Chapter

Combustion Technologies and Heating Systems

3

3.1. Parameters Influencing Biomass Combustion Processes

The following parameters are important in influencing the factors of the biomass combustion process:

- Fuel quality
  - o Combustion temperature
- Mixing of the flue gases in the furnace
- Residence time of the flue gases in the furnace
- Process control

3.1.1. Fuel Quality

- Fuel type
- Size, density and porosity of fuel particles
- Moisture content
- Fuel composition (=> GCV)
- Volatile content and char content
- Thermal decomposition behaviour
- Ash content and ash behaviour

=> The combustion technology has to be appropriately adapted to the fuel quality!

3.1.2. Combustion Temperature

- Too low a combustion temperature
- High CO and TOC emissions, poor char burnout
- Too high a combustion temperature
- Problems with slagging in biomass furnaces
- Problems with hard ash deposit formation in furnaces and boilers

  => reduced lifetime and increased costs for maintenance as well as furnace and boiler cleaning
- Combustion temperature control
- By flue gas recirculation

- By cooled surfaces
- Combination of a) and b)

Without applying flue gas recirculation or cooling, the combustion temperature depends on the fuel composition, the excess air ratio and the combustion air temperature.

3.1.3. Mixing and Residence Time

- Fuel distribution
  - o Homogeneous fuel distribution over the fuel bed is a basic demand for efficient low emission combustion.
- Air staging and air distribution
  - o Provides possibilities to reduce CO and NO_x emissions.
- Mixing of flue gases
  - o Relevant for a complete burnout of the gases and low CO and TOC emissions.
  - o Can be achieved through the appropriate design of the geometry, number and position of the secondary air inlet nozzles, as well as of the furnace geometry.
- Residence time of the flue gases in the hot furnace
  - o Should be long enough to achieve a complete burnout of the gases.

3.1.4. Process Control

- Load control
  - o The process should be run as smoothly as possible.

"Stop-and-Go" operations should be avoided.

- Air staging and air distribution (combustion control).
  - o The process control strategy should provide possibilities for a flexible distribution of the combustion air within the furnace as a basis for a low-emission combustion concept.

The excess air ratio can influence the combustion process as follows:
Too low an excess air ratio causes high CO and TOC emissions.
Too high an excess air ratio causes:

– higher CO emissions

– increased flue gas flows => higher energy demand for air fans and requires a larger combustion unit

– decreased thermal efficiency of the combustion unit due to higher heat losses with the flue gas

–increased particle entrainment from the fuel bed

=> higher amounts of fly ash

- Temperature control

–An appropriate furnace temperature control, so as to avoid problems with slagging and deposit formation, as well as to guarantee a complete combustion, should be implemented.

- Pressure control

–The suction fan should be controlled as smoothly as possible.

3.2. Biomass Boilers

3.2.1. Top Feed Burners

Top feed burners have been specifically developed for pellet combustion in small-scale units. The pellets fall through a shaft onto the fire bed on the grate. During combustion the pellets sink from the top of the fire bed to its bottom, whereas the primary combustion air moves in the opposite direction. The long residence time of the pellets in the fire bed results in a high burnout rate. The separation of the feeding system and the fire bed ensures effective protection against burnback into the storage room. The proper distance between the combustion retort and feeding system prevents early ignition of pellets in the feeding system.

The ash is removed manually or mechanically using a dumping grate. This feeding system allows very accurate feeding of pellets according to the current power demand and is thus often used in furnaces with very small nominal heat flows.

3.2.2. Underfeed Burners

In underfeed burners (underfeed stoker or underfeed retort burners) the fuel is fed into the bottom of a combustion retort. The pellets move upwards in the course of the subsequent drying, gasification and combustion processes. After having reached burnout, the remaining ash is removed from the combustion zone. It drops from the edge of the retort into an ash collector, or a moving grate is used for ash removal.

Primary air is introduced into the combustion retort in the same direction as the fuel. Secondary combustion air can be introduced into the combustion chamber through an airring positioned at the edge of the combustion retort, or through separate air channels. In the first case, the underfeed burner is a very compact unit in which all necessary devices for satisfactory combustion are integrated.

