# An Overview of the Health and Safety issues particularly associated with Biomass Boiler systems

D Bosworth

This report has been based on a HSL report authored by D Shuter (An assessment of the Suitability of Boilers for use with Biomass) with sections on biohazard and chemical safety from a HSL research (Potential Occupational health hazards associated with Emerging Energy Technologies) and input from Richard Brooks HSL

# CONTENTS

# EXECUTIVE SUMMARY

The use of biomass as a boiler fuel presents a number of challenges which are distinct from those present in traditional boilers. As well as the wide range of potential biomass fuels, even within biomass materials of the same type, fuel characteristics (e.g. area, size, moisture content) can vary widely. These characteristics may also change during the combustion process, and introduce different risks and hazards (e.g. fire, explosion, pressure, irritant dusts) than those originally present.

The design of biomass boilers, the choice of fuel and the methods for processing the fuel therefore needs careful consideration. For example, the management of wood-chip and wood-pellet boilers is much more complicated than that of gas-fired boilers because of the need to ensure regular deliveries of fuel and to store it on site. The storage of fuel, the method of transfer to the boiler and the removal/disposal of ash produced will be considered. Appliances must also be exempt under the clean air act to be allowed to burn wood

## Objectives

The main objectives of this work are to review the different challenges posed by biomass boilers compared to "traditionally fuelled" boilers. These in the main arise from the various types of biomass fuels available on the market and the relative hazards of storing, handling and the combustion of these fuels. The report will not consider duel fuel boilers where biomass is burnt with traditional fuels of gas, coal or oil. To facilitate completion the report will be limited to wood, straw and poultry litter biomass fuels.

## Main Findings

1. There are a significant variety of biomass fuels currently available in the UK.

2. A number of biomass combustion hazards have been identified - these can be mitigated by selecting a good quality fuel source, which is compatible with the heating/boiler system in place. It should be noted, however, that biomass fuels are not an exact science – there can be considerable variation, in terms of calorific value, moisture content, the amount of foreign bodies and ash content, even within the same batch.

3. Biomass storage hazards can largely be eliminated by good fuel store design.

4. Biomass boilers of domestic size are regulated within the 'Low Voltage Directive' – 73/23/EEC, the Pressure Equipment Directive – 97/23/EC and the 'Machinery Directive' – 98/37/EC24. An appropriately CE marked boiler is evidence that the manufactured product complies with these directives.

5. Biomass boilers should be installed by a qualified registered engineer. In order to ensure that the biomass boiler/heating system is functioning correctly in service, it should also be regularly maintained by a qualified company.

6. Staff training – Fuel delivery arrangements, operational practices and installation/ maintenance/servicing and inspection of biomass boilers are all significantly different to 'conventional' gas, oil and electric heating. It is therefore essential for staff managing the building to receive training in the operation of the biomass boilers.

# 1 INTRODUCTION

Biomass is a generic term covering material such as crops and forestry, recycled clean biomass and waste material from municipal and commercial sources (sewage, and food and animal wastes). Biomass is renewable and generally has low carbon characteristics. It can be considered to be a ‘carbon neutral’ fuel – where the carbon emissions from the use of biomass as a fuel can be offset by the carbon captured during its growth.

The low carbon economy is currently valued at over £3 trillion globally. Within the EU, biomass currently accounts for around half (44 to 65%) of all renewable energy used. It currently meets 4% of the EU's energy needs (69 million tonnes of oil equivalent (toe)). The aim is to increase biomass use to around 150 million toe by 2010.

The growth in the use of ‘carbon neutral’ fuels throughout the UK has led to an increase in the number of boilers using biomass as fuel for heat, power or combined heat and power (CHP), and a corresponding increase in the manufacture of biomass powered boilers by small and medium enterprises (SMEs).

However, the use of biomass as a boiler fuel presents a number of challenges. Apart from the wide range of potential fuels, even within biomass materials of the same type, fuel characteristics (e.g. area, size, moisture content) can vary widely. These characteristics may also change during the combustion process, and introduce different risks and hazards (e.g. fire, explosion, pressure, irritant dusts) than those originally present.

The design of biomass boilers, the choice of fuel and the methods for processing the fuel therefore needs careful consideration. For example, the management of wood-chip and wood-pellet boilers is much more complicated than that of gas-fired boilers because of the risk associated with storage on site. The method of transfer to the boiler and the removal/disposal of ash produced also have to be considered. Appliances must also be exempt under the clean air act to be allowed to burn wood.

There have been a number of incidents in the UK where biomass boilers have exploded for a variety of reasons. Examples include:

- Biomass boiler explosion at the Eden project;
- Biomass boiler explosion at HMP Morton Hall;
- Internal explosion in biomass boiler at Hospital in Northern Ireland.

This report concentrates on wood, poultry litter and cereal straw as biomass fuels and assesses the relative hazards of storing, handling and the combustion of these fuels.

# 2 TYPES OF BIOMASS

## 2.1 BIOMASS FUELS

There are a significant variety of biomass fuels currently available in the UK at present – see Table 1. The most common types of biofuels utilised in the UK are logs, and increasingly wood chips. Pellets are relatively new to the UK although widely used in Scandinavia and North America. This report will concentrate on wood, poultry litter and cereal straw however the major types biomass fuels are outlined below.

**Table 1.** Non-exhaustive list of biomass feedstocks available within the UK

| **UK feedstocks** | | |
|---|---|---|
| Wood | Forestry residues | Wood chips from branches, tips and poor quality stemwood (Hardwood and softwood tree trunks) |
| | Sawmill co-product | Wood chips, sawdust and bark made when sawing stemwood |
| | Waste wood | Clean and contaminated waste wood |
| Straw | Crop residues | Straw from wheat and oil seed rape |
| Poultry Litter | Poultry waste | Bedding material and poultry excreta |
| Others | Animal manures | Manures and slurries from cattle, pigs, sheep |
| | Energy crops | Short rotation coppice willow or poplar, and miscanthus |
| | Sewage sludge | From Waste Water Treatment Works |
| | Organic waste | Paper/card, food/kitchen, garden/plant and textiles wastes |
| | Landfill gas | Captured gases from decomposing biodegradable waste in landfill sites |

## 2.2 PHYSICAL AND CHEMICAL CHARACTERISTICS OF BIOMASS

The constituents of biomass can vary greatly. This can cause problems in that the calorific value (CV) of the fuel also varies considerably, leading to uneven combustion.

The key determinant of biomass CV is the inherent moisture content. Moisture content is a major issue – it can vary significantly from 5-8% for wood pellets, 35% for 'seasoned' fuel and up to 65% for freshly felled timber. The greater the moisture content the lower the CV, which can cause problems such as:

- Overweight fuel handling;
- Reduced boiler capacity (requires more fuel leading to additional costs);
- Reduced efficiency; and
- Excessive flue gas on flue gas treatment.

Ash quantity and composition is also of importance. Excessive ash production during combustion can lead to:

- Overweight ash removal systems; and
- Hazardous components of waste.

The temperature of the ash can cause various constituents to fuse together and the production of alkaline components, including K, Na and Ca. These can have adverse effects on the boiler bed/gate and other components. Fouling is also likely, causing problems with fuel feed. Ash content is discussed in more detail below. Other impurities from the feedstock (such as fertilisers and salts) can cause high temperature corrosion within the boiler systems.

Compared to oil and gas, biomass fired systems require more specific maintenance procedures. Wood combustion produces about 0.5 – 1.5% by weight of ash depending on fuel quality. This ash collects in an ash pan under the grate. It has to be removed manually at regular intervals depending upon heating demand.

**Note**: It is possible that one batch of fuel will allow a particular piece of equipment to operate according to specification, whilst another similar batch of, essentially the same, fuel may cause blockages in the fuel feed line, inefficient operation, emissions, condensation in the flue, or automatic shut down of the equipment as it moves outside its design operating regime.

In terms of mechanical characteristics:

- The upstream preparation of the feedstock can present significant issues, specifically (as outlined above) when recycled products are utilised.
- Storage of the feedstock prior to processing must be well managed in order to control, moisture content, etc.
- The size of the chips/pellets produced must be well controlled.
- Biomass boilers have also been known to suffer from tripping-out on high water temperature, over-feeding of pellets, and difficulty in reacting to rapid changes in loads.

Many of the aforementioned issues, including feedstock moisture and ash contents, are discussed in more detail in the following sections.

## 2.3 FEEDSTOCK SELECTION

Feedstock/fuel selection depends primarily on the type of boiler, the direct combustion process utilised and boiler size. Smaller boilers, for example, are largely adapted for higher fuel quality (dry wood logs, pellets, wood chips), whereas larger boilers (>40$kW_{TH}$) for large buildings or district heating schemes can use a mixed variety of lower quality biomass feedstocks, including whole straw bales, large-scale wood products and large amounts of industrial (RDF, MSW, etc) and agricultural waste. The following sections outline the benefits/disadvantages of some of the aforementioned biomass feedstocks:

### 2.3.1 Wood

Wood can be divided into two major classes, either hardwood or softwood.

- Hardwoods are typically slow growing deciduous trees such as Beech, Ash and Oak.

- Softwoods are typified as being fast growing evergreens or coniferous species such as Pine, Spruce and Fir.

Hardwoods and softwoods have similar energy contents of around 20MJ/kg (dry basis). However, hardwoods are typically twice as dense as softwoods and so, on a volume basis, only half the amount of hardwood would be required to provide the same heat output as for softwood. Hardwoods are thus preferred for burning. Beech, Ash, Hornbeam and Cherry are considered to be the best hardwoods for stoves.

Moisture content can have a significant effect on the combustion process. Freshly harvested wood can have water contents > 60%. At 60% moisture, wood can have an energy content of typically 6MJ/kg, but at 25% moisture this can increase to 14 MJ/kg[1]. Trying to burn wet wood produces excess steam and also contributes to excessive smoke caused by incomplete combustion. Unburned fuel can result in tar like deposits on the lining of the chimney and can contribute to chimney fires.

Prior to using in an appliance, it is therefore necessary to reduce the wood's moisture content to acceptable levels using a process known as 'seasoning'. The most effective way to do this is to cut the trees into the required lengths for the stove and split these into logs typically 40 to 150mm diameter. These split logs should be stored for a period of time until their moisture content reduces to less than 25%. The seasoning process can take up to two years or more depending on the tree species, when it was felled, and the drying conditions. It is also possible to buy logs that have had accelerated seasoning by being force dried in a kiln to the required moisture content.

### 2.3.2 Waste Wood

Waste wood generally exhibits lower moisture content (18-25%), and is generally preferable to forestry and biomass crops with moisture contents in the region of 40%.

In the U.K., the bulk of the waste wood arises from construction and demolition, municipal solid waste, and commercial and industrial waste. DEFRA suggest that while there has been a rise in the use of recycled wood in the UK, much of the waste wood contains too many contaminants such as plastic coatings and resins. Non–combustible contaminants, such as nails and grit may also cause additional wear to biomass facilities and will add to the disposal costs of ash, making recycling difficult and expensive.

### 2.3.3 Wood pellets

Wood pellets are made from dried and milled sawdust and wood shavings that have been compressed into pellets, typically 10-20mm long and 3-12mm in diameter. They are first passed through a hammer mill to provide a uniform material. This material is then fed into a press where it is extruded through the relevant die. They do not contain any additives or binders, the high-pressure process causing the temperature of the wood to increase, with the lignin in the wood forming a natural 'gluelike' substance that holds the pellet together as it cools down. Due to the fact that the wood fibres are broken down during this process, the finished pellets are not heavily dependent on the type of wood material used. However, it should be noted that pellets conforming to the European standards (see Section 2.4) cannot contain any recycled wood or outside contaminants. [2]

Wood pellets offer many advantages over traditional log heating and wood chips, including easier handling and storage, lower moisture content and less ash. The energy content of wood pellets is approximately 4.7-4.9 MWh/tonne. Wood pellets are over 90% efficient and clean burning. They create extremely small amounts of Ash (the ash content of wood pellets is approx 0.5% by weight), which can be recycled as potash fertiliser. In terms of emissions to air, NOx, SOx and other compounds arising from pellet combustion is low.

---

[1] *HETAS - http://www.hetas.co.uk/*

[2] *http://www.swissmanllc.com/pellets.html*

Wood pellet stoves have a number of advantages over normal wood stoves. Pellet stoves are extremely efficient and produce little smoke or creosote during operation - in most cases the exhaust does not heat up, and hence the stove does not need a typical chimney. Pellet stoves are therefore well suited to urban environments.

### 2.3.4 Wood chips

Wood chips are chipped to a consistent size made from either recycled wood or specially grown crops, e.g. willow or poplar coppice. It is possible to produce up to 12 dry tonnes of willow biomass per hectare per year.[6] As is the case for wood pellets, wood chips require a special burner to extract their energy.[3] They are a simpler cheaper form of biomass fuel than wood pellets. Compared to pellets, they have a lower energy density and a lower volumetric bulk density (energy per $m^3$).

