Biomass heating: a guide to medium scale wood chip and wood pellet systems

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Forestry Commission
BIOMASS Energy Centre
DEPARTMENT OF ENERGY & CLIMATE CHANGE
REA RENEWABLE ENERGY ASSOCIATION

Introducing automatically fed systems

This guide is for automatically fed wood chip and wood pellet biomass boilers of 50 kW and above. The guide covers boilers for commercial applications as very few domestic installations would require a boiler of this size; however, small commercial boilers can usually be installed in large domestic settings and this guide would be suitable.

This guide and the two accompanying publications, *Biomass heating: a guide to small log and wood pellet systems* and *Biomass heating: a guide to feasibility studies* are collectively concerned with low temperature hot water boilers of up to 3 MW, operating at a maximum flow temperature of 95 °C. *A guide to feasibility studies* is recommended for information on system selection, how to carry out a feasibility study, planning and regulations, emissions and chimney heights.

Fossil fuelled boilers

Before describing automatically fed biomass boilers it is useful to look briefly at fossil fuelled boilers as an aid to understanding the differences. Most boilers commonly in use throughout the UK burn fossil fuels such as gas or oil (fuel is usually fed under pressure through a pipe to the burner where it is ignited by an electric ignition system). Ignition is almost instantaneous, as is heat production, and on cessation of a heat demand the burner shuts off, again instantaneously. Complete combustion requires sufficient oxygen to ensure that all the fuel is burned, and all boilers require excess air at the burner for this reason. However, excess air results in disproportionate heat loss via the flue and can lead to increased formation of oxides of nitrogen (NO and NO_2 often collectively referred to as NO_X) at elevated temperatures.

Since 1992 European legislation has required all fossil fuel boilers to meet minimum efficiency standards which necessitates the careful control of fuel feed and excess air by electronically controlled burners. Modern fossil fuelled boilers are steadily replacing the previous generation of atmospheric boilers, some of which have low NO_X burners.

Biomass boilers

Low temperature hot water biomass boilers, those operating at up to 95 °C, can be classified by various methods based on fuel type or on the physical characteristics of the boilers. The classification that follows is based on fuel type. The critical difference between stoves and boilers is that stoves provide radiant room heating while boilers only produce hot water, either for heating or domestic hot water (DHW). Although some stoves will allow the incorporation of a boiler and radiators, stoves are usually much simpler devices than boilers. Figure 1(a) and (b) shows two examples of medium scale boilers that can be used in different commercial settings.

Pellet boilers and stoves

Pellet boilers and stoves range in size from a few kilowatts (kW), for houses or small commercial buildings, to megawatt (MW) size units for district heating systems.

Pellet systems will usually have an automatic hopper-fed fuel system. The hopper can be either built-in, in the case of some smaller systems, or a detached separate unit.

Pellet systems are generally the most responsive of the biomass boilers, have the simplest controls and are the closest to fossil fuelled boilers in terms of maintenance and operation, although there can be large variations between systems from different manufacturers in terms of sophistication and

Figure 1a

Figure 1b

Figure 1 (a) and (b)
Medium scale commercial boilers (Forestry Commission).

features. This guide deals with larger pellet systems (from 50 kW up to several MW). For further detailed information on pellet stoves and small pellet boilers (up to around 50 kW) see ***Biomass heating: a guide to small log and wood pellet systems.***

Log boilers

These appliances run on logs and other larger pieces of wood, including joinery offcuts. Log boilers do not have automatic feed systems and are only suitable for installation where a certain amount of physical labour is available and there is space for a managed wood store. Log boilers are batch fired devices and simple to operate but they do require a large water storage cylinder (also known as a thermal store, accumulator or buffer tank) to capture the heat produced, except in extremely simple small stoves with an integral water-jacket. Log boilers up to 50 kW are covered in detail in ***Biomass heating: a guide to small log and wood pellet systems.***

Wood chip boilers

Wood chip boilers (Figure 1(a) and (b)) are fuelled by an automatic feed of chipped wood, which can be supplied with moisture contents from 15% to 50% [1]. They use a stoker burner or an underfed stoker for burning fuels with between 15% and 30% moisture content, or moving or stepped grate systems for burning fuels with higher moisture contents. Boiler sizes range from small domestic systems of 10–20 kW to medium sized of 50 kW and above to power-station sized boilers of 100 MW and more. Boiler responsiveness is determined partly by the fuel moisture content which the boiler is designed to accept; in general the wetter the fuel, the less responsive the boiler. Wood chip boilers are covered in this guide.

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[1] All moisture contents quoted in this publication are on a 'wet basis', that is $\frac{\text{Weight of water in a given sample}}{\text{Total weight of the sample}} \times 100 = \text{MC\%(wet basis)}$.

Biomass combustion

While several different types of biomass boilers are described in this guide, their principle of operation is the same. In many respects the technology used to burn wood is similar to that used in coal boilers which are still in use in some parts of the UK. Fuel is fed to the grate mechanically where it undergoes combustion to produce energy. Figure 2 outlines the main stages and the temperature ranges associated with them; however it is a simplification and several stages can occur simultaneously.

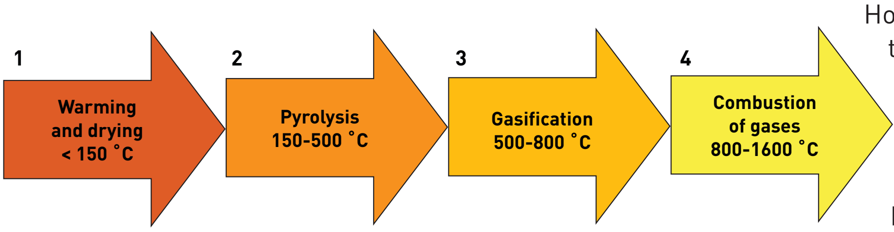


Figure 2
The four-stage combustion process.

Key points to note:

- A number of automatic ignition systems are used on biomass boilers, most notably hot air which dries the first load of fuel on the grate and then heats it to above the spontaneous ignition temperature of 400 °C.
- Stage 1 requires the combustion chamber to be hot above and around where the fuel enters the grate. Most biomass boilers contain some refractory material for this reason. Boilers designed to burn wet wood chips have substantial refractory linings in large combustion chambers. The greater the quantity of refractory lining, the less responsive the boiler to changes in heat demand, the longer the time taken to reach ignition temperature and the greater the residual heat that will need to be dissipated when the boiler is switched off.
- Most of the energy is produced at stage 4 when the combustible gases, which are mainly a mixture of carbon monoxide (CO) and hydrogen (H_2), are burned some distance away from the grate at a high temperature, while maintaining the temperature range on the grate required at stages 1 and 2 to convert the solid material to energy. These features are essential to prevent the formation of slag on the grate.
- Separate control of primary air (from beneath the grate) and secondary air (into the gas oxidation zone) is required to maintain the lower grate temperature for stage 2 while ensuring that a sufficiently high temperature and turbulence exist to oxidise the wood gases completely at stage 4.
- Careful control of the excess O_2 content (often monitored by a lambda sensor) and gas oxidation zone combustion temperature at stage 4 is required to minimise the formation of soot, CO and NO_x and maximise thermal efficiency. However, as complete oxidation of the wood gases usually requires a slightly higher combustion temperature than in fossil fuelled boilers, the quantity of NO_x produced by biomass boilers per unit of heat generated is usually greater than that from gas fuelled boilers.
- If wet fuel is not dried sufficiently by the boiler (because the fuel moisture content is outside the fuel tolerance range of the boiler) incomplete gasification and oxidation will occur and black smoke will be produced. In addition, the tars released at stage 2 will gradually coat the heat exchanger surfaces resulting in reduced heat exchange efficiency and the eventual failure of the boiler. Tar accumulation is also one reason why many manufacturers recommend minimum running periods for their boilers to ensure that combustion chambers and heat exchangers reach full working temperature to drive off the heavy volatiles deposited during the heat-up phase. The energy used to evaporate the moisture is not available to the appliance user.
- If the fuel is too dry for the boiler, grate (stage 2) and oxidation zone (stage 4) temperatures can be too high, resulting in the formation of slag and a higher concentration of NO_2. This latter issue can be addressed by installing flue gas recirculation to primary air. This allows dry fuel to be used in a boiler designed to burn wet fuel by maintaining the primary gas flow rate while reducing its O_2 content, thus reducing the gasification rates (stage 3) on the grate.

