6. Theory of Wood Firing

Efficient and complete combustion is a prerequisite of utilising wood as an environmentally desirable fuel. In addition to a high rate of energy utilisation, the combustion process should therefore ensure the complete destruction of the wood and avoid the formation of environmentally undesirable compounds.

In order for combustion to continue, there are certain basic conditions to be complied with /ref. 48/.

- An adequate mixture of fuel and oxygen (air) in a controlled ratio should be ensured.
- The fire already started in the boiler furnace should transfer some of its heat to the infeed in order to ensure a continuous combustion process.

It is important to understand that gases burn like flames, that solid particles glow, and that during the combustion of wood, approx. 80% of the energy is released in the form of gas and the remaining part from the charcoal.

During mixing of the fuel and air, it is important to achieve good contact between the oxygen of the air and the combustible constituents of the wood. The better the contact is, the faster and more complete is the combustion. If the fuel is in the form of gas, such as natural gas, the mixing is optimal, since we have two gaseous substances that can be mixed to exactly the desired ratio. The combustion may then occur rapidly, and thus the control is fast too, since we can introduce more or less fuel. In order to achieve approximately the same situation with wood, it may be necessary to pulverise the wood to very small particle size (like that of flour). These fine particles will follow the movements of the air. A good mixture can thus be achieved with a combustion resembling a gas or oil flame. The production of wood powder is very expensive, though, and therefore wood powder is only used to a limited extent in Denmark. In practice, fuel is therefore marketed in sizes varying from wood chips to logs.

Firing technology for wood and other solid fuels is thus difficult and more complicated than for example the firing technology in a natural gas or oil-fired heating system.

Stages of Combustion

In order for combustion to occur, the fuel must pass through three stages, which are shown in Figure 13.

- Drying
- Gasification and combustion
- Charcoal burnout

When wood is heated, water begins evaporating from the surface of the wood. Hence two things occur: Gasification occurs at the wood surface - pyrolysis (the heating of a fuel without the introduction of gasification medium, i.e. oxygen and water, is termed pyrolysis) - and the temperature deeper inside the wood will increase resulting in evaporation of moisture from the interior of the wood. As the water evaporates and is passed away, the area that is pyrolysed spreads into the wood.

The gas thus produced is ignited above the fuel and transfers heat to the ongoing evaporation and pyrolysis. The combustion process is continuous. The gasified wood becomes glowing charcoal, transformed by oxygen, until only ash is left.

Fuel Size

The larger the fuel particle is, the longer is the combustion process. Imagine a handful of sawdust quickly burning if it is thrown into a hot fire. There is a good contact between fuel and air, since the small particles quickly dry, give off gases and burn, resulting in a high combustion intensity.

If instead you throw a log into a hot fire, it will take a long time before it is burnt out. It can be compared to a roast that is put in the oven. Although it has roasted for an hour in the oven, it is still raw in the middle. The size of the fuel, therefore, is of great importance to the speed of combustion.

Moisture Content

The moisture content in fuel reduces the energy content expressed by the calorific value, $H_{n,v}$ (see Chapter 4), since part of the energy will be used for evaporation of the water. Dry wood has a high calorific value, and the heat from the combustion should be drawn away from the combustion chamber in order to prevent overheating and consequent damage to material. Wet wood has a low calorific value per kg total weight, and the combustion chamber should be insulated so as to