Since wood chips is not a free flowing material and has a tendency to bridge, and so storage bunkers, or silos, are frequently fitted with agitators.[4]

Most wood chip appliances cater for larger hot water applications i.e. 50-200 kW. Wood chips are currently more widely used in the UK than wood pellets, this is due to their ease of manufacture, lower cost and a current lack of nationwide wood pellet manufacturers and distributors. They are not always suitable for domestic or intensive heating uses since they require considerably more storage space and their energy content is less predictable.[5]

### 2.3.5 Straw

Wheat is the UK's most widely grown arable crop with over 2 million hectares cultivated annually. It is conventionally grown for grain, with the straw as a by–product, but very occasionally it may be harvested early for whole crop production. If harvested at maturity, average yields of 7 – 8 t/ha grain and approximately 4- 5 t/ha straw are obtained.

Typically, as outlined in Table 2, straw has a low moisture content of 16% and contains substantially more ash and corrosive species (including Chlorine and Potassium) than wood chips/wood pellets.

**Table 2.** Typical ash, Cl and K contents of straw compared with wood chips

| **Biomass Material** | **Typical dry weight %** | | |
|---|---|---|---|
| | **Ash** | **Chlorine** | **Potassium** |
| Straw | 4.5 | 0.4 | 1 |
| Wood chip | 1 | 0.1 | 0.2 |

Corrosion rates in biomass boilers can be slowed by reducing the temperature of the gas/metal, changing the boiler design or implementing high temp corrosion resistant material, such as Inconel. However, the latter could be prohibitively expensive.

[3] *Low Carbon Heating with Wood Pellet Fuel. Report by XCO2 conisbee Ltd. 2003*
[4] *Procurement Guidelines for Biomass Heating. Dr R Cooke of Buro Happold Ltd, and Mr A Russell of Mercia Energy Ltd. January 2007*
[5] *Woodfuels handbook. www.biomasstradecentres.eu*

### 2.3.6 Biomass Briquettes

Biomass briquettes are manufactured from waste products such as saw dust. The waste products are compressed and then extrudes it to make a reconstituted log. It is a very similar process to forming a wood pellet but on a larger scale. Typical biomass briquettes are shown in Fig 1. There are no binders involved in this process. The natural lignin in the wood binds the particles of wood together to form a solid. Burning a wood briquette is far more efficient than burning firewood. The moisture content of a briquette can be as low as 5%, whereas green firewood may be as high as 65%.

A wide variety of biomass products can be used in the production of briquettes - including, wheat straw, barks, husks, shells, stalks, dusts and chips, etc.

Briquettes have a number of advantages:

- It can contain a mixture of biomass materials, which can be blended to give specific calorific value/moisture content. Typically briquettes have a thermal calorific value of ~4000 Kcal/Kg.
- They contain lower ash content 2 to 5% depending on blend. There is no fly ash when burnt.
- They have a consistently high burning efficiency due to the low moisture.
- They are dense materials - easy for transportation, feeding & combustion due to unique shape.
- They give uniform combustion compared with other fuels.

**Fig 1** EFB fibre (50%) and sawdust (50%) briquette

## 2.4 FUEL STANDARDS

There are several EU technical standards for biomass fuels being developed by CEN/TC 335. The two most important technical specifications being developed deal with classification and specification (CEN/TS 14961) and quality assurance for solid biofuels (CEN/TS 15234). The classification of solid biofuels is based on their origin and source. Important technical specifications prepared by CEN 335 include:

- CEN/TS 14588:2003 Solid biofuels - Terminology, definitions and descriptions
- CEN/TS 14961:2005 Solid biofuels - Fuel specifications and classes
- CEN/TS 15234:2006 Solid biofuels - Fuel quality assurance
- CEN/TS 14774-1:2004 Solid biofuels - Methods for determination of moisture content - Oven dry method - Part 1: Total moisture - Reference method
- CEN/TS 14774-2:2004 Solid biofuels - Methods for the determination of moisture content - Oven dry method - Part 2: Total moisture - Simplified method
- CEN/TS 14774-3:2004 Solid biofuels - Methods for the determination of moisture content - Oven dry method - Part 3: Moisture in general analysis sample
- CEN/TS 14778-1:2005 Solid biofuels - Sampling - Part 1: Methods for sampling
- CEN/TS 14918:2005 Solid biofuels - Method for the determination of calorific value
- CEN/TS 15103:2005 Solid biofuels - Methods for the determination of bulk density
- CEN/TS 15296:2006 Solid Biofuels - Calculation of analyses to different bases
- DD CEN/TS 14961:2005. Solid biofuels. Annex A gives examples of specifications for high quality classes of solid biofuels recommended for household usage.
- ÖNORM – many Austrian boilers have been installed in the UK and specify fuel according to ÖNORM M7 133 for wood chips (Woodchips for energy generation: quality and testing requirements) and ÖNORM M7 135 for wood pellets (standard for pellet manufacture). According to the latter, standard class 1 pellets are to be made form pure wood free from biocide, glues, and coatings. Only binding agents made from biomass (i.e. starch, flour etc) are allowed.

- Germany: DIN have developed the biomass fuel standard DIN 66 165 relating to particle/pellet size and DIN 51731 which provides specifications for briquettes and pellets.
- Sweden: SS 187120 (pellets) and SS 187121 (briquettes).

There are currently no recognised European-wide standards for levels of particle or other emissions from biomass appliances. In the vast majority of the countries, there are few laws written specifically for pellets. Often biomass appliances come under the jurisdiction of general biomass/renewable-based laws.

A point to note is that the UK Clean Air Act (1993)[6] does preclude the use of pulverized fuels and provides limits on allowable rates of combustion for solid fuels, gases and liquids. However,‘SI. 2343 Clean Air England - the Smoke Control Areas (Exempted Fireplaces)

[6] *UK Clean Air Act (1993).* http://www.opsi.gov.uk/ACTS/acts1993/ukpga_19930011_en_1

(England) (No. 2) Order 2008' [7] does provide a list of exempted fireplaces and biomass fuels, including wood pellets, wood chips and untreated dry wood, amongst others.

# 3 BIOMASS STORAGE AND HANDLING

The key elements of a biomass heating system to be considered are:

- Biomass Fuel reception, storage, and extraction from storage to the boiler unit.
- The biomass boiler.
- Ancillary equipment which may include the following depending on the size of the boiler - flue (chimney), ash extraction mechanism, heat storage, connecting pipework, expansion tank, fire dousing system and controls systems.

This report will only deal with storage, transfer to the boiler, the boiler itself and ancillary equipment.

## 3.1 BIOMASS STORAGE

### 3.1.1 Domestic Fuel storage

The choice of fuel storage type and size and delivery method to the appliance depends on the type of fuel, quantity required and the characteristics of the biomass boiler.

**Log Storage**

Log boilers are mainly stoked manually. Splitting the wood into logs according to the size of the combustion chamber is also done manually or by using a splitter. The size of the wood store depends on whether the owner will be processing their own logs or whether they will be buying logs from a supplier.

**Wood pellets storage**

Pellet fuel should be handled as little as possible and all wood should be stored in a dry location. To prevent pellets from absorbing moisture, they should not be stored directly on a concrete floor. A hopper is a common method of wood storage, which can be located just outside the building.

Key considerations for storage of wood pellets are how pellets are delivered e.g. bags or in bulk (usually a tanker). Pellets are dry and free flowing and can be blown or sucked into a fuel store providing the equipment is available, however dust may accumulate in bulk stores creating a health and safety hazard. The storage of wood pellets can also lead to oxygen deficient atmospheres or hazardous levels of carbon monoxide which have led to fatalities, even in the domestic environment. A typical domestic scale wood pellets boiler uses 10m$^3$ or 6.5 tonnes per year.

**Wood chip storage**

Options for wood chip storage include a bunker or silo. Ideally it should be designed so that the fuel can be tipped into the store. An important consideration for wood chip storage is the moisture content of the chips. If the chips are too wet and there is insufficient ventilation the moulds will grow during storage. According to the Austrian standard ONORM M 7133, wood

[7] *SI 2343(2008). http://www.opsi.gov.uk/si/si2008/pdf/uksi_20082343_en.pdf*

chips with water content of up to 30% are stable in storage. Wetter chips should be stored for long periods in an open store where there is plenty of air and stored in an enclosed bunker only for short periods.

Wood chips are fed from the bunker or silo to the boiler via either a screw conveyor / auger or a conical auger. However, as wood chips are not a free flowing material, simple agitators are fitted into the storage unit to facilitate removal. Types of agitator include articulated or spring rotary stirrers as well as rotary or conical augers.

### 3.1.2 Design of Fuel Stores

The design of storage is critical – the store will need to be well drained, on good quality ground, bounded by walls, with adequate fire protection. A number of key elements which should be addressed in the design and construction of fuel stores are given by the Carbon Trust[14] as:

- Preventing the ingress of water but also having sufficient ventilation to allow the escape of any condensation given off by the fuel residing there, avoid oxygen deficient atmospheres and provide explosion relief.

- Having sufficient strength to be able to tolerate the outward pressure exerted by a full load of fuel (and any inward forces imposed by surrounding earth if using a subterranean store).

- Having a simple method of inspecting the level of fuel (e.g. hatch, window, webcam?).

- Keeping the interior free from electrical sockets, switches, and exposed electrical fittings.

- Meeting the relevant building regulations where they apply (approved document J – Combustion appliances and fuel storage systems provides guidance). Fire protection regulations must be observed.

- Minimising fuel auger distances from the plant.

- Ensuring safety during deliveries (e.g. including a ‘stop bar’) if fuel delivery method requires a vehicle to reverse up to the store (can avoid the need for additional staff to oversee deliveries) and allowing for complete discharge from the supply vehicle particularly if tipping.

- Having appropriate security measures in place (if it is in a place that will be accessible to the public) to prevent illegal access.

- The fuel store and boiler house should not be built from readily combustible material.

- The storage room (including the door) must be dust-proof: Areas for fuel storage containing significant amounts of dust will be subject to ATEX/DSEAR area classification as per BS EN 60079:2009 Explosive atmospheres. In addition static protection should be considered for this type of storage facility with this dusty fuel material.

### 3.1.3 Storage Hazards

A number of hazards associated with biomass storage have also been identified:

- Risk of fire;
- Dust explosion;
- Biohazards
- Asphyxiating atmospheres, and
- Chemical Hazards

Risk of Fire

Biomass storage clearly presents a fire risk not only when the fuel is dry or when dust is allowed to accumulate on hot surfaces but of spontaneous combustion if large dust deposits are allowed to become moist.

Spontaneous combustion
Microbial activity in biomass can generate heat. Enough heat can be generated by microbial activity to raise the temperature sufficiently to start oxidation, which then continues to generate heat, raising the temperature further, eventually leading to combustion. In fuels with moisture content of 60% or more, the heat produced is insufficient to evaporate the water and raise the temperature above $100^0$C to start oxidation. Microbial activity is limited in fuels with 20% or less moisture content. Therefore only fuels with moisture contents of between 20% and 60% are susceptible to microbially caused spontaneous combustion; this however coincides with the moisture content of some biomass such as un-dried woodchips or poultry litter provide ideal environments for microbial heat production.

Micro-organisms naturally present in the soil in which the biomass is grown are likely to be present in relatively low numbers on the biomass after harvest and preliminary treatment, e.g., chopping, chipping, pelleting. The biomass provides the nutrient and growth of the micro-organisms present initially generates heat from their metabolism which builds up in the insulating layers of stored biomass and can pull moisture into pockets from the surrounding material. This increased temperature and moisture allows other micro-organisms to multiply. These thermophilic (heat-loving) micro-organisms include fungi such as Aspergillus fumigatus and a spore-forming bacterial group known as thermophilic actinomycetes. Their optimum temperature is in excess of $40^0$C and temperatures greater than $55^0$C can result in this ‘self-heating’ of the biomass, with the possibility of spontaneous combustion.

Particle size also has significant influence on the amount of heat produced per unit volume. Smaller particles have much greater surface area exposed to air and can therefore support more activity, which produces more heat.

Wood pellets, by virtue of their manufacturing process tend have less than 20% moisture content and are therefore not susceptible to microbially driven spontaneous combustion unless they have been moistened after production. However wood pellet oxidation can also cause an increase in temperature and when stored in bulk, particularly silos, there are reports of long burning silo fires that have occurred in Denmark and Northern Sweden. This has led to research into silo fire control techniques[7]. Straw is also known to spontaneously combust due to the same mechanism.

Burn Back

A fire could also start due to 'burn back' from the combustion chamber via the fuel transfer system into the fuel storage. These risks can be mitigated by the specification of a two, three or even four stage 'burn back' protection system, although two stage systems are the most common. If water dump units are installed external to a building, then protection against freezing (e.g. trace heating or non flammable antifreeze) should be used. If mechanical burn back protection is applied such as flexibly tipped rotary valves, these should be inspected at an appropriate periodicity since the abrasive effect of the fuel can wear them down degrading the seal.[8]

When considering the entire design, installation and operation of the plant (from both manufacturing and installation perspectives), ensuring there are sufficient control interlocks and safeguards to prevent excessive charging of fuel and unwanted air supply as a result of incorrect operator usage.

Fire risks are addressed in the Building Regulations 2000 (Approved Document J – Combustion Appliances and Fuel Storage Systems)[9]; the Regulatory Reform (Fire Safety) Order 2005 [10] and the Electricity at Work Regulations 1989 [11].

Dust Explosion

Continuous processing of biofuels can lead to dust accumulation. Accumulation of dust is undesirable because of increased risk of dust clouds being created which increases the risk of dust explosions.