Figure 3
Ash bin fed by an automatic de-ashing system (RBAN).

When there is no longer a demand for heat from a biomass boiler, the boiler continues to produce heat for some time (unlike a liquid or gas fired fuelled boiler which ceases producing heat immediately). Fuel on the grate will need to be burned off and, depending on the type of boiler, the fuel in the feed system may need to be emptied onto the grate and burned as well. The refractory lining of the boiler will also need to release heat to prevent steam being generated in the boiler. The time taken for a boiler to stop producing hot water will vary between 15 minutes and 2 hours, and the heat produced during this period must be absorbed or dissipated. The usual practice is to store the heat in a large water-filled buffer vessel, sized to the specific boiler output and thermal mass. The buffer vessel acts as a store to absorb part of the boiler output when the system load is below the minimum operating output of the boiler. This stored heat is then used at the start of the heating period each day when the buffer will discharge in a controlled manner to satisfy part or all of the initial peak heat demand while the biomass boiler heats up.

Slag and ash

Slag formation occurs when naturally occurring silica (sand), or unwanted silica in the fuel, converts to glass. While pure silica melts at about 1700 °C, chlorides present in the fuel can reduce this to as low as 773 °C. Therefore, it is important to keep the temperature on the grate below 750 °C. Some boilers are fitted with water-cooled grates and/or flue gas recirculation to ensure that this takes place.

Ash is a by-product of wood combustion, the quantity produced varying from 0.5% to 2% or more of the dry weight of wood chip or wood pellet burned, the exact proportion being dependent on the chemical composition of the fuel. Around 98% of this is bottom ash from the grate and the remaining 2% is fly ash, which is usually captured by a flue gas clean-up system or by a fly ash drop-out chamber within the boiler (Figure 3). Under some circumstances wood ash from combustion appliances can be spread on the soil under Environment Agency (EA) Exemptions, but there are restrictions and the EA should be consulted. This does not apply to domestic boilers for which the restrictions do not apply.

Fuel handling

Fuel storage and extraction

Automatic feed boilers burning wood pellets or wood chips can also be classified by type, and range in size from 10 kW to the very largest boilers. Before describing these main types of boilers it is important to understand the variations in fuel supply systems, starting with the fuel store and ending with the delivery of fuel into the boiler.

Fuel can be stored in a range of ways, including silos, hoppers, containerised stores, flexible fabric silos, and in sheds above fuel extractor systems in large installations. Figures 4, 5 and 6 show combinations of fuel silos and fuel extractor mechanisms.

Fuel silos

Wood pellets are usually stored in a hopper bottom store. Providing the angle of the floor is greater than 40° pellets will flow down into the extractor auger. They can be filled by pneumatic delivery where one of the two hoses (Figure 4) receives the pellets and the other provides pressure relief and recovers the dust produced to the delivery vehicle. While these silos can be fitted with auger outfeed equipment, pellets can also be extracted by a vacuum pump to the boiler's dosing silo. This also requires a pressure relief hose.

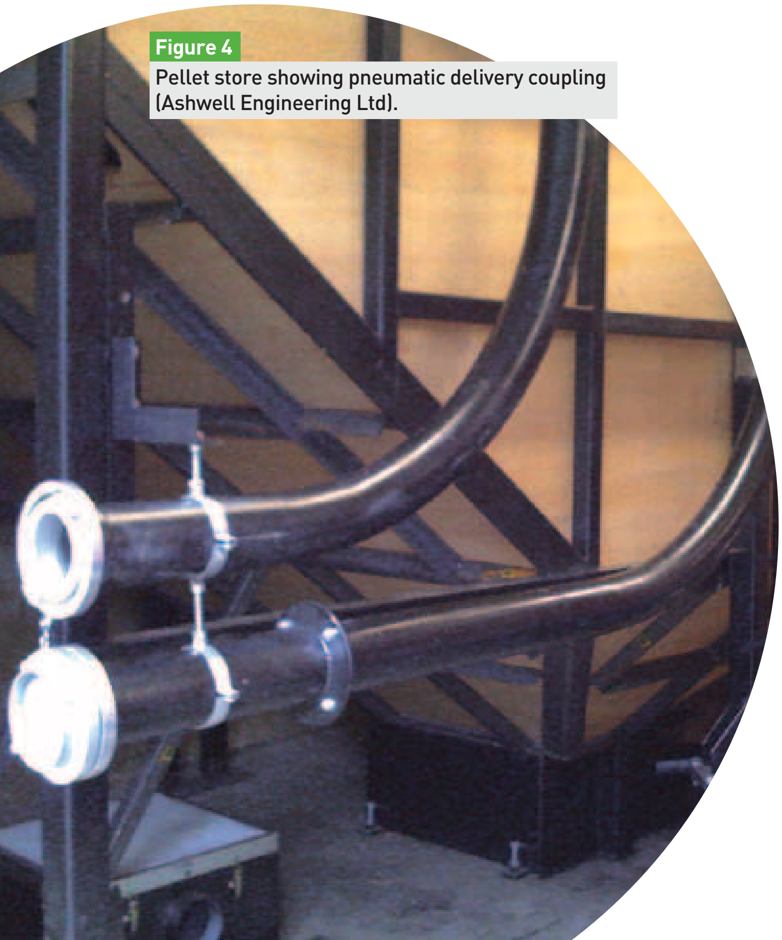


Figure 4
Pellet store showing pneumatic delivery coupling (Ashwell Engineering Ltd).

Wood chips are often stored in a silo with a sloping floor, and extracted using an outfeed mechanism known as an agitator which prevents bridging within the stack and ensures a continual feed of fuel. This usually comprises two sweeping arms which push wood chip onto the extract auger, shown in Figure 5. Alternatively, wood chips with a moisture content less than 35% can be stored in a hopper bottom incorporating a fuel extractor mechanism.

Both chips and pellets can be delivered by tipping into a silo, for example where this is constructed underground or where ramped access is provided. Articulated containers can deliver up to 25 tonnes of wood chip at a time and may either be delivered using a walking floor or pneumatically.

Figure 5
Interior of a chip store showing agitation device (RBAN).

Pneumatic delivery of wood pellets is now routine, and some wood chip delivery companies are offering blown fuel delivery (Figure 6), allowing less accessible stores to be reached. For wood chips blown delivery is slow compared to tipping, and this will add to the cost of fuel delivery.

Figure 6
Pneumatic delivery of wood chips (Forestry Commission).

Containerised fuel stores

Alternatively, wood chips can be delivered in a container or 'hook bin' where the container forms the fuel store and connects to the fuel extractor mechanism on delivery (Figure 7).

Figure 7
Wood chip delivery using a removable container system (Forestry Commission).

Flexible silos

For smaller wood pellet installations a range of prefabricated sectional and collapsible silos manufactured from plastics, steel or fabric (Figure 8) are available. These are designed for installation in difficult to access and confined spaces, and can be assembled *in situ* in basements or loft spaces.

Wood pellet stores

Useful information on the design of wood pellet stores can be found on the Brites website; see Sources of further information (page 20).

Storage sheds

Large or very large-scale fuel storage is best achieved by using storage sheds. Deliveries are either received from articulated vehicles or material is chipped directly into the storage area.

Fuel handling in large stores requires the use of mechanical handling equipment, such as a front end loader or a mechanical grab, with walking floor arrangements or conveyor systems to move the material to the main boiler unit. Alternatively wood chips can also be stored in large sheds and moved to a smaller boiler feed hopper as required.

Walking floors

An alternative method of fuel extraction from a silo is by walking floor. These floors can be designed to take the weight of a delivery vehicle where chips or pellets are tipped directly onto the floor (Figure 9). Lighter weight versions are available where fuel is loaded onto the floor by mechanical shovel.

