combustible substances are present, the flow of air through the fire layer (= thickness of the waste layer) will be balanced.

2.13 The stoking diagram or furnace diagram

A steam boiler and the purposely mounted furnace are designed for a particular capacity. A maximum capacity normally applies for the furnace; this refers to the maximum amount of waste supplied to the furnace per hour expressed in tonnes and the maximum heat that can be generated in the furnace. The latter is referred to as the thermal load. The thermal load is a combination of the amount and the lower calorific value of the waste.
To a large extent the amount determines the mechanical wear of the grate.

Thermal

The thermal load is much more important and the operation should be geared to this for the proper operation and a long life of the boiler, i.e. to minimise corrosion and wear of the membrane walls, evaporator bundles and super-heater bundles it is important to run the furnace and boiler at a thermal load of 100%. The boiler and the furnace are designed for a 100 % thermal load.

Erosion

The flue gas temperatures in combination with the wall temperatures will be such that corrosion and wear (erosion) are minimal. The erosion mainly depends on the flue gas velocity with the load of fly ash. The higher the through-put of a furnace, the more flue gas and fly ash are sent through the draughts of the boiler. This results in more wear.
In order to enable the user to see what he is doing, so-called furnace diagrams or stoking diagrams were made by the designer. These diagrams are made per furnace and are therefore different for each individual furnace. An example of a full stoking diagram is shown in illustration 18.

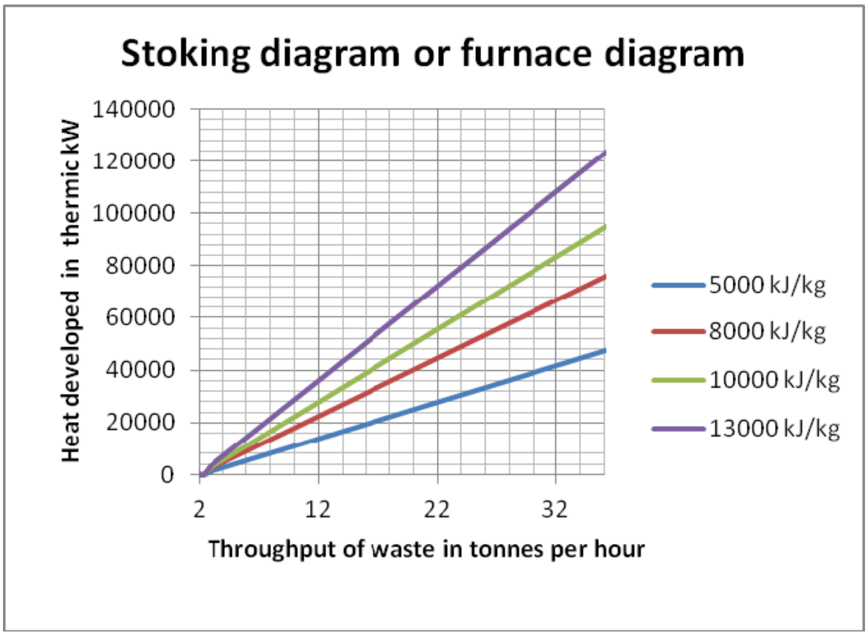

Illustration 18. The stoking diagram or furnace diagram.

In practice only part of the diagram is used. The practical diagram could be like the one shown in illustration 19, for example.