The pneumatic transfer of wood pellets produces a lot of dust due to pellet disintegration. Designs of transfer systems incorporating adequately sized smooth bore pipes with large bends and specified off load rates will moderate dust production. Pipes should also be adequately earthed to prevent static discharge[9].

The ATEX Workplace Directive is applicable in many circumstances where dust-laden biomass is stored. HSE provides information on working with Wood dust [12] and Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR) [13]

Biohazards

At the preliminary stage, shipping and movement of the biomass material involves the use of front end loader diggers to unload from lorries and to handle the material during storage and transfer to the feed conveyors. Such mechanical handling potentially could release into the air biological and chemical components within the material, as well as dust from the material itself. Biomass plants, using woodchip fuels, have been used in Nordic countries for some years and there are some existing reports of potential for occupational exposure to allergens through biological activity in the stored fuel feedstock; essentially due to unplanned composting of the standing material. In a biomass storage context this process must be controlled to avoid spontaneous combustion and/or fungal and bacterial releases from handling contaminated material. These potential problems are acknowledged by the US Biomass Research &

[8] *Health and Safety in Biomass systems: Design and operation guide Carbon Trust 2011*
[9] *Building Regulations 2000: Approved Document J: Combustion appliances and fuel storage systems.*
[10] *http://www.opsi.gov.uk/si/si2005/20051541.htm*
[11] *http://www.opsi.gov.uk/si/si1989/Uksi_19890635_en_1.htm*
[12] *http://www.hse.gov.uk/woodworking/dust.htm*
[13] *http://www.hse.gov.uk/fireandexplosion/dsear.htm*

Development Initiative, (2008)[14], though are little reported on in the peer-reviewed literature. Yet the need to control the biomass storage environment is based on basic microbiological principles, i.e., lignocellulose (plant) material will begin to compost if left damp and unattended. This is likely to be dependent on the nature of the storage vessels used, and has been investigated for wood chip biomass, where microbial emissions and associated off-gassing are known to occur under some circumstances[15][16]. More general risk analysis, applied to the potential emissions during biomass storage, has been considered[17]. Aspergillus fumigatus fungi and actinomycete bacteria both can be present in biomass and produce copious numbers of spores during their growth, which means that any subsequent handling of the biomass could release large concentrations into the air. Especially in confined spaces this could result in workers being exposed; the individual spores are less than 4 microns and therefore respirable, and they are known allergens, in agricultural industries being responsible for Farmer's Lung Disease and similar respiratory syndromes[18]. Consequently it is important that this is taken into consideration and suitable controls used during bulk handling of biomass fuels.
Other microbially derived metabolites may affect worker health following inhalation. Some bacteria give rise to endotoxin, a component of the cell walls of some bacteria that can cause short-term 'flu-like symptoms (inhalation fever) following intense exposure, and volatile chemicals may result from microbial growth (see also 3.4.5).

Personal exposure of workers to inhalable airborne fungi, bacteria, actinomycetes and endotoxin was measured at five Danish biofuel plants[19]. High exposure levels were found to endotoxin (median = 55 EU/$m^3$), thermophilic actinomycetes (median = 1.3x104 colony forming units (cfu)/$m^3$), total bacteria (median = 4.8x105 cells/$m^3$) and total fungi (median = 2.1x105 spores/$m^3$), representing the potential to cause respiratory disorders. Differences in exposure levels were seen between the plants and this may partly be due to differences of the process equipment, tasks and the biofuel handled, for example, endotoxin was found in higher concentrations at straw plants than at wood-chip plants, while the opposite was measured for Aspergillus fumigatus. Some tasks were associated with exposures to micro-organisms and endotoxins at much higher levels than the suggested occupational exposure limits. For example, people working with a straw shredder for at least 30 min during a working day were exposed to a median endotoxin exposure of 23,775 endotoxin units (EU)/$m^3$, which is more than 100 times an exposure limit of 200 EU/$m^3$ proposed for workplace endotoxin exposure by the Dutch standards committee. Storage conditions, not surprisingly, affect the dustiness and microbial content. Wood chips stored for extended periods especially over summer were dustier and with higher microbial content, as was any material taken from the centre of stored piles[20]. Animal studies have demonstrated lung inflammatory response to exposure to biofuel plant dust, especially straw dust[21]. Bacterial endotoxins have been found in significant numbers in various

---

*[14] US Biomass Research & Development Initiative. National Biofuels Action Plan.*
*[15] Kuang X, Shankar TJ, Sokhansanji S, Lim CJ, Bi XT, Melin S. Effect of head space and oxygen level on off-gas emissions from wood pellets in storage. Annals of Occupational Hygiene. 2009; 53: 807-813*
*[16] Cohn CA, Lemieux CL, Long AS, Kystol J. et al. Physical-chemical and microbiological characterization, and mutagenic activity of airborne PM sampled in a biomass-fueled electrical production facility. Environ. Mol. Mutagen. 2010 [E-published ahead of print]*
*[17] Pollard SJ, Smith R, Longhurst PJ, Eduljee GH, Hall, D. Recent developments in the application of risk analysis to waste technologies. Environment International. 2006; 32: 1010*
*[18] Lacey J and Crook B, Fungal and actinomycete spores as pollutants of the work place and occupational allergens. Ann Occup Hygiene 1988;32: 515 – 533.*
*[19] Madsen AM. Exposure to airborne microbial components in Autumn and Spring during work at Danish biofuel plants. Ann. Occup. Hyg 2006; 50: 821–831.*
*[20] Sebastian A, Madsen AM, Mårtensson L, Pomorska D, Larsson L. Assessment of microbial exposure risks from handling of biofuel wood chips and straw - effect of outdoor storage. Ann Agric Environ Med 2006; 13: 139–145*
*[21] Madsen AM, Saber AT, Nordly P, Sharma AK, Wallin H, Vogel U. Inflammation but no DNA (deoxyribonucleic acid) damage in mice exposed to airborne dust from a biofuel plant. Scand J Work Environ Health 2008; 34: 278 - 287*

size fractions of dust in biofuel plants[22] and sub-cellular components of fungi and bacteria, potentially capable of triggering human immunological response, have been found in sub-micron ($PM_1$) sized dust in biofuel plants[23]. In storage, if there is sufficient moisture content, there is the potential for microbial colonisation. This can lead to a composting process in which temperature in the material is raised by microbial activity and preferentially leads to the growth of thermophilic actinomycete bacteria and fungi such as Aspergillus fumigatus, both of which are recognised respiratory sensitisers. Therefore, subsequent mechanical handling of the material to transfer it into the combustion process could potentially expose workers to large concentrations of microbial contaminants, or their by-products such as endotoxin, if made airborne.

There are no workplace exposure limits for micro-organisms, but they are classified under the Control of Substances Hazardous to Health Regulations 2002 (COSHH) as 'substances hazardous to health' and therefore exposure must be controlled. Arguably, based on the above, they are known allergens which COSHH requires control to be to 'as low as reasonably practicable'.

Wood dust

Softwood dust is known to cause, rhinitis, and occupational asthma. It is identified as a substance hazardous to health under COSHH and has a WEL of 5mg/m3 and so exposure should be reduced as far as reasonably practicable. Hardwood dust has the same WEL and is also known to be carcinogenic.

Poultry litter

Poultry litter presents a serious health threat to workers exposed to it on a regular basis. It can cause harm by various mechanisms, including allergic reaction and direct irritancy. Continued exposure to poultry dust is considered likely to cause asthma, rhinitis and eczema. Poultry dust is a complex mixture of organic and inorganic substances derived from bedding, feed, additives, faeces and feathers etc. as well as microbial and invertebrate contaminants such as mites. The dust contains asthmagens, pathogens, endotoxins and fungal spores.

The constituents of poultry dust and potential levels of exposure resulting from continuous processing provide strong evidence of a health risk.

Straw

Dust generated by handling straw is equally likely to be contaminated by the spores of microorganisms. Although being inherently less moist than many other biomass fuels, if harvested or stored damp, these spores will grow on straw and potentially cause similar acute and chronic respiratory problems.

Asphyxiating atmospheres

Emissions from biomass fuels, including wood pellets, during the storage and transportation can have potential health impacts. One recent study[15] in which head space above wood chips stored in a sealed container was analysed, showed the potential for significant emissions of carbon dioxide, carbon monoxide and methane (dependent on oxygen levels) and suggesting potential problems during post storage handling. Significant potential hazards exist during transportation of wood pellets. Although only stored in ships' holds for 37-66 hours, headspaces above wood pellet cargoes were frequently completely oxygen depleted, and one third had carbon dioxide

---

[22] *Madsen AM, Nielsen SH. Airborne endotoxin associated with particles of different sizes and affected by water content in handled straw. Int J Hyg Environ Health. 2010 Mar 31. [Epub ahead of print]*

[23] *Madsen AM, Schlünssen V, Olsen T, Sigsgaard T, Avci H. Airborne fungal and bacterial components in PM1 dust from biofuel plants. Ann Occup Hyg. 2009; 53:749-757*

levels above the immediately life-threatening level of 6%[24]. Where bulk biomass is imported, dock related hazards such as oxygen depletion in containers is a known problem. Several incidents on ships have occurred, with deaths in 2002 and 2006 after personnel entered cargo holds. Wood pellets for boilers are normally stored in a large sealed hopper/tank that is either fitted with a screw feeder (auger) connected to the boiler, or the hopper/tank is mounted over the boiler for gravity feeding. Where the ventilation of large volumes of fuel is low, or in the confined spaces of a fuel store, a hazardous and potentially lethal atmosphere of depleted oxygen and/or increased carbon monoxide can be generated, due to the enclosed nature of these hoppers/tanks. This is caused by the oxidation of the pellets. In the UK in 2012 a fatal accident occurred where a home owner entered a bulk wood pellet storage hopper/tank and was overcome by carbon monoxide (CO) gas. There have been other carbon monoxide fatalities during the bulk transportation and storage of wood pellets. In 2008 two people were killed in Finland when doing work related to the storage of wood pellets in a silo[25,26]. Also excess carbon dioxide could be produced if water is used to douse a fire.

Chemical/toxic hazards

During combustion, the biomass first loses its moisture then as the dried particle heats up, volatile gases including hydrocarbons, carbon monoxide and methane are released, which contribute about 70% of the heating value of the biomass[27]. Finally, char oxidises and ash remains.
Proper design of the facility matched to the specific fuel type and control of moisture levels is important to guarantee adequate combustion quality and low emissions. Emissions caused by incomplete combustion usually result from poor mixing of combustion air and fuel in the combustion chamber which causes local fuel-rich combustion zones, lack of available oxygen, too low combustion temperatures, or too short residence times. However, it is well developed and widely used technology and new boiler geometries and combustion concepts have been developed that result in significantly lower emissions. Examples of such developments are reburning of fuel, air staging, air preheating, radiation shields, advanced combustion control systems, application of novel materials, etc.[30]. Thus, in order to meet stringent environmental emissions limits the potential for occupational exposure is limited during normal operation. Confounding this however is the combustion of novel alternative fuels and any drive to reduce costs, also the development of smaller scale facilities, as they need simple and affordable solutions. Although large installations are more economically equipped with flue gas cleaning, small-scale applications that are based on natural draft and operated batchwise (such as wood stoves and wood log boilers) may release high levels of emissions from incomplete combustion. Gaseous (especially NOX) and particulate emissions are a potential problem for biomass fuels rich in nitrogen and ash, such as waste wood and energy crops. Corrosion within boilers is a potential problem exacerbated by some high chlorine content herbaceous crops, when alkali chlorides and ultimately HCl in the gas phase condense onto surfaces.

Ammonia is given off by chicken litter and when it is stored in large quantities, in an enclosed space, potentially hazardous concentrations can be reached, either as a gas or as a vapour, when humidity is high. Gaseous ammonia is lighter than air and the vapour is heavier. Ammonia interacts immediately upon contact with available moisture in the skin, eyes, oral cavity, respiratory tract, and particularly mucous surfaces to form the very caustic ammonium

*[24] Svedberg U, Petrini C, Johanson G. Oxygen depletion and formation of toxic gases following sea transportation of logs and wood chips. Ann. Occup. Hyg. 2009; 53: 779–787*
*[25] Wood pellet association of Canada - Review of Off-gassing from Wood Pellets - A Canadian Perspective - Staffan Melin, Research Director, February 2010*
*[26] Bulletin 524 -05/07 – Wood Pellets – Combustion hazards/Carbon monoxide Emissions – Worldwide – article produced by Dr J H Burgoynes & Partners.*
[27] *(IEA Bioenergy Biomass co-firing and combustion brochure, http://www.ieabcc.nl/ 2010)*

hydroxide. Ammonium hydroxide causes the necrosis of tissues through disruption of cell membrane lipids (saponification) leading to cellular destruction. As cell proteins break down, water is extracted, resulting in an inflammatory response that causes further damage.
Low molecular weight aldehydes, such as n-hexanal, have been identified as a major component in emissions from stored wood pellets, as has carbon monoxide[28].
Some flue gas cleaning methods used to reduce particulate emissions in large scale systems involve the introduction of reactants such as lime, which is then collected in the ash stream. The resulting ash constitutes a hazardous material which can cause harm when dust is inhaled and on direct contact. Contact with eyes is of particular concern.

Stored animal wastes including poultry litter could also generate hydrogen sulphide as a result of bacterial activity. Exposure to high (around 1000ppm) hydrogen sulphide can cause almost instantaneous loss of consciousness (referred to as 'knock-down'), suppression of breathing and, potentially, death.