Underfeed burners are suitable for combustion of lowash wood chips and pellet fuels. They are built for nominal heat flows of 10 kW up to 2.5 MW.

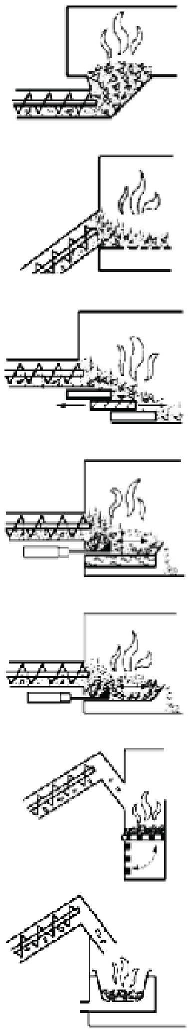
3.2.3. Horizontal Feed Burners

The principle of horizontal feed burners is similar to that of underfeed burners. The fuel is introduced into the combustion chamber from the side (with or without a grate). During combustion the fuel is moved or pushed horizontally from the feeding zone to the other side of the pusher plate or the grate. On its way to drying, gasification and solid combustion take place. The remaining ash drops into an ash container.

Primary air is passed into the primary combustion zone through the grate or, if there is no grate, through air nozzles or air channels. Horizontal feed burners can burn wood chips and pellets, and are built for nominal heat flows from 15 kW up to 20 MW.

A detailed classification of automated biomass combustion systems is shown in Table 3.

Table 3. Detailed classification of automated biomass combustion systems (Hartmann et al. 2003)

Principle	Variation	Type	Scheme	Nominal flow	Fuel
Underfeed				from 10 kW (to 2.5 MW)	wood pellets, wood chips
Horizontal feed	grate-firing	stiff grate		from 35 kW	wood pellets, wood chips
		moving grate (shuttling grate)		from 100 kW (to > 20 MW)	wood pellets (from 15 kW), wood chips, sawdust, bark
	pusher plate firing (without grate)	with water cooling beneath the fire bed		from 25 kW (to 800 kW)	wood pellets (from 15 kW), wood chips, straw, corn
		without water cooling beneath the fire bed		from 25 kW (to 800 kW)	wood pellets (from 15 kW), wood chips
Top feed	with grate	dumping grate-firing		from 15 kW (to 30 kW)	wood pellets, probably high quality wood chips
	without grate	retort-firing		from 6 kW (to 30 kW)	wood pellets, probably high quality wood chips
		tunnel-firing		from 10 kW	wood pellets

3.3. Biomass Boilers

A solid fuel heat plant or a boiler house consists of a number of elements, which can vary depending on the fuel and the combustion method. All solid fuel heat plants consist of (at minimum) fuel reception, fuel storage, fuel handling equipment, fuel combustion equipment, boiler, flue gas cleaning equipment, smoke stack (chimney), ash handling equipment and controlling equipment. On the domestic scale (e.g. central heating boilers) the technical requirements for system automation are smaller and requirements for fuel quality higher (Jalovaara, et al. 2003, Saramäki 2007, Energiateollisuus ry, Ympäristöministeriö 2012).

3.3.1. Fuel Receiving and Storage

Storage facilities may consist of silos (Figure 31), outdoor storage areas (Figure 32) or other buildings where fuel may be stored (Figure 33). Storage facilities can be either at the plant itself or, if it is buffer storage, further away from the plant. If there are great amounts of fuel used, for example in medium and largescale heat plants using fluidised bed combustion, the fuel is normally stored outside and without a shelter, to save costs on storage building construction. In fluidised bed combustion plants consistent moisture content is not necessary as the moister and drier fuels can be mixed, and for this reason, outdoor storage can be used.