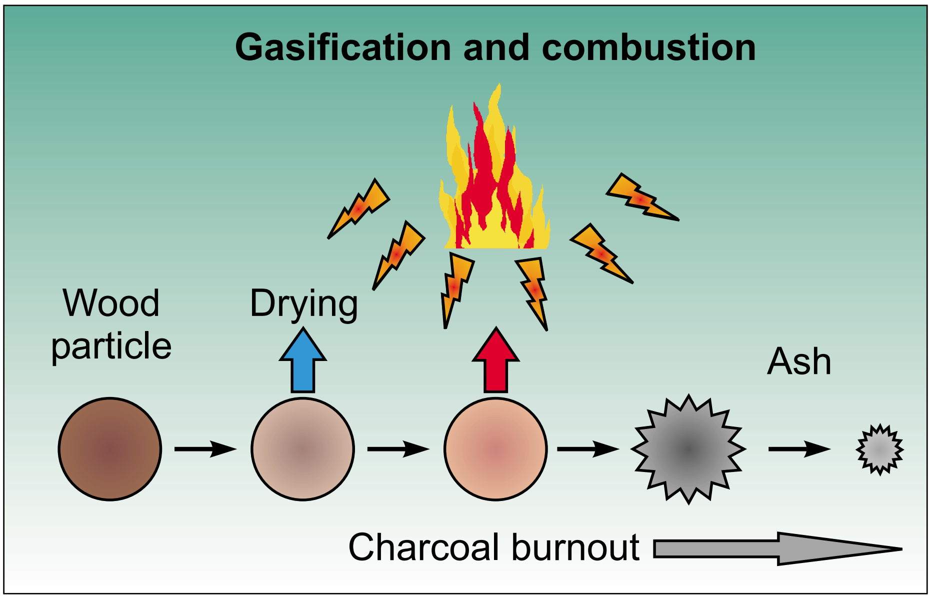

Figure 13. A wood particle combustion route. The green wood particle undergoes drying and gasification, thereby producing flames. The particle burns out and ends as an ash particle /ref. 49/.

avoid reduction in boiler efficiency and enable a continuous combustion process. This is typically accomplished by using refractory linings round the walls of the chamber so as to conserve the heat which is generated. The boiler chamber will therefore normally be designed for burning wood within a certain moisture interval.

A moisture content in wood above 55-60% of the total weight will make it very difficult to maintain the combustion process.

Ash Content

The fuel contains various impurities in the form of incombustible component parts - ash. Ash itself is undesirable, since it requires purifying of the flue gas for particles with a subsequent ash and slag disposal as the result. The ash contained in wood comes primarily from soil and sand absorbed in the bark. A minor proportion also comes from salts absorbed during the period of growth of the tree.

The ash also contains heavy metals, causing an undesirable environmental effect, but the content of heavy metals is normally lower than in other solid fuels.

A special characteristic of ash is its heat conservation property. For wood stoves, the ash layer at the bottom of the stove forms a heating surface, transferring heat to the final burnout of the char. For heating systems using a grate, the ash content is important in order to protect the grate against heat from the flames.

Wood also contains salts that are of importance to the combustion process. It is primarily potassium (K) and partly sodium (Na), based salts resulting in sticky ash which may cause deposits in the boiler unit. The Na and K content in wood is normally so low that it will not cause problems with traditional heating technologies.

	% of DM
Potassium (K)	0.1
Sodium (Na)	0.015
Phosphurus (P)	0.02
Calcium (Ca)	0.2
Magnesium (Mg)	0.04

Table 11: Typical mineral fractions in wood chips expressed in percentage of the dry matter (DM) of the wood. Compared to straw, the K content in wood chips is approx. 10 times lower /ref. 50, 51/.

		Wood chips	Straw (wheat)	Variation according to spec.		
				Beech	Pine	Spruce
Carbon	C % of DM	50	47.4	49.3	51	50.9
Hydrogen	H % of DM	6.2	6	5.8	6.1	5.8
Oxygen	O % of DM	43	40	43.9	42.3	41.3
Nitrogen	N % of DM	0.3	0.6	0.22	0.1	0.39
Sulphur	S % of DM	0.05	0.12	0.04	0.02	0.06
Chlorine	Cl % of DM	0.02	0.4	0.01	0.01	0.03
Ash	a % of DM	1	4.8	0.7	0.5	1.5
Volatiles	% of DM	81	81	83.8	81.8	80
Actual calorific value	MJ/kg DM	19.4	17.9	18.7	19.4	19.7
Typical content	%	35-45	10-15			
Actual calorific value	MJ/kg	9.7-11.7	14.8-15.8			

Table 10: Fuel data for wood chips and a comparison with straw. Note that the elements of dry matter (DM) in the wood vary both with species and the conditions of growth. As an example, Table 10 illustrates the variation between beech, pine wood, and spruce. For wood chips the bark fraction contains approx. 6% ash and the wood fraction only approx. 0.25% ash /ref. 50, 51/.