## 3.2 BIOMASS FUELS - OPERATIONAL CHALLENGES

A number of hazards, which can arise during operation, are outlined in the following sections.

### 3.2.1 Dusty fuel

Small dust particles can cause:

- Risk of fouling in the boiler-house and around fuel handling station;
- Risk of fire and explosion in boiler, ducts and flue gas treatment;

### 3.2.2 Wet fuel

Wetter fuels:

- Can cause overloads to occur in fuel receiving station and excessive stress on conveyors;
- Are responsible for reduced boiler capacity;
- Reduced efficiency and incomplete combustion.

As outlined previously, moisture content in biomass fuels is a major issue. Energy density for biomass, or CV, is heavily affected by moisture content. For wood pellets below 10% moisture (as stipulated by the British BioGen code of good practice[29]), the energy density is widely accepted to be around 16.8 GJ per tonne [8].

Moisture content in wood chips can vary from 10% (dry chips) to 50 % (green chips). Fig 7 shows that the energy density of wood chips halves as the moisture content increases from 10% to 50%. In some cases one tonne of pellets can contain twice as much energy as one tonne of wood chips.

High moisture content in a fuel adversely affects the efficiency of the combustion system. The moisture content of biomasses varies significantly. Fresh wood can be over 50wt% moisture whereas the moisture content of waste wood or straw is often below 15wt%.

---

[28] *Svedberg URA, Högberg H, Högberg J, Galle B. Emission of hexanal and carbon monoxide from storage of wood pellets, a potential occupational and domestic health hazard. Ann. Occup. Hyg., 2004; 48: 339–349*
[29] *British BioGen Good practice Document - http://www.woodfuelwales.org.uk/biomass/Technology/cogpp.pdf*

Natural drying can be effective in reducing moisture content (particularly of freshly cut timber); however, it is dependent to some extent on environmental conditions. If woodchips are stored in a pile, the temperature in the pile will increase due to biological degradation effects. The heat produced by the micro-organisms causes a natural convection process. Consequently, the fuel in the centre dries whereas the vapour will pass to the cooler zones of the pile.

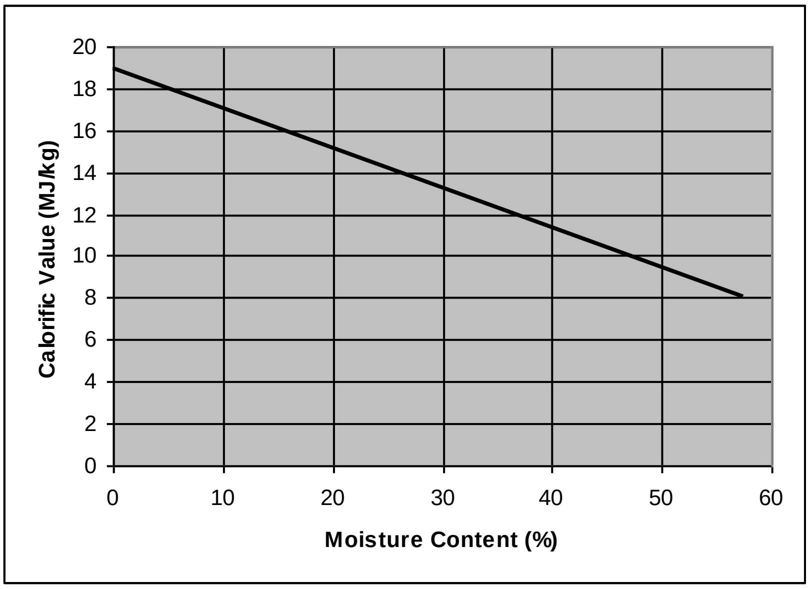



**Fig 7** Energy Content of Wood as a Function of Moisture [11]

For the production of pellets or briquettes, the moisture content of the raw material must be about 15wt%. The large scale drying of biomass has not been undertaken in the UK as yet.

The Bulk density of the material is also affected by moisture content. The higher the bulk density, the more mass of fuel exists in a given volume. However, moisture content will affect bulk density as each particle has a greater mass but does not occupy more space. This is an important point because fuels with higher moisture contents will have greater masses and, therefore, have lower bulk densities. With higher moisture content comes lower CV and therefore the volume of fuel required for a given amount of heat will be much larger.

Again as outlined previously, if fuel remains wet for long periods it will begin to compost and can produce fungal spores, which can be hazardous to health.

### 3.2.3 Dry fuel

Fuel, which is too dry, can also cause problems, including:

- Hazard of overheating and damaging the grate
- Ash melting and/or vitrification can cause bed and refractory agglomeration.
- Sand agglomeration (applicable mainly in larger applications). Recirculation may be needed to control the oxygen level and regulate the combustion.

### 3.2.4 Ash Content

Wood without bark exhibits the lowest ash content, whereas agricultural biofuels typically have high ash content. As mentioned previously the ash content in straw, for example, is over 4 times greater than in woodchips.

Using fuels with low ash fusion temperatures increases the risk of ash slagging in the grate. Fusion slags disturb the combustion process by altering primary airflows; subsequent overheating and corrosion can adversely affect the grate performance.

These problems can be addressed by cooling the grate, re-circulating the fumes by inserting mechanical automatic cleaning (self-cleaning screens) systems or by using calcium additives in the fuel.

Ash can be divided into two categories:

- Bottom ash - A considerable amount of the ash gathers under the boiler grate and it is channelled into a storage tank. It has a mass density of 1.3 t/m3.

- Fly ash - The ash that comes from flue gas cleaning, which can be further divided into:

  - Cyclone light ash;

  - Fine ash particles (normally from electrostatic and bag filters).

As outlined above, mineral matter, e.g. silica, contained within the biomass fuel will be released as ash. Depending on the type of combustion system and the nature of the biomass fuel, some unburned carbon may also be contained in the ash.

Typical ash contents for dry materials are approximately 3% for wood and 8% for bark, with 70% of this ash coming from bottom and second pass ash and 30% from fly ash. It should be noted that approximately 10% of the ash usually remains unburned

For larger biomass boiler systems electrostatic precipitators (ESPs) and bag filters are utilised for collecting dry dusts.

# 4 BIOMASS BOILER REGULATIONS

Domestic boilers are best suited to low density and rural areas with space to accommodate boilers, easier access to biomass supplies, and where Smokeless Zone Regulations do not apply. Amongst other considerations, such as fuel selection, boiler selection will be dependent on a variety of issues, including:

- Flue - The vent material must be specifically designed for wood fuel appliances and there must be sufficient air movement for proper operation of the stove. Chimneys can be fitted with a lined flue.

- Regulations - The installation must comply with all safety and building regulations (see Part J of the Building Regulations).

- Smokeless zone - Wood can only be burnt on exempted appliances, under the Clean Air Act. This mainly applies to domestic appliances.

- Planning - If the building is listed or in an area of outstanding natural beauty (AONB), then a flue may not be allowed.

There are currently around 140 models of small and medium sized biomass stoves/boilers which meet the requirements of the Clean Air Act 1993 and have been exempt for use in UK smoke control areas.

Larger biomass boilers (heat input greater than 20 MW) are regulated under the Integrated Pollution Prevention and Control (IPPC) system regulated by the Environment Agency.

## 4.1 EU DIRECTIVES

Directive 97/23/EC on the approximation of the laws of the Member States concerning pressure equipment.

This directive concerns the manufacture of items such as pressurised storage containers, heat exchangers, steam generators, boilers, industrial piping, safety devices and pressure accessories. It came into force on 29 November 1999. From that date until 28 May 2002 manufacturers had a choice between applying the pressure equipment directive or continuing with the application of their existing national standards. On 29 May 2002 the Pressure Equipment Directive became obligatory throughout the European Union. Boiler manufacturers in Europe must now comply with this standard. Both Denmark and Sweden have their own boiler codes which both comply with the Pressure Equipment Directive (97/23/EC). [38]

Directive 2009/28/EC on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. This directive requires Member States tol ensure that certification schemes or equivalent qualification schemes become or are available by 31 December 2012 for installers of small-scale biomass boilers and stoves, solar photovoltaic and solar thermal systems, shallow geothermal systems and heat pumps. Those schemes may take into account existing schemes and structures as appropriate, and shall be based on the criteria laid down in Annex IV. Each Member State shall recognise certification awarded by other Member States in accordance with those criteria.
Directive 2000/76/EC on the incineration of Waste.

This directive sets stringent emission limits and monitoring requirements on plants where waste is used as a fuel. This will have an effect on the viability of plants that burn fuel such as poultry litter.

## 4.2 APPLICABLE UK REGULATIONS

Typically, biomass systems require delivery by road transport of the solid fuel and storage in a dedicated facility. Sometimes, this facility may be underground (a confined space) or above ground (requiring work at height), and the method of transferring the fuel from the delivery vehicle to fuel store may present other health and safety concerns (e.g. airborne dust, manual handling).

The following may be relevant:

- Confined Spaces Regulations 1997;
- Work at Height Regulations 2005;
- HSE occupational health and safety advice on wood dust;
- Pressure Systems Safety Regulations 2000;
- Provision and Use of Work Equipment Regulations (PUWER)1998;
- Lifting Operations and Lifting Equipment Regulations (LOLER)1998;
- Manual Handling Operations 1992.

Once delivered, the greatest risk associated with biomass systems is fire. This is largely addressed via the Building Regulations 2000 (Approved Document J – Combustion Appliances and Fuel Storage Systems).

Also relevant are the:

- Regulatory Reform (Fire Safety) Order 2005
- Electricity at Work Regulations 1989.

### 4.3 BIOMASS BOILER STANDARDS

Specific biomass heater/boiler standards include:

- BS EN 13240:2001+A2:2004 - Room heaters fired by solid fuel. Requirements and test methods

- BS EN 14785:2006 - Residential space heating appliances fired by wood pellets. Requirements and test methods. This can be used for boilers and roomheaters in and out of living space.

- BS EN 12809:2001+A1:2004 - Residential independent boilers fired by solid fuel. Nominal heat output up to 50 kW Requirements and test methods

- BS EN 303-5:1999 heating boilers - Part 5: Heating boilers for solid fuels, hand and automatically fired, nominal heat output of up to 300kW. Terminology, requirements, testing and marking.

Other bodies have also produced a number of good practice guidelines. For example, British Biogen - a Trade Association to the UK Bioenergy Industry has produced Good Practice for Biofuel pellets and pellet burning (appliances <25kW). [36]

## 5 BIOMASS BOILERS

Biomass is theoretically applicable to any size building requiring heat, however it is more applicable to lower density housing areas due to fuel supply and storage issues. Table 4 outlines typical boiler technologies classified on the basis of use and capacity. For an individual room in a house a stove can be installed, although this would normally only provide space heating. These applications could use logs, wood chips or pellets and would usually provide a heat demand of between 2-12 kW.

**Table 4.** Boiler typologies classified on the basis of use and capacity

| Range of use | Capacity | Type of boilers |
|---|---|---|
| Domestic boilers | 15 – 40 $kW_{th}$ | Thermal fireplaces<br>Wood thermal stoves<br>Pellets boilers<br>Upside down flame boilers |
| Boilers for large houses | 40 – 400 $kW_{th}$ | Upside down flame boilers<br>Fixed grate<br>Pellets boilers |
| District heating boilers | 0.4 – 20 $MW_{th}$ | Moving grate<br>Stoker burner<br>Bubbling fluidised bed (>15MW) |

| | | |
|---|---|---|
| Industrial boilers for power and/or heat production | 1 – 80 $MW_{th}$ | Moving grate<br>Stoker burner<br>Bubbling fluidised bed (BFB)<br>Circulate fluidising bed (CFB)<br>Gasification |
| | 80 – 300 $MW_{th}$ | Stoker burner<br>Bubbling fluidised bed (BFB) |

Various biomass boiler typologies are discussed in detail in Annex X.

## 5.1 BIOMASS BOILER HAZARDS

### 5.1.1 Installation, Operation, Maintenance, Servicing, Inspection & Waste Hazards

Boiler systems are designed for safety and efficiency. The key to safe boiler operation is the operator. History has shown that without proper operation and maintenance, boiler conditions and safety deteriorate, causing potential hazards due to neglect and misunderstanding.

An important point of difference between biomass boilers and traditional gas or oil boilers is thermal inertia. Biomass boilers cannot be extinguished immediately due to fuel continuing to burn which could cause a problem if a rapid shut down is required. This problem is greater with larger boilers and is a function of the fuel source and output required, for example wood chip boilers are typically larger than pellet boilers for similar outputs and thus have a larger thermal inertia. This problem can be addressed by installing a buffer vessel, en emergency heat dump or cooing coils in the design[9].

Correct installation, commissioning, operating system, maintenance, servicing and inspection regime is a prerequisite for safety with all boilers. There are aspects of the operating system, maintenance and servicing that are specifically important for the safe operation of biomass boiler systems.

### 5.1.2 Installation and Commissioning

The safety and efficiency of an appliance varies according to type and design[30]. When a new or replacement system (including the appliance) is installed it is important to verify that it is functioning safely and efficiently. It is particularly important that biomass boilers should never be operated in an environment subjected to a negative pressure unless it is directly vented. Failure to do so can result in excessive CO levels.

