Temperature Concerns around the Landfilling of Coal Ash Waste – Literature Review versus a Thermal Investigation on-site

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ABSTRACT

This paper presents the results of on-site geotechnical and thermal investigations carried out at a dry ash waste landfill in South Africa. These data are compared against a literature review with the purpose of commenting on the geotechnical parameters and generation of heat within the ash waste pile.

The geotechnical variables obtained through the investigation have given good insight into the geotechnical characteristics of the CCP waste at the site under consideration.

The temperature monitoring program undertaken at the specific ash disposal facility has shown that temperatures within the CCP waste do not exceed 43ºC These recorded temperatures are in line with the temperatures from facilities receiving general municipal solid waste and do not pose an additional threat when taking the thermal resistivity of the design into account. As such, no additional thermal protection of the geosynthetic basal lining system is recommended in the design of the case study that is under consideration.

1. INTRODUCTION

Coal Ash Waste is the single largest waste stream in South Africa. In any single day, a large coal-fired power station can result in the generation of a substantial amount of Coal Combustion Products (CCPs) or coal ash waste.

In South Africa, it is common practice to dispose CCPs to both wet and dry ash disposal facilities. Looking at industry trends it appears that the development of Dry Landfill facilities suitable for disposing CCPs is on the increase due to the less onerous water requirements associated with Dry Landfilling practices.

Recent developments in South African environmental protection legislation now require than all new CCP landfills be designed in accordance with the Waste Classification and Management Regulations (WCMR 2012) and subsequent gazetted documentation which imposes the requirement for an engineering barrier protection system to protect the underlying aquifers and surrounding environment.

A literature review on the behaviour of coal ash waste compared to municipal solid waste (Wallace, 2013) highlighted the potential for the generation of excess heat in the ash waste due to the pozzolanic reaction that can take place when CCPs are hydrated post placement. The review further highlighted a gap in the understanding of the geotechnical behaviour of CCPs when they are landfilled as a homogenous, consistent waste material.

Jeffares and Green undertook on-site geotechnical testing and set up a temperature monitoring program at an existing dry ash landfill within the borders of South Africa. The goal of the investigation was to better understand the geotechnical behaviour of the specific coal ash waste and to monitor the temperatures of the ash waste on-site for comparison against the literature and to better inform particular design parameters.

2. LITERATURE REVIEW

<u>Geotechnical Concerns</u>

CCPs are easily eroded by uncontrolled surface runoff primarily due to the fine particle size. CCPs have been shown to be more compressible than typical compacted sands and exhibit a hydraulic conductivity similar to that of fine sand/silt mixtures (Kim, et al., 2005). Loss in shear strength has been noted as a concern when CCPs are saturated prior to compaction at or near optimum moisture content. Once compacted the permeability of the CCPs decreases and saturation is less likely to occur (Hardin & Perrotta, 2011).

Case studies of dedicated coal waste landfills in South Africa have shown no formal compaction occurring in facilities where the CCPs are placed by conveyors or stackers. The literature review indicated that this is not the norm overseas (e.g. the USA).

The literature review highlighted a vast degree of variance in the geotechnical engineering soils parameters for different CCP wastes. A slope stability analysis could not be set up with confidence without undertaking detailed on-site sampling and testing to obtain the necessary geotechnical engineering parameters such as in-situ density and the friction angle of the CCP waste.

Temperature Concerns

Hydration of pozzolans within fly ash has been shown to be an exothermic reaction. The heat of hydration has been used in the concrete industry to predict heat build-up in large scale concrete construction (Hasset and Eylands, 1997).

Limited literature is available when it comes to predicting heat build-up in a waste disposal facility that receives a homogenous Ash Waste as a singular waste.

The content of Calcium Oxide (CaO) present in a source of fly ash is seen as an indicator to the cementitious nature of the fly ash and results in a difference in the heat of hydration (Blondin et al., 1999). ASTM C618 defines two classes of Fly Ash namely Class C and Class F. Class F fly ashes are generally low Calcium, typically less than 10% CaO, while Class C fly ashes typically have a CaO concentration in the order of 10% - 30%.

