Fuel Processing Technology 148 (2016) 395–402

Contents lists available at ScienceDirect

Fuel Processing Technology

journal homepage: www.elsevier.com/locate/fuproc

Research article

Changes in mechanical properties of wood pellets during artificial degradation in a laboratory environment

Shalini Graham [a], Ibrahim Ogunfayo [a], Matthew R. Hall [a,b], Colin Snape [a], Will Quick [c], Susan Weatherstone [c], Carol Eastwick [a,*]

[a] Faculty of Engineering, University of Nottingham, University Park, Nottingham NG7 2RD, UK
[b] British Geological Survey, Environmental Science Centre, Keyworth, Nottingham NG12 5GG, UK
[c] Uniper Technologies Ltd. (formerly E.ON Technologies), Technology Centre, Ratcliffe on Soar, Nottingham NG11 0EE, UK

A R T I C L E   I N F O

Article history:
Received 24 November 2015
Received in revised form 18 March 2016
Accepted 18 March 2016
Available online xxxx

Keywords:
Biomass
Wood
Pellet
Storage
Degradation
Torrefied
Steam exploded

A B S T R A C T

In stockpiles exposed to high relative humidity (RH) and rainfall, woody biomass pellets lose structural integrity, often assumed to be due to the uptake of moisture from the environment. In this study three different types of biomass pellet were artificially degraded in a laboratory environment under controlled exposure to RH (10% and 90% RH) and temperature (range of 10 to 30 °C). White, torrefied and steam-exploded wood pellets were investigated. Daily shear tests were conducted with durability and moisture content measured. The exposure of all three pellet types to high RH coupled with elevated temperatures caused a substantial decrease of shear modulus with values of 50% to 92% decrease compared to fresh pellets after 4 days of exposure.

The steam exploded pellets saw the lowest drop in mechanical durability (5%) but saw the largest decrease in shear modulus, whilst the white wood pellets disintegrated in situ after 4 days. In contrast storage at 10% RH did not cause any observable degradation, with mechanical behaviour of steam exploded and torrefied pellets showing an improvement. This paper presents both testing methodology as well as clear indication of the behaviour of three woody biomass pellets on exposure to high relative humidity.

1. Introduction

As power generators continue their search for alternative energy sources to coal, biomass remains a promising carbon-based renewable fuel [1]. Biomass fuel dedicated combustion and co-firing with coal are being utilised and optimised to improve fuel flexibility in power-plants and reduce greenhouse gas (GHG) emissions. Densified biomass fuels such as pellets are preferred as they provide better economic viability for transport, storage and handling [2]. One of the challenges facing the energy industry is how to store the large quantities of biomass fuel required for thermal power plants [3]. During a study on the long-term impact of weathering on the mechanical and chemical properties of biomass fuels during storage [4], it was noted that the mechanical degradation of the pellets resulting from moisture intake was more substantial than the chemical degradation. Whilst there have been several recent publications relating to storage impacts on the mechanical properties of wood pellets, these have investigated long term impact [5,6] or impact of pre-treatment [7,8]. The systematic investigation of short term storage humidity and temperature on mechanical properties on biomass wood pellets has not been studied. Therefore a study on the effects of relative humidity (RH) and surrounding temperature on the structural changes in wood pellets was carried out using laboratory investigations where the impact of continuous exposure to high RH at ambient and elevated temperatures on the mechanical properties of three different wood pellets (white wood, torrefied and steam exploded) was undertaken.

Previous work has been carried out on biomass fuels in related areas such as of sourcing and procurement [9], logistics of transport [10], effects of storage and handling on physical properties [11–13], conveying and milling operations [14], combustion efficiency [2] and emissions and ash control [15,16]. More relevant to this investigation is the work of Lehtikangas [5] examining changes in the properties of nine different types of pelletised fuel during storage when exposed to heat and humidity/water vapour over a period of five months. No significant changes were observed in the bulk density, individual pellet density, ash content and calorific value. The most noticeable impacts were pellet length, 25 to 50% drop, and durability, measured as percentage of fines <3 mm after tumbling, with an increase of 300% in the worst case. Pellet length reduction as a result of storage was also reported by [6] in their work on canola straw pellets.

The impact of thermal treatment on the properties of pellets has also been investigated [7,8] with a reduction of moisture uptake reported with increasing severity of thermal treatment. Authors also noted

* Corresponding author.
E-mail address: Carol.Eastwick@nottingham.ac.uk (C. Eastwick).

http://dx.doi.org/10.1016/j.fuproc.2016.03.020

changes in strength and hardness although these were dependent on the treatment type and severity. Peng et al. [7] manufactured pellets from sawdust samples torrefied at a temperature range of 240 to 340 °C and compacted at a range of temperatures and pressures, whilst Lam et al. [8] investigated the steam explosion of Douglas fir at four different treatment severities (at 200 and 220 °C and for 5 and 10 min at each temperature).

Peng et al. [7] measured moisture uptake in an environmental chamber set at 30 °C and 90% relative humidity. For an increase in the pellet torrefaction temperature from 240 to 340 °C the moisture uptake over 24 h decreased from 14 to 8% and the pellet hardness decreased by as much as 90%. A decrease in the moisture and volatile contents could have contributed to a weakening of interfacial forces, adhesion and cohesion forces, solid bridges and interlocking forces. However Lam et al. [8] noted that steam treatment led to an increase in pellet elasticity, higher mechanical strength and increased moisture sorption resistance for most conditions.