### 5.1.3 Boiler Operation hazards

Personnel (operators, commissioning and maintenance engineers) could be subject to health hazards associated with:

- Burning incorrect/poor quality fuels, e.g. some waste woods, laminates, household waste, etc;
- Carbon monoxide issues;
- Dust & ash inhalation/ingestion.

[30] *Energy Efficiency Best Practice in Housing Domestic heating: solid fuel systems. Guidance for installers and specifiers. CE47 © Energy Saving Trust. March 2005.*

Combustible gas release/ incomplete combustion

In the case of manual feed boilers, combustible gas release from the loading feedstock hopper should be avoided at all times. Boilers are provided with fans, which can create a forced draught by either sucking air in or forcing air in. A potential risk associated with fans is the method by which they are controlled. Pulse width modulation (PWM) can be used as a way to control the fan speed. If the method for determining the duty cycle is not tightly controlled fan speed can become indeterminate and lead to uncontrolled boiler output temperature.

In the combustion chamber and flue system, an explosion could occur if combustion is incomplete and gives rise to gases (such as CO and $H_2$), which might be caused by a malfunction or operator misuse (e.g. overfeeding a low fire bed or the intentional/ accidental cut-off of mains electrical power during high-load operation).

This can be avoided by not allowing significant quantities of uncombusted fuel to build up in the retort/combustion chamber, following cleaning guidance and not switching off the electrical supply to the boiler without first having removed the load and allowed the boiler to burn residual fuel on the grate. Other ways of avoiding the risk of explosive gases from incomplete combustion can be realised through aspects of the system design – typically already implemented in systems on the market today. These include:

- Building into the design a mechanism by which the rate of release and build-up of volatile matter is matched by a suitable volumetric flow-rate of air, to ensure complete combustion can occur safely.

- Ensuring the ratio of secondary air (above the bed) to primary air (below the bed) is appropriate for biomass fuel firing. Ensuring the right flow-rate and pressure of secondary air will ensure emissions of carbon monoxide and smoke are minimised and combustion is efficient. Detecting carbon monoxide can be a way of identifying poor combustion conditions.

In the case of automatically fed boilers, there can be problems with the use of a secondary air fan on side feed boilers. If the fan goes to full output then there is the potential for runaway heating until fuel is spent and thus excessively high boiler output temperature.

Similarly if the $O_2$ (lambda) sensor fails, the feedback element of the control loop becomes inaccurate. This could lead to increase or reduction of fan speed or fuel feed, in turn leading to incomplete combustion of fuel, and dangerous concentrations of exhaust gas being expelled.

Automatic boiler fuel feed systems should be provided with specific safety devices, which guard against backfire. The failure of any temperature sensor in such a safety system could lead to non-response of thermo-mechanical valve when required. In turn this could lead to system overheat or alternatively premature extinguishing. The use of some mechanical valves in other safety systems can be hindered by clogging of fine dusts.

Ash Accumulation

Fly-ash is airborne, light ash particles which can accumulate around the heat exchangers, at the top of the combustion chamber and in the flue. This ash is captured by special equipment in the plant unit but may also need to be periodically cleaned off manually. If the quantity and pressure of air added above the grate is not correct, combustion may not be complete and carbon monoxide may be given off.

Ash build up in some boilers can have adverse effects on the boiler bed/gate and other components. Fouling can also occur which causes problems with fuel feed and thus boiler temperatures, efficiencies and emissions.

Problems exist in some larger biomass boiler/heating systems where electrostatic precipitators (ESPs) are used to collect dry dust. Concerns over unburned carbon carryover, and the potential fire hazard that can result, usually dictate that a precipitator be used for particulate control in some particular stoker applications. Fires in the ESPs and hoppers have been observed to cause significant damage to the internal parts of the boiler. In wood waste ESPs the fires tend to start on the collector plates and in the ESP hoppers. However, fly ash fires may also occur.[31] Ash handling systems should also be designed so as to remove the fly ash continuously preventing build up, minimizing the amount of solid fuel in the ESP and thus reducing any possibility of fire. Good collection hopper design including:

(i) Good hopper insulation;
(ii) Appropriate hopper wall vibrators; and
(iii) Maximized hopper exit dimensions, will reduce the likelihood of hopper plugging and any subsequent hopper fire and/or explosion

In controlling fires and explosions in ESPs, removing the fuel source is the most appropriate solution. Precipitator fires can be avoided using the above techniques, but also by ensuring optimum boiler combustion, ensuring a reduced level of fly ash and thus a reduction in solid fuel which could feed a fire in the hopper.[25]

Fuel

Fuel related accidents usually occur when the operator fails to purge combustible gases from the fire box before ignition is attempted, e.g. in some cases, it may be possible to override safety devices with jumper wires to restart the boiler leading to unintended ignition of unburned fuel/ gases in the fire box.

### 5.1.4 Servicing

Fuel transfer mechanisms for chips and pellets generate sufficient force to cause serious injuries. All mechanical transfer mechanisms must be provided with a means of isolating from the power supply to enable safe servicing and maintenance. There can be an isolator for each drive or an isolator which covers all drives. Isolators should be easily accessible and located near to the drive. Transfer mechanisms are usually powered by electric motors and controlled automatically by the boiler control system. It should be clear how to isolate each drive. It may be beneficial to enable isolation to feed mechanism drives without isolating the boiler as this could cause significant disruption to operation and additional work which would therefore discourage safe isolation. Instructions regarding isolation of the various parts of the system must be included in the operating instructions and warnings should be shown where necessary requiring isolation before accessing powered moving parts.

The chimney should be inspected and cleaned by an Approved Chimney Sweep.

[31] *'Particulate Control for Biomass fired Boilers.' R A. Mastropietro. Electrostatic Precipitators. Hamon Research-Cottrell, Inc*

### 5.1.5 Inspection

Both external and internal inspections should be performed by a certified boiler inspector annually. The inspector should be familiar with biomass boilers to ensure that any problems specific to biomass boilers, such as chemical corrosion is detected.

## 5.2 Waste

Waste from a biomass boiler is either ash or gaseous emissions from the combustion process. Of the gaseous emissions, hydrogen chloride, carbon monoxide and to a less a degree, sulphur dioxide are the main harmful components emitted. The other hazardous compounds and elements form ash. As the more hazardous of these tend to be more volatile, they generally precipitate on fly ash particles or on the even smaller aerosols. Therefore, these smaller particles tend to have the most hazardous constituents and also the aerosols, by virtue of their size alone have serious health effects for humans when inhaled.

Ash composition is determined by the chemical composition of the fuel and the combustion. Fly ash and aerosols are also the most difficult to capture. They are suspended in the flue gases and unless actively removed using appropriate techniques, most are emitted to the atmosphere.

For small scale, relatively 'clean' combustion systems such as non-industrial wood burning boilers, fly ash collection is relatively simple and only partially effective. As system size increases, to satisfy emission requirements, fly ash and aerosol collection systems must be more sophisticated. Generally, the smaller the particles, the more significant their health effects and also the more sophisticated (and therefore more expensive) the equipment required to remove them.

An efficient combustion system together with sophisticated particulate collection therefore has the effect of refining harmful ash constituents, leaving the majority of the ash (grate ash) benign and concentrating the more harmful particulates in the fly ash. From and health and safety perspective, it means having to deal with more hazardous substances.

The amount of chlorine present influences the amount of hydrogen chloride in the combustion gas, some of which will be captured in the ash and the rest will be emitted in the flue gas. This has potential consequences of acid rain and also influences the production of dioxins and furans, which are serious health hazards. Both of these may also be considered as environment health issues. The presence of hydrogen chloride also causes corrosion in boilers and flues. This can influence the safety-related integrity of pressurised parts of boilers, such as heat exchangers. Similarly, the presence of sulphur in flue gases can increase corrosion rates significantly.

Biomass fuels also contain significant amounts of silicon, calcium, magnesium, sodium and phosphorus, which account for the main ash forming constituents of the fuel. Higher concentrations of these elements mean more ash production, which typically means higher dust emissions and also requires ash control/collection equipment with higher capacities. The concentrations of these ash forming elements influence the sintering, softening and melting temperatures of the ash produced.

Biomass fuels broadly fall into one of three categories regarding ash fusion characteristics;-

- High silica/high potassium/low calcium ashes, with low fusion temperatures, including many agricultural residues - including straw

- Low silica/low potassium/high calcium ashes, with high fusion temperatures - including most woody materials

- High calcium/high phosphorus ashes, with low fusion temperatures, including most manures, poultry litters and animal wastes

Calcium and magnesium tend to increase melting temperature whereas potassium and sodium reduce it. Low ash melting temperature increases the tendency for the build-up of slag on grates and ash deposits on combustion chambers and heat exchangers. Combustion equipment must therefore be designed to take account of the ash melting temperature, in particular, the temperature at the grate and combustion chamber/heat exchanger surfaces should be kept below ash softening and sintering temperatures. The accumulation of slag and ash deposits does not directly influence safety but it will lead to diminished performance and require increased intervention, which is likely to have safety-related consequences.

Higher concentrations of potassium and sodium, as well as reducing ash melting temperatures, also significantly increase corrosion rates. In addition to this, these metals condense in cooling flue gases to form sub micron fly ash particles, which are difficult to filter and present environmental and health risks.

Heavy metals also occur in biomass fuels. Of these, cadmium, zinc and lead are the most significant. These metals vaporise during combustion and condense on cooling, either on flue surfaces or on fly ash particles and so the majority of heavy metal content of biomass fuels end up in the ash with fly ash containing the highest concentrations. A smaller proportion of the heavy metals remain gaseous or as aerosols (i.e. emitted by the flue), although this can be higher for mercury due to its volatility.

# 6 CONCLUSIONS

There are a significant variety of biomass fuels currently available in the UK. The hazards from biomass combustion are not new, but arise from both establishing on a commercial scale methods that have previously been used at a domestic level and the utilisation common material such as poultry litter as novel fuel sources. This scale-up of technology provides challenges to achieve its goals and, having achieved them, there remain questions as to whether this creates potential health hazards through occupational exposure. In some cases large scale use of the technology has in-built controls to reduce emissions of environmental pollutants and therefore also reduces potential exposures in the workplace. However, problems of occupational exposure could exist in the ‘half way house’ medium sized facilities, such as community scale biomass energy generators that may have only a limited amount of dedicated maintenance support. Such facilities are likely to remain the focus of occupational health and safety attention as these initiatives develop and become more commonplace.

As is the case with many areas of the industrial workplace, significant potential exposure to harmful substances may come not during normal operational conditions, but during maintenance, clean up and repair, where exposure controls may be less easy to apply. Again this may be more likely to occur at the community scale or with facilities. In particular, those workers tasked with basic clean up responsibilities are those who may also be less knowledgeable about the whole process. Unless appropriate protocols and control measures are in place, with which these workers are familiar, then such staff are particularly vulnerable to any chemical or biological hazards within the equipment that they clean.

Another area of potential exposure to chemical and biological hazards is prior to the use of biomass as a fuel, where bulk storage may result in emissions of chemical volatiles, of asphyxiant gases, or of potentially allergenic bioaerosols following biodeterioration. Although some published data exist, some of it related to other industrial processes that use similar feedstock material (e.g. composting), this is an area that will require on-going assessment, to ensure that safe storage and transportation conditions are maintained for these bulk materials.

Many of the hazards can largely be eliminated by good fuel store design, or mitigated by selecting a good quality fuel source, which is compatible with the heating/boiler system in place. It should be noted, however, that biomass fuels are not an exact science – there can be considerable variation, in terms of calorific value, moisture content, the amount of foreign bodies and ash content, even within the same batch.

It is also important that biomass boilers should be installed by a qualified engineer. In order to ensure that the biomass boiler/heating system is functioning correctly in service, it should also be regularly maintained by qualified competent engineers.

Staff training in fuel delivery arrangements, operational practices and installation/ maintenance/servicing and inspection of biomass boilers are all significantly different to ‘conventional’ gas, oil and electric heating. It is therefore essential for staff managing the building to receive training in the operation of the biomass boilers.

# Annex 1 Types of Biomass Boilers

## 1. MANUAL FEED BOILERS

Manual feed boilers range in size from 20kW to 500kW. They are particularly flexible and allow batch fuel feed operations, making them suitable for light industrial and farm use. [32]

### Feedstock

Manual feed boilers tend to have less sophisticated feed mechanisms and, therefore, generally require more seasoned biomass material (having a moisture content between 20 and 25%), for example, bales of straw/ miscanthus, or with large billets of wood, logs, and other off-cuts

### Feed Mechanism and Associated Risks

Manual feed boilers only require manual filling the combustion chamber or hopper each day, although the exact frequency depends on the site heating profile.

Small boilers are provided with a front door to the loading hopper; however a door located on the top is preferred for larger boilers, as the hopper can be completely filled.

Combustible gas release from the loading feedstock hopper should be avoided at all times. Boilers are provided with fans, which can create a forced draught by either sucking air in or forcing air in. When the loading hopper door is opened, normally the fan, which blows air into the boiler, would be automatically shut off; however where fans suck the air in, the fan speed must be increased in order to avoid any gas release. A potential risk associated with fans is the method by which they are controlled. Pulse width modulation (PWM) can be used as a way to control the fan speed. If the method for determining the duty cycle is not tightly controlled fan speed can become indeterminate and lead to uncontrolled boiler output temperature.

