The University Of Sheffield.

E-Futures

Mini-project report

Torrefaction of Biomass

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Mini-Project Mark Sheet

Student: Charlotte Bjorck **Grade:** fail/satisfactory/good/very-good/excellent

Supervisor:

Feedback:

	Excellent	**Good**	**Average**	**Poor**	**Very Poor**	**Not Done**	**Not applicable**
Introduction to the problem / subject							
Statement of aims							
Experimental description							
Presentation of results / findings							
Quality and depth of discussion / interpretation							
Relevance of conclusions							
Quality of English							
Use of reference material							
Evidence of external reading							
Quality of presentation							
Use of figures							

Comments:

Torrefaction of Biomass

1. Introduction

In a move away from fossil fuel derived energy, the use of biomass is considered a promising alternative as a sustainable, carbon neutral fuel that is available from a range of resources. A number of technologies can be exploited to produce energy from biomass including thermochemical (combustion, gasification, pyrolysis), biochemical (anaerobic digestion, fermentation) or chemical processes (esterification) [1]. In the short term the most promising use is direct combustion of the biomass, however due to its higher efficiency, it is desirable that gasification becomes increasingly applied in the future [2].

There are however many properties of raw biomass that make it a problematic fuel particularly its high oxygen content, low calorific value, high moisture content and high hydrophilic nature [1, 3-7]. Its fibrous structure and heterogeneous composition also pose problems in process design and control [1, 3, 5, 7].

Torrefaction is a technology that has been developed as a means to improve the quality of biomass fuels, and so offering a solution to the above problems. The thermal pre-treatment method operates in the low temperature range of 220-300 °C under an inert atmosphere [8]. In torrefaction the hemicellulose fraction, the most reactive part of the biomass, is decomposed followed by degradation of lignin and cellulose to a lesser degree [3, 9]. The level of torrefaction is dependent on the composition of the biomass and the operating conditions [5, 7, 9, 10].

Torrefaction of biomass involves many complex reactions through which the raw biomass is converted into a mixture of solid, liquid and gaseous products [6, 9, 10]. The solid fraction, known as char, is the product of interest and comparable with low grade charcoal [6]. By release of mainly gaseous H_2O and CO_2 from the biomass, the overall effect is a large loss in mass and a smaller loss in energy resulting in a net increase in energy density [1, 10]. Increasing the severity (that can roughly be considered the product of temperature and residence time) reduces the relative yield of the solid product [5, 9]. The altered molecular structure of the biomass constituents offers increased ease in particle size reduction, improved hydrophobicity, and also allows for use of a diverse nature of feedstocks by making the biomass product more homogeneous [6].

The majority of torrefaction research to date has focussed on using woody lignocellulosic material as the feedstock [1, 3-11], however Solid Recovered Fuel (SRF) is gaining increased interest as a fuel source [12-14]. A product of non-recyclable agricultural, commercial and industrial waste, SRF pellets are of a consistent quality with a beneficial ease of handling and storage. It is anticipated that the relative benefits attained in the torrefaction of lignocellulosic material will be comparable for torrefaction of SRF.

1.1 Aims

1. Investigate the effect torrefaction has on woody biomass and SRF, and whether any noted differences are observed in the differing biomass feedstocks.

2. Investigate the effect differing reaction temperature has on the level of torrefaction of biomass.

3. Investigate the effect differing reaction time has on the level of torrefaction of biomass.

The effect and level of torrefaction was analysed by changes in the properties of the biomass. The biomass appearance and structural integrity were recorded, and the mass reduction after torrefaction used to calculate the mass yield. Measurement of the gross calorific value (GCV) of the samples was used to determine the energy densification and energy yield after reaction. Changes in the hydrophobicity of the biomass were evaluated as being relative to the % mass increase after submersion of the samples in water.

2. Experimental

2.1 Torrefaction of raw biomass

To encourage even and comparable reaction rates, SRF and wood pellets of similar sizes were selected for use. Cylindrical pellets of 20 ± 2 mm in length, and 16 mm and 6 mm diameter respectively for the SRF and wood

were used. All biomass samples were dried according to ASTM standard (D1762-84) procedure, at 105 °C to constant weight prior to treatment. Torrefaction of the raw biomass was carried out in a Carbolite LHT 4/30 oven at temperatures ranging from 230 to 250 °C. The biomass samples were weighed (~15g), placed in the centre of the furnace in ceramic crucibles, and the heating program commenced. The temperature program consisted of a dynamic heating period, at a rate of 5 °C/min, followed by an isothermal heating period. After the desired residence time (30-60 min), the sample was removed and allowed to cool to room temperature in a desiccator. The solid products were collected for further analysis.

