5. Boiler Plants for farms

The present use of straw firing in agriculture expanded heavily due to the energy crisis in the 1970s with the following subsidy schemes and easy terms concerning depreciation on straw-fired boilers. In the middle of the 1980s, approx. 14,000 straw-fired boilers had been installed. In 1997, it is estimated that there are approx. 10,000 straw-fired boilers in agriculture. The reason for the drop in numbers is that the early installed boilers were small, primitive boilers designed for batch firing that have not all of them been substituted by a straw-fired boiler.

photo: maskinfabrikken faust

"Tractor firing". The tractor feeds a round bale into a batch-fired boiler. The boiler is located inside the house in a way that offers easy access for the tractor both for firing and for the removal of ash.

There are two types of boilers, the batch-fired and the automatically fed boilers. The batch-fired boilers are always installed in combination with a storage tank that can absorb the heat energy from one firing (1-4 bales). Thereby, the energy content of the straw is utilised better, because the boiler can operate at full boiler load. Automatically fed boilers are fed by a conveyor that, e.g., is loaded with straw approx. once every 24 hours. The conveyor feeds bales into the boiler automatically, concurrently with the consumption of heat.

Over the recent 10-15 years, great technological advances have been made in respect of these boilers with a view to achieving a greater efficiency and reducing the smoke nuisance. Greatest technological advances have been in the field of batch-fired boilers, where the efficiency has increased from 35-40% in 1980 to 77-82% in 1997. This can be ascribed, in particular, to a better control of the air supply required for combustion. The smoke nuisance is reduced considerably with increased combustion quality.

Batch-fired Boilers

Whereas the small straw bales earlier dominated the market, most batch-fired boilers are to-day designed for big bales (round bales, medium-sized bales, or big bales). The boilers are often built together with a storage tank as an all-in-one unit for outdoor location. The outdoor location highly reduces the danger of fire.

The batch-fired boilers are produced in a wide range of sizes, containing from one medium-sized bale to three big bales in the combustion chamber. The most widely used boiler size is a boiler for one medium-sized bale or alternatively 8-10 small bales.

When disregarding firing with small bales, firing and the removal of ash are usually performed by a tractor with front-end loader.

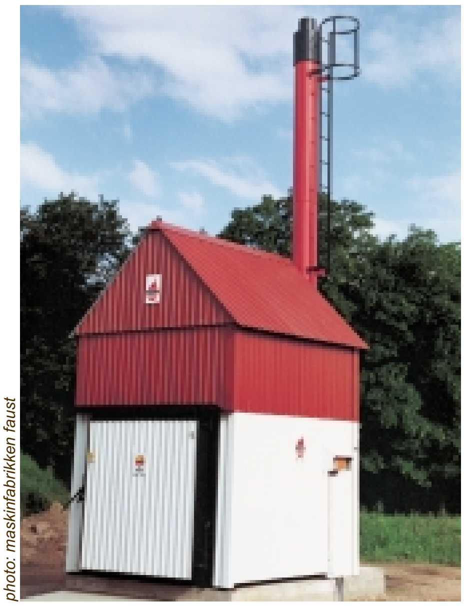


photo: maskinfabrikken faust

Batch-fired boiler for round bales or big bales located in a separate housing, thereby eliminating the danger of fire in respect of the farm buildings.

Control of Air Supply for Combustion

Today, all batch-fired boilers are equipped with combustion air fans, where the amount of air and the distribution of air between primary and secondary air is controlled by an electronic control unit. The flue gas temperature and oxygen content are used as a control parameter. In addition, the boiler has refractory linings of firebricks round the walls of the combustion chamber in the upper part in order to secure a high combustion temperature.

Measuring of the flue gas temperature secures that the boiler output is kept within certain determined limits, as, e.g., a high flue gas temperature is an expression of the boiler being overloaded, i.e., the combustion produces more heat than can be absorbed by the water in the boiler. Similarly a too low flue gas temperature is an expression of a too low boiler output.

