THE REUSE OF SPENT MUSHROOM COMPOST AND COAL TAILINGS FOR ENERGY RECOVERY

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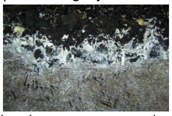
Introduction

Reusing wastes, such as spent mushroom compost (SMC) and coal tailings, for energy recovery can mitigate the impacts of unsustainable energy generation and waste management.

Spent Mushroom Compost:

- SMC is an agricultural waste, composed of a straw-based substrate, with a peat casing layer.
- The generation rate in the UK is 200,000 t/a, where approximately 5 kg is produced for every 1 kg of mushrooms.
- After the nutrients are consumed, it is disposed of in landfill or is reused as an agricultural fertiliser, which are environmentally-degrading.



Coal Tailings:

- Coal tailings are formed when coal is separated from its impurities by cleaning processes and are deposited in lagoons, usually in close proximity to the mining area.
- Removing coal tailings from these locations will eliminate the risks associated with environmental contamination and lagoon failure.

Project Aims and Objectives:

This project aimed to produce a source of renewable fuel for industry using these materials, thus providing a sustainable waste management solution for both. Experimental phases include material characterisation, pelletisation and thermal treatment, in addition to the modelling industrial implications.

Material Characterisation

ANALYSIS	CONSTITUENT	BASIS	COAL TAILINGS	SMC SUBSTRATE	SMC CASING
Moisture (%)		ar	~ 40	65.70	68.56
Proximate Analysis (%)	Ash	dry	41.25	26.89	28.87
	Volatile		20.51	61.80	60.18
	Fixed Carbon		38.24	11.31	10.95
Ultimate Analysis (%)	Carbon	dry	47.87	35.13	35.72
	Hydrogen		2.90	3.59	3.01
	Nitrogen		1.01	2.85	1.11
	Chlorine		-	0.51	0.70
	Sulphur		1.38	2.95	2.16
Elemental Analysis (mg/kg)	Aluminium	dry	4360	442	1435
	Calcium		2940	40900	118500
	Iron		9700	1240	2580
	Potassium		1070	18650	3685
	Magnesium		2420	4620	4265
	Sodium		450	2095	600
CV (MJ/kg)	NCV	dry	19.22	13.33	11.71
		ar	10.55	3.08	2.51

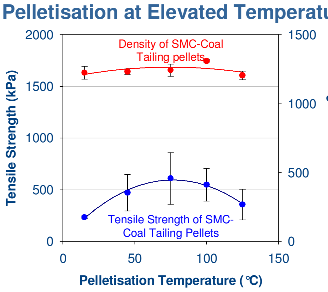
Pelletisation

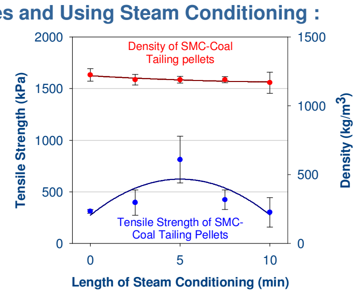
Coal tailing pellet

OPTIMUM PELLETISATION CONDITIONS	
Initial Moisture Content	10-11 %
Drying	fully air-dried
Minimum Pressure	2500 psi (17 MPa)
Maximum Pressure	6000 psi (41 MPa)
SMC:Coal Tailing Ratio	50:50 wt%

SMC pellet

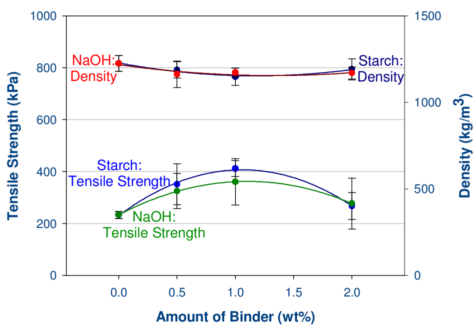
Pelletisation at Elevated Temperatures and Using Steam Conditioning :





- Heating the SMC-coal tailing mixture to 75 °C prior to pelletisation significantly improved overall pellet quality, due to the softening of lignin and cellulose present in the SMC to enhance agglomeration.
- Conditioning the SMC and coal tailings using super-heated steam at 120 °C prior to pelletisation also significantly improved pellet quality, for the same reason. 5 mins of conditioning was optimal.