Fuel is extracted from the walking floor by either a cross-feed auger (Figure 10) or a hydraulically operated ram-stoker system.

Figure 9
Chip store using a walking floor (Ashwell Engineering Ltd).

Figure 8
Flexible bag type chip store (Organic Energy (UK) Ltd).

Figure 10
Cross-feed auger (RBAN).

Health and safety in fuel storage and handling

Apart from the well-understood issues of working in confined spaces (see Sources of further information, page 20) and in silos containing materials which flow, there are specific and separate issues relating to the delivery and storage of wood chips and wood pellets.

Wood chips

Unless wood chips are reasonably dry, typically less than 30% moisture content, they may degrade in storage. Microbial activity can lead to piles of wood chips generating heat as they decompose. The loss of calorific value via decomposition has been measured at 1% per month. Under the right conditions fungal spores will develop in the chip pile and these spores are released when the pile is disturbed; if inhaled they can cause an incurable disease commonly known as 'farmers lung'. To avoid the formation of spores moist or wet wood chip should be stored for as short a period as possible, and should be used within 1 month of being chipped.

In very large piles of wood chips it is possible for the heat released from microbial action to lead to an increase in temperature in the heart of the pile, sufficient to give rise to spontaneous ignition, causing a fire. The potential for this to occur will depend on a number of factors, including the moisture content of the chips, ambient conditions and the store design; advice on the maximum safe size for piles of chips varies between countries and sources, with figures quoted from 8 m to 15 m. In any case, chips in long-term storage should be turned regularly to prevent microbial activity and aid drying.

Wood pellets

The safety risk with wood pellets relates to the dust produced during delivery by pneumatic conveying. When pellets are blown into a silo a proportion break up and produce the sawdust from which they were manufactured. If the dust concentration is not controlled it is possible for an explosive mixture of dust in air to be created which could explode if an ignition source is present. Minimising dust build up, and ensuring no ignition sources are present will prevent this, and can be done by the combination of design, maintenance and operation. Buying quality pellets with a low dust content and good mechanical durability is also important.

Abrasion and impact during delivery of pellets can generate fine dust. This can be prevented by using smooth metal delivery pipes, with any bends of large radius, and a yielding impact baffle opposite the point of exit from the delivery tube to ensure that pellets are not shattered on impact with the opposite wall of the store. It is also important that, during delivery, tanker drivers avoid excessive pressure and there is some mechanism for dust collection. This will vary between different pellet store designs and size. The store should be regularly checked for build up of dust and periodically cleaned out.

To ensure that no possible ignition source is present there should be no electrical fittings within the store, or if they are required, that they meet the appropriate Explosives Atmospheres (ATEX) specification. Delivery pipes must also be securely bonded to earth to avoid build up of static charge.

Other safety mechanisms include zoning to classify potentially hazardous areas, ensuring dust is effectively contained within the store and cannot escape into other areas (such as the boiler room), a fireproof partition between the fuel store and boiler room, and in extreme cases inclusion of an explosion relief panel.

For information on DSEAR (The Dangerous Substances and Explosive Atmospheres Regulations 2002) and ATEX (Explosive Atmospheres Directives 99/92/EC (ATEX 137) and 94/9/EC (ATEX 100)) and guidance on safe storage practice see Sources of further information (page 20).

Supplying the boiler

Many physical system layouts are possible using combinations of the fuel store and fuel extractor systems described on pages 6–8. The fuel store and boiler do not have to be on the same level, nor do they have to be contiguous (although this is preferable as long feed augers increase the risk of blockages and jams, reducing reliability). Fuel is fed by the fuel extractor mechanism to the boiler feed mechanism via at least two physical safety devices to prevent the fire in the boiler burning-back to the fuel store.

Boiler feed mechanisms

Fuel is usually fed into the boiler by either a rotary auger or a hydraulic ram-stoker. Auger feed mechanisms (see Figure 10 on page 7) are the most common feed systems in use on automatic feed biomass boilers. Although generally made of steel, flexible plastic augers may be found on small pellet fired installations, and can minimise costs and weight.

Augers range in size up to a maximum of 300 mm diameter when used to supply boilers of up to about 2 MW. Larger installations require multiple augers or a hydraulic feed system. Known variously as feed augers or stoker augers, they usually provide the last component in the fuel feed system to the boiler connecting the primary burn-back device to the grate, although some manufacturers use a burn-back device at the end of the feed auger immediately before the grate. Hydraulic feed mechanisms tend to be used on the larger and more expensive boilers where they provide more reliable fuel feed.

Table 1 provides a comparison between auger and hydraulic feed mechanisms.

Boiler fuel feed safety devices

All biomass boilers have a number of fuel feed safety devices to prevent the fire on the grate burning back up the fed mechanism in the event of fuel delivery failure or incorrect set-up of fuel air ratios: this is often known as burn-back. It is normal for a minimum of two devices to be installed between the combustion grate and the main fuel store or silo. Figure 11 shows a system with two safety devices: rotary valve, and mains water drench valve.

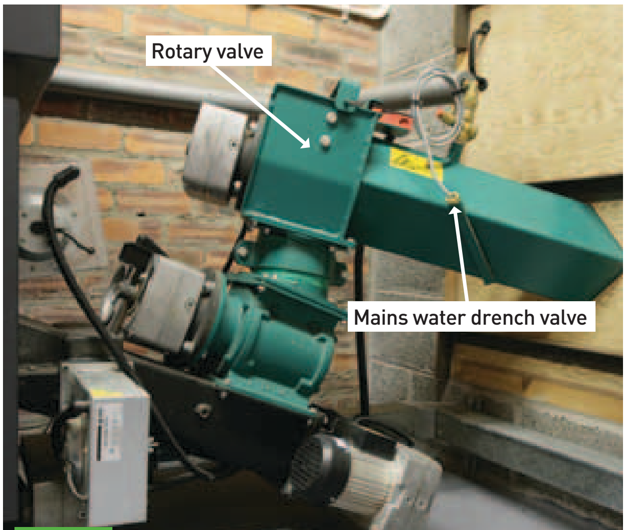


Figure 11
Fuel feed safety devices: rotary valve and mains water drench valve (RBAN).

Rotary valve

Fuel from the extractor auger is dropped onto the top of a rotary valve which meters fuel onto the boiler feed auger below. The segmented design of the rotary valve enables it to provide a positive seal between the two augers every time it rotates, physically preventing the fire from travelling to the fuel silo. The inclined stoker also provides a degree of burn-back protection. A burn-back flap valve may be used as an alternative to a rotary valve.

Table 1
Auger and hydraulic feed mechanisms: advantages and disadvantages.

	Advantages	Disadvantages
Auger feeds	Can be configured into a series of augers to allow fuel to be moved between levels and around corners. Generally cheaper than hydraulic feeds.	Will only accept fuels of a consistent quality and not exceeding certain dimensions. Only the larger augers would be able to accept wood chips with a dimension of up to 100 mm (P100 grade). Do not work well with large and thick shards of timber which can cause augers to jam, but can incorporate a sliver breaker. In very cold weather wet wood chip can freeze in the extract augers, causing the boiler to shut down.
Hydraulic feeds	Can handle very large pieces of wood, breaking all but the most oversized pieces. Generally contain splitting knives to break up very large pieces of wood. Can handle frozen wood chip. More reliable than auger feeds and very difficult to jam.	Generally more expensive than auger feeds. Very expensive to achieve significant changes of level. Usually need to be on the same plane and in line with the boiler fuel inlet. There is a possible fire risk with a fine mist leak onto an ignition source. Use of fire resistant hydraulic fluid is advised.

Bi-metallic strip

Some manufacturers install a bi-metallic strip within the feed auger casing immediately outside the combustion chamber. This strip is set to operate if the temperature in the auger housing exceeds about 90 °C, and sends a disrupt signal to the boiler control system to stop the extractor auger, rotary valve and feed auger from operating.

Wax plug and drench bottle

Another option is a wax plug which will melt at a temperature of about 80 °C. Located at the bottom of a pipe served by a gravity bottle full of water, the bottle dumps into the feed auger if the wax plug melts.

