FUEL PROCESSING TECHNOLOGY 89 (2008) 269–275

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Pelletised fuel production from coal tailings and spent mushroom compost — Part I Identification of pelletisation parameters

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ARTICLE INFO

Article history:
Received 9 May 2007
Accepted 16 November 2007

Keywords:
Briquette
Coal tailings
Pelletisation
Fuel pellets
Spent mushroom compost (SMC)

ABSTRACT

This study investigates the technology of manufacturing pellet blends for energy production from two discarded materials in industry. Coal tailings material is the fine discard produced as a result of coal cleaning. Although it still has a significantly high calorific value, over a million tonnes of coal tailings are deposited in lagoons every year in the UK alone. Spent mushroom compost (SMC) consists of fibrous compost substrate and a wet casing layer used during mushroom production. In the form of pellets, these materials become more homogeneous, easily stored and transported, and suitable for use in power plants or gasifiers. The characterisation of the fuel properties shows that the two materials have a complimentary status for pelletisation and energy production in terms of particle types, carbon source, calorific value and volatile matter content.

Pelletisation tests were carried out using a small compression rig for various pressures, moisture contents and mixture compositions. The quality of the pellets was assessed using density, swelling, tensile strength and durability. It was necessary to keep the moisture contents for coal tailings at about 10% and for SMC at 20% before pelletisation in order to maximise the bonding strength of the originally wet materials. Pressures above 6000 psi did not produce noticeably denser or stronger pellets. The pellets from coal tailings and SMC blends had a tensile strength proportional to the SMC fraction. The SMC pellets were more durable than the coal tailing pellets due to the intertwined compost fibres. It was also noted that the SMC addition to the coal tailings did not increase the durability of the pellets due to the limited binding effect between the two materials.

1. Introduction

Coal tailings are the fine discard from coal separated by the coal preparation process at a colliery. It is also referred to as colliery spoil, sludge, washery reject, fines or silt. The amount of coal tailings produced is about 7.5–12% of the total coal mined. Coal tailings have been deposited in large lagoons. There are several million tons of coal tailings available at colliery sites in Yorkshire and Northumberland, UK. This mixture of water with fine coal particles (a few microns to 0.5 mm) and minerals displays properties of liquidity or plasticity depending on the moisture content. When very wet, it is in the form of a slurry, having the property of liquidity as the interaction between the particles is weak. As the moisture content decreases by long—term dewatering in a lagoon or by mechanical extraction, coal tailings gradually become sticky or mouldable. It has a good potential to be used as fuel because the calorific value can be as high as 20 MJ/kg on a dry basis. However, this requires drying of the coal tailings combined with pelletisation or briquetting for better handling and feeding.

A successful use of coal tailings in a power station was re ported by Radloff et al. [1], as part of a colliery rehabilitation

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doi:10.1016/j.fuproc.2007.11.035

project in Australia. In this scheme, 70 kt/yr of 50 mm diameter briquettes with 10–20% moisture content a were produced using a double roller press. The pellets were successfully burned at a local power station at a rate of up to 10% of fuel feed. However, the details of the briquetting conditions, binder used or the quality of the product were not presented in the above mentioned paper.

Any fibrous biomass materials can add more value to the pellets of coal tailings by increasing the pellet quality and carbon-neutral energy content. Yaman et al. [2] showed that some lignite and biomass blends increase the strength of the briquettes. The potential materials to be considered for mixing include straw and herbaceous energy crops; however, the present study focuses on fibrous biomass from an agricultural residue — the spent mushroom compost (SMC). The raw mushroom compost contains straw, poultry manure, horse manure and gypsum conditioned for about 3 weeks. Once compacted into about 6-inch thick substrate, the compost is covered by a 2-inch thick layer casing material that is a mixture of pure peat and chalk. After around 5 weeks of the mushroom production process, SMC is collected for disposal. The mushroom growing industry in the UK generates over 400 kt/yr of SMC. Some SMC is sold for horticultural purposes but the main disposal route is currently landfill or landscaping. A few other routes are available but there are environmental impacts such as eutrophication of watercourses. The use of SMC as fuel has been assessed in Ireland [3], but no actual work has been found in the literature on its use for fuel pellet manufacture or energy production.