Measuring of the oxygen in the flue gas is used for adjusting the combustion excess air by opening and closing the primary and secondary air. The ideal target is an oxygen percentage in the flue gas of 6-7% which is equal to an excess air, lambda, of approx. 1.5.

The oxygen content is measured continuously by an oxygen probe of almost the same type as that used for controlling the petrol injection in modern car engines. The electronic control unit converts the signals from the probe into air-inlet-open- and shut-off impulses to the motor-driven air valve. If the oxygen percentage is too high, a small amount of primary air is allowed to enter, thereby shutting off a bit the secondary air inlet. Similarly, the primary air inlet shuts off a bit, and the inlet of secondary air opens a bit if the oxygen content decreases too much.

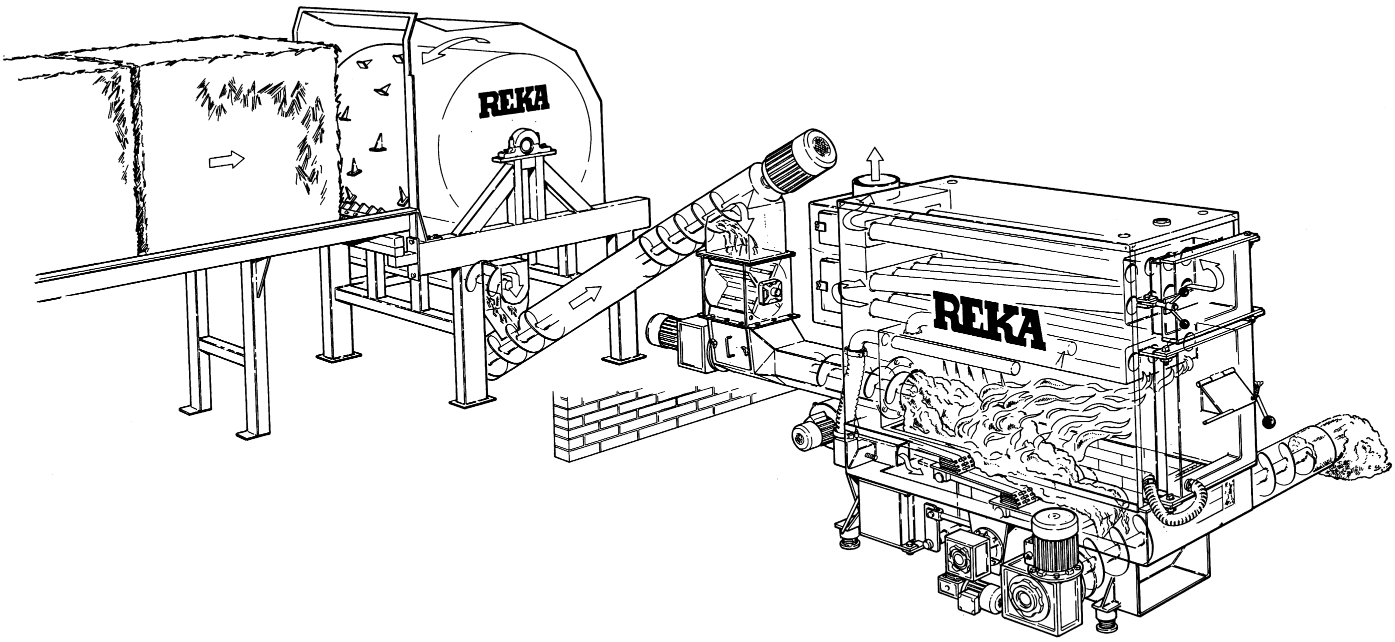
It is important that the electronic control unit is capable of keeping the oxygen percentage constant, since fluctuations in the oxygen percentage result in too high CO values and too low boiler efficiency. Therefore ongoing developments aim at improving the straw-fired boilers by developing a very accurate and reliable control system with oxygen probe. In addition, it is also important that the air nozzles are designed and positioned so that the proper turbulence is created in the combustion zone.

