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# Raw and steam exploded pine wood: Possible enhanced reactivity with gasification hydrogen

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ABSTRACT

A commercial thermally treated biomass known as ‘steam exploded biomass’ or ‘black pellets’ was compared with the raw yellow pine wood feedstock to the process using the Hartmann dust explosion equipment. The aim was to investigate the difference in pulverised biomass reactivity and minimum explosible concentration, MEC. The reactivity was determined from the initial rate of pressure rise prior to the vent bursting in the Hartmann equipment. The flame speed in the vertical tube of the Hartmann equipment was also determined as a reactivity parameter. Steam exploded milled pellets (BP) was found to have a higher reactivity, leaner MEC and higher flame speed, than the raw pine. The enhanced reactivity of BP was due to the greater proportion of fine particles. Both raw pine and BP had a high reactivity for very rich mixtures and this was due to the gasification reactions in rich mixtures that released CO and hydrogen. The very lean MEC for both biomass also may have been enhanced by hydrogen release.



## Introduction

Concerns over global warming and the high $CO_2$ emissions from pulverised coal fired power plants are discouraging the use of coal as a fuel for electric power generation. Sustainable and consistent fuels need to be sourced to replace fossil fuels. Renewable pulverised biomass can be employed as a substitute for coal in existing coal fired electric power generation plants. Pulverised wood is increasingly being used for electric power generation as one way of meeting the mandated European renewable energy proportions of electricity supply. In 2014 5.8% of the UK's supplied electricity was generated from pulverised biomass, mainly used in existing coal fired power stations. This was a 25.7% increase on 2013 and in 2014 was 19.69 mtoe [1]. It was the fastest growing renewable electricity source between 2013 and 2014.

Currently most wood used for power generation is raw wood, pulverised at source, dried and compressed into pellets. This pelletisation increases the density of the fuel and the drying improves its energy density so that more biomass energy can be shipped in the fixed volume of a ship's hold. The palletisation also enables the pulverised fuel to be transported with minimum dust generation and hence with lower explosion risk. At the power station the pellets are stored in silos from which they are fed to the coal mills, which break up the pellets into the pulverised biomass. The mills are not intended to pulverise the biomass further, all the pulverisation is done at the palletisation plant in the country from which the biomass originated. This work investigates a further

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development of the palletisation process that of steam exploded biomass which is a thermal treatment process that produces a more consistent pellet that is easily milled with a higher calorific value than the raw biomass pellets.

## Biomass and hydrogen production

Hydrogen production from steam methane reforming of methane is the current major source of commercial hydrogen, particularly for oil refinery use to reduce the aromatic content of diesel, the other main products are CO and $CO_2$ [2]. Steam reforming of coal and biomass can be used for the production of hydrogen and if the CO is converted to $CO_2$ and the total $CO_2$ solvent extracted and captured, then low carbon hydrogen can be generated from coal or biomass [3–5]. In the combustion of rich mixtures of biomass, as studied in this work, the equilibrium products are essentially those of a gasification process with high CO and $H_2$ [6]. Peak hydrogen formation is usually around an equivalence ratio of 3 and the present work has rich flames propagating with a relatively high reactivity for equivalence ratio >3. Both pyrolysis and gasification of biomass can result in hydrogen production [5,7,8] and the pulverised biomass propagating flame studied in the present work involve pyrolysis reactions due to flame heating of particles. For rich mixtures gasification reactions occur that produce hydrogen. For lean mixtures flame front pyrolysis of biomass will produce some hydrogen. It is known that the addition of hydrogen to hydrocarbons extends the lean limit and thus makes the mixture more reactive [9]. It is possible that the present very lean minimum explosible concentrations for biomass are contributed by the pyrolysis release of hydrogen in the flame front. A method for calculating the hydrogen produced in volatiles from the biomass heating is developed in this work and this shows that the proportion of hydrogen is relatively low, so that for lean mixtures the MEC enhancement would be low.

## Thermal treatment of biomass

Thermal treatment processes such as torrefaction aim to break up the fibrous nature of woody biomass and make it more brittle so that it can be more easily milled alongside coal or on its own in the same mills as used for coal. These thermal treatment processes would be based at the source of the biomass alongside the pelletisation plant. They have the advantage of low water in the biomass, a higher pellet density and less tendency for the pellet to fracture and form dust clouds in transport. At present it is not clear whether the potential advantages of torrefied biomass outweighs the increased cost of manufacture, for power generation.

Biomass materials have a low bulk density, a fibrous structure and have low heating values [10,11]. The cost of transporting raw biomass from source to the power generation plant for milling is too high. Thermal pre-treatment of the biomass potentially can reduce these transport costs. Torrefaction is one of the advanced and attractive pre-treatment that gives the following benefits [12,13]: they are more compact (higher bulk density), have a higher heating value and are more easily pulverised as the biomass fibres are broken up by the thermal treatment. Torrefaction results in a significant loss of volatiles from the biomass depending on the torrefaction conditions; these are usually recycled to provide the heat for the torrefaction process. Thermally treated biomass materials are often referred to as bio coal as they are closer in some properties to coal than to the original biomass.

An alternative thermal treatment to torrefaction is 'steam exploded biomass' [14]. This is a commercial process at the pilot plant stage, that treats the woody biomass with pressurised hot water (1.2–1.7 MPa, 170–250 °C) for a short time (up to 10 min) and then releases the pressure to flash vaporise the water. This process inside the woody biomass structure shatters the particles into finer fractions [15,16]. These steam exploded biomass materials are transformed into pellets known as 'Steam exploded pellets' for the easiness of transportation. They are often referred to as 'black pellets' due to their black colour.

Black pellets have similar properties to that of torrefied biomass. The steam exploded biomass process has potentially a lower energy consumption than for torrefied biomass with a lower loss of volatiles. The steam exploded process is intended to have a lower tar formation and less cracking of the raw biomass material. The resultant pellets potentially have a higher proportion of the original biomass energy than for torrefied biomass.

The steam exploded biomass treatment and palletisation process produces a pellet with an externally sealed outer surface due to the treatment process. This leaves them less sensitive to absorb water than for torrefied biomass. The biomass fibres in the pellets are destroyed and the pellets are easily pulverised, which are similar to the benefits of torrefied biomass. Steam exploded biomass is potentially a lower cost product than torrefied biomass and a better product in terms of energy content as a proportion of the original biomass energy on a daf (dry ash free) basis [14]. However, until commercial scale production plants are available for both technologies the final cost of the two thermal treatment techniques is not known.

## Biomass dust explosion hazards

Pulverised biomass, when mixed with air, may explode if there is an ignition source and the flame propagation is the same as that which occurs in pulverised biomass burners. Thus the study of biomass explosions has both safety and pulverised biomass flame propagation measurement applications. The high volatile content of biomass and thermally treated biomass and the oxygen bound into the structure of the biomass fibres make pulverised biomass very reactive [17–20]. Pulverised biomass samples have a lower MEC than pulverised coal [21–23] and are hence more reactive. The porous structure of biomass with higher volatile content makes them more reactive.

Dust fires or explosion are common in biomass plants [24] and a recent UK incident was the wood floor mill explosion at Bosley Mill near Macclesfield. This resulted in the loss of four lives and almost complete destruction of plant. Some recent