Yoshisa and Rowe (2003) modelled heat transport in a landfill due to conduction and water flow. The equation applied to model this heat transport is a one dimensional heat equation which has been seen as sufficient in this case due to landfills generally being much larger in surface area than in height (Rowe and Hoor, 2009).

Yoshida and Rowe (2003) presented observed temperatures versus temperatures calculated from the heat transport equation at a landfill in Tokyo that received both general and ash waste. The paper shows a strong correlation between observed and calculated values and the landfill is shown to reach internal temperatures in the region of 60°C over 20 years.

Variables from the heat modelling equation by Yoshida and Rowe (2003) were obtained as part of the testing schedule undertaken at the soils laboratory for the ash disposal facility under investigation. This was done in order to carry out a rudimentary comparison of the CCP waste against the available literature. The variables to be used in the comparison are presented in Table 1.

Table 1: Thermal Conductivity Parameters from Literature (from Yoshida et al. 2003)

Parameters	sign	units	value
Landfill layer(unsaturated)			
Water content	w	[%]	28.9
Apparent density	ρ_e	[kg/m^3]	1157
Specific heat	C_e	[J/(kg)]	1939
Effective thermal conductivity	k_e	[J/(ms)]	0.35
Landfill layer(saturated)			
Water content	w	[%]	42.3
Apparent density	ρ_e	[kg/m^3]	1424
Specific heat	C_e	[J/(kg)]	2363
Effective thermal conductivity	k_e	[J/(ms)]	0.96

Table 2 presents a comparison of waste temperatures against liner temperatures for various landfill facilities (Rowe & Islam, 2009). The entry for Ingolstadt, Germany represents a landfill facility receiving CCPs. It is noted that the liner temperature recorded at the coal ash landfill was not shown to be substantially higher than average liner temperatures experienced in MSW facilities, however, the CCP waste body is shown to reach a temperature of 87°C which is substantially higher than comparable MSW waste body readings.

Table 2: Landfill temperatures recorded at various facilities (adapted from Rowe & Islam, 2009)

Location	Waste thickness (m)	Leachate level (m)	Time (years)	Waste temperature (°C)	Liner temperature (°C)
Altwarmbüchen, Germany	40	–a	4pc	–	38
Pickering, ON, Canada	60	20	11	60	–
Hannover, Germany	70	<0.1	13	–	33
Philadelphia, PA, USA, wet	70	<0.1	6	–	50–54
Stage 1, Maple, ON, Canada	65	1	0–5	–	12
South of France		7	14	–	37
Alaska, USA		7	14–21	–	37
Stage 2, Maple, ON, Canada	65	1	0–3	–	9–11
New Mexico, USA		1–5	18	–	35–36
Stage 3, Maple, ON, Canada	65	<0.3	0–6	–	10
Croydon, UK		<0.3	16	–	37
Stage 4, Maple, ON, Canada	65	<0.3	1	–	7
		<0.3	1–15	–	7–35
Ingolstadt, Germany (ashfill)	9	<0.3	0.25	87	23
	9	<0.3	1.5	64	46
Philadelphia, PA, USA, wet	9	<0.3	3	43	40

-a = Not known
pb = Post closure

3. GEOTECHNICAL INVESTIGATION

Samples of CCPs from the site under investigation were taken from four unique locations. Three temperature monitoring boreholes were established as part of the thermal investigation, ash samples were taken from each of the three boreholes. The final sample set came from a trail pit established in the existing ash landfill. Samples were taken every 5m during the drilling of the boreholes and the samples were analysed to determine a moisture content distribution for the full depth of the borehole. Table 3 shows the moisture content distribution. The average moisture content was found to be 18.6%.