In order to attain a good combustion with a low CO content in the flue gas, it is also of decisive importance that the straw that is used is of a good quality. That means first and foremost that the straw should be dry before baling and be stored in a dry place. But also, the straw should be well field cured (i.e. it has been left in the field exposed to rain and has turned grey) before baling, since the too early gathered "yellow" straw normally has poor combustible properties (see Section 2).

photo: maskinfabrikken reka

The gate is open to the combustion chamber of an automatically fed fire tube boiler. The straw is fed by screw stoker behind the flames, and the flue gas passes though the four tubes and further through the boiler vessel. Below on the right, the gear motor of the ash conveyor is seen.

In order for the boiler to keep a stable rate of combustion at maximum boiler load without interruptions throughout all combustion stages, all batch-fired boilers designed for straw are equipped with a storage tank. The storage tank will usually contain 60-80 litres of water per kg of straw contained in the combustion chamber. This is equal to the temperature in the storage tank increasing 30-40°C at the time of firing if not simultaneously heat is drawn from the tank. The storage tank is typically a separate tank that is located on top of the boiler, but the boiler may also be built into the storage tank. Figure 15 illustrates the principle of separate tank.



graphic: maskinfabrikken reka

Figure 14: Automatic boiler. The straw is being shredded by a slow-speed shredder and fed via screw stoker on to the grate where the combustion takes place. The forward and backward movements of the grate pushes the ash towards the ash chute and further out with the ash conveyor. The flue gases are cooled by passing several passes where the fire tubes are surrounded by boiler water.

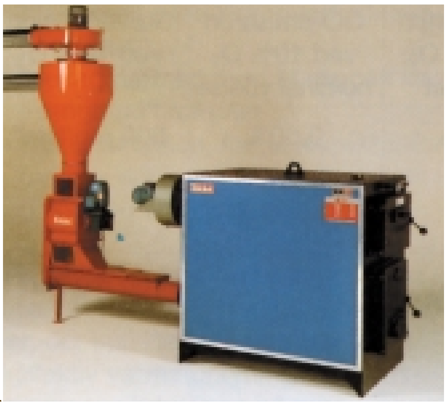


photo: linka maskinfabrik

An automatic boiler. The chaffed straw is sucked into the lower, bright tube of the cyclone. The upper tube is the cyclone exit air. The straw is separated from the transport air in the cyclone and is dosed via a rotary valve under the cyclone down on to the screw stoker that passes the straw into the boiler. The flue gas fan is seen on the back of the boiler.

Automatically Fired Boilers

The first boilers with automatic feeding device were developed in order to primarily ease the work of firing with small bales, since the originally simple batch-fired boilers could often only contain 2-4 small bales.

At automatic firing, a bale conveyor of, e.g., 10-20 m length is filled with straw bales once every 24 hours. From there, the bales are slowly conveyed towards the boiler. Before the firing, the straw is being disintegrated by means of a rotating shredder/cutter. The transport system between the shredder and the boiler may be either a worm conveyor or a blower system. The most widely used system is the blower system, since it offers the greatest flexibility by positioning of the shredder in relation to the boiler, and in addition, it gives a good security against backfire/burn-back between the boiler and the shredder. However, the blower system is more energy consuming than is the worm conveyor system. The straw is fed into the boiler by a worm conveyor, often called the screw stoker.

Continuous firing results in a more stable combustion in the boiler and thereby a higher efficiency and reduced smoke nuisance compared to batch-fired boilers. The boiler heat transmission is adjusted by on/off operation, controlled by a thermostat that reacts on the boiler water temperature.

