An Assessment of Tarong Bottom Ash for use on Agricultural Soils

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Abstract

Coal Combustion By-products (CCB's), including fly ash and bottom ash, present a waste disposal problem in Australia due to a continuing demand for coal fired power. Pozzolanic Enterprises handle ash produced by the Tarong Energy coal-fired power station in SouthWest Queensland, which produces approximately 1,200,000 tonnes per annum of CCB's. This comprises roughly 1,100,000 tonnes of fly ash and 100,000 tonnes of furnace bottom ash. The volume and unique properties of the Tarong bottom ash present a significant opportunity for agronomic use. Of particular interest is the ability of Tarong bottom ash to markedly improve the water holding capacity of soils. Given Australia's rural environment is currently enduring a 'one-in-one-hundred-year' drought a study of the ability of Tarong bottom ash to improve water holding capacity is timely. This paper details physical and chemical properties relevant to agronomic use and water holding capacity of ash/soil blends along with some results from initial field trials.

1. INTRODUCTION

Coal Combustion By-Products (CCBs) in Queensland are produced by utility boilers burning pulverised coal. For these boilers the coal is ground to a high fineness (typically 70% < 75 um) and injected into the boilers where combustion of the organic matter (volatile and fixed carbon) occurs. The coal burns at a high temperature (> 1500°C) and the inorganic material melts and agglomerates into spheres. Upon leaving the combustion zone the ash particles are cooled quickly and solidify. About 90% of the ash formed from the burnt coal is carried out of the furnace, extracted from the flue gas, and is know as Fly Ash. The remaining coarser fraction falls to the bottom of the furnace where it sinters together to become the Furnace Bottom Ash.

To date, the furnace bottom ash from Tarong Energy has not been extracted, processed or marketed on a commercial basis. The volume of material available and its unique properties represent a significant opportunity for Tarong Energy and Pozzolanic Enterprises. This material has been given the tradename TARONG FLASH and is the subject of a wide-ranging market development program.

CCBs can be a valuable addition in many agricultural applications CCBs have the possibility of being used as a soil amendment, as a carrier for agrochemicals, or as a fertiliser. CCBs can improve soil texture, increase the water holding capacity and air contents, and provide necessary mineral ingredients. CCBs from black coal also has a low toxicity which allows it be used in many applications.

Pozzolanic see the goal of achieving beneficial use of fly ash in soils used to grow crops as particularly attractive and are currently investigating a number of opportunities. This work involves analysis of the fly ash (chemical analysis, leaching, particle size), laboratory and greenhouse test programs and field studies. Whilst the company has the manufacturing, distribution and market expertise to underpin this strategy, it lacks the necessary agricultural and ecological expertise, and there is, therefore, a clear need to encourage closer ties with academia. For example, this has been achieved through links with research groups at the University of Queensland.

Investigations into the application of Tarong bottom ash in agriculture is part of a larger overall project aimed at determining the markets and applications for CCBs in agriculture. The work is being undertaken in two areas. The first area aims to determine the effect of the application of CCBs to the physical and chemical nature of the treated soils. This involves determining the soil characteristics as well as the chemical behaviour such as leaching. The second area of investigation is aimed at determining the effectiveness of CCB application in identified agricultural markets. Following is some of the work that has been undertaken with Tarong bottom ash.

2. CHARACTERISTICS OF TARONG BOTTOM ASH

2.1 Physical Characteristics

Tarong bottom ash is a new product, produced as a by-product of the burning of fossil fuels for power stations, and hence needs to be fully characterised so that the applications for this material can be realised.

Tarong bottom ash differs physically from the traditional Fly Ash commonly utilised in concrete. Tarong bottom ash has a bulk density of about 0.56 t/m^3 and consists of lightly sintered porous, hollow and solid particles. The average relative density of this material is about 1.5 t/m^3 and it can be compacted to give a bulk density of over 1 t/m^3. The particle size distribution is shown below on Figure 1 and reveals that the Tarong bottom ash has a grading similar to a “fine sand” used in concrete manufacture (particle size range between 0.01 and 1 mm).