Table 3: Moisture Content Distribution at the Temperature Monitoring Boreholes

BH Depth	Moisture Content (%)		
	BH01	BH02	BH03
5	22.5	18.5	19.5
10	23.2	17.6	17.9
15	24.8	18.2	16.6
20	18.8	17.9	15.9
25	20	17.1	16.1
30	18.8	18.3	16.4
35	18.2	17.5	15.4
40	17.5	18.4	17.1
45	22.3	27	-
48	16	15.8	-

An undisturbed sample was taken from the trial pit sited in the existing CCP landfill at a depth of 1 to 1.5m. This undisturbed sample underwent shear box testing and in-situ bulk density analysis at a soils laboratory. The results of the testing are shown in Table 4.

Table 4: Undisturbed Ash Sample Soils Parameter Test Results

Undisturbed Ash Sample	Value	Unit
Bulk Density	1109	kg/m^3
Dry Density	978	kg/m^3
Moisture Content	13.5	%
Friction (φ')	33.6	°
Cohesion (c')	2.9	kPa

The results of the Mod. AASHTO moisture/density testing are shown in Figure 1. An interesting outcome to note is that the optimum moisture content for maximum compactive effort is very similar to the in-situ moisture content of the undisturbed ash sample (Table 4). The variables obtained from the geotechnical investigation are to form part of a detailed slope stability analysis which will inform elements of the final design of the final landfill design.

Figure 1 through Figure 3 below show captioned photographs from various stages of the geotechnical investigation on-site.

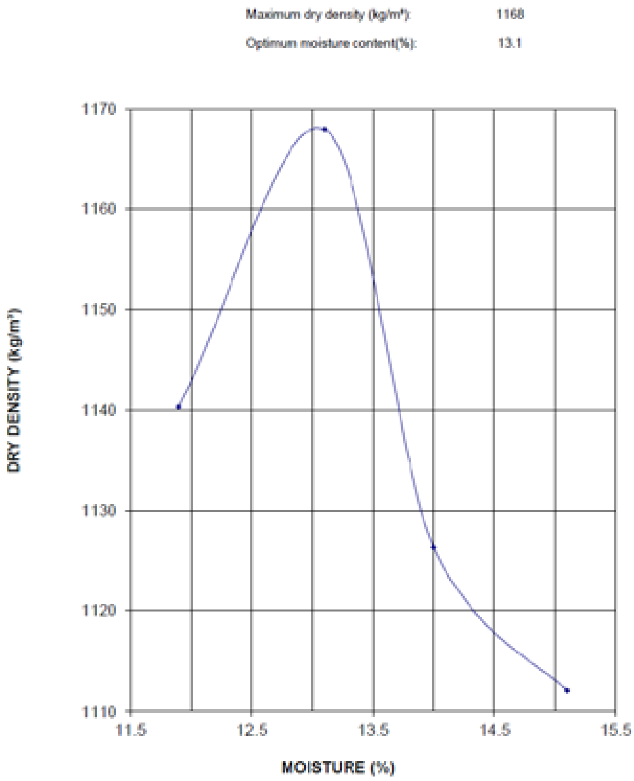

Figure 1 - Moisture/Density Relationship (MOD AASHTO Compactive Effort)

Figure 2 - Removing the undisturbed ash sample

Figure 1 - Ash Samples from Borehole for Borehole Logging

4. THERMAL INVESTIGATION

4.1 Thermal Conductivity

Table 5 presents the results of the thermal conductivity testing that was carried out on the CCP waste.

Table 5: Thermal Conductivity of Ash Waste

SAMPLE	SAMPLE DESCRIPTION	MOISTURE (%)	THERMAL CONDUCTIVITY (J/ms.K)	SPECIFIC HEAT (J/kg.K)
BOREHOLE 1	Dry	-	0.140	742
	In-Situ Moisture	14.5	0.548	1304
	Saturated	19.7	0.661	1625
BOREHOLE 2	Dry	-	0.128	670
	In-Situ Moisture	15.1	0.563	1218
	Saturated	18.1	0.620	1545
BOREHOLE 3	Dry	-	0.130	748
	In-Situ Moisture	13.3	0.547	1299
	Saturated	16.7	0.598	1237

A full panel of chemical testing undertaken by a soils laboratory in June 2012 on Ash Waste from the Disposal facility under consideration shows the CaO concentration of two ash samples to be between 3.9% and 4.6%.