Control of Firing

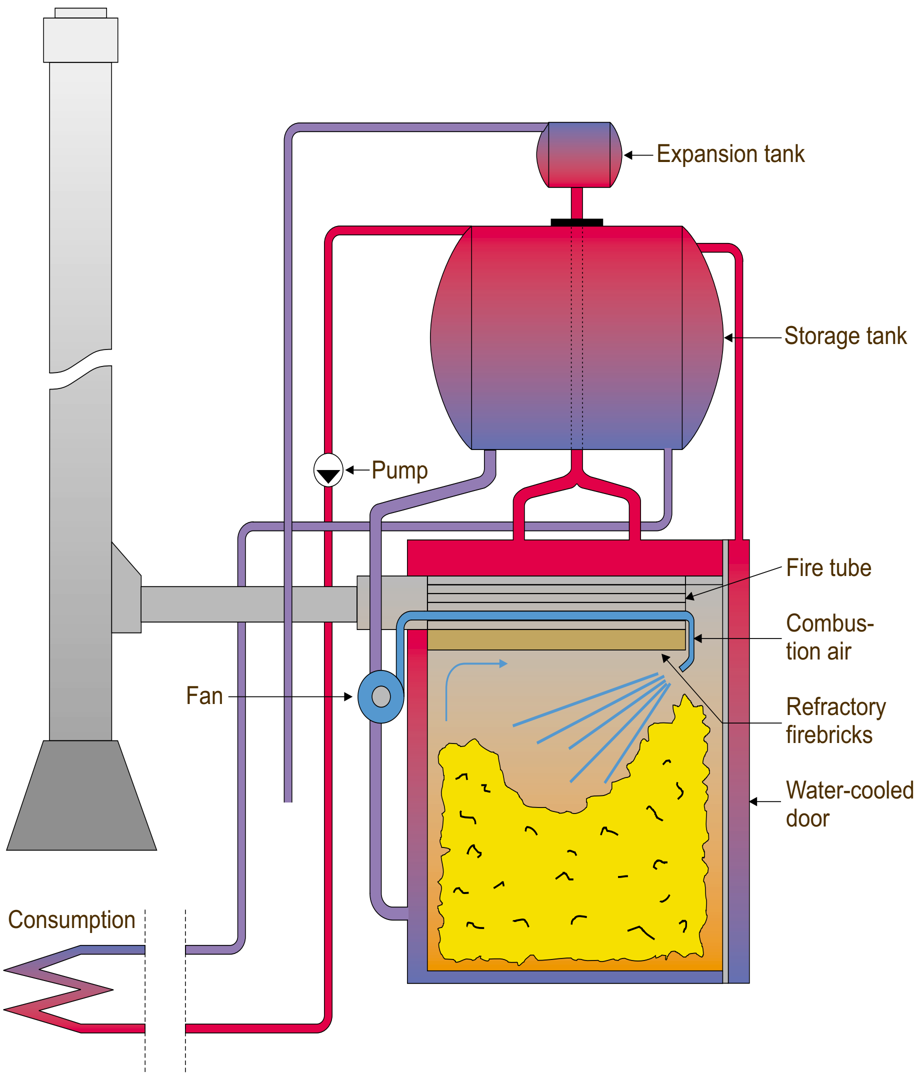
In order to achieve a good combustion, the amount of straw fired should be adapted to the amount of combustion air that is introduced by a fan. In order to secure a constant amount of straw being fed, the newest automatic boilers are therefore equipped with oxygen-controlled screw stoker which means that the amount of straw fired is automatically adjusted to the oxygen content in the flue gas from the boiler. The oxygen content in the flue gas is recorded by means of the same type of oxygen probe that is described under batch fired boilers, and the amount of straw is thus adjusted by starting and stopping the screw stoker at short intervals.

Traditionally, the aim is an oxygen content of the flue gas of approx. 7%. If the oxygen content exceeds this level considerably, the screw stoker operates uninterruptedly until the oxygen content drops to about 7%. Then the automatic step function will try to keep this oxygen percentage by stopping the screw stoker at short intervals. If the oxygen content drops to a level far below 7%, the screw stoker stops completely, until the oxygen content starts rising again.

