in the fly ash remain more or less the same. When the ash comes in contact with water, these salts that go in the solution are likely to effect the pH as well as the level of dissolved oxygen (DO). While the change in pH is likely to alter the salinity and cause all the problems associated with higher pH of the water the depletion in DO level will have adverse effect on aquatic animals and higher plant life (Tebbutt, 1992). The degree of impact would depend on the amount of soluble salts present in the ash. Any depletion in the DO level below 5 ppm should be a matter of concern considering bio-accumulation (the accumulation of the chemicals within the cellular components in the living organisms) and bio-magnification (the accumulation of the chemicals in the food chain as it passes through the various tropic levels). This is a hypothesis proposed by the investigators that has led to the present work. This hypothesis was further strengthened by the preliminary findings, which led to the detailed investigation.

Literature Review

The use of ash particularly as a fill material or in the embankments was suggested to not pose any problems that differed greatly from those associated with the disposal of the municipal wastes (Morgenstern, 1991). This was recommended as an environmentally acceptable material on the basis of the chemical analysis and leachate quality tests performed which indicated that the material did not exceed with the EPA Hazardous Waste Standards for inorganic materials (Han, 1996).

Though the chemical composition contains large quantities of silica, alumina, ferric oxide and smaller quantities of various other oxides, almost any trace element present in the earth's crust may be present in the coal as well. This leads to a large number of traces that can be found in fly ash depending on the coal source. These traces commonly found are as shown in the Table 1.

Table 1 : Trace Metals In Effluents From Coal Fired Furnaces (after Stephens et al., 1974)

Constituents	Fly ash, ppm	Drinking water level, ppm
Arsenic	8-120	0.05
Cadmium	0.01-8	0.01
Cesium	100-8000	*
Cobalt	7-90	*
Chromium	90-120	0.05
Copper	90-150	1.0
Mercury	0.15-0.7	0.02
Magnesium	1200-50000	*
Manganese	110-150	0.05
Sodium	1200-12000	*
Nickel	110-150	*
Lead	110-150	0.05
Tin	0.01-15	*
Selenium	25-75	0.01
Titanium	9000-20000	*
Vanadium	115-150	*

* not available to the Authors

Presence of these might turn hazardous in the long run due to the tendency of persistence of these chemicals in the environment. Hence the leachate from the ash is of prime concern as the traces present might lead to contamination of the ground water.

The dissolved solids in the ash consist of calcium with free lime accounting for part of the soluble calcium, sulphate and smaller quantities of magnesium, sodium, potassium, and silicate ions (GAI Consultants, Inc. Fly Ash Structural Fill Handbook, 1979). The solubility of these traces affect the pH ranging from 6.2 to 11.5 (Rohrman, 1971) as compared to the allowable pH range specified as 6.5 to 9.0 for the protection of fish life (Mark, 1986).

In the present work, effort has been made to study the effect of fly ash leachate on the depletion of DO level and increase in salinity in water. As we know, the depletion of DO level beyond the allowable limits will be detrimental to all organisms consuming this water.

Table 2 : Constituents of Flyash

Flyash Constituents	Proportion %
Fe_2O_3	5.08
SiO_2	41.2
Al_2O_3	33.6
TiO_2	2.31
Na_2O	0.1
CaO	6.45
K_2O	0.44
MgO	3.0
P_2O_5	< 0.05

Materials used

Fly ash: The fly ash was collected from the Morupule Thermal Power Station, the only thermal power station in the country situated about 350 km north of the capital city, Gaborone. It produces more than 300 tons of fly ash everyday. More than 95% of its production is disposed as a waste material into the waste lagoons, which poses a great problem in terms of cost, land and environment. The chemical composition of the fly ash used is given in Table 2.

Water: Samples of tap and dam water were obtained with the intention to study the effect of fly ash on them by analyzing the DO level and change in pH caused by fly ash.

Raw sewage: The sewage was collected from the sewage treatment plant at Glenn Valley in Gaborone. This was used to assess the degree of pollution of dam water and tap water with fly ash as compared to raw sewage.

Methodology

Preliminary work

Two sets of suspensions of fly ash were prepared by suspending 4g and 8g of fly ash in 250ml of distilled water. One set was boiled for about 15 minutes to enhance the dissolution of soluble salts in water. The other set was stirred mechanically for 15 minutes. The pH and DO level of the stirred suspensions were measured immediately after stirring and after a period of two days, while the pH and DO level of boiled suspension was measured only once, immediately after boiling. These values were compared with the pH and DO level of fresh distilled water. Results are tabulated in Table 3.

