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Development of a value-added soil conditioner from high shear co-granulation of organic waste and limestone powder

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ABSTRACT

This paper reports on a technical feasibility study of the production of organo-mineral fertiliser from the co-granulation of limestone powders with tea waste. The results from this preliminary study show that the co-granulation of tea waste provided an alternative method of waste recovery, as it converts the waste into a value-added product. Fertiliser granules were successfully produced from various compositions of limestone and tea waste. The effect of tea waste concentration on granule strength was analysed; the granule strength was in the range 0.2 to 1.8 MPa depending on powder composition; increasing the tea waste mass fraction resulted in a reduction in granule strength. Varying the tea waste to limestone ratio also influenced the compressibility of the granules; the granules compressibility increased with increasing tea waste mass fraction. It was further found that increasing the mass fraction of tea waste in the binary mixture of powder reduced the granule median size of the batch.

1. Introduction

The United Kingdom is the second largest consumer of tea in the World, with an average per capita consumption of 2.1 kg. More than 170 million cups of tea are consumed each day and more than 90% of these cups are brewed from tea bags. This translates to about 370 tonnes of tea consumed each day in the UK. A large fraction of the tea bags end up as municipal solid waste (MSW) and eventually in landfills whilst a small fraction of them are composted.

There are numerous reports in literature where attempts to reuse or recycle tea waste material have been made. Most of the applications have been as an adsorbent material for the removal of metals from contaminated wastewater, for instance; for the removal of copper, lead, zinc, and chromium [1–9]. In related work tea waste has also been used as a low cost adsorbent for the removal of dyes from contaminated waste water [7].

In another study tea waste was used as a feedstock material in a fast pyrolysis process with the aim of producing synthetic solid and liquid fuels [10]. The study revealed that the maximum yields for oil and char were 30.4% at 773 K and 43.3% (at 763 K) respectively. The use of tea waste as a construction material, in the production of bricks has been reported in literature [11]. Tea waste was added to clay used for the brick moulding. The study revealed that the mechanical strength of both fired and unfired bricks produced from a mix of clay and tea waste was higher than that of pure clay bricks. There are also reports in literature on the possibility of using tea waste in the production of feeds for livestock due to its high nutritional value [12].

Tea waste has also been used in mushroom cultivation for producing the casing material in which the mushroom is grown [13]. Peat is commonly used as a mushroom cultivation casing. Work reported in reference [13] shows that mixing the tea waste with peat increased the mushroom production yield. Numerous trials on the use of tea waste for the production of activated carbon can also be found in literature [14–16].

In this project the process of granulation was employed for a waste-minimisation method of producing a value added product using tea waste as a raw material. The aim of the current research was to investigate the possibility of producing a value-added soil conditioner product from the granulation of tea waste as an alternative option to landfill. Tea waste (TW) was co-granulated with limestone in different proportions using different binder solutions. Limestone is a major constituent in the formulation as it is extensively used as a conditioner and liming agent to control the pH of the soil. It has been shown that the addition of organic matter improves the physical properties of the soil, i.e. structure and water holding capacity, the chemical properties of the soil, i.e. (nutrient and cation exchange capacity) and the biological properties [17–19]. The addition of tea waste would add texture, organic content and nutrient value to the soil.

The limestone and tea waste powders could be applied directly to the field as soil conditioners, however there are problems related to handling of these materials associated with the particle size and dustiness of the material. Material loss during application and health hazards related to inhaling fine particles during application are some of the

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other challenges of these materials. These problems can be eliminated by transforming these fine powders into larger particles using a size enlargement process. The ideal size would be 2 to 4 mm, which is the typical size range of the synthetic fertilisers; this will mean that the same equipment used by the farmers for the application of the fertiliser can still be used. Combining the two powders into one product will also mean that the application of these materials can be done in one operation as opposed to two; this could result in cost savings.

Two approaches were considered in this project. In the first approach wet granulation is used to transform limestone and tea waste powders into a granular product which can then be used directly as a soil conditioner. For direct application as a soil conditioner/fertiliser the size of the granules should be between 2 and 4 mm and the typical granule strength should be in the range 3 to 4.8 MPa, to reduce caking during storage and survive handling operations [20,21]. The second approach would be a two stage process; a wet granulation step followed by a tabletting step. The product of the second process will be pellets of uniform size. In the second approach the role of the granulation step is to improve the compression characteristics of the raw materials by addition of a binding agent. The granulation step also reduces segregation of the tea waste and limestone particles which would occur during the filling of the tablet press, if raw powders were to be compressed directly.

The granulation process is non-trivial as the product attributes are affected by a number of process and formulation variables [21–26]. The mechanical properties of the granular product formed were analysed in terms of the size distribution, strength and compressibility.