Figure 2 shows a photomicrograph of the Tarong bottom ash revealing a mixture of spherical and angular particles that are either separate or loosely bonded together. In addition, many of the particles are porous or hollow providing the lightweight and absorbent nature of the Tarong bottom ash.

Figure 1. Particle size distribution curve for a range of Tarong bottom ash.

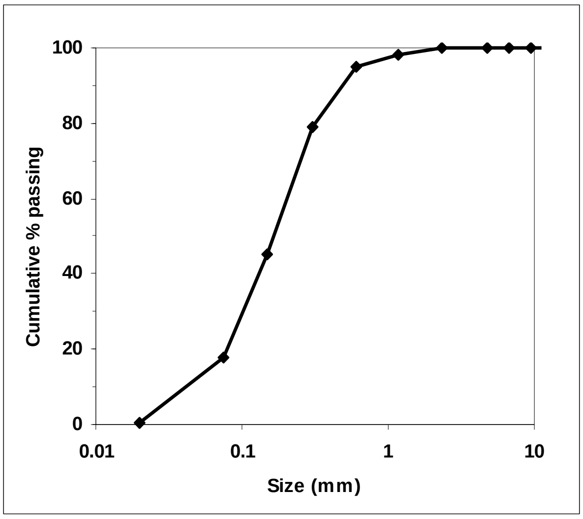
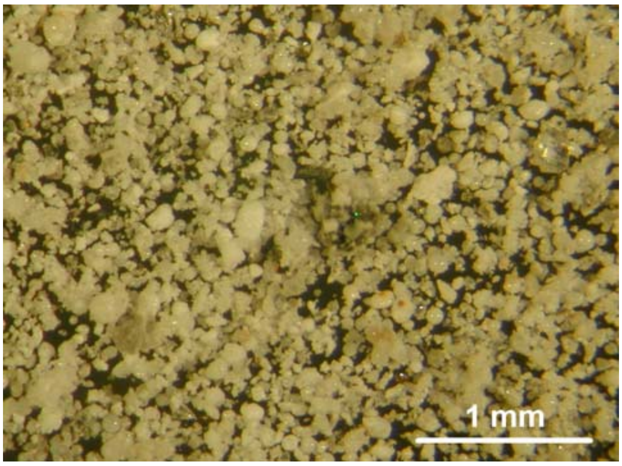


Figure 2. Photomicrograph of the Tarong bottom ash.



2.2 Chemical, Mineral, and Leaching Characteristics

The structure, composition and properties of the fly ash and furnace bottom ash particles depend upon the structure and composition of the coal and the combustion processes by which they are formed.

Tarong bottom ash consists mostly of the oxides of Si and Al. Table 1 shows a typical composition, determined by X-Ray Fluorescence (XRF), for the main elements found in Tarong bottom ash. The elemental concentrations are expressed as the expected oxides and Loss On Ignition (LOI) represents the weight loss of the fly ash (when burned at < 1000°C) and is related to the presence of “free” carbon, combined water, and carbonates. Of these possible components of LOI "free" carbon is the major component and LOI values are generally taken as the amount of “residual carbon”.

One major disadvantage of CCBs can be an inherent variation in quality, which is a result of varying coal sources and changes in coal combustion processing (Aiken *et al.*, 1984). For CCB’s produced at Tarong Energy, though, the consistency in composition and size is considered to be very good due to the large and uniform coal reserves and consistent process conditions (“mine mouth”/ “base load station”). This consistency of composition is important when considering possible uses of ash that have stringent requirements on the chemical or physical properties.

Table 1. Typical Composition found for Tarong bottom ash.