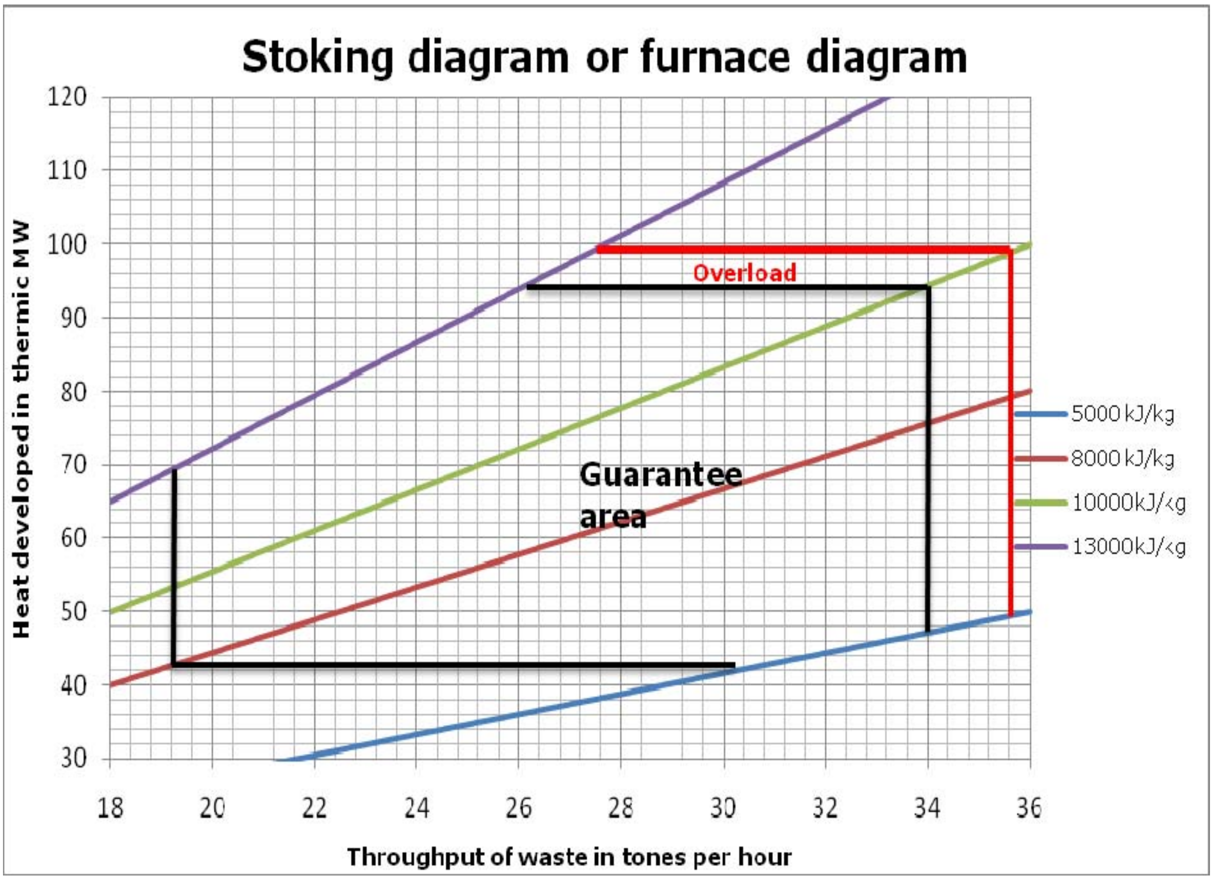

Illustration 19. The stoking diagram in practice.

In this stoking diagram we can see that the furnace is set-up for a waste throughput of 34 tonnes per hour with a lower calorific value of 10,000 kJ/kg. The heat developed in the furnace is then:

$$\dot{Q}_{supplied} = \dot{m}_{waste} \cdot H_0 \quad \left[kW\ thermic\right]$$

$$\dot{Q}_{supplied} = \frac{34,000}{3,600} \cdot 10,000 = 94,444 \quad kW\ thermic$$

$$\dot{Q}_{supplied} = 94.4 \quad MW\ thermic$$

We can now find the amount of heat developed simply by looking at the diagram. There is no need to calculate it.

If the lower calorific value increases and the through-put remains the same, the heat developed in the furnace will increase and the furnace will be thermally overloaded. If we stick to the furnace diagram and the lower calorific value increases, for example, we will have to reduce the through-put in order to maintain the same maximum thermal load.

Guarantee area

The so-called guarantee area has been defined by a black line. This is the area in which the waste will burn without auxiliary fire and without air heating. If we drop below the 5000 kJ/kg line, i.e. when we are dealing with waste with a lower calorific value of less than 5000 kJ/kg, we might require an air heater and auxiliary fire. The area defined by a red line is the so-called overload area. This is only permissible for a short time during proper operation.

MCR

The point marked MCR in illustration 19 refers to Maximum Continuous Rating or Maximum Nominal Capacity.

2.14 Flue gas re-circulation

Partial load

In power plants, flue gas recirculation is occasionally used to ensure that the required furnace final temperature and the required steam exhaust temperature are achieved, also in cases of partial loads. This in particular applies to boilers fitted with a re-heater. In WIP's this is applied for a different reason. In WIP's flue gas re-circulation is used to limit the amount of NO_x produced. Downstream of the economizer and downstream the E-Filter or cloth filter, some of the flue gasses are discharged and fed back to the furnace with the aid of flue gas re-circulation ventilators.
The flue gasses can be fed back in two ways:

- At the bottom of the furnace below and above the grate.
- At the top in the furnace.