2. Materials and methods

2.1. Raw material physical properties

Powdered limestone was provided by Killwaughter Chemicals Ltd UK. XRD analysis of the powder sample shows that it is mainly composed of calcite mineral and quartz. The powder was used as received from the supplier. The TW was collected from the cafeteria at Queen's University Belfast. It was washed thoroughly in de-ionised water and dried in temperatures over 70 °C for a period of 24 h. The particle size distributions of the tea waste and limestone powder are shown in Fig. 1. It is evident from this figure that the tea waste particles are bigger than those of the limestone powder. The limestone powder is finer and exhibits a bimodal distribution; more than 80% of the limestone particles have an equivalent particle diameter of less than 100 μm.

2.2. Binder preparation

Carboxymethylcellulose, sodium salt, high viscosity grade (CMC) supplied by MERCK UK, was used as a binder in the granulation experiments. CMC is a white solid powder at room temperature and is water soluble. Solutions were prepared by dissolving a known mass of the CMC powder in a known mass of distilled water to obtain the desired concentration and viscosity. The mixture was stirred for about 30 min to obtain a homogenous solution. The viscosities of the binder solutions were determined using the Brookfield Viscometer (DV-II+ PRO Digital Viscometer, Brookfield-USA).

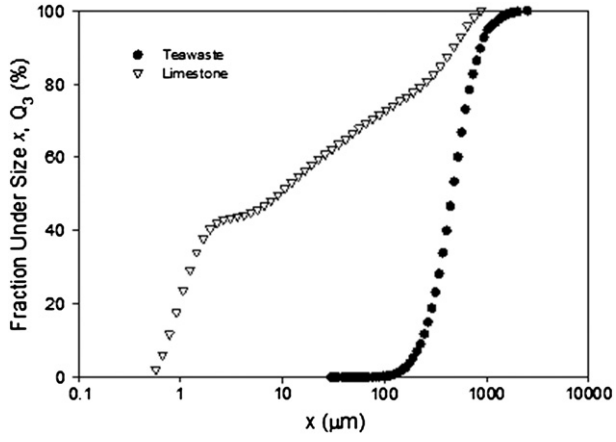

Fig. 1. Particle size distribution of limestone and tea waste powders.

2.3. Granule production

The granulation experiments were carried out in a small bench scale high shear granulator; which consisted of a small beaker (diameter 80 mm and height of 128 mm) with an overhead mechanical stirrer as the impeller. The impeller has 6 equally spaced blades with diameters, height and thickness of 9.5 mm, 76 mm, 2 mm respectively, all inclined at an angle of about 90°. The schematic of the experimental set-up is shown in Fig. 2.

Before mixing the tea waste with the limestone powder, it was sieved through a 500 μm sieve to remove particles larger than 500 μm. The powders were pre-mixed for 3 min at an impeller speed of 490 rpm. The pre-mixing stage was then followed by a binder addition phase for a period of 2 min. The composition of the powder mix was varied according to Table 1.

After granulation the granules were dried in a microwave (Panasonic, Model MN-T543W) oven for 5 min at full power. They were then sieved using Retsch sieves on an orbital sample shaker (Stuart Orbital Shaker, Cole-Parmer, UK) for 5 min at a speed of 180 rpm. The aperture sizes are as follows; 106, 350, 500, 600, 710, 850, 1000, 1180, 1400, 1700, 2000, 2360, 3350, 4000 and 4750 μm.

The study of the effect of binder viscosity on the formation of tea granules was carried out using CMC binder solutions of different concentrations. The details of the concentrations are given in Table 2. For this set of experiments tea waste was granulated without mixing with limestone powder. In these experiments a liquid to solid ratio of 0.8 was used (tea waste 25 g, binder 20 g). The granulation time and impeller speed were 490 rpm and 4 min respectively.

2.4. Determination of granule median size and product yield

The size distribution data obtained from the sieving of the granules was fitted to the Rosin–Rammler equation [21];

$$Q_3 = 1 - \exp^{-(x/A)\beta}. \quad (1)$$

In Eq. (1) Q_3 is the mass based fraction of granule size less than x, A is the median granule size and β is the shape parameter. A non-linear regression fit was performed on the size distribution data using commercial software to determine the parameters A and β. The typical fits of Eq. (1) to cumulative size distribution data are shown in Fig. 3.

Eq. (1) can be re-arranged to give the granule size for any percentile of cumulative undersize mass;

$$x_p = A[-\ln(1-Q_3)]^{1/\beta}. \quad (2)$$

The equation Eq. (2) was used to calculate granule sizes x_{10}, x_{50}, x_{60} and x_{90} corresponding to 10, 50, 60 and 90% cumulative undersize mass respectively.

The span of the granule size distribution was determined from;

$$S = (x_{90} - x_{10})/x_{50} \quad (3)$$

where: x_{10}, x_{50} and x_{90} are the granule size in mm in the 10th, 50th and 90th percentiles of the cumulative mass distributions respectively.