Component	*TARONG BOTTOM ASH (wt%)*
LOI	1.44
CaO	0.22
SiO_2	70.55
Al_2O_3	26.00
Fe_2O_3	0.63
MgO	0.01
SO_3	0.07
Na_2O	0.19
K_2O	0.22
SrO	0.00
TiO_2	1.43
P_2O_5	0.01
Mn_2O_3	0.00
Total	100.77

Apart from these major elements Tarong bottom ash contains trace elements in the ppm range (mg/kg). Table 2 shows indicative values for the trace elements found in Tarong bottom ash.

Table 2. Concentrations of trace elements found for Tarong bottom ash.

Component	*TARONG BOTTOM ASH (mg/kg)*
B	<20
Cd	<1
V	6
Cr	<1
Co	<1
Ni	<1
Cu	2
Zn	6
As	<1
Se	<1
Mo	2
Sn	5
Sb	<1
Ba	2
Hg	<0.1
Pb	<1
Mn	2

Due to the rapid cooling of Tarong bottom ash in the power plant and the high silica content of the original molten material the most abundant phase in Tarong bottom ash is likely to be a non-crystalline or amorphous high silica glass. Smaller amounts of crystalline material such as Quartz, Mullite and Ferrite Spinel (impure "magnetite") are also likely to be present. The trace elements present in Tarong bottom ash are found in both the amorphous and crystalline phases. For example, the "network modifiers" (eg. CaO, Na_2O, K_2O, SrO, Fe_2O_3) are concentrated in the "glass" phase, while elements that can isomorphically substitute for Al and Si in Mullite (e.g. V, Cr, Ti) or for Fe^{2+} or Fe^{3+} in the Ferrite Spinel (e.g. Mg, Mn, Co, Ni, Cu, Zn, Al) are concentrated in the crystalline phases.

For an ecological evaluation it is not the absolute content of heavy metals or trace elements that is of greatest importance but rather the mobility or potential for these metals to leach into the environment. The Toxicity Characteristic Leaching Procedure (TCLP) was performed on Tarong bottom ash and the results are shown in Table 3

Briefly, the test requires that the sample is reduced to a specified size (<9.5 mm) and then continuously extracted with the appropriate acidic solution (Extraction Fluid #1, pH = 4.93±0.05) for approximately 18 hours. The resulting mixture is then filtered and the liquid extract analysed for the specified contaminants. It should be noted that leaching tests do not generally represent the situation encountered in a "real world" situation, but rather are used to provide comparative information on the leaching potential of a given material under "standard" conditions. The results from the TCLP tests (Table 3) show the pH of the extraction fluid after 18 hours, the concentrations of the metal ions analysed for in the leachate produced and the limits of resolution (detection limits) for each of the metal ions.

The only results that were above the limit of detection (LOD) were Barium (0.33mg/L), Manganese (0.02 mg/L), Molybdenum (0.04 mg/L), Vanadium (0.06 mg/L) and Zinc (0.26 mg/L). The final pH of the extraction fluid (initially 4.93) has also risen slightly to 5.2.

In summary, it can be clearly seen that the trace elements present in the fly ash are not in a form where they are easily leached from the matrix (glass, quartz, mullite, ferrite spinel) and therefore do not present a significant environmental risk.

Table 3. Concentrations of trace elements reported in TCLP leachates for Tarong bottom ash.

Analysis Description	*TARONG BOTTOM ASH*
Initial pH	7.6
After HCl pH	-
Extraction Fluid Number	1
pH after Extract	5.2
As (mg/L)	<0.01
B (mg/L)	<1
Ba (mg/L)	0.33
Cd (mg/L)	<0.01
Co (mg/L)	<0.01
Cr (mg/L)	<0.01
Cu (mg/L)	<0.01
Mn (mg/L)	0.02
Mo (mg/L)	0.04
Ni (mg/L)	<0.01
Pb (mg/L)	<0.01
Sn (mg/L)	<0.01
V (mg/L)	0.06
Zn (mg/L)	0.26
Hg (mg/L)	<0.01
Sb (mg/L)	<0.01
Se (mg/L)	<0.1