By using oxygen control at an automatic boiler, the efficiency is improved by 5-10 percentage point on a rough estimate, because the conditions for the combustion are better. Simultaneously, the CO content of the flue gas is reduced, and the smoke nuisance from the boiler is reduced.

Type Testing of Small Biofuel Boilers

So far, there has been no tradition in Denmark for type testing of boilers for solid fuels - except from boilers for



graphic: maskinfabrikken faust

Figure 15: The principle in a batch-fired boiler. The storage tank is big enough to contain the energy generated by combustion of the straw that the combustion chamber will hold.

straw that have been tested at Research Centre Bygholm, Horsens, in connection with previous subsidy schemes. The market for small boilers has been uncontrolled, i.e., so far there have been no statutory requirements in respect of type testing of energy-, environmental-, or safety properties. The only statutory requirements are safety requirements that are laid down in the Directory of Labour Inspection Publication No. 42 dealing with safety systems for hot-water boilers including requirements for pressure testing.

With the introduction of general subsidies for small biofuel boilers in 1995, type testing became of great immediate interest to the manufacturers. That was because the Danish Energy Agency required as a precondition for subsidies being granted that the boiler should be type approved, thereby complying with a wide range of requirements for emission and energy utilisation. The type testing was carried out at the Test Laboratory for small Biofuel Boilers in accordance with test directions setting out the guidelines for testing and the requirements to comply with in order to achieve a type approval. The directions are drafted on the basis of suggestions for a joint European standard for solid fuel systems. However, the requirements in respect of efficiency and emissions have been restricted and grouped according to firing technology (batch or automatic) and fuel type (straw or wood). The requirements are established in a joint collaboration between the manufacturers of biofuel boilers, the Test Laboratory for small Biofuel Boilers, the Danish Energy Agency, and the Danish Environmental Protection Agency.

The type testing can be carried out on the basis of various fuels, e.g.: Forest wood, straw, wood pellets, wood chips, cereal grain or saw dust/cuttings. The type approval does only apply for the fuel that was used during the testing. The scheme applies to automatic boilers up to 200 kW and for batch-fired boilers up to 400 kW. By raising the level to 400 kW, a reasonable combustion time is achieved for big bales. The list of type-approved boliers can be seen in /ref.39/.

Testing Requirements

The values for CO emission, dust emission, and efficiency are determined by type testing as the mean value over 2 x 6 hours at nominal boiler load. The nominal load is often stated by the manufacturer and is an expression of the optimal point of operation when the efficiency is high and emissions low.

In addition to testing at nominal output, the type testing also includes testing at low values, i.e., 30% of the nominal output. The requirements in respect of dust- and CO emissions are stated in Table 3, whereas the efficiency should at least be as that stated in Figure 16.

Other important requirements are:

- Securing against backfire/burn-back in storage (e.g. mechanical damper or by spraying with water)
- Maximum allowable surface temperatures
- Leakage tightness to prevent flue gas leakage in the room
- Documentation, e.g., technical information, operational instructions, installation manual etc.

The subsidy scheme applies to biofuel boilers, including straw-fired boilers that are installed in areas without district heating supply. The subsidy percentage is calculated on the basis of the testing result, and the sum is calculated in proportion to the consumer's expenses for boiler and installations. The subsidy scheme is ad-

Fuel	Firing	CO-emission at 10% O_2,30% boiler load	CO-emission at 10% O_2 nominal output	Dust emission at 10% O_2
Firewood, pellets,cuttings, wood chips, cereal grain	Batch (manual)	0.50%	0.50%	300 mg/Nm^3
Firewood, pellets,cuttings, wood chips, cereal grain	Automatic	0.15%	0.10%	300 mg/Nm^3
Straw	Batch	0.80%	0.80%	600 mg/Nm^3
Straw	Automatic	0.40%	0.30%	600 mg/Nm^3

Table 3: Maximum allowable CO emission and dust emission at normal output and at low boiler load during type testing.