When comparing the thermal conductivity (Table 5) and specific heat of the specific CCP waste against the values presented by Yoshida and Rowe (2003), it is noted that both the thermal conductivity and the specific heat of the tested CCP waste are lower than in the example presented by Yoshida and Rowe (2003).

Due to the low concentration of CaO (free lime) and the lower thermal conductivity and specific heat of the Ash waste under consideration, it is anticipated that the on-site thermal monitoring will measure temperatures well below 60°C.

4.2 Temperature Monitoring

The investigation entailed establishing four monitoring stations that were to carry out continuous temperature monitoring. Each test station had the ability to monitor four temperature probes at each station.

The first three test stations were setup by using a rotary percussion borehole drilling rig to drill through ash placed within the past two years until such time as the underlying in-situ ground level was reached. Two thermal probes were placed at 5m and 10m deep from surface level respectively. The fourth probe was placed at the bottom of the ash pile and the third probe was placed 5m above the fourth (i.e. the two deep probes were placed at approximately 35m and 40m deep from current surface level respectively).

The fourth thermal test station was setup by placing two thermal probes into the advancing ash face in order to monitor the development of heat in freshly placed ash. The final two probes in test station four were left on the surface of the landfill to monitor ambient temperatures experienced over the monitoring period.

Figure 4 through to Figure 6 present captioned photos depicting the various stages of the on-site work that was undertaken for the Thermal Investigation.

Figure 2 - Initial Temperature Readings from Borehole Test Station

Figure 5 - Placement of Thermal Probes into Advancing Ash Pile Borehole

Figure 6 - Test Station Complete

We experienced disturbances with the recordings due to the storm damage that occurred during the excessive rainfall that was experienced while undertaking the temperature monitoring. This resulted in some stations going offline for a period. We further experienced technical difficulties for brief instances at logging station 1 and 3. Despite the setbacks we have recorded good, reliable results.

Table 5 presents a tabulated summary of the four temperature logging stations including maximum and minimum temperatures recorded during the on-site temperature monitoring. The loggers were set to record temperature every minute for the entire duration of the investigation. Figure 7 through to Figure 8 show a graphical representation of the recorded temperature data for the four respective logging stations.

Minimal statistical manipulation was necessary to present the data as shown below. The maximum recorded temperature (Not considered a gross outlier due to technical fault) across all four logging stations did not exceed 43°C. The standard deviation for thermoprobes that did not experience technical disruptions was less than 1°C which has given further confidence in the results.

Table 6: Temperature Investigation Summary

Logging station	Nature of Logging Station	Estimated Time Elapsed since Ash Placement	Probe Depth				Minimum Temp	Maximum Temp
			Probe 1	Probe 2	Probe 3	Probe 4		
1	Borehole	1 - 1.5 years	5m	10m	43m	48m	27.9°C	39.8°C
2	Borehole	1.5 - 2.5 Years	5m	10m	43m	48m	31°C	40.12°C
3	Borehole	1 - 1.5 Years	5m	10m	40m	45m	21°C	41.2°C
4	New Ash Waste Pile	Newly Placed Ash	Landfill Surface (offline)	Landfill Surface	10m	15m	36.5°C	42.8°C

CONCLUSION

The geotechnical variables obtained through the investigation have given good insight into the geotechnical characteristics of the CCP waste at the site under consideration, for the purposes of determining stability and basal lining systems (pollution prevention mechanisms).

A review of the thermal conductivity variables against values from the literature review lead to the assumption that temperatures within the disposal facility should be lower than those predicted by Yoshida and Rowe (2003).

The temperature monitoring program undertaken at the specific ash disposal facility has shown that temperatures within the CCP waste do not exceed 43ºC These recorded temperatures are in line with the temperatures from facilities receiving general municipal solid waste and do not pose an additional threat when taking the thermal resistivity of the design into account. As such, no additional thermal protection of the geosynthetic basal lining system is recommended in the design of the case study that is under consideration.