2.3 Agronomic Characteristics

Preliminary testing of the Tarong bottom ash was undertaken to determine the chemical and physical properties of the material for agronomic purposes. Agronomic soil test results for Tarong bottom ash and a Peanut Farm Soil from Kumbia are presented in Table 4. These test results indicate that the Tarong bottom ash has compared to the farm soil:

- high pH
- low concentrations of plant available nitrogen, phosphorus, copper, manganese and iron
- moderate concentration of plant available sulfur, potassium, calcium, magnesium ,sodium, chloride, zinc and boron
- moderate calcium/magnesium ratio
- high exchangeable sodium percentage;
- low buffering capacity (cation exchange capacity)
- good texture (particle size distribution and sharp particles)
- low toxicity (for parameters measured)

Table 4. Agronomic soil test results for Tarong bottom ash and Peanut Farm Soil (Kumbia) ([1]Plant Available Concentration of the Nutrient)

Parameter	*TARONG BOTTOM ASH*	*Peanut Farm Soil*
Colour (Munsell)	White	Dk Brown
Soil Texture (Field)	Sand	Light Clay
pH (1:5 water)	8.1	6.0
pH (1:5 CaCl2)	7.9	5.0
Electrical Conductivity (dS/m)	0.78	0.5
Organic Carbon (%)	<0.1	2.0
Nitrate nitrogen[1] (mg/kg)	0.6	23.3
Sulfur (mg/kg)	249	23.0
Phosphorus (Colwell) [1] (mg/kg)	1	58.0
Potassium[1] (meq/100g)	0.08	0.22
Calcium[1] (meq/100g)	1.69	8.58
Magnesium[1] (meq/100g)	0.61	6.26
Sodium (meq/100g)	2.02	0.69
Chloride (mg/kg)	725	20.0
Copper[1] (mg/kg)	<0.1	0.6
Zinc[1] (mg/kg)	0.2	0.9
Manganese[1] (mg/kg)	<1	55.0
Iron[1] (mg/kg)	<1	69.0
Boron[1] (mg/kg)	2.2	1.30
Cation Exchange Capacity (meq/100g)	4.4	15.82
Calcium/Magnesium Ratio	2.78	1.37
Sodium % of cations (ESP)	45.98	4.34

The ability of a soil to sustain plant growth is highly dependent on the available water in the soil. This is determined by the difference between the maximum amount of water available (field capacity) and the amount of water that cannot be extracted by the plant (permanent wilting point). The effect of Tarong bottom ash additions to the water holding capacity (or field capacity) and air contents of sand and clay rich soils was determined.

A number of fly ash and bottom ash materials were tested along with "available soils" and blends of both. Generally, soils for plant growth require an air content > 5% and a water capacity of > 30%. Tarong bottom ash was found to have an air filled porosity of about 5 vol% and a water holding capacity of about 56 vol%.

Figures 3 and 4 show the effect of adding Tarong bottom ash to sand rich (low water holding/high air content soil) and clay rich (high water holding/low air content soil) soils. The Tarong bottom ash dramatically increased the water holding capacity in the sandy soil while maintaining the air contents above 5% while the addition of Tarong bottom ash to the Clay rich soil also increased the water holding capacity and increased the air contents. This means that Tarong bottom ash will improve the soil characteristics of most soil types.

The available water (difference between total water holding capacity and water at permanent wilting point) for clayey soil, sandy soil and Tarong bottom ash are shown in Figure 5. It is clearly seen that the Tarong bottom ash has a far greater amount of available water then either the sandy or clayey soils. Organic materials are commonly utilised to increase water holding capacities (ie. pine bark, peat moss) but, unlike Tarong bottom ash, these materials decompose over time and need to be constantly applied to maintain increased soil moisture levels. They also tend to retain high levels of moisture at the permanent wilting point.

Figure 3. Effect of adding Tarong bottom ash to sand rich soil type.