A thermal relief valve should also be provided in order to assure a vent to the system in case the water temperature reaches 95˚C. If the water temperature exceeds 95°C, the electricity supply (if any) to the burner would be shut off and the valve opened in order to gradually drain the water circuit until a normal temperature is reached.

### Ignition Mechanism

Modern manual feed boilers use the principle of low draught or upside down flame. Based on this principle, the flame emanates from beneath or beside the burner. A fan introduces the combustion air, which is directed in two air channels: primary air that allows upside-down burning of the wood, and pushes the wood gas into the second chamber, where, the secondary air flow burns it – see Fig 8. This type of burning (pyrolysis) greatly improves the efficiency of burning, up to 89% - 90%.

Larger boilers (25 to 40 kW) sometimes have a secondary heat exchanger that assures a constant hot water flow.

[32] *Impianti termici, ARSIA*

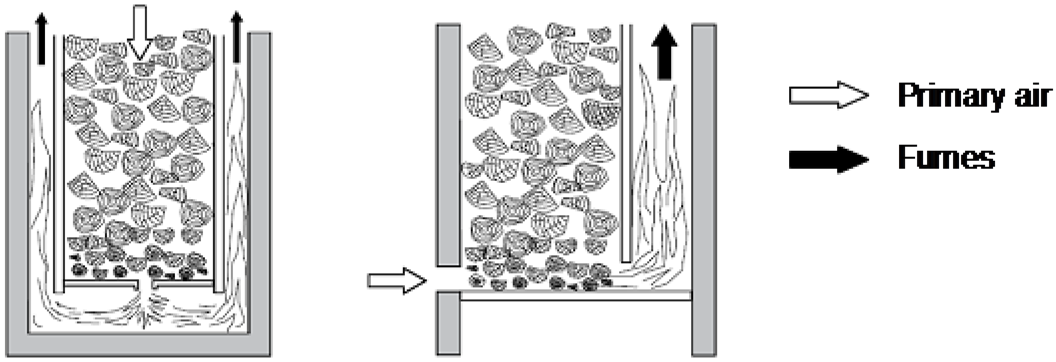



**Fig 8** Low draught or upside down flam boilers [35]

**Note:** An issue with lateral flame boilers is the likely formation of residual wood not completely burned near the burner. Additional primary air can be thus introduced through a grate. This additional air would be able to remove any ash produced.

## Heat Exchanger

Manual feed boilers usually incorporate a plate or 'shell in tube' heat exchanger. A vertical 'shell in tube' heat exchanger requires more space but such a design enables dust to be removed far more easily from the heat exchanger tubes. Spirals, located inside the tubes, slow down the fume release. These spirals are often connected to a mechanical device (auto or manual), which causes them to move vertically in order to facilitate the cleaning. Failure to clean tubes would compromise heat exchange. In cases where this mechanical device is automatically controlled, a boiler management system (BMU) would normally be used.

## Operating Instructions

All 3 phases of boiler combustion need to be set correctly:

(i) Start up phase - The required working temperature is not achieved during this stage, so a higher emission of unburned substances (CO and $C_nH_m$) will be evident.

(ii) Steady phase - The required working pressure is achieved due to the introduction of air, which allow to obtain a controlled shut down phase.

(iii) Shut down phase - In this phase, both the power and the temperature decrease, but the level of unburned gas can increase. Unlike the start up phase, during the final combustion phase an increase in CO from the gasification process can occur.

In manual feed boilers the amount of fuel fed into the boiler will directly affect the power and combustion setting. The primary air affects the amount of gas extracted from wood and thus thermal power; secondary air controls the oxidation of fuel gas.

Manual feed boilers may be grouped according to how the combustion and power outputs are set:

- Full load boilers - These boilers have non-adjustable power, with natural draught. Heat production mainly depends on air provided by chimney draught and the position of air nozzles.

- Adjustable power boilers - These boilers are equipped with a fan, which controls the amount of primary air, by varying the fan speed.

- Adjustable power and combustion boilers - The quality of combustion can be regulated through the quantity of air introduced by fans or the ratio between primary and secondary air. Some more modern boilers use drills to detect combustion temperature and the level of CO in exhaust fumes.

## Ancillary Devices

The hydraulic plant of boilers should be equipped with an anti-condensation device. This is a hydraulic link between delivery and suction, which allows the return temperature to remain above 60˚C. In this way fume condensation phenomena, which could cause corrosion and reduce the useful life of boiler, are minimised.

A circulatory pump is required and should be correctly sized and equipped with an inverter in order to regulate the number of rounds per minute. An oversized pump will consume additional power and would thus affect the overall boiler efficiency.

It should be noted that for domestic boilers, there are some key requirements for chimney design:

- It must have sufficient height - the temperature difference between flue gas and outside air provides the necessary updraft or 'pull' to expel the fumes.

- There should be no sharp bends or obstructions, which offer resistance to the flow.

- Air leakage must be minimised to prevent unnecessary cooling of the flue gases.

- Careful planning of the chimney termination is needed to avoid high pressure zones.

- All chimneys must have provision for sweeping.

There must also be an adequate air supply to solid fuel appliances in order to ensure complete combustion of the fuel and the correct functioning of the chimney. Incomplete combustion leads to increased levels of smoke and CO, which is a serious health hazard.

Extractor fans must not be installed in the same room as an open-flue appliance or the room in which the permanent vent is located. There are some exceptions to this rule, e.g. in large rooms where there is sufficient replacement air to avoid spillage of combustion gases (although a spillage test must be carried out).

It is essential for safe and efficient operation that solid fuel chimneys are regularly inspected and cleaned.

Solid fuel appliances must be sited on a hearth constructed of suitably robust materials. Its dimensions should be such that, in normal use, the building fabric and furnishings are prevented from catching fire.

### Summary – Manual Feed Boilers

Advantages:

- Simple and cost-effective solution where biomass material and labour are available at low cost and efficiency is not a prime consideration for the system;
- Robust designs mean lower (non-fuel) maintenance issues.

Disadvantages:

- The fuel must be fairly dry: preferably <25%;
- A high level of user input – often on a daily basis.

## 2. AUTOMATIC-FEED BOILERS

In this case the fuel is fed automatically into the boiler from the fuel store using mechanisms such as auger screw systems (see Fig 9). Automatic boilers burn wood chips, pellets, and mischanthus; however, as wood chips are less compact than pellets, they will require more hopper space than pellets between automatic top-ups. The different kinds of fuels used can be interchangeable, for instance boilers using chips can be also fed with pellets but not in all cases and for all fuels. Care should be taken in fuel selection.

A number of boilers which use automatic feeding of wood logs (Fig 10) are currently on the market [33] - they range in size from 24 to 45 kW.

In automatic feed boilers, the fuel burns in the combustion chamber, where a regulated flow of oxygen ensures a clean and efficient combustion process. The resulting hot gases then heat water in a heat exchanger which in turn feeds the hot water storage tank, or for smaller stoves, a back boiler.

[33] www.hobag.ch

**Fig 9** Wood chip auger screw

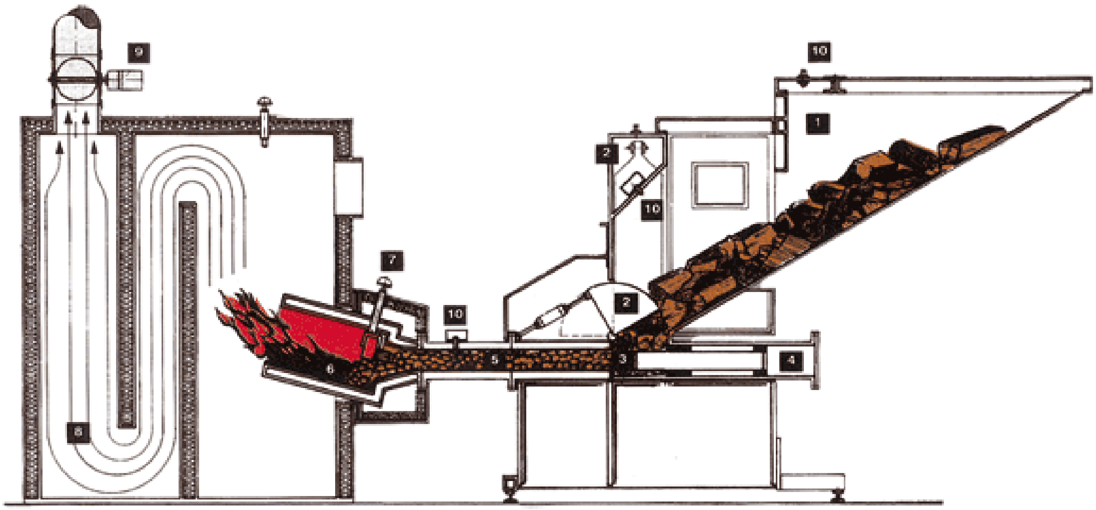


**Fig 10** Wood logs automatic-feed boiler [35]

### Plane Grate Systems

Plane grate systems tend to be most common in boilers in the 25-300kW range (up to 500kW on pellets), and can use both pellets and woodchips (however, a change of grate may be required in some models).

Plane grate biomass systems use either underfeed or side-feed combustion chambers. The main difference to the moving grate system is that the combustion bed is much smaller. The plane grate is widely used for the combustion of drier fuel, (e.g. joinery waste), good quality woodchip, and wood pellets.

Plane grate systems are suitable for fuel with moisture content below 35% mainly because the fuel is fed directly into the combustion chamber by the fuel feed mechanism, rather than being dried first as in the case of the inclined grate plants. Some plane grate plants can tolerate higher moisture contents if they have a ceramic-lined combustion chamber.

## Underfeed boilers

Typically underfeed boilers range in size from 10kW to 2.5 MW and use wood chips, and/or pellets.

In the case of the underfeed boiler, fuel is fed by auger into the base of an inverted cone. Primary air is supplied below the fuel and secondary air above. Underfeed stokers are usually supplied as part of a complete plant package. On larger units, the stoker may be situated within the combustion chamber of a shell-and-tube plant.

Ash is created on all sides of the combustion zone, and its removal from the combustion bed relies on simple displacement due to the emergence of new fuel in the centre of the combustor. The removal of ash from the bottom of the combustion chamber is either carried out manually or automatically (via an ash augur from the bottom of the combustion bed to an external ash bin).

The feedstock quality should be chosen to suit the combustion chamber features, e.g. if a boiler is designed for woodchips with 50% moisture content, using dried chips could cause excessive high temperature and damages to materials, in addition to ash fusion.

Underfeed boilers are best suited to woodchip fuels with low ash contents. Pellets can also be used, but bark and mischanthus should be avoided.

## Side-feed boilers

Typically side-feed boilers are normally greater than 25kW and use wood chips, and/or pellets.

In the case of side-feed grates, the grate is vibrated regularly to shake ash through holes within the grate. The grate is tipped periodically in order to allow for the removal of larger non-combustible items. In terms of their ability to tolerate moisture content in fuels, side-feed units offer an intermediate option between underfeed and moving grate systems. A typical side feed boiler is shown in the schematic in Fig 11.

There can be problems with the use of a secondary air fan on side feed boilers. If the fan goes to full output (i.e. 100% PWM duty cycle) then there is the potential for runaway heating until fuel is spent and thus excessively high boiler output temperature. Similarly if the $O_2$ (lambda) sensor fails, the feedback element of the control loop becomes inaccurate. This could lead to increase or reduction of fan speed or fuel feed, in turn leading to incomplete combustion of fuel, and dangerous concentrations of exhaust gas being expelled.

The main advantages of a plane grate system are:

- A smaller combustion area and less refractory material means that these types of plant have a smaller spatial footprint
- Commonly dual fuel plants, therefore providing flexibility of operation.
- They are cheaper than moving grate systems due to the simper design and exclusion of refractory material.

The main disadvantages of a plane grate system are:

- Due to the smaller combustion bed, the plant requires lower fuel moisture content - typically 20-35 %.

- Due to the smaller combustion bed and lower moisture content tolerances, these systems require consistently good quality fuel.

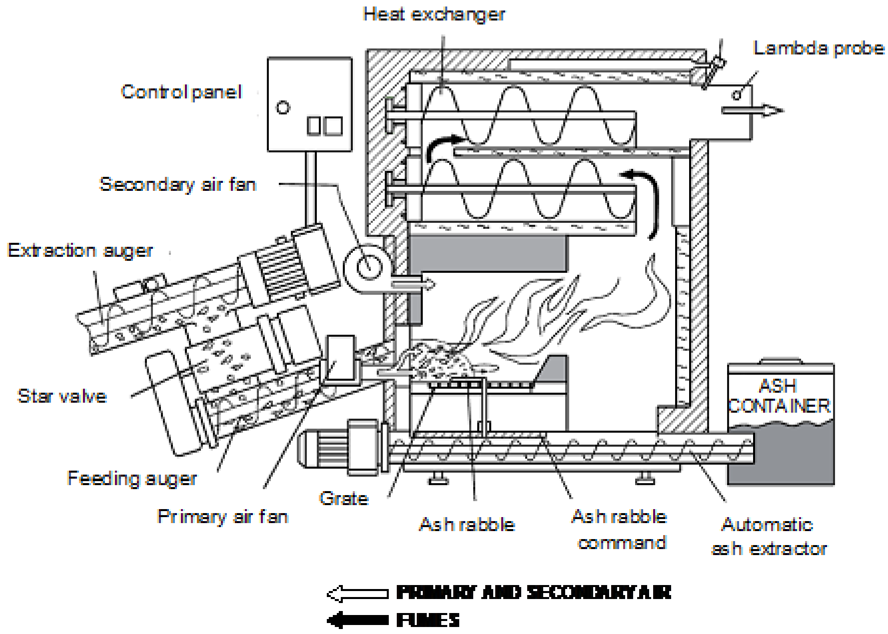



**Fig 11** Side-feed boiler with automatic ash remover [34]

## Moving Grate Systems

Moving grate systems are the most versatile (in terms of flexibility of fuel tolerance) but the large combustion space required and the additional equipment (e.g. hydraulics) involved often make them more expensive than other types.