Volatiles

Wood and other types of biomass contain approx. 80% volatiles (in percentage of dry matter). This means that the component part of wood will give up 80% of its weight in the form of gases, while the remaining part will be turned into charcoal. This is one reason why a sack of charcoal seems light compared to the visual volume. The charcoal has more or less kept the original volume of the green wood, but has lost 80% of its weight.

The high content of volatiles means that the combustion air should generally be introduced above the fuel bed (secondary air), where the gases are burnt, and not under the fuel bed (primary air).

Excess Air

A given fuel requires a given amount of air (oxygen) in order to be converted stoichiometrically, i.e. the amount of excess air (lambda) should be equal to 1. The fuel is converted stoichiometrically when the exact amount of oxygen that is required for the conversion of all of the fuel under ideal conditions is present. If more oxygen is introduced than an amount corresponding to is equal to 1, oxygen will be present in the flue gas. At, e.g. is equal to 2, twice as much air is introduced as necessary for the combustion of the fuel.

In practice, combustion will always take place at an excess air figure higher than 1, since it is not possible to achieve complete combustion at a stoichiometric amount of air. In Table 12, the typical excess air figures are shown together with the corresponding, resulting oxygen percentage in the flue gas.

As shown in Table 12, the excess air figure depends to a high extent on the heating technology and to some extent on the fuel.

Environment

The fuel has an influence on the combustion efficiency. At complete combus-

	Excess air ratio λ	O_2 dry (%)
Fireplace open	>3	>14
Wood stove	2.1-2.3	11-12
District heating forest chips	1.4-1.6	6-8
District heating wood pellets	1.2-1.3	4-5
CHP wood powder	1.1-1.2	2-3

Table 12: Typical excess air figures, λ, and the resulting oxygen content in the flue gas /ref. 23/.

tion, carbon dioxide (CO_2) and water (H_2O) are formed. An incorrect mixture of fuel, type of heating system, and introduction of air may result in an unsatisfactory utilisation of the fuel and a consequent undesirable environmental effect.

An efficient combustion requires sufficient:

- High temperature
- Excess oxygen
- Combustion time
- Mixture

This ensures a low emission of carbon monoxide (CO), hydrocarbons, polyaromatic hydrocarbons (PAH), and a small amount of unburned carbon in the slag. Unfortunately, these conditions (high temperature, a high amount of excess air, long combustion time) are also directly related to the formation of NO_x. The technology applied should therefore be a so-called "low-NO_x" technology, i.e., a technology applying methods resulting in a reduced NO_x emission.

In addition to CO_2 and H_2O, the flue gas will contain air (O_2 , N_2 and Ar) and a high or low amount of undesirable reaction products, such as CO, hydrocarbons, PAH, NO_x etc.

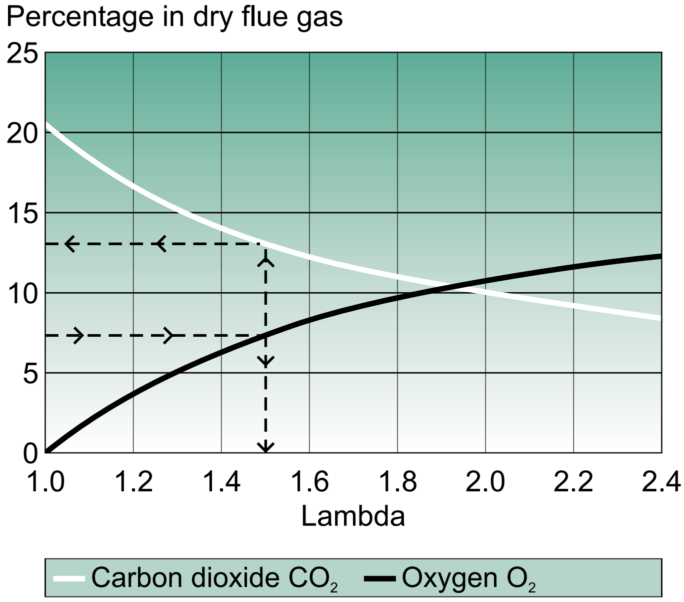

Figure 14: Ideal combustion of wood takes place at an excess air figure λ between 1.4 and 1.6. The oxygen percentage in the flue gas will thus be 7.5%. The curve illustrates that the carbon dioxide percentage is approx. 13% and the excess air 1.5.