Table 3 : Variation of pH and DO Level with the Addition of Flyash

	DW	DW+ash (soon after mixing)		DW+ash (Mixture boiled)		DW+ash (Mixture after 2 days)	
		4g in 250ml	8g in 250 ml	4g in 250ml	8g in 250ml	4g in 250ml	8g in 250ml
pH	7	10	10	10	10	10	10
DO ppm	1.6	0.6	0.4	0.6	0.4	0.5	0.4

Table 4 : Variation of DO Level with the Addition of Flyash

Time	DO level in ppm				
	Tap water		Dam water		Sewage
	With ash	Without ash	With ash	Without Ash	
Initial	2.9	7.2	3.3	7.9	2.3
1 hr	3.0	6.6	3.7	7.1	2.1
2 hrs	2.4	6.8	3.3	6.7	1.8
4 hrs	1.8	6.6	2.1	6.3	1.6
6 hrs	1.8	7.0	2.5	6.5	1.5
1 day	0.5	6.7	0.8	5.9	0.8
2 days	0.4	6.5	0.7	5.9	0.8
5 days	2.6	6.1	2.5	6.7	0.2
8 days	3.4	6.6	4.3	6.8	0
13 days	3.4	7.1	4.3	7.6	—

Table 5 : Variation of pH with the Addition of Flyash

pH	Tap water		Dam water	
	With ash	Without ash	With ash	Without ash
Initial	10.0	7.0	10.0	7.0
Final	11.0	8.0	11.0	8.0

Further investigations

In continuation to the preliminary work, two more sets of suspensions were prepared with 1.5kgs of fly ash suspended in 6 liters each of dam and tap water samples. At various time intervals, the DO levels of the dam and tap water with and without the ash were measured with DO meter, HI 9142 (portable waterproof). For comparison purpose, the DO level of raw sewage was also measured simultaneously (Table 4).

The pH of various suspensions and the water samples without fly ash were determined at the initial and final stages of the experiment using the universal pH tablets (Table 5).

Results and Discussions

The results of preliminary investigations are shown in Table 3.

The results clearly indicated that the salts present in fly ash easily go in solution. While the dissolution of these salts increased the pH from 7 to 10, it decreased the DO level from 1.6 to 0.4. Both these parameters were altered beyond the permissible value of 9.0 for pH and 4 to 6 ppm of DO level for fish propagation and wild life. The reduction of DO level to 0.4 ppm cannot be taken as accurate quantitatively as the initial DO level of distilled water was 1.6ppm as against 9.2 ppm at 200°C for clean water. However it does give a qualitative picture of the effect of fly ash in water.

Based on these observations, further investigations were carried out with water collected from tap and Gaborone Dam. The water from the Gaborone Dam is used by the Department of Water Utilities for domestic and industrial supplies after due treatment. The results of these investigations are tabulated in Table 4.

Variation in DO level

DO levels observed at various time intervals were plotted on semi-log plot with DO levels on normal scale and time elapsed on logarithmic scale (Fig. 1). It was observed that with the addition of fly ash, the DO level of tap and dam water first decreases and then increases. Initially soon after the mixing of fly ash in water, the DO level decreased from 7.2 ppm. to 2.9 ppm in tap water and from 7.9 ppm to 3.3 ppm in dam water. The DO level of raw sewage was found to be 2.3 ppm. This showed that the degree of pollution in tap water was 88 % of raw sewage and in dam water, it was 82 % of the raw sewage immediately after the addition of fly ash.