Flue gas recirculation with return above the grate:
Illustration 20 shows a waste fired 4 tube boiler. In the convection section we first see the evaporator bundle (blue) followed by three super-heaters (red) and two economizers (green).
When the flue gasses exit the boiler they are first taken through an E-Filter or cloth filter before any flue gas is re-circulated. The flue gas is first stripped of fly ash to prevent erosion of the ventilator. The flue gasses are brought above the grate and mixed with the secondary air. The flue gas that is re-circulated contains approximately 6 vol% oxygen; in the secondary air this amounts to 21 vol% oxygen. Because the flue gas is mixed with the secondary air, the oxygen concentration will be less than 21 vol%. As a result the incineration will slow down and become intense. The flame temperature will also be reduced as a result of which less NO_x is produced.

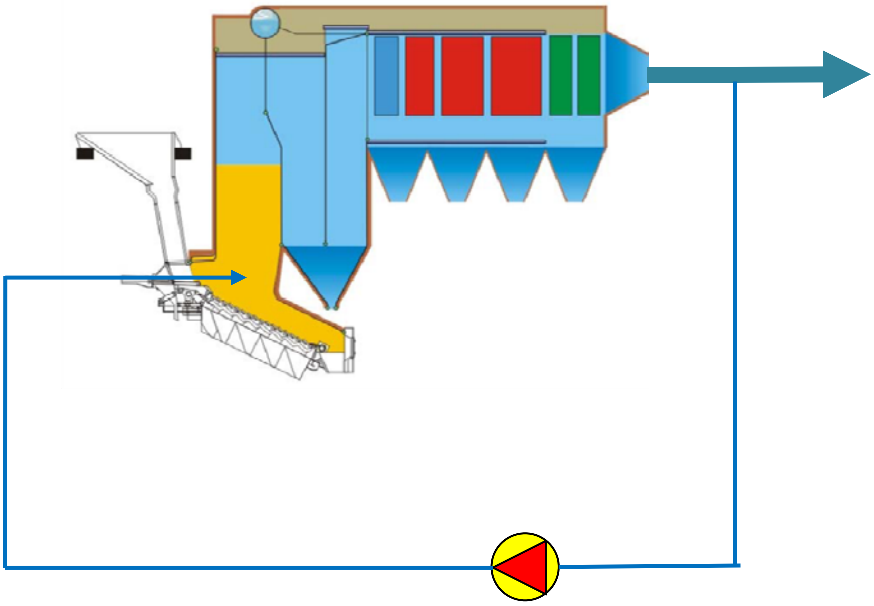

Illustration 20 Flue gas recirculation with return above the grate.

The average furnace temperature drops, as a result of which the heat emission to the furnace also drops. This causes more heat to remain in the flue gasses, which can be absorbed by the super-heater and the economizers. The change of the heat absorption in the aforementioned components is shown as a function of the amount of re-circulation in illustration 21; in the case of a boiler type that is schematically represented in illustration 20.
It causes the heat absorption in the furnace to drop and the heat absorption in the other components to rise. This illustration also shows that the biggest change takes place in the economizer and to a slightly lesser extent the super-heater. This can be explained as follows. As a result of the drop in heat absorption in the furnace, the furnaces final temperature remains practically unchanged, despite the fact that the flue gasses are mixed with colder flue gasses.

