6. Combustion of wood pellets

This chapter describes the theory of wood pellet combustion.

6.1 The combustion phases

There are more or less four consecutive phases to burning pellets:

1. Drying and evaporation of water
2. Gasification (pyrolysis)
3. Gas combustion
4. Coke burnout

When combusting wood pellets, approximately 80 % of the energy is released as gas, and approximately 20 % is released from the remaining coke.

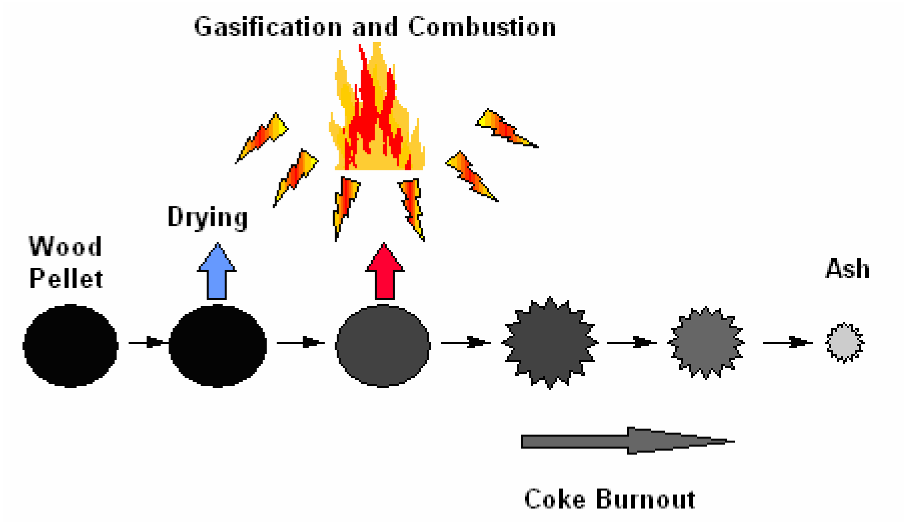

Figure 6.1. Combustion of a wood pellet. The fresh wood pellet goes through drying and gasification, whereby the flames are created. The pellet is burned out leaving ash behind. [1]

Drying

When a portion of wood pellets are being fed into a combustion chamber where combustion is already taking place, the heat from the combustion will make the water which is contained in the wood pellets evaporate. This evaporation demands heat. The heat is taken from the combustion already in progress. Since the water content of wood pellets is relatively low, this phase will quickly passes into the gasification phase.

Gasification (pyrolysis)

With further heating the wood pellets start to emit gases. At approximately 270 °C gasification will produce the heat necessary to continue the process. Carbon monoxide (CO), hydrogen (H_2) and methane (CH_4) are created along with other hydrocarbons.

Gas combustion

If there is sufficient oxygen present the gases will be ignited when they reach their ignition temperature. The hydrogen will react with oxygen and create water and the carbon of the hydrocarbons and the carbon monoxide will burn into carbon dioxide and water vapor. If the temperature is not high enough or there is not enough oxygen to feed the combustion, the gasses will be seen as smoke that will burst into flames, when the temperature or the inflow of oxygen is increased.

Burnout of coke?

When the wood has emitted all gases, the remaining carbon particles will burn out, helped by temperature, primary air and turbulence. There will be embers but almost no flames. The remaining ash residue consists primarily of incombustible minerals.

6.2 Heating value

The heating value is an indication of the amount of energy that a certain fuel contains. When calculating the heating value, one often assumes that the fuel is completely dry and that the ash is not included in the calculation. You are then talking about heating value on a dry and ash free basis (daf).

Heating value is usually described in megajouoles per kilogram of fuel, shortened to MJ/kg or in gigajoules per ton (GJ/t). The fuel weight is stated inclusive of water content, which is why it is important to know the percentage of moisture that the stated heating value refers to. In practice it is the heating value and the water content of the fuel that is of most importance.

Wood has a heating value on a dry basis of 19.0 MJ/kg. If the water content is estimated at 7 % the heating value of wood pellets can roughly be calculated as

$$19.0 - (0.2145 * 7) = 17.5 \text{ MJ/kg}$$

6.3 The impact of the fuel on the plant technology

Water content

Dry wood has a high heating value and the heat from the combustion has to be diverted from the combustion chamber in order to prevent high temperatures damaging the plant. Wet wood has a lower heating value and the combustion chamber has to be insulated in order to keep the heat in and the combustion process going. This is typically done by insulating the combustion chamber with fireproof and heat insulating tiles.

Normally therefore the boiler will be designed to burn wood at a specific moisture content. Because of this wood pellets should only be used in a plant that has been designed to combust wood pellets. Likewise, other fuels should not be used in a plant that has been designed to burn wood pellets.

Ash

In wood pellets there are different impurities consisting of non-combustible components, namely ash. In itself, ash is undesirable, since it involves particle-purification of the flue gas and the disposal of ash and slag. The ash content in wood is caused by dirt and sand retained in the bark and from salts absorbed during the tree’s growth period.