The torrefied biomass samples were denoted as SRF-X-Y (for the SRF pellets) or WP-X-Y (for the wood pellets), X indicating the treatment temperature (in °C) and Y indicating the residence time (in minutes).

2.2 Analytical Methods

2.2.1 Energy content

The gross calorific value (GCV) of solid samples was measured in a Parr 6200 bomb calorimeter to BS1016 part 5 (1977).

2.2.2 Hydrophobicity

The samples (~3 g) were accurately weighed and placed in DI water (~20 mL) at ambient temperature. After 1 h the samples were removed, excess surface water removed and re-weighed. The weight change in % was calculated, and attributed to adsorption of water. The mass increase of torrefied samples relative to the raw biomass can be approximated as a measure of change in hydrophobicity.

3. Results

The following section presents the results of torrefaction of wood pellets and SRF pellets and the effect of differing reaction conditions:

During planning work it became apparent that the available furnace was not equipped with a gas inlet line and so torrefaction would necessarily be performed in air rather than under an inert atmosphere as is normally required. The initially proposed reaction conditions were therefore reconsidered, and lower temperatures selected, to reduce the risk of combustion of the biomass. At 230 °C, the lower limit at which torrefaction occurs the reactions appeared successful, however at 250 °C after ~5 min smouldering of the SRF pellets produced significant amounts of smoke and so the reaction was abandoned. For this reason there is no analytical data for SRF-250-30, however reaction of WP-250-30 appeared satisfactory.

3.1 Visual observations

A noted change in colour was recorded for all torrefied samples compared with the raw biomass; the originally pale brown wood pellets turned dark brown, and the mostly grey SRF pellets turned black (Figure 1.). The harsher the torrefaction conditions i.e. increased temperature and residence time, the darker the product colour.

From manipulation of samples after torrefaction, the originally dense, high strength pellets seemed more brittle. No change in particle size and shape was recorded and is attributed to the stationary nature of reaction within the furnace and the raw biomass used being pre-processed and pressed into high strength pellets.

*SRF-250-30 was only reacted for ~5 min after which time the reaction was abandoned. Photograph is of product after this reduced time.

Figure 1: Visual appearance of biomass before and after torrefaction.

Table 1: Mass yield and energy yield of biomass after torrefaction

Sample	Mass yield (%)	GCV (MJ/kg)	Energy densification ratio	Energy yield (%)
WP-raw	—	19.1	—	—
WP-230-30	93.4	—	—	—
WP-230-60	91.0	19.9	1.04	94.6
WP-250-30	85.3	—	—	—
SRF-raw	—	21.7	—	—
SRF-230-30	89.0	—	—	—
SRF-230-60	85.3	18.4	0.85	72.5

3.2 Mass and Energy yields

Mass yield, energy densification ratio and energy yield are three important values used in this study which are defined as:

$$\text{Mass yield} = \frac{\text{Mass of torrefied solid}}{\text{Mass of raw biomass}} \times 100$$

$$\text{Energy densification ratio} = \frac{\text{GCV of torrefied solid}}{\text{GCV of raw biomass}}$$

$$\text{Energy yield} = \text{mass yield} \times \text{energy densification ratio}$$

CV analysis was performed on the biomass samples in both their untreated state and after torrefaction at 230 °C for 60 min. As these were the most harsh conditions successfully tested it was predicted they would generate products with the most pronounced difference in energy content to the untreated biomass.

As summarised in Table 1, the results show that both reaction temperature and time are significant variables in the torrefaction of wood and SRF. For both biomass types, increasing the severity of the reaction conditions, i.e. temperature and residence time, caused a reduction in the mass yield and is a result of greater degradation and vaporisation of biomass constituents. Reaction of wood at 230 °C for 30 min gave a mass yield of 93% decreasing to 91% for reaction for 60 min, and similarly for SRF at 230 °C a reaction time of 30 min gave 89% mass yield that decreased to 85% for 60 min reaction time. The overall mass loss was greater for SRF than wood. This is believed to be a result of the combination of high stability lignocellulosic woody material and the presence of relatively low melting point plastics generating volatile organic compounds in the SRF.