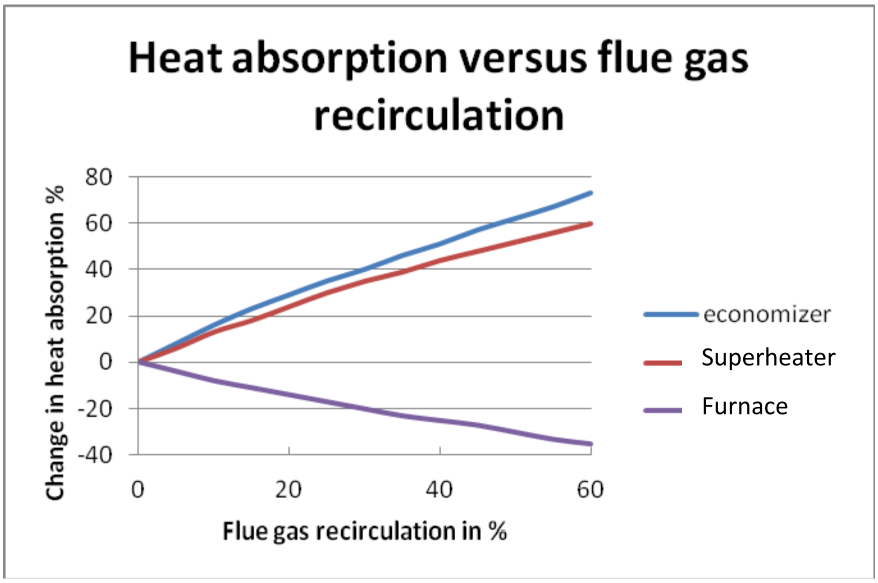

Illustration 21. Heat absorption versus flue gas re-circulation

Flue gas re-circulation mixed with combustion air:
In modern boilers the re-circulation flue gas is also supplied via the incineration air ducts below the grate. Below the grate we then get warm “air” (a combination of air and flue gas) with an oxygen percentage of less than 20%. This slows down the incineration and also lowers the average flame temperature, which leads to a reduction in NO_x emissions. A sketch of such an installation is depicted in illustration 22.

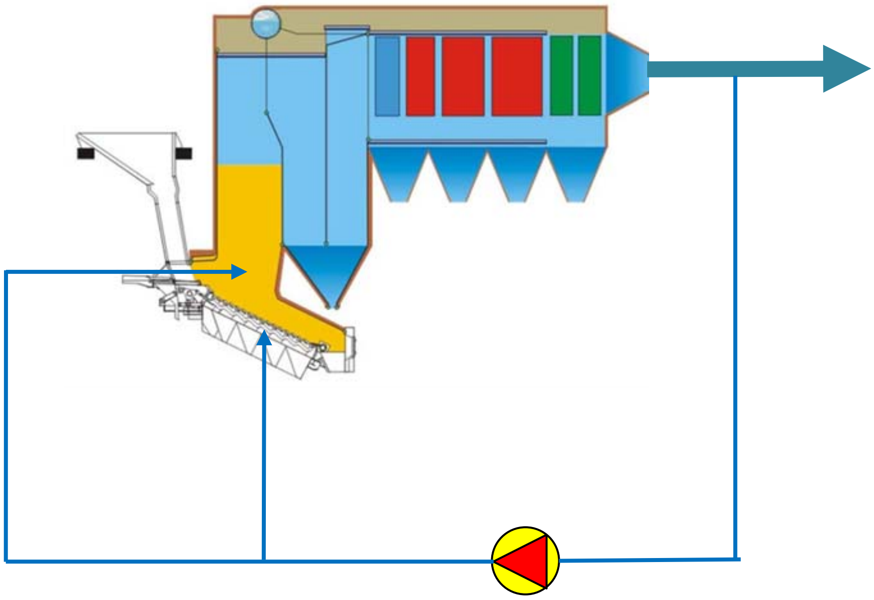

Illustration 22. Flue gas re-circulation above and below the grate.

The economizer and the super-heaters have a convection characteristic which makes them sensitive to an increase in the amount of flue gas. In large boilers a combination of flue gas re-circulation and flue gas tempering may be applied.

Flue gas tempering:
Flue gas tempering is another form of flue gas re-circulation. In this case the re-circulating flue gasses are not supplied just above or below the grate but at the top of the furnace, so in the first, second or third draft.

Heat emission

As a result the furnace temperature and therefore also the heat emission in the furnace is only reduced at the furnace exhaust. This means that the flue gas temperature drops upon entry into the convection section.