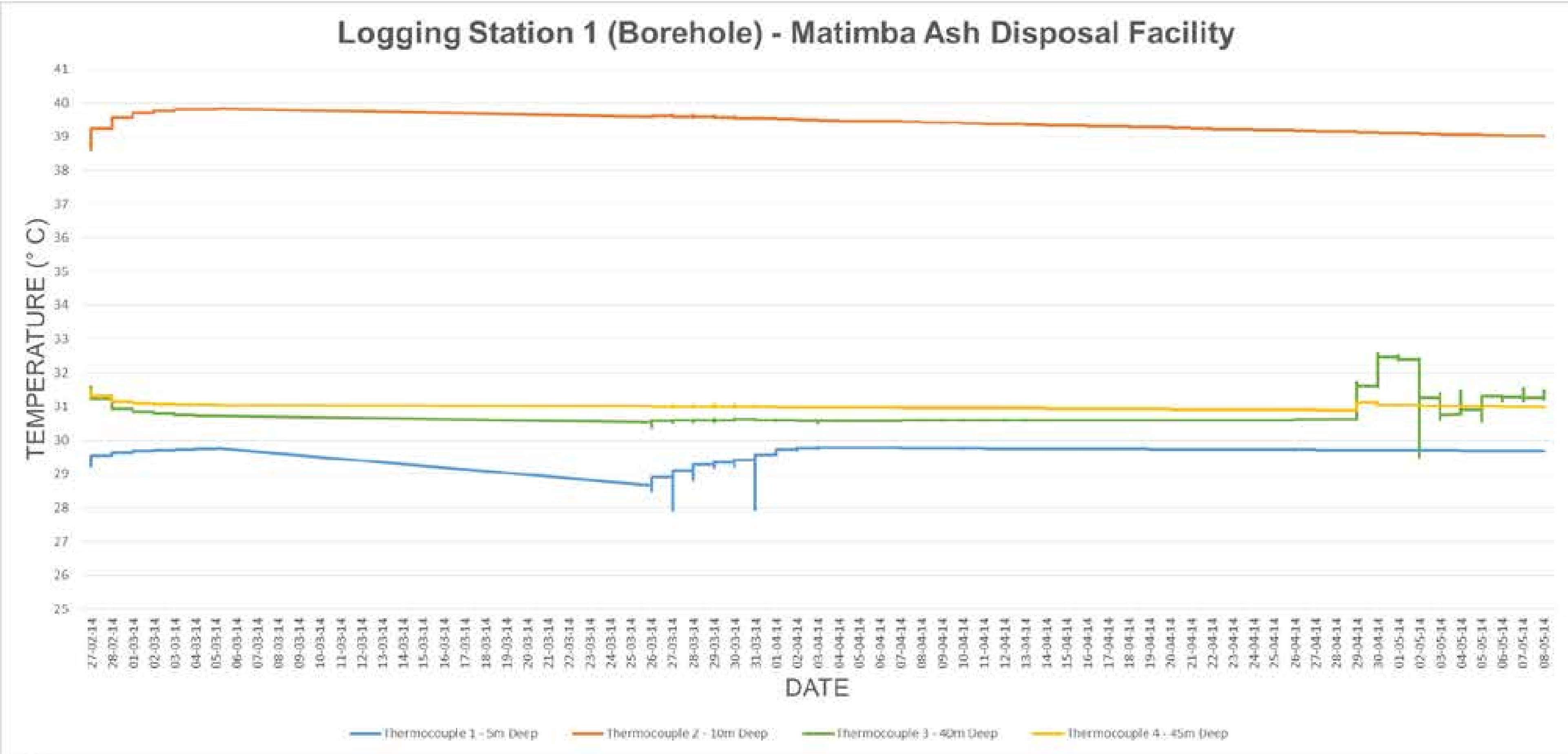

Figure 3 – Temperatures recorded at Logging Station 1 (Borehole 1)