Mains water drench valve

The final line of defence on the majority of boilers is a mains water drench valve (Figure 11) operated by a direct acting thermostat located on the extractor auger. This valve will only activate if the fire manages to pass the rotary valve and, once activated, will continue to flood the fuel silo until it is switched off manually.

Where a drench mechanism is used with wood pellets, the pellets will absorb water and expand and solidify around the auger. As this requires considerable work to clear the auger, drench mechanisms are fitted farthest from the boiler in the hope that an earlier burn-back prevention device activates to avoid the need for activation of the drench valve.

Burn-back flap valve

On boilers fed by a ram-stoker, and some other types of boilers, a spring-return electrically operated flap valve or hydraulically operated vertical lifting door opens briefly to allow fuel to be pushed onto the grate. These devices provide an airtight seal between the boiler and the fuel store to prevent burn-back. The flap valve is an alternative to the rotary valve. A mains water drench valve is used as the primary fire safety back-up to the flap valve or hydraulically operated door.

Other potential hazards

Wood gas escape

The nature of biomass boilers with inspection doors and feed augers means that not all manufacturers fully seal their boilers against the escape of wood gases from the combustion chamber. The worst case scenario is a complete electrical failure while the boiler is running at full output. The fuel load on the grate will continue firstly to gasify and then to pyrolyse in the absence of oxygen. A problem is unlikely to occur providing the boiler flue has been designed to evacuate the boiler combustion chamber in the event of a total electrical failure. While it is usually safe to switch off a fossil fuelled boiler by removing the mains power, it is important that the manufacturer's control system be allowed to shut down a biomass boiler in a controlled fashion before removing electrical power from the boiler house.

Combustion chamber flash back

Great care should always be taken when opening combustion chamber doors as partly burnt gases very occasionally flare out into the boiler room. While this risk is low, boiler operators must be aware of the risk of flash-back from the combustion chamber. These gases expand when burning and can cause the boiler door to open violently. If your boiler has an oxygen reading on the display panel of less than 3% O_2 on start up, you risk causing a flash back.

Automatic feed burner types

Stoker burner boilers

Stoker burner boilers are the simplest boilers, having a relatively small grate attached directly to the end of the feed auger (Figure 12). The potential for burn-back along the auger is high, requiring the auger to be emptied on boiler shut down. However, a flap valve may be installed immediately prior to the grate to avoid the need to empty the feed auger.

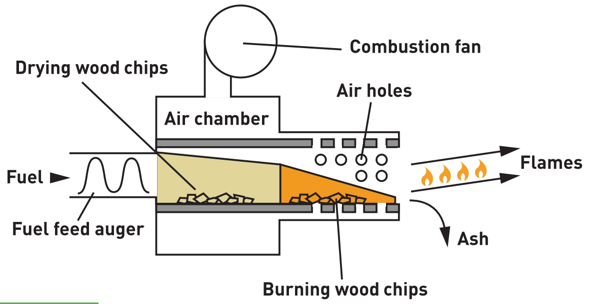


Figure 12
Diagram of a boiler using a stoker burner combustion system (after R. Landen).

Stoker burner boilers can burn wood pellets and wood chips up to 30% moisture content (MC). These boilers usually have moderate levels of refractory lining and are not of the high water content (HWC) type in order to produce a fast response to heating load demands.

On small stoker burner boilers there may be only one combustion fan as shown in Figure 12, which means that it is very difficult to separate the primary air supply to the grate from that in the final combustion zone above the grate. As a result the potential for overheating and subsequent slag formation on the grate is very high, and some boiler manufacturers have included a water cooling circuit within the grate as a preventative measure.

Underfed stoker boilers

In an underfed stoker boiler the fuel is pushed up through an inverted cone to form a dome of fuel on which combustion takes place (Figure 13). The auger enters beneath the combustion chamber and, because combustion occurs upwards, may not need to be emptied at boiler shut down.

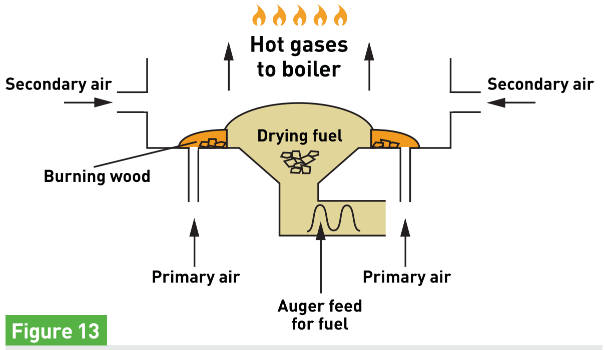
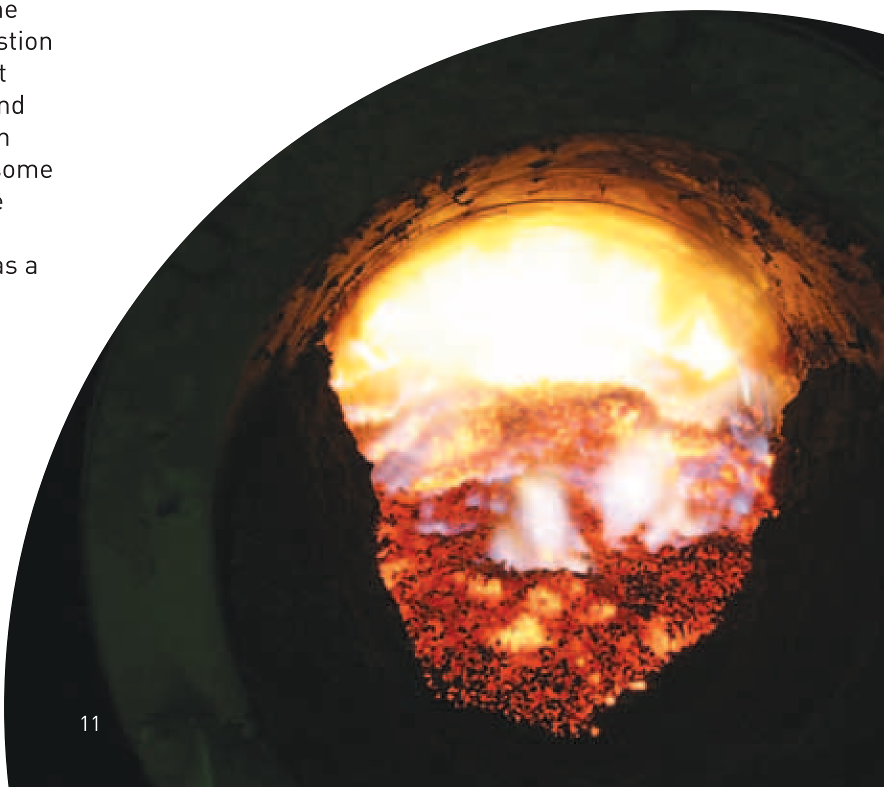


Figure 13
Diagram of a boiler using an underfed combustion system (after R. Landen).

Underfed stoker boilers can burn wood pellets and wood chips up to 30% MC. Some may be designed specifically for use only with pellets, in which case very little refractory lining may be installed. For wood chips up to 30% MC a moderate level of refractory lining will be installed, and the boiler is usually limited in the size of wood chip it can accept. Again, they are designed for a reasonably fast response to heating load demands.

Underfed stoker boilers are always auger fed and do not have a HWC capability. It is not possible to install a flap valve beneath the grate.

Most underfed stoker boilers have separate primary and secondary air fans to provide an independent combustion control on the grate and in the final gas combustion zone.



Moving grate boilers

Moving grate boilers (Figure 14), also known as stepped grate or inclined grate boilers, allow the greatest flexibility in boiler design but usually have the slowest response because of the much greater levels of refractory lining installed to enable them to be used with wood chip of up to 50% MC.