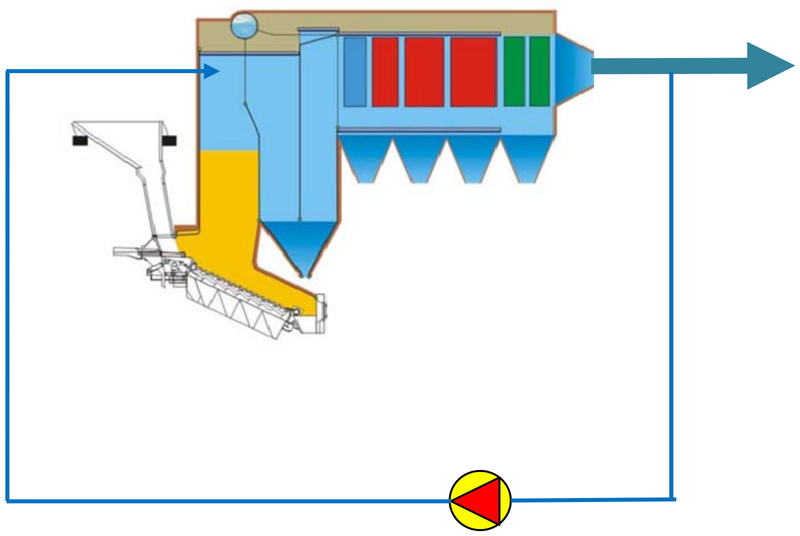

Illustration 23. Flue gas tempering.

The change of calorific intake in the various components in this system is shown in illustration 24

Temperature drops

From this it is possible to deduce that the calorific intake in the furnace only drops slightly, while the flue gas temperature plummets considerably; see the sample calculation below. it also appears that the super-heater and economizer absorb more heat due to their convection characteristics.

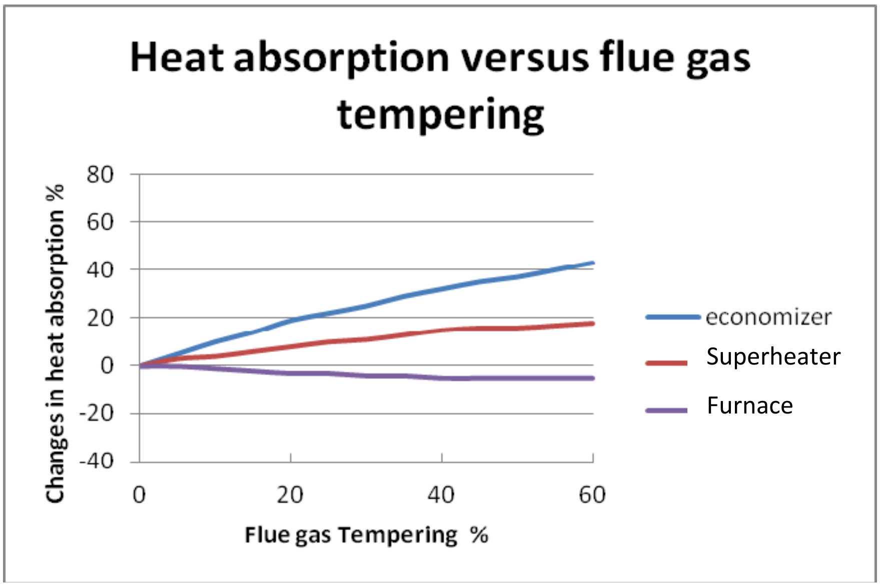

Illustration 24. Heat absorption versus flue gas tempering.

In contrast to what happens in flue gas re-circulation, the flue gasses do not participate in the incineration in the flue gas tempering. In other words the re-circulation flue gas cools the flue gas in the boiler. This is easy to calculate using the so-called mixing rule.

Example:
During incineration, 80,000 m^3 of flue gas is produced per hour in a boiler. The temperature of the flue gasses upon exiting the first draft is 900 °C. Downstream of the E-Filter 20,000 m^3 flue gas is re-circulated per hour by means of the flue gas re-circulation ventilator; the temperature of the flue gasses is 210 °C.
These re-circulation flue gasses are supplied at the end of the first draft.
The specific heat of the flue gas is assumed to be 1.2 kJ/(kg·K).
We will now work out the flue gas temperature at the end of the first draft in flue gas tempering.

This results in the following equations:

$$\dot{m}_{Fluegas} \cdot c_{Fluegas} \cdot t_{Fluegas} + \dot{m}_{Recigas} \cdot c_{Fluegas} \cdot t_{Recigas} = \left(\dot{m}_{Fluegas} + \dot{m}_{Recigas}\right) \cdot c_{Fluegas} \cdot t_{Gas}$$

$$80,000 \cdot 1.2 \cdot 900 + 20,000 \cdot 1.2 \cdot 210 = \left(80,000 + 20,000\right) \cdot 1.2 \cdot t_{Gas}$$

$$80,000 \cdot 900 + 20,000 \cdot 210 = \left(80,000 + 20,000\right) \cdot t_{Gas}$$

$$t_{Gas} = 762\ ^{o}C$$

We can see that the flue gas temperature drops considerably upon exiting the first draft.