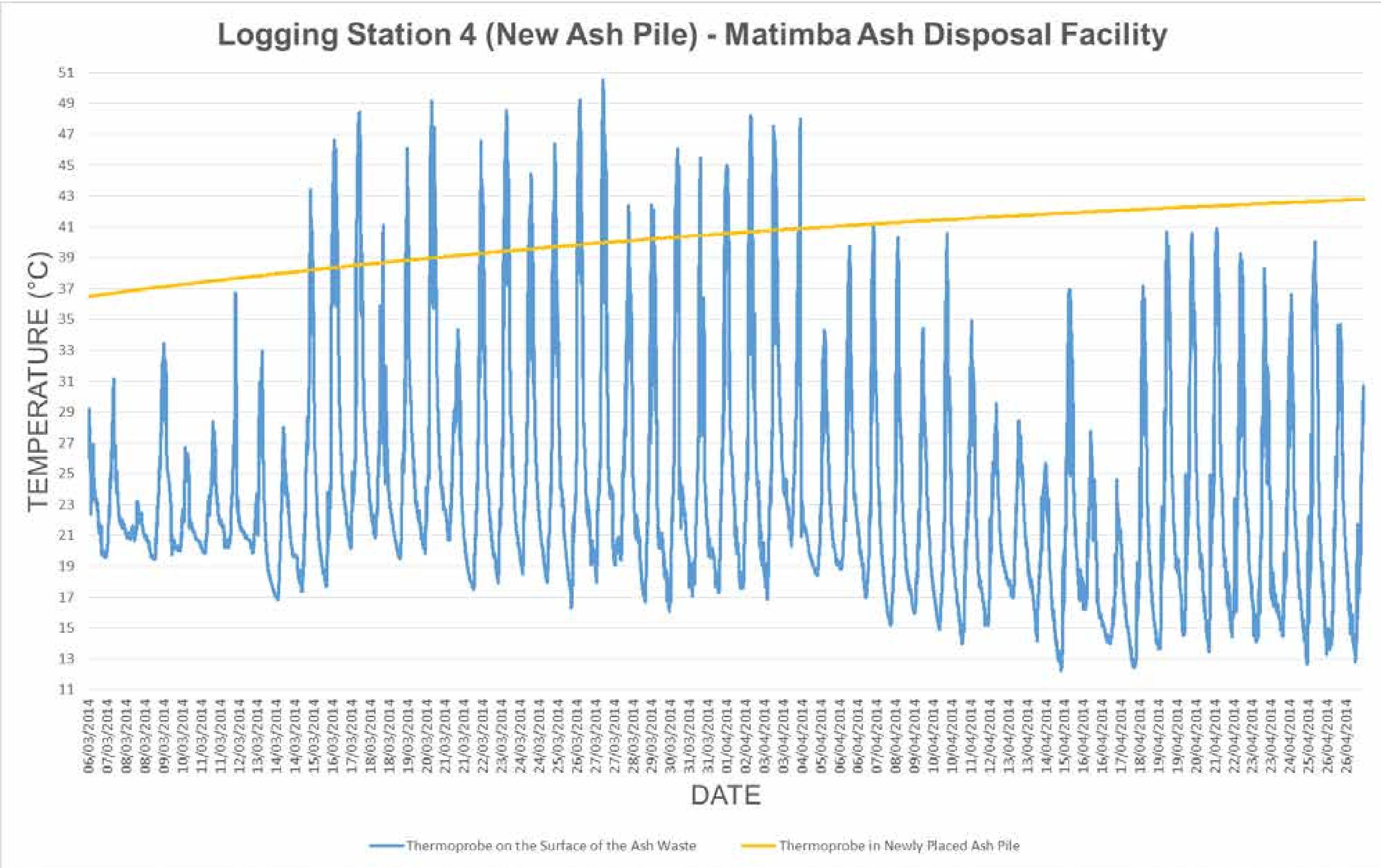

Figure 4 - Temperatures recorded at Logging Station 4 (New Ash Pile) from February to April 2014

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