



# An automated ash fusion test for characterisation of the behaviour of ashes from biomass and coal at elevated temperatures

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## HIGHLIGHTS

- ▶ We show how images from the ash fusion test can generate a characteristic profile.
- ▶ Each profile is linked to the ash composition of the pellet and source material.
- ▶ These profiles help predict how the ash material might slag or foul in a boiler.
- ▶ Biomass ash profiles are shown to be significantly different from coal profiles.

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## ABSTRACT

The benefits of blending biomass with coal for power generation include less CO<sub>2</sub> emissions and a reduced dependency on non-renewable fossil fuels. However, there is a need to understand the role of biomass during direct combustion and co-firing, particularly in terms of the effect of biomass use on ash slagging and fouling. A new image analysis based technique has been developed to characterise the behaviour of ashes from biomass, coal and coal/biomass blends using a single heating test at elevated temperatures. It is a reproducible test that combines the conventional ash fusion test, dilatometry and sinter strength test by means of image analysis. An oven is used to heat the cylindrical ash pellets from room temperature to 1520 °C, while the in-built camera captures still images of the samples throughout the temperature range. An automated image analysis code has been developed to provide behaviour profiles for each ash sample (across the temperature range) by quantifying dimensional changes upon heating. The error for the determined ash characteristic temperatures is approximately 15 °C, which is approximately 50% lower than for a conventional ash fusion test. Cylindrical ash samples from 9 biomasses (corn stover, DDG, DDGS, miscanthus, olive residue, wheat shorts, wheat, rapeseed, sunflower seed) and a standard UK coal (Daw Mill) were tested using this method and each was found to produce unique profiles.

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## 1. Introduction

Whilst electricity generation from oil and natural gas generates little or no ash respectively [1], coal combustion can produce significant amount of ash that unavoidably leads to ash related problems. Ash slagging and fouling have always been major factors with regards to boiler design and operation, particularly as power stations now generally buy coals from all over the world. Coals from the world market have huge variations in total ash content and mineral composition [2].

Slagging deposits are normally located in the high temperature region of boilers with direct exposure to the combustion flame

[3,4]. They are commonly found in the radiant section of boilers where the formation process is associated with the sintering and fusion of ash particles on surfaces, at temperatures in excess of 1000 °C [5]. Fouling deposits, however, occur in areas that are not directly exposed to thermal radiation, such as in the convection sections of a boiler [3,4]. This process involves lower temperatures, and is predominantly driven by the deposition of volatile inorganic species. Hurley and co-workers [6] reported that 20–40% of the ash produced in a boiler occur within the boiler itself, especially in the hoppers at the bottom section of the furnace and/or on the interior surfaces as slag. The remaining 60–80% exits with the flue gas for collection in mechanical and electrostatic separators. Although furnace design and operating conditions may contribute to the occurrence of slagging and fouling, ash characteristics play a major role. Ash chemical and mineral compositions determine its melting characteristics and fusion temperatures [7].

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A new challenge for boiler operators has been the introduction of biomass which has become increasingly popular in recent years as a carbon neutral energy source. Its lower melting temperature (compared to coal) can be problematic and limit the utilization of biomass in both direct combustion and co-firing. This phenomenon is mainly due to the high alkaline content of biomass ash, particularly in herbaceous biomasses [8]. Alkaline salts, such as alkaline silicates, melt and soften at low temperatures [9], forming a sticky liquid phase [10] which increases the stickiness of the surface of the ash deposit, leading to an increase in collection efficiency of incoming fly ashes and deposit growth [4,11]. These deposits are complex, heterogeneous, multiphase and porous materials [12] and commonly consist of alkali and alkaline earth metals [4], coupled with their chlorides, sulphates, carbonates and complex silicates [13].

Potassium is the main source of alkali in most biomass fuels [5,14] located in the inherent mineral matter and is the main cause of ash deposition and corrosion. Nielsen and co-workers [15] reported that potassium salts, mainly KCl or  $K_2SO_4$ , play a significant role in ash deposition by acting as glue bonding the individual fly ash particles together. Also, KCl is responsible for the corrosion of the superheater tubes in biomass fired boilers. However, KOH is formed when the level of chlorine is low. Other less stable potassium containing compounds may form but they are unlikely to enter the gas phase [16]. This is in contrast to coal, where sodium is the dominant and most problematic alkali metal [5,14].

The slagging and fouling propensity of a particular solid fuel can be predicted using various approaches including the ash fusion test [1,7,17–19] dilatometry/shrinkage [3,20,21], sinter strength test [17,22], viscosity measurements [7,23], various empirical indices [1,23–26] as well as pilot-scale trials. Each test has advantages and disadvantages which can include cost, reliability and complexity.

