ENVIRONMENTAL IMPACTS OF FLY ASH

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Alarmingly high accumulation of fly ash globally has led Geotechnical engineers into finding a solution for the use of fly ash as a construction material in the recent past. As of now, although the material has been used in a limited way in the construction of roads, embankments, dykes and by cement industries, most of it is still being dumped as a waste material. There is a general opinion amongst the Geotechnical engineers that fly ash is a non-hazardous material. However, the authors felt that it may not be entirely true due to the fact that fly ash does contain quite a significant proportion of soluble salts. These salts would leach into water if fly ash comes in contact with water or if the ground water leaches through a bed of fly ash. The investigation revealed that Dissolved Oxygen of fly ash polluted tap and dam water is reduced to a level far below the permissible limit for aquatic life. The authors would like to emphasise that the findings of the present investigation are being submitted to open an agenda on the issue of water pollution by the fly ash leachate, may it be ground water, water in the vicinity of the ash being used in the construction of dykes, dams, river training structures or for land reclamation on sea shores.

1 INTRODUCTION

Rapid industrialisation and urbanisation 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, is 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 recently made a nation wide pledge in the News Bulletin [1], 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. In many countries, a limited amount of research has led to the use of fly ash in the construction of roads and embankments and in the production of cement. Nevertheless, the bulk of it is still being dumped as a waste product and globally, engineers are facing the challenge of finding a solution for its consumption. This problem is more critical to countries like Japan, with scarce land for the fly ash disposal.

There is a general belief amongst 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 ash remain more or less the same [2]. When the ash comes in contact with water, these salts that go in the solution are likely to affect 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 could have adverse affects on aquatic animals and higher plant life [3]. The degree of impact probably depends 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. 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.

2 LITERATURE REVIEW

The use of ash particularly as a fill material or in the embankments was suggested not to pose any problems that differed greatly from those associated with the disposal of the municipal wastes [4]. 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 the EPA Hazardous Waste Standards for inorganic materials [5].

Though fly ash 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 also be present in the coal as well. This leads to a large number of trace elements that can be found in fly ash depending on the coal source. Those commonly found are as shown in the table 1.

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	*

Table - 1 [6] trace elements commonly found in fly ash and their permissible level in drinking water.

Presence of these elements in fly ash 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 trace elements present in the ash might lead to contamination of the ground water [2]. 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 [2]. The solubility of these salts affect the pH ranging from 6.2 – 11.5 [7] as compared to the allowable pH range specified as 6.5 - 9.0 for the protection of fish life [8].

In the present work, the effect of fly ash leachate on the depletion of DO level and increase in pH in water was investigated. Depletion of DO level beyond the allowable limits will be detrimental to all organisms consuming this water [8].

3 MATERIALS USED

3.1 Fly ash – the fly ash was collected from the Morupule Thermal Power Station, the only thermal power station in Botswana situated about 350 km north of the capital city, Gaborone. It produces more than 300 tons of fly ash everyday that is being disposed off 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.

Fly ash 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

Table – 2 : salts commonly present in fly ash.

3.2 Water – water samples from tap and Gaborone dam 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.

3.3 Sewage – the sewage to be treated was collected from the Glenn Valley sewage treatment plant in Gaborone. This was used to compare the degree of pollution of dam water and tap water with fly ash as compared to raw sewage.

4 METHODOLOGY

Preliminary work - Two sets of suspensions of fly ash were prepared by suspending 4 g and 8 g of fly ash in 250 ml 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. These values were compared with the pH and DO level of distilled water and boiled suspensions of fly ash. Results are tabulated in table-3.

Further investigations - Following the preliminary work, two more sets of suspensions were prepared with 1.5 kg 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 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).

5 RESULTS

The results of all the investigations are shown in tables 3, 4 and 5.

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

(DW – distilled water)

Table – 3: variation of pH and DO levels with the addition of fly ash in distilled water.

	DO level in ppm				
Time	Tap water		Dam water		Raw Sewage
	With ash	With out ash	With ash	With out 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
13days	3.4	7.1	4.3	7.6	-

Table – 4 DO levels of tap and dam water polluted with fly ash as compared to sewage.

	Tap water		Dam water	
pH	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

Table – 5 pH of tap and dam water with and without fly ash

6 DISCUSSION

Distilled water was used for preliminary investigation just to verify whether there is any dissolution of salts from fly ash or not. Although, in normal field situations, fly ash would never be boiled with water, one set of the sample was boiled for experimental purposes for accelerated reaction rate. The results, shown in table 3, indicated an increase in pH which can be attributed to the dissolution of salts present in fly ash. While the dissolution of these salts increased the pH from 7 to 10, it decreased the DO level from 1.6 to 0.4. In practical situations, since it is surface water which is going to come in contact with fly ash, further investigations were done with dam and tap water. Results are indicated in table 4 and 5. The water from the Gaborone Dam is used by the Department of Water Utilities for domestic and industrial supplies after due treatment.