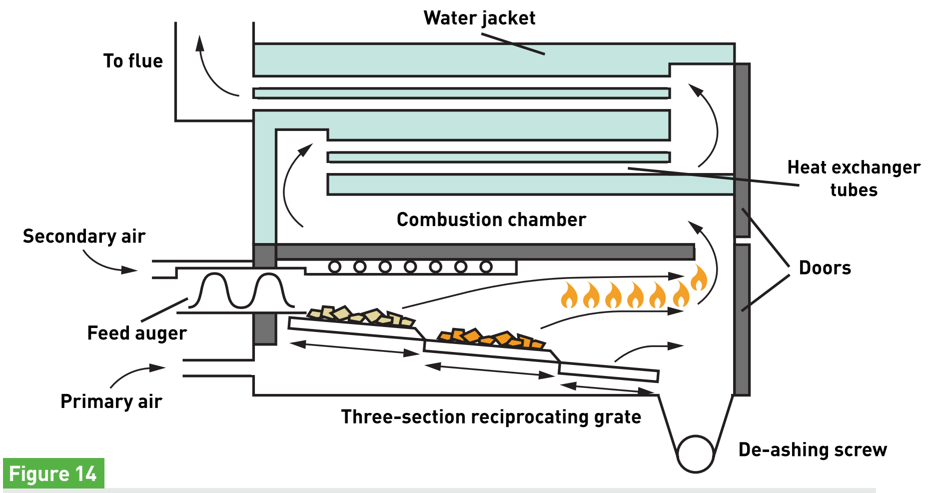


Figure 14

Diagram of a boiler using a moving or stepped grate combustion system (after R. Landen).

Moving grate boilers are designed to burn wood chip with a MC of between 30% and 50%. The boiler can be either auger or ram stoker fed. Moving grate boilers are also suitable for burning dry wood chip and some will also burn pellets, but this usually requires the addition of flue gas recirculation to limit the combustion temperature above the grate. A side entry moving grate boiler will also take the larger sizes of wood chip.

A high level of refractory lining will be used together with a combustion chamber that is physically larger than those found in other boiler types. Moving grate boilers can also be of the HWC type. The minimum buffer vessel size required for a moving grate boiler burning wood pellets will be between that required for a high MC moving grate boiler and that for an underfed stoker boiler designed to burn pellets.

As with underfed stoker boilers, moving grate boilers have separate primary and secondary combustion fans, and on the largest boilers tertiary fans to ensure the complete combustion of all wood gases.

Boiler maintenance

Biomass boilers have greater maintenance requirements than fossil fuelled boilers. The boiler manufacturer's representative or boiler installer will usually carry out an annual maintenance which will include a full internal and external inspection of the boiler, the replacement of worn components (particularly grate components on moving grate boilers), lubrication and cleaning.

The main maintenance interventions required by the user at regular intervals are a weekly visual inspection, emptying of the ash bin, greasing of induced draught fan bearings and manual brushing of the flueways. If automatic flue cleaning is installed a significant reduction in boiler down time and in maintenance time is possible, reducing manual flue cleaning from a weekly to a 6-monthly exercise. The cleaning system comprises a series of compressed air jets or nozzles installed on the ends of the flueways which are pulsed in succession at regular intervals to blow soot from the boiler. This happens automatically while the boiler is operation. The system requires a small compressed air supply in the boiler house.

Buffer vessels and boiler controls

A frequently encountered problem with biomass boiler installations to date is the low seasonal efficiency of biomass systems, with many users reporting values of as little as 50%. Recent work undertaken in the UK has identified oversized boilers, undersized buffer vessels and inadequate boiler control systems as commonly found, preventable reasons for low system efficiency.

Potential problems and pitfalls

Oversized boilers

Wood pellet boilers have a typical turndown ratio (the ratio between their maximum and minimum outputs) of 4:1 or 25% of rated output. For wood chip boilers the value is 3.1 or 33%. Biomass boilers are not normally sized to meet the peak heat load but rather to provide a large percentage of the annual heat requirement for reasons of capital cost and overall system efficiency.

For example, a boiler sized on 50% of the peak load will normally provide between 85% and 90% of the annual heat energy required, and at this size it is usually able to meet the typical minimum heat requirement when operating at its minimum output in summer.

An oversized boiler attempting to meet a load less than its minimum output without a buffer vessel, or an undersized buffer vessel, will operate by constantly switching on and off, resulting in under-temperature operation of the boiler, inefficient combustion and excessive emissions of pollutants. In the long term this will cause tar accumulation in the boiler flueways and chimney and eventually premature failure of the boiler.

Undersized buffer vessels

A buffer vessel must be sized for the specific type of boiler burning a particular fuel. While the range of buffer vessel sizes required varies from 0 to 60 l/kW or more, it is important not to apply a rule of thumb based on one manufacturer's advice or generalised rules about sizing. An undersized buffer will not be able to capture sufficient heat from the boiler on shutdown, resulting in inefficient boiler operation, nor will an undersized buffer be able to prevent short cycling of the boiler when supplying loads lower than its minimum output. Furthermore, an undersized buffer vessel will be unable to supplement the boiler output adequately to meet peak heat demands.

Buffer vessel operation

A buffer vessel is more than just a hot water cylinder. In a typical domestic hot water cylinder, or commercial hot water calorifier, the intention is to produce hot water by creating convection currents within the cylinder. When drawing hot water the mixing action continues such that the water temperature gradually reduces as the cylinder is discharged.

However, this situation is of no use in a buffer vessel where a constant hot water temperature is required from the top of the store as it discharges. Buffer vessels are fitted with sparge pipes on their return inlets which introduce the cooler return water at very low velocity to minimise mixing and allow stratification. When charging, the hot interface moves down the buffer vessel, while discharging causes the cold interface to move up the vessel as shown in Figure 15.

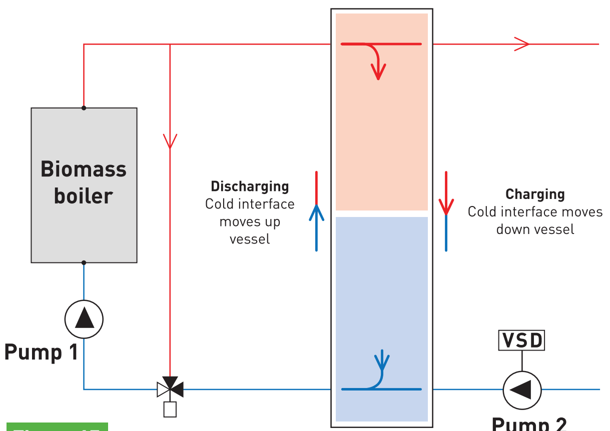


Figure 15

Buffer vessel operation (after D. Palmer).

The boiler is usually fitted with a constant speed pump (pump 1) whereas the connection to the load circuits must have a variable speed pump or variable speed drive (VSD; pump 2) installed if the system is configured for thermal storage operation as opposed to a simple buffer vessel. Figure 15 shows thermal storage operation. If the system is configured for a buffer vessel, and not a thermal store, a fixed speed pump is normally used for pump 2.

When charging, the heat produced by the boiler is greater than the heat demand from the load circuit and the flow rate through pump 2 is less than that of pump 1. When discharging, the output from the boiler is insufficient to meet the load, and the speed of pump 2 is greater than that of pump 1. The speed of pump 2 is often determined by setting a constant temperature difference across the load circuit, allowing the pump flow to be varied to meet the power demanded by the load.

Why buffer vessels are important

Some boiler manufacturers claim that they have designed their boilers such that a buffer vessel is not essential for the protection of the boiler; however, this does not mean that a buffer vessel is not beneficial to the end user. As well as offering protection to the boiler, a buffer vessel is likely to improve the overall efficiency of the boiler system, reduce emissions (see page 19) and also enable a biomass boiler to meet a greater proportion of the annual heat energy required than would otherwise be the case.

Boiler control systems

Many boiler manufacturers use a simple boiler/buffer control system based on two temperature sensors, one near the top of the buffer vessel and the other near the bottom. Figure 16 shows the buffer vessel fully charged and fully discharged. The boiler ceases firing when the hot water interface has reached the bottom sensor when charging (T2) and firing re-commences when the buffer vessel has discharged to the level of the upper sensor (T1). The problem with this simple control arrangement is that at daily start-up the buffer vessel empties fully before the boiler fires, leaving the auxiliary boiler to provide 100% of the load while the boiler is heating up. The energy consumed during the daily heat-up phase can represent a significant portion of the annual energy requirement and, depending on the boiler, this heat-up phase can take an hour or more before the biomass boiler comes on line. This could be overcome by using a larger buffer vessel, i.e. providing thermal storage rather than simple buffering.