By pelletisation, a raw material is converted into a value-added fuel with homogenous properties, shapes and sizes. This allows better handling, storage, transportation and feeding properties of the material. For bulky biomass such as sawdust and straw, pelletisation densifies the materials and reduces transportation cost. Pelletisation or briquetting of material is performed by applying pressure, shear or a combination of both. Among the many types of the pelletisers used in industry, the main categories are hydraulic presses, screw extruders, ring rollers, ring-dies and double rollers [4,5]. The common fuel pellets are coal briquettes, wood pellets and refuse-derived fuel.

Compared to the pelletisation of biomass and waste, the briquetting of coal for domestic and industrial uses is an old technology. The typical example is pillow-shaped charcoal for barbeques. Coal briquettes are produced from various types of coals typically by hot briquetting with the use of a binder. The common binders are coal tar, petroleum residue, sulphite liquor and starch [6]. Coal briquettes can be also produced by binderless briquetting at ambient temperature by applying high pressure alone [5]. This is more desirable in terms of production cost. Mangena et al. [7] investigated binderless briquetting of fine coals and suggested that the clay minerals particularly kaolinite may contribute to the bonding in the briquettes.

The bonding of particles in a pellet is determined by several mechanisms: van der Waal's force, liquid bridging force [8], particle interlocking [5] and, if used, high viscosity binder. In all of the above mechanisms, large contact areas between particles are essential to increase their cohesion strength. Under pressure, highly plastic particles easily deform to increase the contact area and to reduce the voidages. The plasticity of a particle is also affected by temperature (softening or thermal decomposition) and moisture content. Excessive moisture content increases the gap between particles and wastes the compression energy, while too low moisture content reduces the plasticity of the particles and increases the friction during pelletisation. Therefore, the main parameters become pressure, temperature, moisture content and mixture composition. Other factors include the particle size distribution and interweaving of fibres, if any, in a pellet. In the production of wood pellets, for example, the ideal moisture content is 10–15% which requires drying for wet materials [9]. No additives are used because lignin acts as a natural binding material which softens at elevated temperatures (~90 °C).

Pellets made from coal tailings and SMC are suitable for use in chain grate furnaces, industrial gasifiers or conventional pulverised fuel-based power stations where they can be fed into the mills. Fortunately, many mushroom farms are reasonably close to the colliery sites. SMC also contains lime which can help reduce sulphur emissions from coal combustion.

This paper presents the pelletisation properties of coal tailings, SMC and blends. The two basic materials were characterised for their physical, chemical and thermal properties. The pelletisation tests for the materials were carried out using a small compression pelletiser with a 1-inch diameter mould in order to identify the effects of process conditions such as pressure, moisture content and mixture composition. The pellet quality was assessed for density, swelling, tensile strength and durability.

2. Characterisation of SMC and coal tailings

Table 1 shows the results of standard fuel analysis of SMC and coal tailings. The raw SMC is very wet (moisture content of about 70%) and has a high ash content (34%dry). This leads to a very low net calorific value (1.6 MJ/kg — ar and 11.9 MJ/kg — dry). The volatile matter to fixed carbon ratio is about 4.5 which is lower than for typical biomass due to the presence of peat in the casing layer and the loss of some volatile matter during composting. The sulphur content is significant in SMC due to gypsum ($CaSO_4{\cdot}2H_2O$). However, sulphur in SMC is not

Table 1 – Fuel properties of SMC and coal tailings

Materials		SMC	Coal tailings
Moisture content (%ar)		~70	~40
Proximate analysis (%dry)	Volatile matter	53.57	25.07
	Fixed carbon	12.43	30.79
	Ash	34.00	44.14
Ultimate analysis (%dry)	C	39.86	47.87
	H	3.80	2.91
	N	2.12	1.01
	Cl	1.10	0.00
	S	0.62	1.38
	O (by difference)	18.50	2.69
Net calorific value	MJ/kg — dry	11.06	21.76
	MJ/kg — as received	~1.61	~12.08