Wood pellets have low ash content, often at around 0.5 %. The ash consists partly of non-combustible minerals from the biomass and partly from mineral matter, sand and dirt that can be in the bark or be absorbed from the forest floor. Wood chips and firewood have an ash content of 0.5-3.0 %, while straw can contain up to 8 % ash. The ash content is importance as it forms a part of the fuel that cannot be used for, since the ash does not give off heat, but on the contrary demands heat for its formation.

In the ash there are small amounts of heavy metals, which are a source of unwanted contamination, but the content of heavy metals are generally lower than in the ash from other solid fuels.

Salts

Wood pellets also contain salts that have an influence on the combustion process. The salts are mainly potassium and partly sodium. Potassium and sodium give a tacky ash, which are more likely to cover the surfaces of the boiler. The content of potassium and sodium in wood is normally so low that no problems occur when firing it through traditional heating technologies.

	% of dry matter
K	0.1
Na	0.015
P	0.02
Ca	0.2
Mg	0.04

Figure 6.2. Typical mineral fractions in wood chips stated in % of the dry matter of the wood. In comparison to straw the content of potassium in wood chips is approx. 10 times lower [2 and 3]

When the ash is heated sufficiently the ash particles become soft and tacky. The temperature of softening varies between the different kinds of biofuel. For most wood fuels, including wood pellets, the softening temperature is approx. 1100 °C. If the ash particles in the flue gas are heated to more than 1100 °C, they will stick to the walls in the boiler unit and create an isolating layer which reduces the transfer of heat to the boiler water. This then demands frequent cleaning of the boiler piping and so on. On further heating the ash will melt completely and create slag, which is very difficult to remove.

Volatile elements

Wood pellets contain approximately 80 % volatile elements (in % of dry matter). This means, that the component part of the wood during heating will release 80 % of its weight as gasses, while the remaining part will be turned into charcoal. The high content of volatile elements means that combustion-air has to be added over the fuel bed (secondary air) where the actual combustion of gases takes place, and not under the fuel bed (primary air).

6.4 Combustion technique

An effective and complete combustion is a necessity for the effective utilisation of wood pellets as an environmentally friendly fuel. Besides ensuring a high energy efficiency the combustion process has to ensure, that there are no unwanted environmental components created.

Fundamentals for good combustion

In order to sustain combustion, certain fundamental conditions have to be met [4]:

- The effective mixing of fuel and oxygen (air) to ensure a certain ratio
- There has to be a radiation of heat from the fuel in the combustion chamber to the new fuel in order for the combustion process to proceed.

It is important to understand that gasses burn as flames and that solid particles smolder, and that during the combustion of wood 80 % of the energy is released as gas and the rest is released from the charcoal remains.

High mix of wood pellets and air during crushing

During the mixing of the fuel and the air it is important to achieve good contact between the oxygen in the air and the flammable components of the wood. The better the contact the quicker and better the combustion. If the fuel is a gas, as for example natural gas, the mixture is optimal because the two gaseous matters can be mixed in the exact proportions wanted. The combustion can proceed fast and it is easy to regulate as we can supply more or less fuel. In order to obtain approximately the same scenario with wood pellets it is necessary to grind the pellets into very small particle sizes (like flour). These fine particles will follow the movement of the air. A good mixture can thereby be obtained with combustion that resembles a gas or oil flame.

The combustion technology for wood pellets and other solid fuels is therefore more complex and more complicated than for example the combustion technology in a natural gas or oil-fired boiler.

The crushing of wood pellets and the production of wood dust is only used in to a limited extent. At Avedøre II, a Danish large CHP plant, the solution found has been to crush the wood pellets in coal mills with the resulting wood dust being used in dust-burners In order to burn pellets in this way it is necessary to have a power plant boiler which has a high rate of efficiency (and controllability) which can burn a large range of fuels.

6.4.1 Excess air

Excess air (λ)

For combustion to occur, fuel requires the presence of a given amount of air (oxygen).

In the event of stoichiometric combustion (where all fuel is burned completely), the excess air figure λ (lambda) equals 1.

If more air than is required is present, there will be oxygen in the flue gas and λ is said to equal greater than 1 (e.g. when λ equals 2, twice the amount of air required to combust the fuel is being supplied).

Typical excess air number

In practice combustion will always take place with an excess air figure higher than 1, since it is impossible to achieve complete combustion with a stoichiometric amount of air. In figure 6.3 the typical excess air figures are shown along with the corresponding oxygen content left in the flue gas.

	Air-surplus number, λ	**O2, dry (%) (O2 is oxygen?–not sure what this heading means**
Fireplace, open	>3	>14
Wood stove	2,1-2,3 [should be 2.1 etc?]	11-12
District heating, wood chips	1,4-1,6	6-8
District heating, wood pellets	1,2-1,3	4-5
Power plant producing heat, wood dust	1,1-1,2	2-3

Figure 6.3. Typical air-surplus numbers, λ, and the resulting air-content in the flue-gas [5]

The excess air depends on combustion

The excess air figure is to a great extent dependent on the combustion technology and to some extent on the fuel. The amount of excess air when combusting wood pellets is typically lower than when combusting wood chips. The best combustion of wood fuels is *technology*

attained at an excess air figure λ of between 1.4 and 1.6. [6]

6.4.2 Combustion quality

The fuel influences the quality of combustion. At complete combustion only carbon dioxide and water are created. The wrong combination of fuel, plant type and supply of air can cause the bad utilisation of the fuel with consequential undesirable environmental effects.