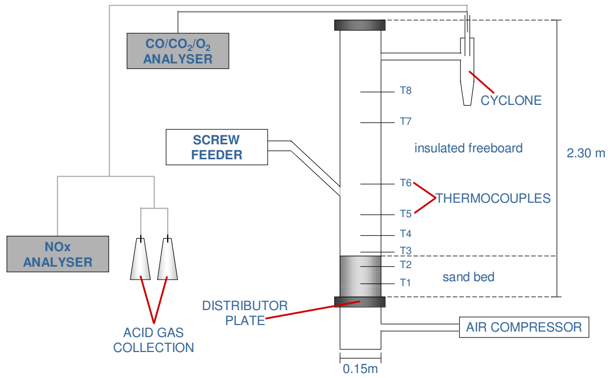
Organic and Inorganic Binders – Starch vs. Caustic Soda:

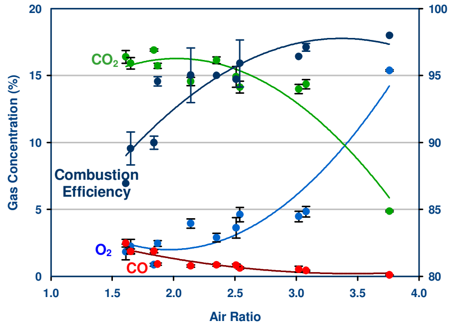


- Up to 1 wt% of both binders improved pellet tensile strength, but not their density.
- The organic starch binder performed better than the inorganic caustic soda (NaOH) for most tests.
- Elevated temperatures of 75 °C further enhanced the use of both binding agents (1 wt%).
- Whilst both binders were cost-effective, the use of elevated temperatures or steam conditioning would drastically increase the overall pelletisation costs.

In-Depth Study of Fluidised-Bed Combustion

- Combustion in fluidised- and packed-beds were compared and then contrasted with gasification and pyrolysis. SMC-coal tailing pellet combustion in a laboratory-scale bubbling fluidised-bed was more efficient and thus used for further combustion tests (see below).
- The pellet feedrate, primary/fluidising air flowrate and sand bed depth were investigated and the optimum operating conditions for this combustor were determined, based on the minimum air ratio of 2.5, which was required to achieve high combustion efficiencies – around 97 %.
- Acid gases (NOx, SOx and HCl) were found in limited concentrations, as species remained primarily as inorganic compounds in the flyash. These were compared to the limits outlined in the Waste Incineration Directive (WID).
- Slagging/fouling were likely, due to alkali metal (K and Na) oxides in the flyash. Ash agglomeration could also be caused by the presence of Al, Si, P and Fe in the ash.





OPTIMUM COMBUSTION CONDITIONS	
Pellet Feedrate	180 kg/m²hr
Air Flowrate	650 kg/m²hr
Bed Depth	0.22 m

	MAXIMUM EMISSIONS	WID LIMITS
NOx	91 mg/m³	400 mg/m³
SOx	123 mg/m³	50 mg/m³
HCl	25 mg/m³	10 mg/m³

- Combustion tests were completed where 1 wt% of each binder was added to the pellets. The gas concentrations were impacted, increasing CO levels and thus reducing the combustion efficiencies to 88 % from 95 %, although the temperatures were similar to the control, where no binder was included. The increased amounts of Na from the caustic soda binder increased the likelihood of slagging, fouling and ash agglomeration, by reducing the ash fusion temperatures.

Industrial Implications

Heat and Power Generation:

- Potential heat and power production were estimated from mass and energy balances for a theoretical furnace and steam turbine set-up. An overall process efficiency of 18.6 % was assumed.

	CASE 1	CASE 2	CASE 3	CASE 4
Fuel Pellet Composition	SMC	SMC-CT	SMC-CT	SMC-CT
Fuel Feedrate (t/a)	10,000	20,000	200,000	400,000
Energy to Condenser (MWth)	0.50	2.80	28.02	56.04
Electricity Output (MWe)	**0.09**	**0.53**	**5.27**	**10.53**

FLUENT Modelling:

- FLUENT – a computational fluid dynamics code – was used to evaluate the transport disengagement height (TDH), the distance above the bed that entrained particles return to the bed. Various scenarios were modelled to explore which parameters were most suitable for imitating the experimental results for gas concentrations and temperature. These conditions were then used to assess particle injections, at speeds of 1.0-2.0 m/s. A maximum TDH of 22 cm was noted for the fastest speed, thus sufficient freeboard height was provided.

Conclusions

- Drying and pelletisation of the wastes are crucial to improve their fuel characteristics, such as density.
- Although pellet quality was enhanced using the appropriate pelletisation conditions, the use of 1 wt% of a starch binder, elevated temperatures (45-75 °C) or steam conditioning (5 mins) further improved pellet quality, specifically in terms of tensile strength, without impacting combustion.
- Fluidised-bed combustion of SMC-coal tailing pellets performed significantly better than other thermal treatments, where efficiency was further improved by employing suitable conditions within the reactor.
- Acid gas concentrations were low thus minimal gas cleaning would be needed to meet WID limits.
- Slagging, fouling and ash agglomeration were likely, due to the alkali metal (Na and K) oxide content of the ash, along with high proportions of other elements, such as P, Fe, Al and Si.
- Additions of the binders to the fuel reduced the combustion efficiency, whilst the NaOH also negatively impacted the behaviour of the flyash, increasing the likelihood of slagging, fouling and agglomeration.

Acknowledgements

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