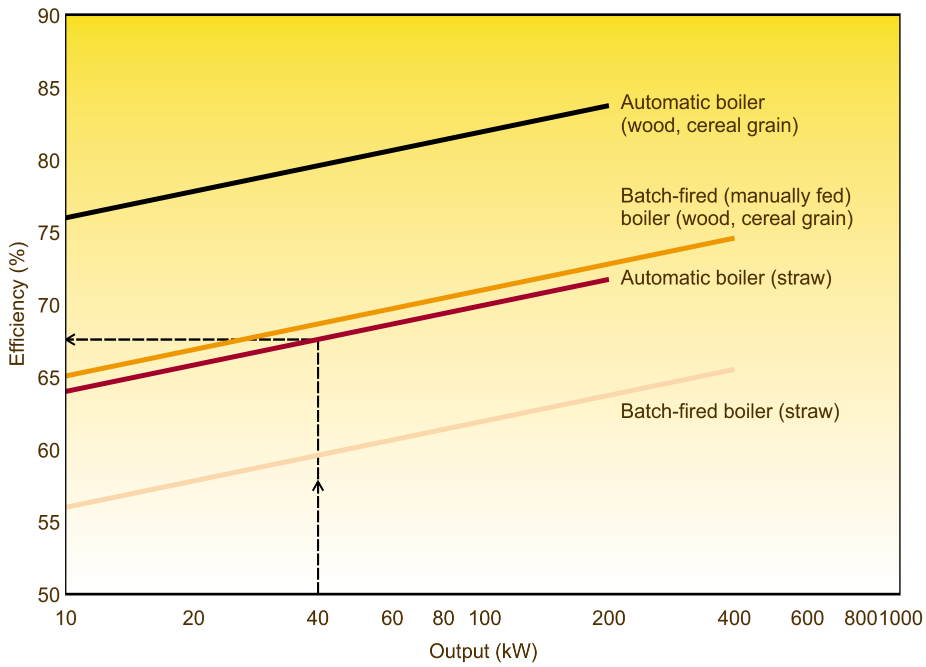


Figure 16: Efficiency minimum values depending on the type of boiler. For an automatic straw-fired boiler of 40 kW to be approved, a minimum efficiency of 67% is required.

ministered by the Danish Energy Agency.

Experiences and Future Developmental Requirements

Since implementing the systematic type testing in 1995, a wide range of experience has been gained in the field of small boilers. It was evident at the beginning that many manufacturers marketed boilers whose output far exceeds the requirement for typical installations. This meant that there was an obvious disparity between the supply of boilers with an output of less than 20 kW and the consumers' actual demand. However, this has changed tremendously since then, and today most manufacturers offer systems with an output in the range of 10-20 kW or are developing new boilers. The small boilers are often designed for wood pellets or perhaps boilers for grain.

There are still a need for improving the efficiency of boilers designed for straw firing. There are several possibilities, e.g.:

- Improving the boiler convection unit, so that the flue gas temperature can be reduced from the present 250-300°C to 150-200°C.
- Improved lining and design of air nozzles, thereby keeping the excess air and the CO content of the flue gas constant, thereby contributing to reducing the dust emission. However, it should be mentioned that the dust emission does not always depend on the combustion. Variations in straw quality may result in varying emission levels.
- Improvements on devices for the cleaning of the fire tubes and for the removal of ash.
- Improvements on the boiler control equipment so as to ensure an optimal environmentally desirable and energy efficient operation with a high user comfort where the time consumed by the weekly attendance is minimal. It should be mentioned that several boilers have advanced controls with several output options and in a few cases oxygen control which to a high extent has regard to the variations in consumption in a typical central heating installation. For this reason, the Danish Energy Agency is funding a research and development project with the objective to develop a cheap, universal oxygen control unit adaptable for most small boilers in the market.

photo: m. g. larsen

The engineer responsible for the testing is preparing the boiler for type testing at the Test Laboratory for small Biofuel Boilers at Danish Technological Institute in Aarhus.