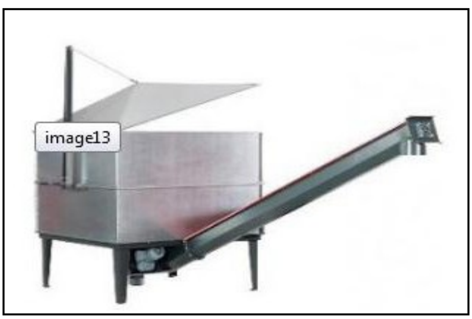


Figure 31. Fuel silo (Multiheat.fi)

Figure 32. Outdoor fuel storage area (EUBIONET2)

Silos and storages are scaled so that they can hold a sufficient amount of fuel for a few days use at peak time. The size of the plant, fuels used, capacities of transport vehicles and organisation of the transport dictates the fuel reception and storage system requirements. A general rule of thumb is that the size of the storage should be at least 1.5 times the capacity of the transport vehicle. On the other hand, in case no fuel deliveries take place during weekends, storage should be sufficient for at least 64 hours runtime on full capacity. The construction of silos and storage buildings should take into account the way the fuel will be unloaded into the storage. The energy content and densities of the fuel matter: the storage must be sized for the minimum values of energy content and densities of the fuel matter.

The doors in storage rooms should be big enough and open wide enough (Figure 33), and the drop height of the unloading site should be adequate, for trucks and tractors to unload easily (Figure 34) (Saramäki 2007, Energiateollisuus ry, Ympäristöministeriö 2012).

Figure 33. Chip storage building (Uusimaaseutu.fi)

Figure 34. Unloading of chips to fuel storage (Alakangas, 2013)

3.3.2. Fuel Feeding

Once the chips or other fuel is unloaded into the silo or other storage, it needs to find its way to the fuel burner. Dischargers and unloaders are used for this, together with conveyors. The dischargers and unloaders move the fuel in the storage for the conveyor to transport it forwards. Depending on the type and shape of the storage, and the type of fuel, different applications are used.

Fuel in storage can be moved with spring (rotor) feeders, bar (or scraper or moving floor) unloaders, or chip discharger augers. Spring unloaders can be used for unloading silos or storage bunkers and containers. A spring is attached to the middle of the storage area, and the spring rotates, with its "whiskers" moving the fuel in the storage. An auger is commonly attached to a spring unloader (Figure 35 and 36) or a push bar unloader is connected to an auger conveyer (Figure 37), which forwards the fuel to the combustion chamber. In larger installations drag chain unloaders (Figure 38) can also be used, where the scrapers are moved in the storage by a chain. Bar, also referred to as scraper or moving floor, unloaders are suitable for rectangular or square bunkers or silos, with a flat bottom (Saramäki 2007, Energiateollisuus ry, Ympäristöministeriö 2012).

Figures 35 and 36. Spring feeder (Kardonar.com)

Figure 37. A hydraulic push bar unloader with auger conveyor. The fuel is pushed from the storage on the right side to the auger (EUBIONET2)

Figure 38. Drag chain unloader (EUBIONET2)

3.3.3. Combustion Technology

Wood fuels can basically be combusted using a stoker, grate combustion, or fluidised bed combustion. Stoker burners are more common in farmhouses and are suitable for the small scale burning of mainly wood chips. Grate combustion is used in small and medium sized heat plants, whilst fluidised beds are used in larger scale plants.

3.3.3.1. Stoker Combustion

Stoker combustion is best suited to small scale, single-house boilers, which have up to approximately 100 kW output. The biggest stoker applications can have output up to 3 MW. A stoker burner combusts the fuel (usually wood chips, grain, briquettes or pellets) in the burner, where the fuel is fed in automatically, and not in the boiler itself. The fuel is fed to the burner using an auger, and air is blown from under the fuel to provide primary air, and over the fuel to provide secondary air (Figure 39). A large flame passes through the boiler, heating the water. The moist fuel is dried in the auger by the burning chips in the burner. Ash is removed at the end of the combustion process, where it falls into an ash container.

Stoker burners are available in many different sizes. Usually the silos for the smallest ones are filled manually (day silo size usually 0.5 m^3). Larger ones have larger silos e.g. 8 m^3 and can be filled using the front loader of a tractor. All silos over 0.5 m^3 must be located in a separate fuel storage room or outside the boiler house due to fire safety regulations (Figures 40 and 41).