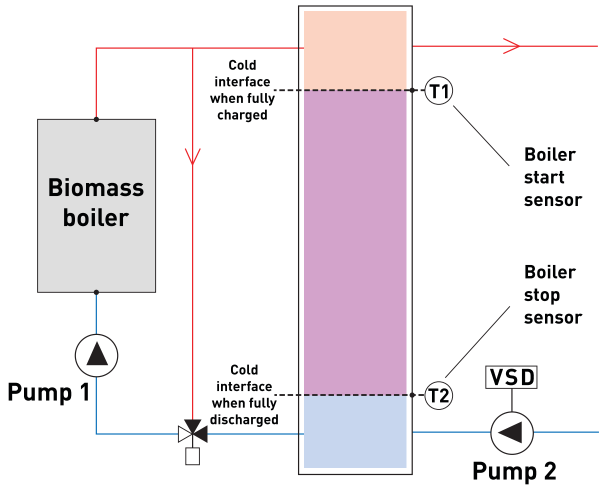


Figure 16

Boiler/buffer control system based on two temperature sensor (after D. Palmer).

Figure 17 shows a typical winter load profile for a building occupied between 08:00 and 18:00 with a representative pattern of operation of a biomass system with a buffer vessel superimposed. The biomass boiler is sized at 50% of the peak load on the 'design winter day[2]' with a buffer vessel capacity ratio of 34 l/kW at a temperature drop across the buffer of 25 °C. When the heat demand occurs at 06:00 pump 2 will switch on and begin to discharge the buffer vessel. The biomass boiler will only fire once the buffer vessel has fully discharged (the cold interface having reached the upper temperature sensor).

While it is heating up, shown as a one-hour period in Figure 17, the auxiliary boiler has to fire to provide much of the heat during the pre-heat period. When the biomass boiler eventually comes on line the load is shared between the biomass boiler and the auxiliary boiler. In this example 85% of the energy is being provided by the biomass boiler.

In order to prevent the auxiliary boiler from supplying the full load at any point during the day either an improved control system or a much larger buffer vessel is required. These options are explored below. The problem described above can be alleviated by moving the boiler start sensor further down the tank or programming the boiler to run immediately a heat demand is received, although this may not be possible on simple systems.

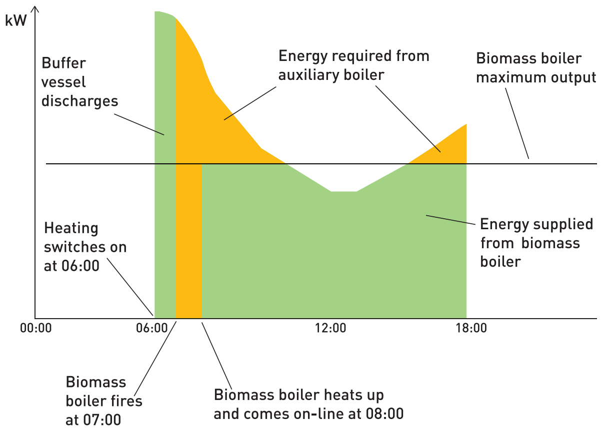


Figure 17
Typical winter load profile for a building occupied during the daytime (after D. Palmer).

Progressive control systems

All of the more expensive and sophisticated boiler systems, and some of the smaller and cheaper ones, use a progressive control system. Progressive control uses a number of temperature sensors, typically between 5 and 9, installed in a line up the buffer vessel. At daily start-up, pump 2 begins to draw water from the buffer vessel as before, but as soon as the cold interface reaches the next temperature sensor, shown in Figure 18 as T4, the boiler fires. The output of the boiler then modulates so that it is at full output by the time the cold interface reaches the top sensor.

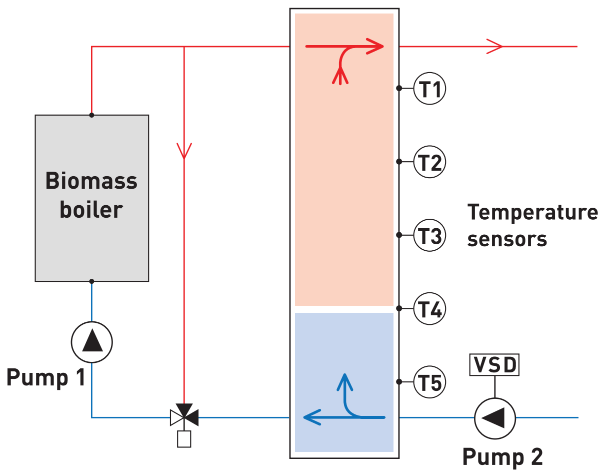


Figure 18
Progressive buffer vessel control system using multiple sensors (after D. Palmer).

Clearly it is important that the energy storage in the buffer vessel is matched to the time it takes for the boiler to start up, and this will usually determine the buffer vessel capacity required. Some of the boilers using this system are sufficiently sophisticated to have little or no need for a buffer vessel to protect the boiler or improve its efficiency, the buffer vessel being required to meet as great a proportion of the annual heat energy demand as possible.

[2] The 'design winter day' is the one used to represent the worst case winter temperature profile expected for a given location.

System design

Recommended connection methods and design considerations

Flash steam

There are a number of principal considerations when connecting a biomass system to an existing or planned heating system. Most heating systems are designed to operate at 82 °C flow, 71 °C return, to avoid producing steam in the heating system in the event of a sudden system depressurisation or system overheating. This is a major safety consideration. Steam, known as flash steam, will form in a system pressurised to more than 1 bar if the system depressurises rapidly. The operating pressure will be well over 1 bar even in systems pressurised by a gravity header tank. By holding the design operating temperature down to 82 °C, a flash margin of 18 °C is provided so that flash steam cannot be produced. However, to maximise the thermal storage capacity of a buffer tank it is better to operate the biomass system at up to 95 °C and where possible to design the heating circuits to return at a temperature lower than 71 °C.

Corrosion prevention

To prevent corrosion within the boiler, the minimum return temperature when burning drier fuels (20% MC and below) should be 60 °C, but a return temperature of 65 °C is required when burning fuels with 50% MC. This is achieved in the majority of systems by using a three port back-end protection valve and boiler circulating pump, and these components (valve and pump 1) are shown in all the figures in this section on system design.

Hydraulic stability

Another consideration is the hydraulic stability of the overall system. By far the best way of connecting a biomass boiler is via a low loss header, as shown in Figures 19 and 20. Current practice is to design new boiler installations using a low loss header.

The use of a variable speed drive pump, necessary to allow water to be drawn from both the buffer vessel and the boiler simultaneously, means that hydraulic instability would occur if the boiler and buffer were to be connected to split headers.

Split headers are separate flow and return headers with all of the pumps on one or other of the headers. Split headers result in variable flows through the boilers as load circuit pumps switch on and off (which are commonly found in existing boiler houses).