The GCV of raw SRF is higher than wood at 21.7 MJ/kg compared with 19.1 MJ/kg and can be attributed to the high plastic content of the SRF pellets. After torrefaction at 230 °C for 60 min the GCV for the wood pellets increased slightly from 19.1 MJ/kg to 19.9 MJ/kg, having an energy densification ratio of 1.04, with the small increase explained by the relatively mild torrefaction conditions employed. Under the same conditions, the GCV of the SRF pellets appeared to decrease from 21.7 MJ/kg to 18.4 MJ/kg with an energy densification ratio of 0.85. This is unexpected and due to inherent process errors in CV analysis it would be of benefit to repeat the analysis. Repetition of the reaction would also be beneficial due to the heterogeneous, inconsistent composition of individual SRF pellets.

The possibility of partial combustion of the biomass would explain the observed trends in the mass yields and the apparent decrease in GCV and energy yield for the SRF. Had the most reactive portion of the biomass reacted in the oxidising atmosphere, both the energy content and mass yield would decrease.

The mass and energy yield data collected for wood pellets in this study, 91.0% and 94.6% respectively, is comparable with literature values for torrefaction of various biomass materials at 230 °C for 60 min. Pach et al. obtained a mass yield of 92.4% and energy yield of 96.5% for pine wood [15], and Zanzi et al. quoted values of 96.5% mass yield and 97.5% energy yield for wood pellets [16]. The exact composition of wood pellets used by Zanzi et al. is unknown, and also as both these studies performed torrefaction in a N_2 atmosphere direct comparisons cannot be drawn. It is however believed that the slightly lower yield values obtained in this study can be attributed to the oxidising atmosphere under which the torrefaction was performed.

Yield data for the torrefied SRF product is significantly lower than any quoted data, enforcing the belief that partial combustion occurred.

3.3 Hydrophobicity

The approximate method of measuring the mass increase of the biomass after submersion in water was used as an indicator of the increase in hydrophobicity of torrefied biomass.

In lignocellulosic biomass, moisture can be absorbed into the cell walls and hydrogen bonded to hydroxyl groups of the cell wall components. During torrefaction these are broken down and the solid becomes increasingly hydrophobic [6]. This is beneficial for biomass fuels as they can be stored without risk of biological degradation and transportation costs are reduced.

Table 2 shows the torrefied solids become more hydrophobic in comparison with the raw biomass feedstocks. The mass of water absorbed by the biomass decreases with increasing torrefaction temperature and residence time, with the increase in mass reducing from 200% for raw wood pellet to 6% (WP-230-60) and from 8% for raw SRF to 3% (SRF-230-60).

This effect is much more pronounced for wood pellets over SRF pellets. This is attributed to the minimal water absorption of SRF due to the lack of lignocellulosic material and the highly hydrophobic nature of plastics which make up a high proportion of the SRF bulk.

Table 2: Mass increase of raw biomass feedstock and torrefied solid products as a measure of hydrophobicity.

Sample	Mass increase (wt %)
WP-raw	199.8
WP-230-30	6.9
WP-230-60	6.0
WP-250-30	5.6
SRF-raw	8.0
SRF-230-30	5.1
SRF-230-60	3.2

4. Conclusions

1. Due to equipment constraints it was not possible to perform the torrefaction in an inert atmosphere. It is proposed that rather than the desired torrefaction reactions, partial combustion of the SRF biomass feedstocks occurred which would be consistent with collected mass yield and GCV data.

2. Both the wood pellets and SRF changed from their original colour to dark brown/black. Increasingly harsh reaction conditions produced an increasingly darker coloured torrefied biomass.

3. For both biomass types, increasing the severity of the reaction conditions caused a reduction in the mass yield. This is a result of greater degradation and vaporisation of biomass constituents.

4. The GCV of wood pellets increased slightly after torrefaction. Unexpectedly the GCV of the SRF pellets decreased, however this is believed to be due to exothermic reaction of the biomass so reducing the energy content.

5. The method for hydrophobicity measurement is acknowledged as being primitive however it offered a rough qualitative way of presenting the increased hydrophobicity of biomass after torrefaction.

6. The heterogeneous nature of SRF means the exact composition of individual pellets could be vastly different and so to remove this uncertainty, multiple repeats would be necessary for reaction and analysis of the SRF.

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