The maximum moisture content for the fuel used in stoker systems is 45%. Usually the smaller the system is, the higher the demand for fuel quality (even particle size, low moisture content, no stones, long particles, dirt or other impurities) (Jalovaara, et al. 2003, Saramäki 2007, Energiateollisuus ry, Ympäristöministeriö 2012).

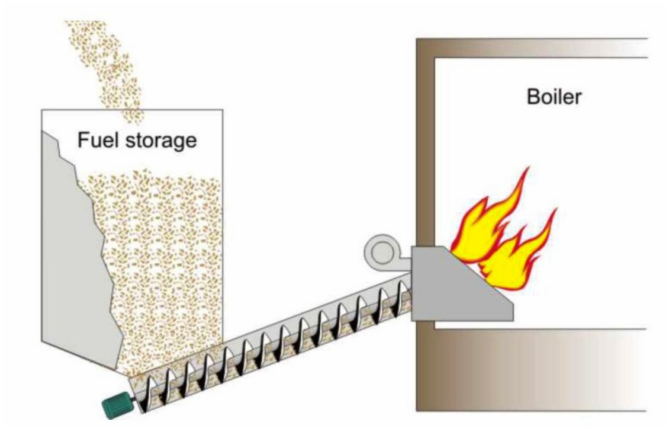


Figure 39. Typical stoker burner (EUBIONET2)

Figure 40. Manually filled stoker burner (40 kW) and a boiler (30 kW), common system for a single family house (0.5 m³ container)

Figure 41. Stoker burner with 8 m³ container for systems with output of 40–500 kW (bioenergianeuvoja.fi)

3.3.3.2. Grate Combustion

Grate combustion was originally designed for the firing of coal. Usually it is applied to a large extent for the firing of biomass. Grate combustion is suitable for heat plants under the size of 30 MW using solid fuels. Grate combustion is used for example, in single family houses (15–40 kW), boilers in larger buildings or clusters of buildings (40–400 kW) and district heating plants (400 kW–20 MW). The grates are mechanical surfaces, where the fuel is combusted. Grates can be fixed or moving, and they can be flat or sloped. The holes between the grate bars supply primary air for the combustion process. In the first section of the grate, into which the fuel is fed, the fuel dries and heats up using the burning fuel ahead of it in the combustion chamber. At the end of the grate the only remaining substance is ash. During combustion in the grate the fuel is gasified in the primary air, and the secondary air is used for combusting the gases. The heat is recovered in the convection area. There are different types of grates, which all have a slightly different operating method. The types are:

- Flat, fixed grate;
- Skew, fixed grate (inclined grate);
- Skew, moving grate;
- Skew, moving rotating grate;
- Chain grate;
- Other special grates (waste incineration grates).

The small grates are usually cooled with primary air and larger ones with circulating cooling water. With modern grate technology, heterogeneous biomass fuels can be combusted efficiently. With specialised grates, fuels with a moisture content of up to 65% can be fired, and it is the fuel feeding technology that sets the limit for particle size, not the grate technology. Suitable fuel includes bark (possibly mixed with sawdust and cutter shavings), logging residue chips and, as a small share also agricultural biomasses such as straw and reed canary grass.

Fixed grates are mainly suitable for single-family houses, as they are quite demanding in the type and moisture of the fuel used. As the grate is static, it leaves little room for adjustment. Fuel is fed into the top of the grate (inclined grate), and moves down along the grate with the help of gravity and, in the case of a flat grate, onto the grate directly. Fixed grates (Figure 42) are economical but as their adjustability is poor, manual feeding is necessary. Primary combustion air is supplied from below, through the grate bars, which also speeds up drying of the fuel. The combustion process heats the grate as well, and the grate can be cooled down by water pipes in the grate or with the primary combustion air. If moist fuel is used, the fuel needs to be warmed with preheated air to enable complete burning. The fuel needs to be spread evenly on the grate, and a sufficient amount of fuel needs to be present. The ash is collected at the end of the process into a container, and can be removed using screws or scrapers.