Fuel is delivered onto a series of inclined, stepped or flat panels or a laminated roll grate. Flat panels move in a sequence so that the fuel travels slowly down the grate towards the far end of the combustion chamber. The fuel dries and then combusts as it moves down the grate (primary air is supplied under the grate). This sequenced combustion is one of the great strengths of the design: by fine tuning the grate speed, fuel feed and air supply, it is possible to burn a wide range of fuels of varying moisture content. The addition of a ceramic arch over the grate reflects heat back, encouraging drying and subsequent ignition, and thus permits the combustion of wet fuels – tolerating up to 60% moisture content.

Once the wood has combusted, the remaining ash falls off the lower end of the grate, and is removed mechanically into the ash pan or ash bin. Grates can be provided with a water cooling system in order to minimise ash fusion, which can disturb the combustion process and compromise the useful life of materials.
Moving grate plants are popular in Northern Europe and Scandinavia where unseasoned softwood is commonly used for fuel. Moving grate plants can use pellets or woodchips, although woodchips are used more commonly because of the capacity of the plants to burn wet

[34] www.heizomat.de

fuel. Moving flat panels are more effective for woodchips, pellets, bark, and sawdust in 15 kW to 20 MW boilers; laminated roll grates are mostly used for woodchips and pellets in smaller boilers, in the range 4 kW to 450 kW.

The main advantages of a moving grate system are:

- Wide tolerance of fuel type, moisture content (up to 60%), and particle size
- As a result of wide fuel tolerance, cheaper fuel may be procured, helping to offset higher capital cost
- Positive movement of fuel down grate avoids clinkering and blockages
- Well-regimented combustion leads to high efficiency.

The main disadvantages of a moving grate system are:

- Relatively large fuel inventory in the plant leads to a slow response to load swings, although modulating controls improve controllability.
- Large amounts of refractory (heat reflective) material on wet wood plants can result in a long warm-up time from very low to full-load (up to 2 hours).
- Prolonged low-load mode operation can result in higher maintenance costs and reduced efficiency as a result of tarring of heat exchangers and condensing gases.
- More complex design and bulky components can lead to higher capital costs.

## Automatic Boilers - Components and Connected Systems

Condensation heat exchanger

Wood chip boilers can work with horizontal heat exchangers in order to obtain a more compact device. In this case, easy access should be provided for convenient cleaning of exchanger. Using solid bio fuels reduces the useful life of these exchangers due to corrosion, even in the case of stainless steel equipment.  With a supplementary exchanger and condensate separator, boilers can be converted to condensation boilers. Due to the efficient gas cooling and vapour condensing process, thermal power output can be increased by 10-20 %. The condenser also enables more effective dust separation.

Extraction and feeding systems

Automatic boilers have a mechanical feeding system of fuel from silo.  The silo should be located near the boiler, as shown in Fig 12. Extraction systems are outlined in Table 5 (below).

**Fig 12** Domestic extraction and feeding systems

**Table 5.** Fuel Extraction Systems

| **Extraction type** | **Commentary** | **Fuel type** | **Scale of applicability** |
|---|---|---|---|
| Batch fed | Only appropriate for batch-fired plants. Requires continued manual intervention (daily). | Logs | 10 $kW_{th}$ + |
| | | Bales of straw | 30 $kW_{th}$ + |
| Augers (screw feed) | The primary means of moving woodchip and wood pellet material from the fuel store to the plant unit. Blockages at transfer points between augers can arise if the manufacturer's fuel specification is not adhered to. Length of auger should be minimised to reduce risk of blockages. | Chip | 30 $kW_{th}$ + |
| | | Pellet | 10 $kW_{th}$ + |
| Gravity fed | The use of gravity-fed systems is only appropriate for pellet plants. Wood pellets are either augured along the length of a tapered floor, or funnelled to a central point via a bagged store, etc. From here gravity drops it to the plant unit or a secondary auger/pneumatic feed. | Pellet | 10 $kW_{th}$ + |
| Pneumatic/ vacuum feed | These systems require careful design, consideration of bends, length, size of vacuum tubes, and blowing pressures. This system is usually limited to applications smaller than 50 $kW_{th}$ and is only applicable to pellet systems. | Pellet | 10 kW-50 $kW_{th}$ |

| | | | |
|---|---|---|---|
| Agitator arms with auger | Agitator arms with an auger run are the most cost-effective means of fuel transfer at the medium scale, and consequently they are the most widely used. Essentially the spring arms agitate the fuel, making sure it feeds into a central auger, which in turn feeds the plant. | Chip | 30 $kW_{th}$ + |
| | | Pellet | 30 $kW_{th}$ + |
| Walking floor | Walking floors shuffle the fuel along the length of the fuel store towards an auger that feeds the plant. The fuel is moved forward via hydraulic rams/fins that sit upon a concrete pad.<br>Walking floor-based systems can receive bulk delivery and are therefore suited to larger systems.<br>The concrete pad and the walls of the store need to be sufficiently strong to withstand the forces and pressures exerted by a full load of fuel. | Chip | 1 $MW_{th}$ + |
| | | Pellet | Generally not used for pellets, although technically they are compatible. |
| Conveyor | Conveyor (belt, chain or hydraulic reciprocating) or mechanical grab systems are generally concentrated at the large scale of wood fuel installations, where there is a significant throughput of material, or where the fuel is of a large particle size that prevents the use of augers. | Chip | 11 $MW_{th}$ + |
| | | Pellet | Not applicable to pellets at this scale. |
| Grab | | Chip | 3 $MW_{th}$ + |
| | | Pellet | Not applicable to pellets at this scale. |

### Safety Systems

Automatic boiler fuel feed systems should be provided with specific safety devices, which guard against backfire. These are usually located between the extraction and the feed augers.

A fire (water-based) extinguisher should be provided which in case of a backfire would flood the feed auger. This would happen over a certain critical temperature. Failure of the temperature sensor in the fire extinguisher safety system (see Fig 13) could lead to non-response of thermo-mechanical valve when required. In turn this could lead to system overheat or alternatively premature extinguishing.The main disadvantage, however, is that any water leaks from the extinguisher valve will wet the fuel in the feed auger.

Another possible safety system is the tip-up shutter system, whereby the shutter is activated by a thermo-mechanical regulator (see Fig 14). However, the problem with this approach is that mechanical valve operation can be hindered by clogging of fine dusts.

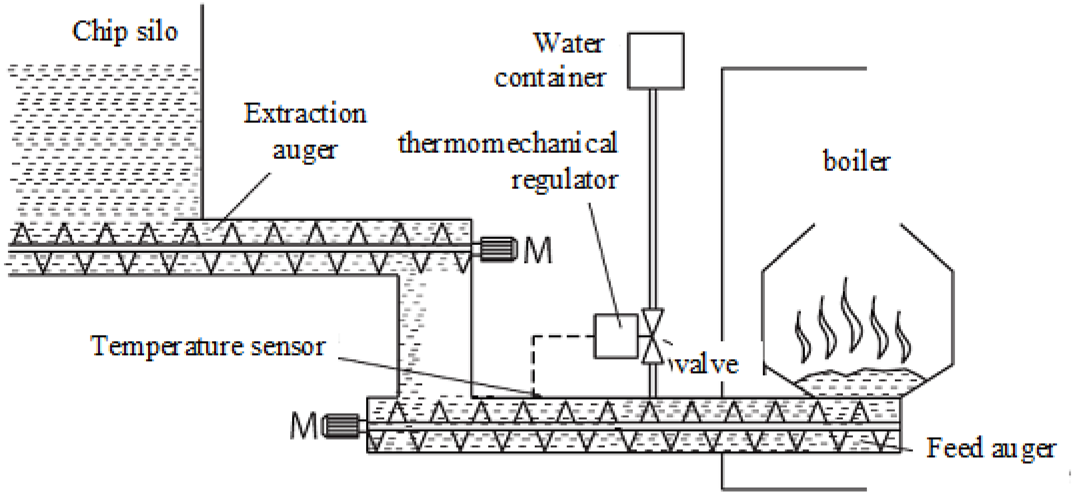



**Fig 13** Fire extinguisher safety system

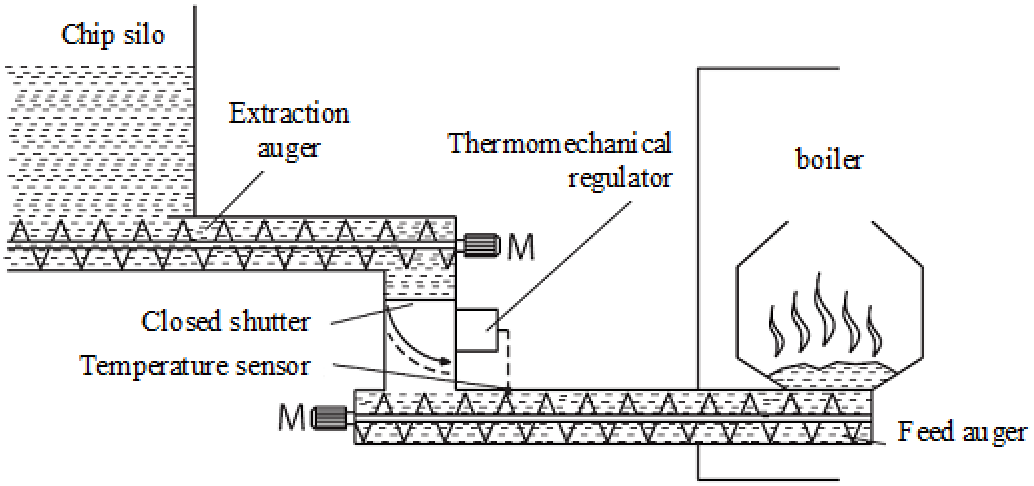


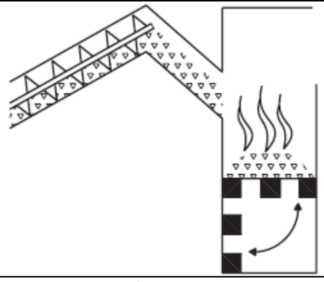
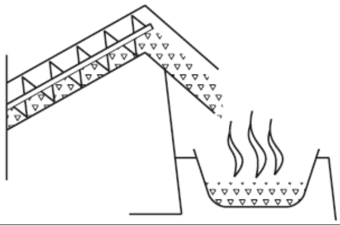
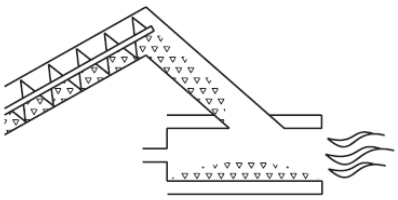

**Fig 14** Tip-up shutter system

## 3. TOP FEED BOILERS

Pellets are often used in top feed boilers, which can be considered another different typology of automatic-feed boilers. The constructive variants have been specifically tuned for pellets, thus this kind of boilers are not suitable for wood chips. In fall-feed boilers pellets are augered and made fall from above on a brazier bed which leans on a tip-up grate or a cup brazier or a tunnel (burner). Here primary and secondary air is introduced from below and laterally through injections holes. In the tip-up grate ash is periodically discharged in an ashbin beneath.

Typical top feed boiler feed schemes are outlined in Table 6 below.

**Table 6**. Typical top feed boiler feed schemes[35]

| Typology | Scheme | Scale | Fuel |
|---|---|---|---|
| Tip-up grate |  | From 15 kW to 30 kW | Chips, pellets |
| Cup brazier |  | From 6 kW to 30 kW | Pellets |
| Tunnel brazier (burner) |  | From 10 kW | Pellets |

## STOKER BURNER SYSTEM

### Domestic Stoker Boiler

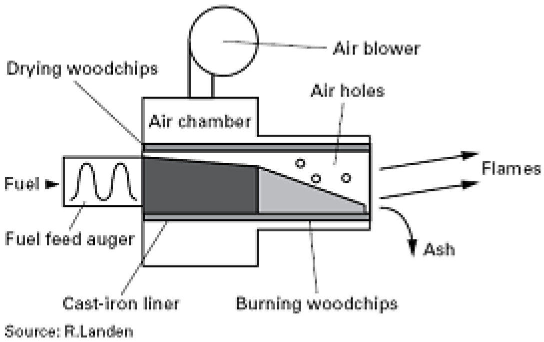
Stoker burner systems are often cheaper than plane grate or moving grate options because they are generally less sophisticated.

They are most common in the size range 30-500 kWth, but there are also some examples of industrial applications (see below).