As previously stated, the long term study [4] by the authors identified there may be a link between pellet degradation behaviour in outdoor/non fully enclosed storage where high relative humidity levels (90%) and temperatures above 20 °C were encountered, and this is the hypothesis investigated within this paper. By carrying out a small scale study simultaneously investigating exposure to combinations of relative humidity and temperature at short time scales, and measuring the extent of mechanical degradation (pellet durability and three point flexural shear modulus), a more systematic analysis of the impact of relative humidity and temperature was achieved. These tests simulated pellet storage in outdoor or exposed (for example an open barn) environments with sensitivity tests at lower humidity included for comparative purposes. In the long term storage trials [4] completed between April 2011 and December 2012, the relative humidity and ambient temperature were measured and recorded continuously for a period of twenty months, with variations in relative humidity from 65 to 95%, the summer months averaging 10–15% higher than in the winter months. The relative humidity trend over the storage period showed higher levels of humidity for sustained periods (90% and above for 16 consecutive weeks) compared to past years [17]. Ambient temperature matched UK year on year averages (measured at Waddington weather station, Met Office UK) [17] very closely, and ranged from −10 to 30 °C.

2. Material and methods

Two different laboratory storage environments were used in this work. In the first, wood pellets were enclosed in sealed containers and subjected to uncontrolled high relative humidity for several days; and in the second pellets were tested in an environmental chamber at controlled temperatures and relative humidity for varying time periods The first method was trialled to establish whether simple testing would provide sufficient indicative trends to allow a low cost and quick method to be utilised in the biomass transport and storage industry in assessing the resistance of pellets to moisture uptake and mechanical degradation in outdoor/not enclosed storage scenarios. The second test in the environmental chamber provided a more robust test with controlled parameters to verify the results of the simple container test and therefore validate the method for simple low cost testing. The three pellets types investigated included a white wood pellet manufactured from de-barked virgin softwood, a torrefied pellet manufactured from a mixture of softwood and hardwood and a steam exploded pellets also manufactured from a mixture of softwood and hardwood. Two properties used to assess the mechanical strength of wood pellets were pellet durability [18] and shear modulus [3] under three point flexural testing. Durability measures the pellet's resistance to breakage during handling/motion according to the test stated in BS EN ISO 17831:1 [19] and the three point flexural shear represents the pellet's resistance to crack formation when a force is applied [4]. Typical dimensions of the three pellet types utilised during these tests are summarised in Table 1.

Table 1
Typical dimensions of each pellet type before storage tests.

Biomass pellet	Diameter (mm)	Length (mm)
Untreated white wood	6.00 ± 0.20	21.60 ± 2.00
Steam exploded	6.30 ± 0.10	18.00 ± 1.90
Torrefied	8.00 ± 0.10	15.70 ± 0.60

2.1. Artificial degradation experiments in a sealed container

2.1.1. High humidity (ambient temperature)

For each pellet type, a high humidity environment at ambient temperature was generated by pouring 1 l of tap water into a sealed container kept at an average temperature of 20 °C. A metallic mesh 100–150 mm above the water surface held a mass of 250 g of pellets at the start of testing. Each day a sample of 15 pellets was removed for mechanical testing, these were randomly selected. A type-T thermocouple (silicone type) connected to a temperature data logger was positioned to measure in-situ pellet temperature. In addition, a Lascar EL-USB-2 + humidity data logger (Lascar Electronics Ltd., Salisbury, UK) was secured to the inside of the container lid to monitor relative humidity levels. The container was sealed (air-tight) during the trial to maintain a high level of in-situ humidity (Fig. 1 — not drawn to scale).

The temperature was recorded at a frequency of 30 s, whilst the humidity was recorded every 10 s, with readings being downloaded every 24 h. The mean and range (variation) of each 24 h period was determined. The mean daily temperature was 20 °C with a variation of ±0.9 °C as the room temperature was managed. The relative humidity initially was at a value of 70% RH (the background relative humidity level in the room) rising rapidly to an average of 95% RH with a daily variation of ±1% RH. The test lasted 17 days at which point severe pellet degradation had occurred and shear testing was no longer possible.

2.1.2. High humidity (elevated temperature)

A similar setup as in Section 2.1.1 was used. However the 1 l of water in the bucket was introduced at an elevated temperature of 60 °C. Each morning, the cooled water (20 °C) in the bucket was replaced by fresh hot water at 60 °C. This was to investigate the effect of a combination of higher temperatures and relative humidity on pellet degradation and the impact of a changing temperature regime (exaggerated day and night variations seen in the long term storage trial) on the pellets. The buckets were sealed and positioned in an insulating box. As in Section 2.1.1, temperature was recorded every 30 s and humidity every 10 s. As expected there was a large daily temperature variation; 60 °C in the morning with the temperature gradually decreasing to 20 °C by the evening. Relative humidity varied with the temperature profile seeing a range in values from 70 to 91% RH across the day. As there was a wide variation of temperature and relative humidity experienced by the pellets in these tests, follow on tests employing the environmental chamber sustained realistic higher temperature and relative humidity (Section 2.2). Storage at elevated temperatures only lasted 7 days due to the increased degradation rate seen by the pellets, making mechanical testing increasingly impractical with some pellets unable to be tested after 4 days.

2.2. Environmental chamber experiments

In the experiments in the enclosed containers described in Section 2.1, pellets were exposed to uncontrolled temperature and humidity variations. The variations in both temperature and humidity made it difficult to draw accurate conclusions about the impact of each separately. Therefore, an environmental chamber TAS LT CL 600 Series 3 [20] (TAS Ltd., West Sussex, UK) was used to enable the