Figure 42. The BioGrate grate burner for moist fuels (Metso Power, range 4–20 MW). The fuel is fed with an auger, from below to the centre of the grate. The fuel dries in the middle of the grate by means of the heat radiating from the refractory lining bricks and the flames, without disturbing the burning fuel bed in the combustion zone. From the centre the fuel travels towards the outer circle of the grate, moved by the grate fuel feeders. After almost complete combustion of the residual carbon, the ash falls from the edge of the grate to the ash space filled with quenching water (Metso Power)

The basic principle of the moving grate (Figure 43) is similar to the fixed grate; it operates as a surface for the combustion, whilst at the same time drying the fuel which has not yet ignited. A step grate is moved by hydraulic cylinders and pumps, which make the fuel “roll” down from the top. If there are clusters of ignited fuel, they are also efficiently reduced to smaller clusters by the movement. Moving grates can also be moved by a chain, and the flat, horizontal grates are attached to each other by a chain. The fuel is fed from the other end, and once the chain grates have transferred the fuel though to the end of the combustion chamber, the ash falls into the ash container. The advantages of using moving grates are that they enable the combustion of lower quality fuels, and the combustion process is cleaner, as the moving of the grate minimises the amount of incompletely burned fuel by breaking it to smaller clusters (Saramäki 2007, Energiateollisuus ry, Ympäristöministeriö 2012).

Figure 43. Fixed grate system. Fixed step grate solutions are excellent for heating plants fuelled by wood chips. The traditional fixed step grate is a cost effective and tried burner solution in the 700–3,000 kW category (Ariterm Group)

Figure 44. A moving grate system manufactured for the scale of 40–1,500 kW. A moving grate bio burner is designed to utilise several different kinds of solid bio fuels. The burner is able to use wood chip of varying quality, wood and peat pellets, peat and various agro biomasses. The grate of the burner is fully mobile and this enables the fuel to mix efficiently on its surface. The grate's mobility improves transport of the ash from the burning head to the ash compartment (Ariterm Group)

3.3.3.3. Fluidised Bed Combustion

Fluidised bed boilers are suitable for larger scale heat plants, and well established at the scale of 10 MWth upwards, although installations with an output of 2 MW exist. These can be divided in two groups based on their operational characteristics: circulating fluidised bed boilers (CFB) and bubbling fluidised bed boilers (BFB). CFB technology is usually available at the scale of >100 MW and thus this report will focus on BFB technology. In the fluidised bed boiler the fuel is fed into the boiler and is then blown from under the bed into a moving phase with air. The bed is made with hot sand or minerals and when the fuel comes into contact with the hot substances they are quickly vaporised and ignited. In addition to the hot sand or minerals, ash can be used, and there is also some ash from the fuel in the bed. As a result of the flow of air, the bed material, which is usually sand and the fuel, float in the furnace, more or less fluid-like.

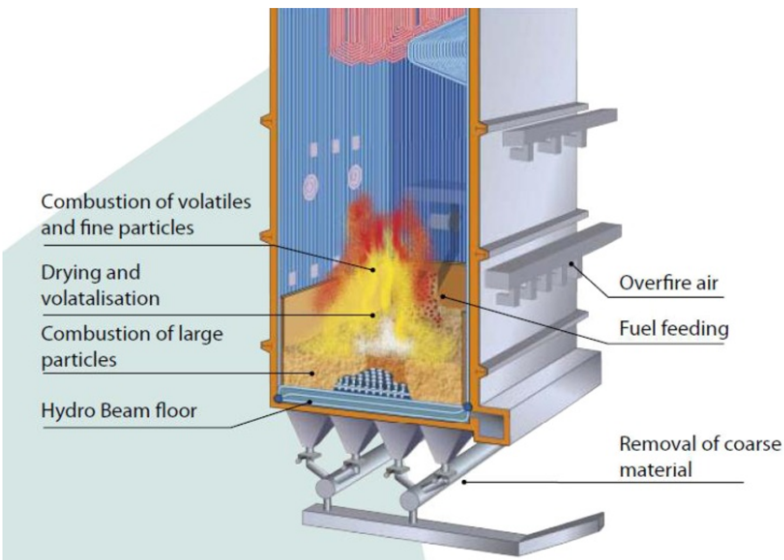


Figure 45. Bubbling fluidised bed boiler (Metso Power)

Two different types of fluidised bed boilers are generally used in biomass combustion; bubbling fluidised bed and circulating fluidised bed. Different versions of these beds are also used. Fuel is fed into the boiler from above the bed or to the bottom of the bed by auger feeders, pneumatic blowers or spreaders. The combustion process is stable and at a rather low temperature, 750–900 °C, which leads to smaller NO_x and SO_x emissions. The fluidised beds tolerate mixtures of fuels of different quality and moisture content. Usual biomass fuels are forest chips, bark, sawdust and milled peat (Jalovaara, et al. 2003, Saramäki 2007, Energiateollisuus ry, Ympäristöministeriö 2012).