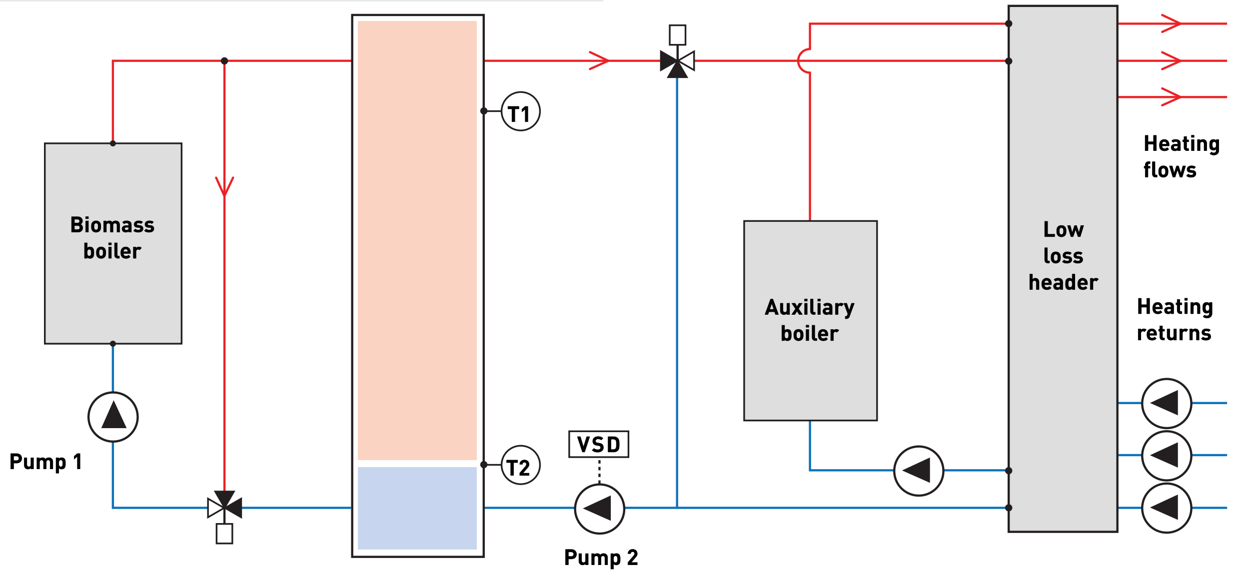
Instability, or poor performance from the biomass boiler, may also occur if the boiler is sized as a base load boiler or at a low percentage of the peak load. A low loss header is strongly recommended and, if this is not possible, the biomass boiler should be connected via a plate heat exchanger as discussed in System optimisation (page 17).

Low loss header

A low loss header is a section of pipe connected across the boiler flow and boiler return connections which is larger in diameter than the pipes connected to the boiler. The water velocity in this header is low, resulting in low pressure losses (hence the name 'low loss header') and this enables water to be drawn from and returned to the header on the load side without disturbing the pressure or flow balance through the boiler(s).

Figure 19

Direct connection method using a low loss header (after D. Palmer).



Where a large buffer vessel or thermal store is employed this can itself act as a low loss header, simplifying the design of systems. The actual configuration required will depend on the whether existing fossil fuel boilers are to be connected as part of a biomass system and how these are connected to both the biomass system and the load circuits.

Figure 20 is an example of a system incorporating both fossil fuel and biomass boilers.

System optimisation

A biomass boiler can be connected directly to a system operating at 82 °C flow providing the temperature in the buffer vessel does not exceed this temperature by more than a few degrees. With a typical mean circuit return temperature greater than 60 °C, the temperature difference across the buffer vessel is only 20 °C. Since the energy storage capacity of a buffer is directly proportional to the temperature difference across it, a low temperature difference means a larger buffer vessel is needed to store the required heat. If only variable temperature (external temperature compensated) load circuits are present the associated control system will allow the buffer vessel to operate at a higher temperature together with low return temperatures to optimise the energy storage capacity.

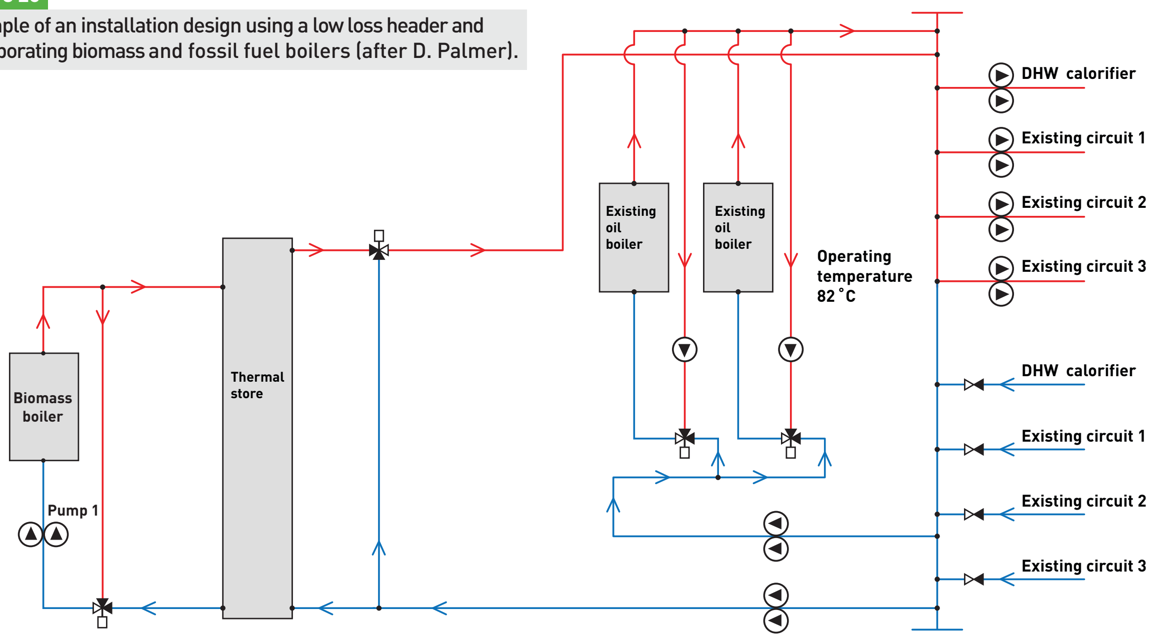
This means that it is not uncommon to operate biomass boilers at a temperature of up to 95 °C, and sometimes as high as 110 °C on larger boilers. Unfortunately, if a boiler and buffer vessel operating at above 85 °C are directly connected to a system operating at 82 °C, the system pressure may need to be increased to accommodate the higher operating temperature (to prevent flash steam formation).

Depending on the nature of the lower temperature heating system it may not be possible to increase pressure sufficiently to provide an adequate flash margin. In this case it may be necessary to isolate the biomass boiler from the heating system and auxiliary boiler by using a plate heat exchanger, to allow an increase in the system pressure accordingly. While some manufacturers design their boilers to operate at 90 °C or 95 °C, a more expensive boiler and equipment designed to operate at a higher pressure (including the buffer vessel) may be required; this will always be the case with operation at 110 °C.

When connecting to an existing heating system, if it is not possible to reconfigure the system to a low loss header system as shown in Figures 19 and 20, the simplest way to ensure the existing system remains hydraulically balanced is to replace one of the existing boilers with a plate heat exchanger. Providing the pressure loss on the secondary of the plate heat exchanger at full load is equal to that of the boiler it replaces, the existing heating system should continue to operate as before without the need for a circuit rebalancing exercise.

Figure 20

Example of an installation design using a low loss header and incorporating biomass and fossil fuel boilers (after D. Palmer).



An example biomass system

Figure 21 shows an actual system designed to operate at 110 °C and driving a district heating system operating at 6 bar. Plate heat exchangers are installed in every building served by the district heating system. The control is progressive and a large head space is left at the top of the first buffer vessel to allow the biomass boiler to contribute to the daily heat-up demand together with the buffer vessels. The buffer vessels sit side by side in the boiler house but the effect is of a very tall buffer vessel due to the way in which they are connected. The system operates at a temperature differential of 40 °C which, with 60 000 litres of buffer capacity, gives an energy storage of 2800 kWh which is equivalent to the biomass boiler operating for almost 2 hours. The biomass boiler is sized at 30% of the system peak load of 4.8 MW, and this combination of boiler and buffer capacity is able to supply 95% of the annual heat demand.

Biomass system design software

It is important to understand that the sizing for every boiler will be different, based on the heat load demand pattern for the building or process being serviced and the winter peak load, and that sizing must not be based on generalised advice or experience.

The Carbon Trust has released biomass system design software which is available as a free download from their website here: www.carbontrust.co.uk/emerging-technologies/current-focus-areas/biomass/pages/biomass-tool.aspx. This software was designed specifically to address the issue of oversized boilers and undersized buffer vessels, and allows the system designer to size a boiler and buffer combination accurately while minimising capital cost and maximising carbon savings.