Any deviation of the plotted graphs from smooth curve could be due

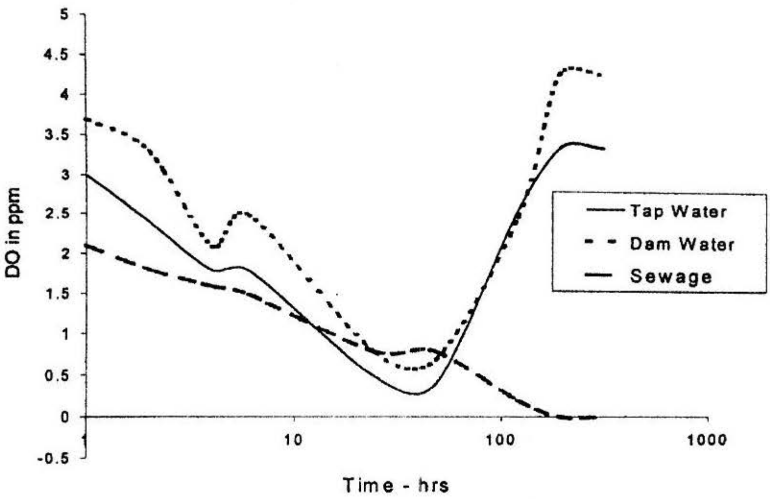

FIGURE 1 : Effect of Flyash on DO Level with Time

to the effect of temperature on DO level as well as the sensitivity of the DO meter which was +1.5% of the range (0.0 to 19.9 ppm) which can contribute a variation of +0.3 ppm. It may be noted that there was a temperature fluctuation of +8°C around mean temperature during the period of experiment.

It is observed that due to fly ash, the decrease in DO level is very sharp in the first few hours and then slows down. All the depletion is more or less complete in two days after which reaeration appears to start dominating over the process of deoxygenation and DO level starts rising. It continued to rise for 7 days and became stable. The stable value of DO level was found to be about 50% of the initial DO level. It indicates that the recovery of DO level by nature (aeration) would take very long to bring the DO back to its original. It is also noted that the stable value of DO level (3.4 ppm for tap water and 4.3 ppm for dam water) achieved within the period of investigation is at lower limit of the permissible level for most of the aquatic life. DO level of raw sewage continued to deplete due to microbial decomposition of organic matters present in it.

Generally, deoxygenation could be caused by reducing agents that bring about an immediate oxygen demand, or by biological decomposition of waste organic matter. Since the media being investigated did not contain any waste organic matter, the deoxygenation can solely be attributed to the soluble salts present in fly ash. Any water medium is originally saturated with DO. As soon as the oxygen demand begins to be exerted, the DO falls below saturation and reaeration starts. Reaeration is a process of absorption of atmospheric oxygen by the surface water. It is proportional to the DO deficiency and is the primary source of oxygen input into the water bodies. With increasing saturation deficit, the rate of reaeration increases until a critical point is reached where the rates of deoxygenation and reaeration are equal. At the critical point, minimum DO is reached and as further time passes the DO will increase due to reaeration. Although the oxygen deficit regulates the rate of reaeration, the actual amount of oxygen absorbed depends on the physical and hydrological characteristics of the water body in terms of factors like temperature, salinity, atmospheric pressure, water depth and surface area. The rise in the DO value of the fly ash contaminated dam and tap water, after a period of 5 days, may be due to the effect of reaeration as there were no microorganisms.

Effect of DO on aquatic life

The depletion in oxygen in the water media may suffocate the fish and other aquatic animals, which require the presence of an appreciable concentration of DO. Effect of fly ash on depletion of DO level to a magnitude of 0.4 ppm seems to be fatal as it is much lower than the required limits of DO at saturation levels for aquatic life (5-6 ppm). With mild pollution, fish may acquire a flavor that renders their flesh unfit for use as food whereas with more severe contamination, the fish sicken and die. Fish are most frequently used as the so-called target organisms in developing criteria and setting standards for water quality.

Recommended limits for DO were given by the National Committee on water quality in the US to protect communities and populations of fish and aquatic life against mortalities as well as to prevent adverse effects on eggs, larvae and population growth (Water Quality Criteria, Technical Advisory Committee to EPA, 1968). According to these documents, DO should be greater than 5 ppm nearly all the time in warm water. For short periods, concentrations of 4 to 5 ppm are tolerable, but it should never become less than 4 ppm. In cold water environments, concentrations should be greater than 7 ppm for successful spawning, egg and larval development. DO greater than 6 ppm should exist for growth and 5 to 6 ppm for survival over short periods of time. These values may not be sufficiently restrictive for all species of fish. Minimum levels for adult survival may be low even for fish having a low tolerance to DO depletion. For e.g. 1-3 ppm is sufficient for a short time survival for the cold water species such as Salmon. These could feed and reproduce at 3 ppm. However the level required to sustain a long-term survival and normal reproduction of these desirable species such as salmon and trout is much higher. To ensure maximum production of many desired species of fish, a DO content near air saturation (9.2 ppm at 20°C) should be maintained for the critical stages of life (Doudoroff and Shumway, 1967).