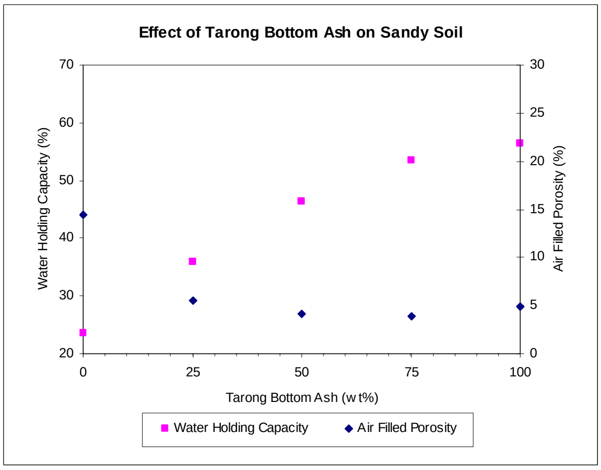


Figure 4. Effect of adding Tarong bottom ash to clay rich soil type.

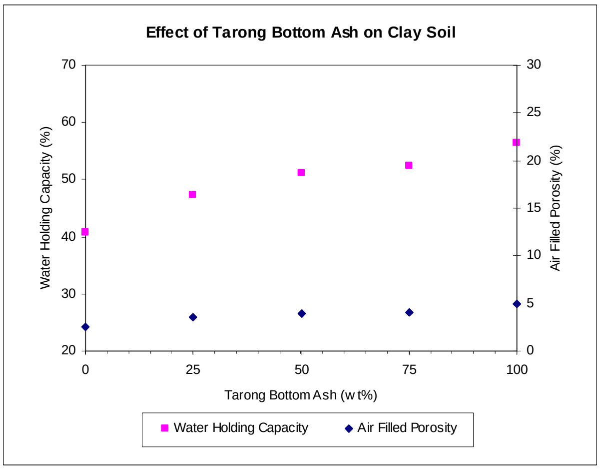
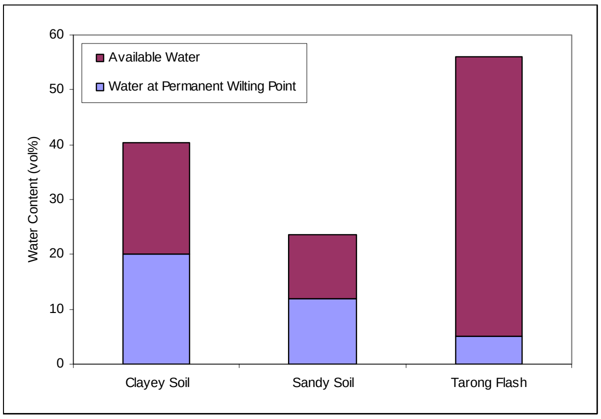


Figure 5. Available Water and Water Held at Permanent Wilting Point



3. KUMBIA TRIAL 2001 2002

3.1 Background

Peanuts are summer legumes grown primarily in Queensland. The South Burnett is the traditional peanut growing region and hence is within a reasonable distance of Tarong Energy allowing the low cost supply of Tarong bottom ash. Currently, Australia is unable to satisfy its domestic consumption of peanuts of about 50,000 tonnes with the balance being imported.

Approximately seven acres of peanut farm in Kumbia was hired in 2001 for a trial to assess the effect of Tarong bottom ash on the performance of the crop planted. Five different areas were prepared and planted. The depth of mixing was about 15 cm and the rates of application were 0 tonnes/acre, 10 tonnes/acre, 20 tonnes/acre, 40 tonnes/acre and 60 tonnes/acre. For perspective, a 60 tonne/acre treatment is equivalent to 15 kg/m^2 or Tarong bottom ash added as a layer of about 2 cm.

In this field trial, a large seeded Virginia type peanut, VB97, was planted in rows 92 cm apart and spaced at 13 cm apart in each row. This is equivalent to a seeding rate of 33,000 plants/acre.