Forestry Commission technical development have also designed a simple tool available here: www.biomassenergycentre.org.uk/portal/page?_pageid=74,373197&_dad=portal&_schema=PORTAL

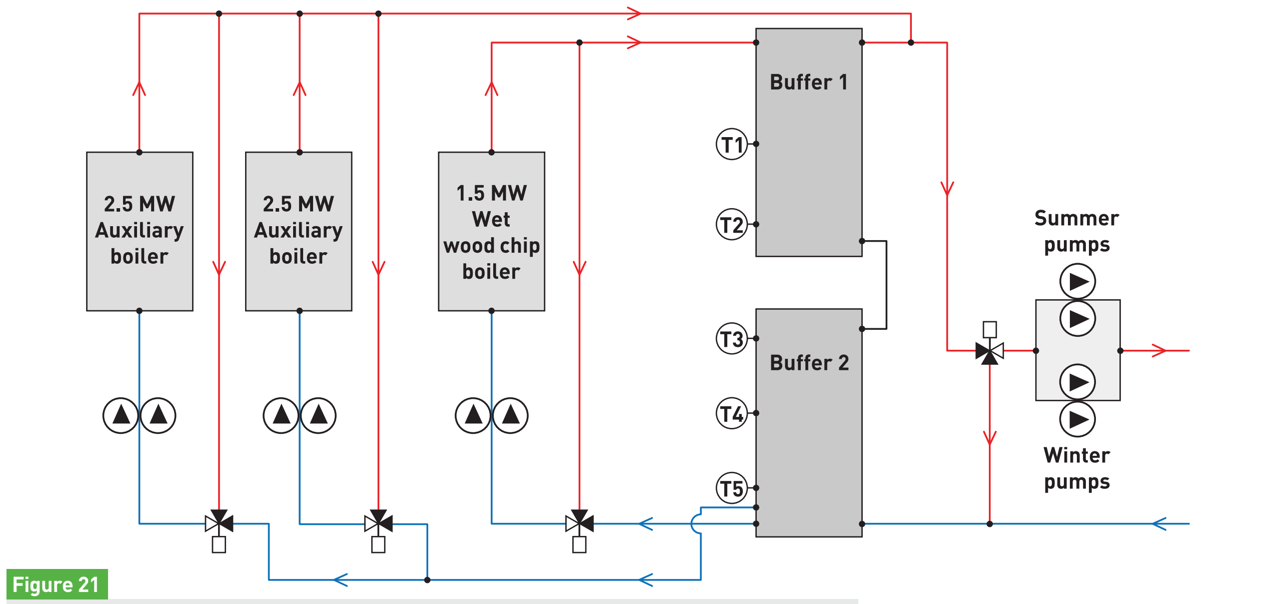


Figure 21

Case study: wood chip and auxiliary boiler installation designed to drive a district heating system (courtesy Queen Margaret University, Edinburgh and Buccleuch Bioenergy Ltd).

Emissions and abatement technologies

Emissions

The complete combustion of wood produces emissions of fine particulates, nitrogen dioxide (NO_2) and carbon dioxide (CO_2), whereas the incomplete combustion of wood results in the release of volatile organic gases, much higher levels of particulates, carbon monoxide (CO) and other undesirable substances, some of which are carcinogenic. The emission of black smoke from a chimney is a visible sign of incomplete combustion. In order to ensure the complete combustion of wood fuel, biomass boilers require the following features:

- An adaptive fuel feed mechanism which adjusts the amount of fuel fed into the boiler in real time, depending on the instantaneous load on the boiler.
- The monitoring of boiler flow and return temperatures, and their use via a control system, to regulate the fuel feed rate and the speed of combustion air fans.
- Separately controllable primary and secondary combustion air (also tertiary air control on boilers above about 5 MW).
- A flue gas oxygen sensor (Lambda sensor) to monitor the oxygen content in the flue and, via a control system, to ensure sufficient excess oxygen is supplied for complete combustion by regulating secondary and tertiary air fans. This is not always used.

In order to avoid the production of black smoke from a biomass boiler chimney the following conditions must be met:

- The boiler must operate within its turndown band, e.g. a 300 kW boiler with a 3:1 turndown ratio must not operate if the load falls below 100 kW. Either the boiler must switch off, or it must enter a slumber mode, or it must operate with a buffer vessel in parallel to accept the excess energy produced.
- The moisture content of the fuel must be within the range the boiler can accept. In particular, fuel with a moisture content greater than that which the boiler can accept will invariably produce black smoke.

Abatement technologies

Table 2 details the available emissions abatement technologies and their properties. Many of these technologies require significant maintenance, have high operating costs and require the disposal of waste.

Further detail on emissions from biomass combustion can be found in ***Biomass heating: a guide to biomass feasibility studies.***

Table 2

Emissions abatement technologies and their advantages and disadvantages.

Technology	Advantages	Disadvantages
Cyclone grit arrestor	Will take out most particulates down to about 20 micron.	Will not take out a significant proportion of PM_{10} and smaller. Will not take out any gas including NO_2.
Bag filter	Will take out most particulates down to about 1 micron (0.001mm) diameter. Will take out almost all PM_{10} and $PM_{2.5}$ particulates.	Regular filter cleaning required. A cyclone in series is advisable to reduce the load on the bag filter from larger particulates. Will not take out any gas including NO_2. Pressure losses through the filter can be very large if fine particles are to be filtered out. This requires a large induced draught fan. Unlikely to be commercially viable if flue gas temperatures exceed 200 °C.
Electrostatic filter	Will take out almost all particulates down to ultrafine particles, i.e. smaller than $PM_{2.5}$.	Must be used in series with a cyclone. Will not take out any gas including NO_2.
Wet scrubber	Will take out almost all particulates down to ultrafine particles, i.e. smaller than $PM_{2.5}$. Will dissolve gases including CO_2 and (less effectively) NO_2. Enables a high degree of heat recovery from the boiler flue gases.	Must be used in series with a cyclone. Weak acid produced as gases dissolve; requires neutralisation and the removal of salts from the scrubber water. Significantly reduces flue gas buoyancy.
Ceramic filter	Able to remove most particulates from high temperature flue gas. Long life expectancy.	Will not remove any gas including NO_x. Must be used in series with a cyclone. High cost.

Sources of further information

- DSEAR. *Dangerous substances and explosive atmosphere regulations 2002: approved code of practice and guidance L138*. HSE Books, 2003.
- *ATEX Explosives Atmospheres Directives 99/92/EC (ATEX 137) and 94/9/EC (ATEX 100).*
- *The Carbon Trust have a new biomass sizing tool available to download at: www.carbontrust.co.uk/emerging-technologies/current-focus-areas/biomass/pages/biomass-tool.aspx*
- Information on wood pellet stores can be found at: *www.brites.eu/downloads/Delivery_Checklist_brites_Commercial.pdf*
- *The Confined Spaces Regulations 1997, HSE.* A guide to the regulations *(Safe work in confined spaces)* can be found at: www.hse.gov.uk/PUBNS/indg258.pdf
- *Identification and characterisation of factors affecting losses in the large-scale, non-ventilated bulk storage of wood chips and development of best storage practices.* FES B/W2/00716/REP & DTI/Pub URN 02/1535 First Renewables Ltd 2002 can be found at: www.biomassenergycentre.org.uk/pls/portal/docs/PAGE/BEC_TECHNICAL/BEST%20PRACTICE/LOSSES%20IN%20CHIP%20STORAGE%20FILE14947.PDF

Biomass heating guides series

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Other guides in this series:
Biomass heating: a guide to small log and wood pellet systems
Biomass heating: a guide to biomass feasibility studies

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Written, co-ordinated and produced by David Palmer, Ian Tubby, Geoff Hogan and Will Rolls, and peer reviewed by members of the Renewable Energy Association.

Information on flue design and specification kindly supplied by HETAS.

For further information please contact: www.biomassenergycentre.org.uk
email: biomass.centre@forestry.gsi.gov.uk

Editing: Jenny Claridge

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