Embryonic and Larval Development

The growth of Salmonid embryos and the size of the fry that emerge from gravel in streams are limited by the supply of DO (Shumway et al., 1964). For most species studied which included a range from cold water to warm water fishes, the time to hatching increased, growth decreased and survival decreased as DO was reduced.

The greatest effect was observed below 50% saturation, which was usually 5-6 ppm at the test saturation temperatures used (Fig. 2). With species such as the white sucker detrimental effects were not observed unless the DO level was less than 50%.

Although it is clear that the survival dropped off at concentrations around 1-5 ppm for all species, three of these namely salmon, trout and catfish showed poorer survival even at concentrations higher than 5 ppm. Furthermore, delayed hatching, delayed feeding and slower growth were also identified with species at levels between 100 and 50% saturation (Carlson and Siefert, 1974; Carlson and Herman, 1974; Siefert and Spoor, 1973).

Detrimental effects on larval development occurs with both cold water and warm water species when any reduction in DO occurs to levels lesser than 100% saturation even though the greatest damage is at concentrations lesser than 5 ppm (Shumway et al, 1964) which is more than 0.4 ppm found

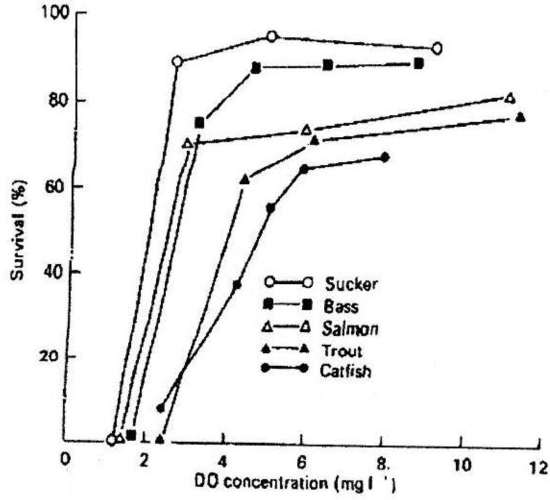

FIGURE 2 : Effect of DO Concentration on Survival of Fish Larvae from te Embryo Stage of Four Species

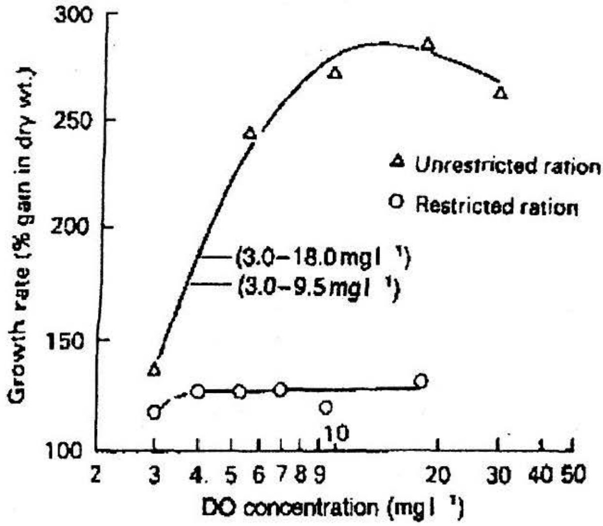

FIGURE 3 : Growth Rate of Juvenile Coho Salomon fed Restricted and Unrestricted Rations at Diurnally Fluctuated Oxygen Concentrations

after I day in tap water with fly ash. It is worth noting that even after 13 days, the DO level recovered (3.4 ppm) is less than 5 ppm. Since the recovery of DO level due to aeration is very slow even after 8 days the detrimental effects due to lower DO levels would likely exist for a considerable period of time.

Food consumption and growth

It has been observed that in general, the amount of food consumed by aquatic life is progressively impaired below DO saturation. Studies made by Warren (Warren, 1971) on juvenile largemouth bass and salmon have verified it.

The growth rate of juvenile coho salmon does not vary significantly with diurnal fluctuations of DO concentrations if fed with restricted ration while it decreases with the decrease in DO concentration even if fed with unrestricted ration (Doudoroff and Shumway, 1967). This is largely because irrespective of the availability of the food, its consumption will be less at lower DO levels since the food metabolism is directly proportional to the oxygen levels available.