This type of combustion system is similar to a pressure jet oil burner. Biomass fuel is augured into a burner head, which has a special cast iron liner to reflect heat back onto the fuel. Air is introduced by a small fan, which passes around the outside of the cast-iron liner, thus heating up. The air then enters the fuel space via small holes, some below the fuel to provide primary air, some above to provide secondary air. The burner head produces a vigorous flame in the combustion chamber, and the resultant hot combustion gases pass into the heat exchanger unit.

Ash from the burner head is pushed away and into the ash pan by the incoming fuel. De-ashing is almost always manual, especially on smaller units.

The stoker burner is probably the lowest-cost biomass plant available that can use both pellets and woodchip, but it does have limitations as described below (see Fig 15). A potential risk associated with the fan /air blower is the method by which they are controlled. Pulse width modulation (PWM) can be used as a way to control the fan speed. If the method for determining the duty cycle is not tightly controlled fan speed can become indeterminate and lead to uncontrolled boiler output temperature.



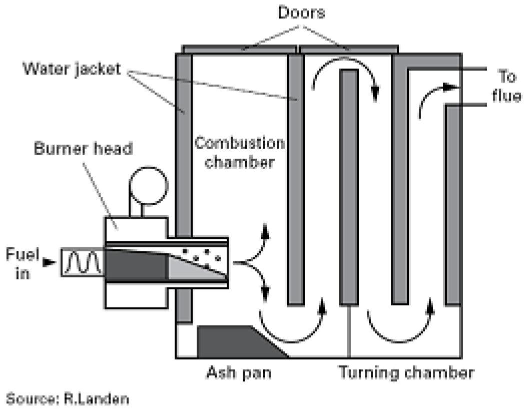




**Fig 15** Spreader stoker biomass boiler

### Industrial Stoker Boilers

Modern stoker units for wood firing are normally mechanical rotating grates or water/air-cooled vibrating grates depending on the fuel moisture content. Fuel is typically introduced into the boiler through multiple fuel chutes. [35]

Air is supplied under the grate as well as above via an over fire air (OFA) system. Depending on the fuel moisture content, the combustion air is pre-heated to 180 to 350˚C. The combustion zone temperature is typically neither measured nor controlled and can range from 1200 to over 1700˚C.

Sand classifiers are also typically required to **separate out the high abrasive silica content of the fly ash** before re-injection into the furnace. These re-injection systems are high maintenance items and have been shut down at many plants.

A mechanical dust collector is also typically installed to prevent any heavy particle carryover from reaching the precipitator. Concerns over unburned carbon carryover, and the potential fire hazard that can result, usually dictate that a precipitator be used for particulate control in stoker applications.

## 4. FLUIDISED BED BOILERS

Fluidised bed combustion (FBC) offers multiple benefits, such as: compact boiler design, flexibility with fuel used, higher combustion efficiency and reduced emissions of noxious pollutants such as $SO_x$ and $NO_x$. The fuels burnt in these boilers include coal and typical biomass. Fluidized bed boilers have a wide capacity range- 0.5 T/hr to over 100 T/hr.

### Combustion Mechanism

When an evenly distributed air or gas is passed upward through a finely divided bed of solid particles such as sand supported on a fine mesh, the particles remain undisturbed at low velocities. As the air velocity is gradually increased, a stage is reached when the individual particles are suspended in the air stream and the bed is called "fluidised".

[35] *Bubbling Fluidized Bed or Stoker – which is the right choice for your renewable energy project? De Fusco, Mckenzie and Fick. CIBO Fluid Bed Combustion XX Conference May 2007*

With further increase in air velocity, there is bubble formation. The bed of solid particles exhibits the properties of a boiling liquid and assumes the appearance of a fluid – “bubbling fluidized bed”.

At higher velocities, bubbles disappear, and particles are blown out of the bed. Therefore, some amounts of particles have to be re-circulated to maintain a stable system and is called as “circulating fluidized bed".

Fluidisation depends largely on the particle size and the air velocity. The mean solids velocity increases at a slower rate than does the gas velocity. If sand particles in fluidised state are heated to the ignition temperatures of fuel and fuel is injected continuously into the bed, the fuel will burn rapidly and the bed attains a uniform temperature.

FBC takes place below the ash fusion temperature, melting of ash and associated problems are avoided. The lower combustion temperature is achieved because of high coefficient of heat transfer due to rapid mixing in the fluidised bed and effective extraction of heat from the bed through in-bed heat transfer tubes and walls of the bed. An FBC system releases heat more efficiently at lower temperatures. Using a limestone particle bed control of $SO_x$ and $NO_x$ emissions in the combustion chamber can be achieved.

### Bubbling Fluidised Bed (BFB) Boilers

Bubbling fluidised bed (BFB) is one of the most important types of FBC boilers as it can be used for variety of fuels - such as agricultural residues and even low quality coal. BFB boilers are able to burn a wide range of conventional fuels and waste fuels with high moisture, including:

- Wood wastes and bark
- Paper mill sludges
- Recycled paper facility sludges
- Sewage sludge
- Tire-derived fuel, in combination
- Oil and natural gas
- Coal, in combination
- Peat
- Biomass
- Sugar cane waste
- Agricultural waste

They are particularly useful in combined heat and power (CHP) applications. [38,36]

In BFB boilers the fuel is sized depending on the type of fuel and the type of fuel feeding system and is fed into the combustion chamber. The atmospheric air, which acts as both the fluidisation air and combustion air, is delivered at a pressure and flows through the bed after being preheated by the exhaust flue gases. The velocity of fluidising air is in the range of 1.2 to 3.7 m /sec. The rate at which air is blown through the bed determines the amount of fuel that can be reacted.

[36] *Technical study report on Biomass Fired Fluidised Bed Combustion Boiler Technology for Cogeneration, UNEP, Division of Technology, Industry & Economics 2007*

Almost all BFB boilers use in-bed evaporator tubes in the bed of limestone, sand and fuel for extracting the heat from the bed to maintain the bed temperature. The combustion gases pass over the super heater sections of the boiler, flow past the economizer, the dust collectors and the air pre-heaters before being exhausted to atmosphere. For efficient sulphur retention, the temperature should be in the range of 800°C to 850°C.

Fuel Feeding System

Fuel is typically introduced into the BFB through fuel chutes on one or more of the walls. Because less under-bed air is used compared to a stoker, velocities in the bed are lower. Mechanical attrition of the fuel due to the bed fluidization, coupled with the lower bed velocities, minimizes the potential for any significant large-particle unburned carryover from the BFB. The unburned combustible loss leaving the boiler is less than 1% on a fuel efficiency basis. Due to little or no carryover, BFB systems do not usually have fuel re-injection systems since there are no cinders to capture and re-inject. This also eliminates the need for mechanical dust collectors (MDC) downstream of the boiler.

Air Distributor

The purpose of the distributor is to introduce the fluidizing air evenly through the bed cross section thereby keeping the solid particles in constant motion, and preventing the formation of de-fluidization zones within the bed. The distributor, which forms the furnace floor, is normally constructed from metal plate with a number of perforations in a definite geometric pattern. The perforations may be located in simple nozzles or nozzles with bubble caps, which serve to prevent solid particles from flowing back into the space below the distributor.

Bed & In-Bed Heat Transfer Surface

- Bed - The bed material can be sand, ash, crushed refractory or limestone, with an average size of about 1 mm.

- In-Bed Heat Transfer Surface – With a fluidized in-bed heat transfer process, it is necessary to transfer heat between the bed material and an immersed surface, which could be that of a tube bundle, or a coil. The heat exchanger orientation can be horizontal, vertical or inclined.

Ash Handling System

- Bottom Ash Removal - In the FBC boilers, the bottom ash constitutes roughly 30 – 40 % of the total ash, the rest being the fly ash. The bed ash is removed by continuous over flow to maintain bed height and also by intermittent flow from the bottom to remove over size particles, avoid accumulation and consequent defluidisation.

- Fly Ash Removal - The amount of fly ash to be handled in FBC boiler is relatively very high, compared to conventional boilers. This is due to elutriation of particles at high velocities. Fly ash carried away by the flue gas is removed in number of stages; firstly in convection section, then from the bottom of air pre-heater/economizer and finally a major portion is removed in dust collectors.

The types of dust collectors used are cyclone, bag filters, electrostatic precipitators (ESP’s) or some combination of all of these. To increase the combustion efficiency, recycling of fly ash is practiced in some units.

# 7 REFERENCES


1. HETAS - http://www.hetas.co.uk/
2. http://www.swissmanllc.com/pellets.html
3. Low Carbon Heating with Wood Pellet Fuel. Report by XCO2 conisbee Ltd. 2003
4. Procurement Guidelines for Biomass Heating. Dr R Cooke of Buro Happold Ltd, and Mr A Russell of Mercia Energy Ltd. January 2007
5. Woodfuels handbook. www.biomasstradecentres.eu
6. UK Clean Air Act (1993). http://www.opsi.gov.uk/ACTS/acts1993/ukpga_19930011_en_1
7. SI 2343(2008). http://www.opsi.gov.uk/si/si2008/pdf/uksi_20082343_en.pdf
8. Health and Safety in Biomass systems: Design and operation guide Carbon Trust 2011
9. Building Regulations 2000: Approved Document J: Combustion appliances and fuel storage systems.
10. http://www.opsi.gov.uk/si/si2005/20051541.htm
11. http://www.opsi.gov.uk/si/si1989/Uksi_19890635_en_1.htm
12. http://www.hse.gov.uk/woodworking/dust.htm
13. http://www.hse.gov.uk/fireandexplosion/dsear.htm
14. US Biomass Research & Development Initiative. National Biofuels Action Plan
15. Kuang X, Shankar TJ, Sokhansanji S, Lim CJ, Bi XT, Melin S. Effect of head space and oxygen level on off-gas emissions from wood pellets in storage. Annals of Occupational Hygiene. 2009; 53: 807-813
16. Cohn CA, Lemieux CL, Long AS, Kystol J. et al. Physical-chemical and microbiological characterization, and mutagenic activity of airborne PM sampled in a biomass-fueled electrical production facility. Environ. Mol. Mutagen. 2010 [E-published ahead of print]
17. Pollard SJ, Smith R, Longhurst PJ, Eduljee GH, Hall, D. Recent developments in the application of risk analysis to waste technologies. Environment International. 2006; 32: 1010
18. Lacey and Crook 1988
19. Madsen AM. Exposure to airborne microbial components in Autumn and Spring during work at Danish biofuel plants. Ann. Occup. Hyg 2006; 50: 821–831. Madsen 2006
20. Sebastian A, Madsen AM, Mårtensson L, Pomorska D, Larsson L. Assessment of microbial exposure risks from handling of biofuel wood chips and straw - effect of outdoor storage. Ann Agric Environ Med 2006; 13: 139–145

21. Madsen AM, Saber AT, Nordly P, Sharma AK, Wallin H, Vogel U. Inflammation but no DNA (deoxyribonucleic acid) damage in mice exposed to airborne dust from a biofuel plant. Scand J Work Environ Health 2008; 34: 278 -287

22. Madsen AM, Nielsen SH. Airborne endotoxin associated with particles of different sizes and affected by water content in handled straw. Int J Hyg Environ Health. 2010 Mar 31. [Epub ahead of print]

23. Madsen AM, Schlünssen V, Olsen T, Sigsgaard T, Avci H. Airborne fungal and bacterial components in PM1 dust from biofuel plants. Ann Occup Hyg. 2009; 53:749-757

24. Svedberg U, Petrini C, Johanson G. Oxygen depletion and formation of toxic gases following sea transportation of logs and wood chips. Ann. Occup. Hyg. 2009; 53: 779–787

25. Wood pellet association of Canada - Review of Off-gassing from Wood Pellets - A Canadian Perspective - Staffan Melin, Research Director, February 2010

26. Bulletin 524 -05/07 – Wood Pellets – Combustion hazards/Carbon monoxide Emissions – Worldwide – article produced by Dr J H Burgoynes & Partners

27. IEA Bioenergy Biomass co-firing and combustion brochure, http://www.ieabcc.nl/ 2010

28. Svedberg URA, Högberg H, Högberg J, Galle B. Emission of hexanal and carbon monoxide from storage of wood pellets, a potential occupational and domestic health hazard. Ann. Occup. Hyg., 2004; 48: 339–349

29. British BioGen Good practice Document - http://www.woodfuelwales.org.uk/biomass/Technology/cogpp.pdf http://www.hse.gov.uk/pubns/indg294.pdf

30. Energy Efficiency Best Practice in Housing Domestic heating: solid fuel systems. Guidance for installers and specifiers. CE47 © Energy Saving Trust. March 2005.

31. Particulate Control for Biomass fired Boilers.' R A. Mastropietro. Electrostatic Precipitators. Hamon Research-Cottrell, Inc.

32. Impianti termici. ARSIA. Agenzia Regionale per lo Sviluppo l'Innovazione nel settore Agricolo-forestale. 2009.

33. www.hobag.ch

34. www.heizomat.de

35. Bubbling Fluidized Bed or Stoker – which is the right choice for your renewable energy project? De Fusco JP, Mckenzie PA and Fick MD. CIBO Fluid Bed Combustion XX Conference May 2007

36. Technical study report on Biomass Fired Fluidised Bed Combustion Boiler Technology for Cogeneration, UNEP, Division of Technology, Industry & Economics 2007