Effective combustion requires:

- High temperature
- Surplus oxygen
- Retention time
- Mixing

In this way a low emission of carbon monoxide (CO), hydrocarbons and polyaromatic hydrocarbons (PAH) are ensured together with only a low content of unburned carbon in the ash. Unfortunately these very conditions (high temperature, high air surplus, long retention time) are the main reason for the creation of nitrous oxides (NO_x). Thus, the used technology should be so-called "low-NO_x"-i.e. technology which uses ways to reduce emissions of NO_x.

Apart from CO_2 and H_2O the flue gas will contain air (O_2, N_2 and Ar) and to a greater or lesser degree unwanted reaction-products such as CO, hydrocarbons, PAH, NO_x and so on.

Because of the homogenous structure of wood pellets with a large surface area and a uniform water content it is easier to obtain a homogenous combustion than with firewood or wood chips.

6.5 Combustion of wood pellets in smaller plants

Wood pellets contain a high level of so-called volatile gases. In order to achieve an inflammable mixture these gases have to be mixed with oxygen. To ensure complete combustion and thereby the largest possible utilisation of the energy in the fuel, it is important that combustion air is supplied all the time, in the right amount and in the right place.

6.5.1 Combustion air

The correct supply of air is is important

If sufficient air is not supplied some of the inflammable gasses will not get enough air to burn out and the flue gas will leave the chimney containing carbon monoxide (CO). If there is too much air the heating of the surplus air will require heat, and the flue gas will leave through the chimney with too high a temperature. A large surplus of air can also cause the flue gas to cool, so that the fuel does not burn out sufficiently.

Primary and secondary air

Besides a correct supply of air, a good mixing of air and gasses is necessary. This is achieved by supplying air partly early in the combustion zone (primary air) and partly later, where the air is mixed with the flue gas (secondary air). The mixing must happen before the gasses are cooled by passing the walls of the combustion chamber or by rarefaction with excess air.

Controlling the

In wood stoves and small solid fuel boiler systems the air supply happens by natural *air supply*

draught produced by the warm flue gas going up through the chimney. By this means negative pressure is created in the combustion chamber and fresh air is drawn both as primary and secondary air.

In most heating plants for wood pellets the supply of combustion air happens artificially, either with an air-blower or with a flue-exhaust fan. Air supply and distribution between primary and secondary air is controlled either manually or by different kinds of automatic controls. The most advanced control of the combustion air happens with the help of a lambda probe in the flue gas duct. This probe registers the excess oxygen in the flue gas and regulates the air supply according to this.

To ensure the right air supply, the minimal vacuum in the flue gas duct given by the manufacturer - usually 10-20 pascal or 1-2 mm water column – must be respected. Because of the pressure difference over the tubing the vacuum in the combustion chamber of many boiler systems can be as low as 1-2 pascal.

6.5.2 Combustion temperature

Combustion temperature approx 900-1000 °C

The necessary combustion temperature, approximately 900-1000 °C, is sustained partly by the right design of the combustion chamber relative to the fired amount of wood pellets and partly by matching the amount of air to the amount of fuel that is used.

Too low combustion-temperature is unwanted

If the temperature in the combustion chamber is too low, there is a risk that some of the hydrocarbons (PAH) from the wood will go unburned through the chimney. Since PAHs are both harmful to health and can cause a smell-nuisance, it is important to avoid their emission. A consistently low smoke temperature smoke can also induce corrosion in boiler and flue gas ducting.

6.6 References

[1] Falster, H. 1996: Brændsler, forbrændingsteknologi og rensning. Kompendium til kursus i Teknik og grønne afgifter, dk-TEKNIK.

[2] dk-TEKNIK, Elkraft, Elsam, Risø 1996: Biomasses brændsels- og fyringskarakteristika. – dk_TEKNIK, Elkraft, Elsam, Risø

[3] Videncenter for halm- og flisfyring 1996: Træflis – kemisk sammensætning. – videnblad nr. 106. Videncenter for Halm- og Flisfyring. 2 s

[4] Falster, H. 1989: Fyringsteknologi, andre brændsler. I Bech, N. & Dahlin, J. (ed.) 1989. Forbrænding I teori og praksis. Polyteknisk Forlag.

[5] Gamborg, C. & Stenholm, M. 1998: Fysisk karakterisering af træbrændsler. – Skovbrugsserien nr. 24 – 1998, Forskningscentret for Skov og Landskab, Hørsholm. 133 s.

[6] Videncenter for Halm- og Flisfyring. ”Træ til energiformål. Teknik – Miljø – Økonomi.” 2. udgave 1999

[7] Materiale fra kursus i forbrænding. Teknologisk Institut. 2002