6.1 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).

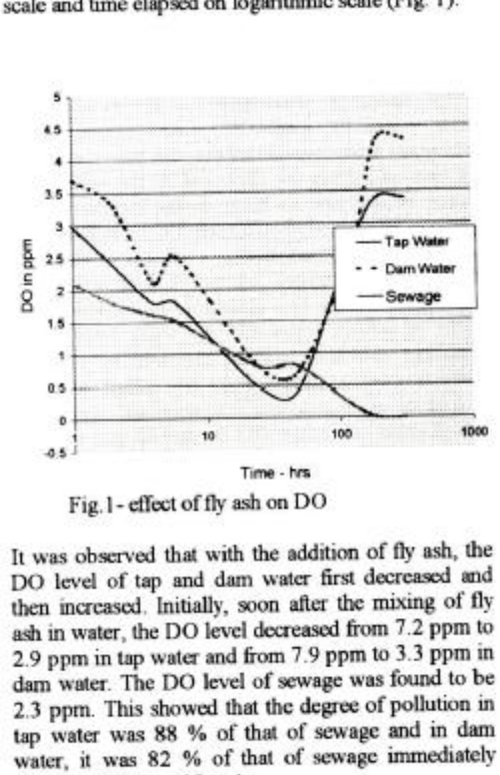

Fig.1- effect of fly ash on DO

It was observed that with the addition of fly ash, the DO level of tap and dam water first decreased and then increased. 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 sewage was found to be 2.3 ppm. This showed that the degree of pollution in tap water was 88 % of that of sewage and in dam water, it was 82 % of that of sewage immediately after the addition of fly ash.

Any deviation of the plotted graphs from smooth curve could be due 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 19.9ppm) which can contribute a variation of ±0.3ppm. 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 in general, the decrease in DO level was very sharp in the first few hours and then slowed down. All the depletion was more or less complete in two days after which reaeration appeared to start dominating over the process of deoxygenation and DO level started 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 without the ash. It indicates that the recovery of DO level by nature (reaeration) would take time to bring the DO back to its original. It is also noted that the stable value of DO level (3.4ppm for tap water and 4.3ppm for dam water) achieved within the period of investigation is at lower limit of the permissible level which is 4 to 6 ppm for fish propogation depending on the warm or cold water fishes and fresh water or salt water fishes [8].

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 in this case can solely be attributed to the soluble salts present in fly ash. 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.
field investigations be carried out to study the effect of fly ash polluted water on aquatic life.

In this study, the proportion of fly ash was randomly chosen at 25% of water. This was taken to see the probable maximum effect of fly ash pollution. In

6.2 Effect of DO on aquatic life

Any depletion in the DO levels may suffocate fish and other aquatic animals, which require an appreciable concentration of DO. The effect of fly ash on the 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 (4-6 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 [8].

7 CONCLUSION

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

1. The fly ash in water increased its pH from the 7.0 to 11.0 but decreased its DO levels from 7.2 to 0.4 ppm in tap water and from 7.9 to 0.7 ppm in dam water.

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 reaeration.

3. The recovery of DO level due to reaeration 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 time for the recovery of DO level back to its safer limits would depend on the minimum level of DO.

8 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 dykesand land reclamatio,n it is important that some practice, however, the degree of pollution is expected to depend on the proportion of fly ash.

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 of fly ash.

ACKNOWLEDGEMENTS

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.

9 REFERENCES.

1. Sridharan, A. "Presidential Address". News Bulletin of Indian Geotechnical Society, Vol. 29 No.1, Jan – Mar. 1997 pp 1-8.

2. GAI Consultants, Inc. Fly Ash Structural Fill Handbook, EPRI EA-1281, Project 1156-1, Final report, Monroeville, Pennsylvania, Dec 1979.

3. Tebbutt, T.H. Y. "Principles of Water Quality Control". Pergamon Press, New York, 1992, pp 76.

4. Morgenstern, N.R. "The Emergence of Environmental Geotechnics", Presidential Address for 9th Asian Regional Conference, ISSMFE, 1991, pp 10.

5. Han, D. "Use Potential of Fly Ash Residual Soil Mixture as a Dyke Material", Environmental Geotechnics, Kamon (ed), Vol.2, Balkema, Rotterdam, 1996, pp 721-726.

6. Stephens et al. "Trace Metals in Effluents From Coal-Fired Furnaces." In Proceedings of the Fourth Annual Environmental Engineering And Science Conference, University of Louisville, Louisville, Kentucky., March 4-5, 1974.

7. Rohrman, F.A. "Analyzing the Effect of Fly Ash on water Pollution." Power, Aug. 1971.

8. Mark, J.H. "Water and Wastewater Technology" , 2nd edition, Prentice-Hall International Editions, 1986, pp 167.