Studies on the effect of DO level on standard metabolism have shown that the metabolic rate is directly proportional to DO level. Observations made by Graham (1949) on brook trout (Salvelinus fontinalis) are shown in Fig. 4.

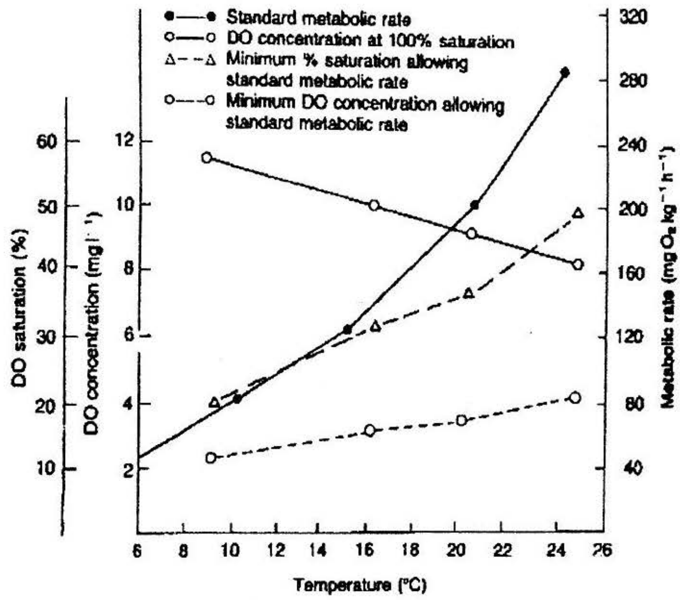

FIGURE 4 : Standard Metabolism of Brook Trout (Salvelinus Fontinalis) in Relation to Minimum DO needed in Concentration and Percent Satuation

It is observed that the standard metabolic rate is less than 60 mg O_2/kg/h at DO level of 2 ppm. Since the decrease in metabolic rate is rather sharp with the decrease in DO concentration it is expected to be negligible at the DO levels of 0.4 ppm which was the minimum DO level found in tap water with fly ash.

In real life, the pollution of water by fly ash is expected to be observed in three situations:

1. In the structures like dykes, dams and river training structures constructed using fly ash where fly ash would directly be in contact with water.

2. Dumping sites of fly ash: the water leaching through the bed of fly ash contaminating the ground water. The degree of pollution of ground water would depend on the type and nature of minerals present in the soil strata through which the leachate from fly ash would pass before it mixes with the ground water.

3. Offshore land reclamation using fly ash.

Conclusion

The findings of our present investigations can be concluded as follows:

1. The fly ash in water increases its pH from the neutral value to 11.0 but decreases its DO levels to 0.4 ppm.

2. The depletion in DO level is rapid in the beginning and reaches its minimum level within 2 days beyond which it starts increasing due to aeration.

3. The recovery of DO level due to aeration is faster in the beginning but slows down exponentially with time.

4. The minimum DO level of 0.4 ppm observed is much below the recommended limits given by the National Committee for Water Quality in the US.

5. The decreased DO level to a limit of 0.4 ppm will cause delayed hatching of the larvae, delayed feeding and a slower growth of the aquatic organisms in general.

6. The time for the recovery of DO level back to its safer limits would depend on the minimum level of DO, depth and surface area of the water body.

7. The severity of adverse conditions by fly ash would depend upon the proportion of fly ash in a water body.

Recommendations

Since a stage has come where the geotechnical engineers are beginning to work on the use of fly ash for the construction of embankments, dams and dykes, it is important that some field investigations be carried out to study the effect of fly ash polluted water on aquatic life.

It is strongly recommended that the findings of the present work should be treated as a point to open an agenda on the issue of water pollution by the leachate, may it be ground water or the water in the vicinity of the ash used in the construction of dams, dykes or river training structures.

Acknowledgement

The authors gratefully acknowledge the following for their support in completing the work:

1. University of Botswana for its financial support.

2. Mr. Walker, the Operation Manager of Morupule Thermal Power Station for collection and supply of fly ash.

3. Mr. Mothusi and Mr. Mokolodi for their assistance in the laboratory work.

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