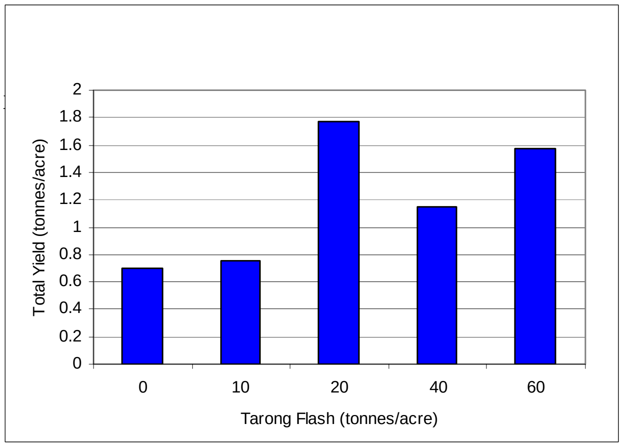
3.2 Peanut Yield

The peanut farm used in this trial was harvested in April 2002. The following describes the initial results obtained.

The in-situ soil at this farm was a high iron rich clay that had a water holding capacity of 55%, total available water content of 31%, but a low air content of about 2%. This made this soil quite hard, particularly after being compacted and dried. The addition of Tarong bottom ash significantly "lightened" this soil. Once the peanuts had been harvested forty random plants from each area were collected. Soil samples from each area were also taken for chemical analysis. Each of these peanut samples were then air dried, weighed and shelled. The kernels were then weighed and graded using a set of nested screens producing yield and quality information. Samples from each area were then sent for Aflatoxin and heavy metal analysis.

Figure 6 shows that the yield has increased with the amount of Tarong bottom ash addition. What is not clear is whether this is a "step curve" or a linear increase with the 20 tonnes/acre result showing a high error. The percentage of kernel also increased from 47% to 65%.

Figure 6. Total yield obtained at each area.



Peanut growers are paid directly on the quality of their peanuts. A sample is taken from each load and tested for shell and kernel contents, moisture content, aflatoxin content and grading. A significantly higher premium is paid for Extra Large Kernels or Jumbo peanuts. Each of the peanuts sampled have been graded using a set of nested screens. The results showed that the amount of larger sized peanuts have also increased with the addition of Tarong bottom ash with the percentage of kernels larger than 9.5 mm increasing from about 63% to 78%.

3.3 Heavy Metal Analysis

A significant part of this project was accurately determining the "mass balance" that occurred with heavy metals and peanut growth. Ingestion of metals such as arsenic, barium, cadmium, chromium, lead, and mercury may pose great risks to human health. Approximately 60 elements were tested for by ICP-MS, but only 21 showed levels higher than the 0.05 mg/kg detection limit, none of which were of concern. For example, results showed that the amounts of arsenic and cadmium were less than 0.05 mg/kg and the amount of mercury was less than 0.005 mg/kg for all soils. Heavy metal analysis also showed that the metal content for the elements tested either decreased with increasing Tarong bottom ash addition or there was no significant difference between the treated and untreated areas. For example, it showed that for the 0 tonnes/acre trial, lead was at 0.098 mg/kg, but for the rest of the trials (10 tonnes/acre, 20 tonnes/acre, 40 tonnes/acre, and 60 tonnes/acre) the amount of lead dropped to less than 0.05 mg/kg.

4. CONCLUSION

Tarong bottom ash has the chemical and physical properties to be a valuable addition in many agricultural applications. Tarong bottom ash can improve soil texture, increase the water holding capacity and air contents, and provide some necessary mineral ingredients.

In addition, the results obtained from the initial field trial at Kumbia were very encouraging with an increase in yield and quality of peanuts formed. While this initial trial is quite promising, there are still a number of issues that need to be investigated before the value of Tarong bottom ash to peanut farmers can be quantified. Further trials are currently in progress (since September 2002) for a number of peanut operations.

5. REFERENCE

Aitken, R.L., Campbell, D.J. and Bell, L.C. (1984) Properties of australian fly ashes relevant to their agronomic utilization. Aust. J. Soil Res. 22, 443-53.