3.3.4. Fuel Sampling

Fuel suppliers are often paid according to the energy content of their fuel, and therefore the moisture content and density of the fuel must be determined. Another important factor is the volume of the load. With these three factors the energy content of each received fuel load can be determined.

For most accurate results it is recommended to first take samples from falling streams while unloading the fuel transport vehicles, if possible. Unloaded fuel stockpiled in for storage may have different moisture layers, which makes it difficult to take a representative sample, but it is recommended that at least 10 increments are taken from the falling stream and then put together for a combined sample (50 litres). The combined sample is then divided for to provide an analysis sample for moisture content determination by using, for example, coning and quartering (Figure 46 and 47).

Figure 46. Fill the container (0.05 m^3, 50 litres) and drop it freely from 15 cm height onto a wooden board. Repeat shock two times (photo on the left) and then remove surplus material by using a small scantling, which is shuffled over the container´s edge in oscillating movements (photo in the middle). Weigh the container (photo on the right). The weight of the sample is the total weight minus the weight of the empty container (scaled earlier) (SolidStandards)

Figure 47. Corning and quartering for moisture content analysis. Divide as many times as needed to provide a sample for moisture content analysis (at least 300 g) (SolidStandards)

Moisture content at a plant can be analysed using a normal kitchen oven, by drying the sample (at least 300 grams) in an oven for a maximum of 24 hours at 105°C. The moisture content is the change in the weight of the sample before and after drying compared to the initial weight. Bulk density analysis is carried out using a 50 litre container. It is possible to combine moisture content and bulk density sampling. First bulk density is analysed according to Figure 46 and then the sample is divided for moisture content analysis by coning and quartering according to Figure 47 (SolidStandards-project, Jalovaara, et al. 2003).

3.4. Biomass District Heating Systems

The network pipes are used for transferring the heat from the boiler to the customers. The pipes consist of two pipelines, the feed and return pipes, which are insulated. The network piping is normally installed underground, below the ground frost level. The network is generally made of iron or steel pipes, although plastic pipes are also used nowadays. If the pipes are installed in a new unbuilt area, they can be installed at the same time as other pipes and cables. This saves resources, as they can all be put underground simultaneously. If the pipes are installed in a built-up area, extra care needs to be taken with existing piping and cabling. The piping material is chosen based on the maximum allowed temperature of the heating water, and the steel pipes tolerate hotter water. Plastic piping is suitable for small networks. The heating network is dimensioned according to the consumer's maximum power for heating and ventilation, and the water flow used for heating household water (Jalovaara, et al. 2003, Saramäki 2007, Energiateollisuus ry, Ympäristöministeriö 2012).

3.5. Applications for End Users

The only applications or devices needed by the end user are a heat meter and a heat exchanger. Heat is normally measured at the client's premises (Figure 48), which is the border where the ownership of the pipes changes. Correct operation of the heat meter is essential: if the heat meter is not functioning properly, the invoicing will be mismatched to the overall heat supply, causing loss to one or both of the parties (Saramäki 2007).

Figure 48. Heat exchange equipment (Rakentaja.fi)

If all the heat produced in the heat plant is sold to one building only, it is possible to invoice the heat based on the total heat produced in the plant. In most cases, the heat is sold to many buildings, although it is done through a single client. If the heat is sold to separate buildings, the heat may be invoiced according to the heat delivered to the client, and verified from the heat measuring device. Heat is generally invoiced monthly and the normal basis for pricing is MWh (Saramäki 2007, Energiateollisuus ry, Ympäristöministeriö 2012).