The ash fusion test remains one of the most popular methods for studying fuels in terms of ash behaviour. The test is relatively inexpensive and simple with a significant number of publications that discuss its application [1,7,17–19] and methods to predict ash fusion temperatures [7,18,25,27–29]. Typically, pyramidal ash pellets are heated in a furnace under either oxidising or reducing conditions to over 1500 °C, and depending on the eventual shape and size of the pellets, four characteristic temperatures are determined for each sample (Fig. 1). The characteristic temperatures initial deformation, sphere, hemisphere and flow temperatures – indicate the behaviour of ashes in a boiler.

The major drawback associated with the ash fusion test is the reliance on visual observation rather than an objective physical measurement i.e. the results are dependent on the subjective judgment of the operator. Inevitably there are inherent reproducibility issues, particularly between operators when a different operator is

**Table 1**  
Types of samples used and their associated ash content.

Fuel	Type	Ash content (wt.%)
Corn stover	Agricultural waste	4.2
Wheat shorts	Agricultural waste	4.6
Miscanthus	Energy crop	2.8
Wheat	Industrial waste	3.3
Sunflower seed	Industrial waste	1.9
Rapeseed	Industrial waste	4.9
Olive residue	Industrial waste	13.4
Distillers dried grain (DDG)	Industrial waste	3.9
Distillers dried grain with solubles (DDGS)	Industrial waste	3.5
Daw Mill	ECE/ISO classification 711 vitrinite reflectance (0.60%)	8.4

involved. Differences of 400 °C have been reported for the initial deformation temperature of a single sample obtained from different laboratories [3].

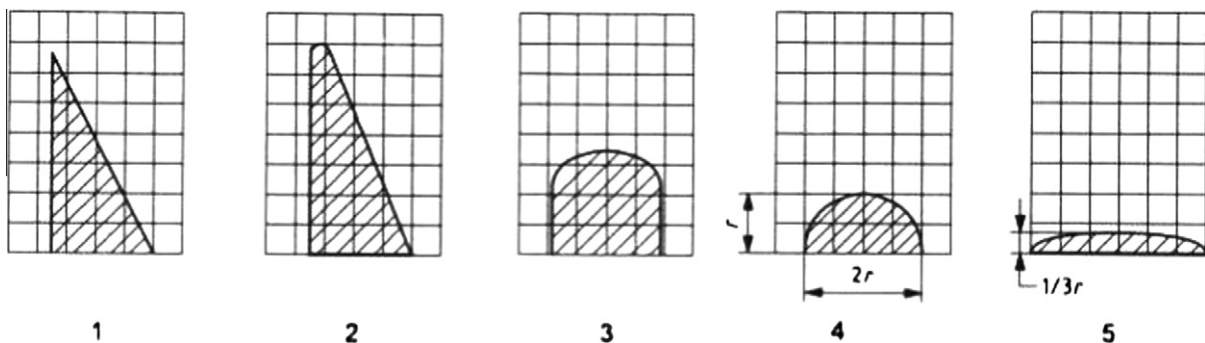
This work describes a new experimental test to characterise the complete behaviour of ashes by creating a fusion profile, rather than producing four specific temperature values. It is a test that combines ash fusion test, dilatometry and sinter strength test by means of image analysis. This measurement test is more reproducible because it is not based on manual identification. This test remains inexpensive (by using existing standard ash fusion kit) and straight forward.

## 2. Materials and methods

A standard UK high volatile bituminous coal, Daw Mill as well as nine different biomasses were used for this study (Table 1). These biomasses cover a range including energy crops, agricultural wastes and industrial wastes.

### 2.1. Ashing

Ash samples for this study were produced in a laboratory using a muffle furnace. All biomass samples were ashed at 650 °C. Large amounts of each biomass were ashed in order to generate the required amounts for pellet manufacture due to the inherent low ash contents (Table 1). The ashing temperature for coal is higher than that used for biomass. These temperatures represent the lowest temperatures to give loss on ignition (LOI) smaller than 5% after ashing. Preliminary results have shown that the difference in compositions between coal ashes prepared at 650 °C and 800 °C is



**Fig. 1.** Pyramidal ash pellet at different characteristic temperatures: (1): original pellet, (2): at deformation temperature, (3): at sphere temperature, (4): at hemisphere temperature, and (5): at flow temperature, where  $r$  is the radius of the pellet at hemisphere temperature (BS ISO 540:2008)[30].

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