# 7. District Heating Plants

photo: biopress/torben skøtt

*Sabro Halmvarmeværk (straw-fired heating plant) west of Aarhus. The plant was constructed in 1991 and has an output of 3.2 MW. The straw storage is seen on the right, on the left the boiler house, control room, workshop and a room for the ash container. The annual consumption of straw is approx. 4,000 tonnes.*

**Straw-fired district heating plants have been constructed since 1980, and 58 plants are now in operation. There have been 61 plants, but recently 3 of them have been converted to other fuels (wood chips) or closed down in connection with shifting to natural gas and waste-fired combined heat and power generation.**

The term “district heating plant” always refers to plants with heat production but without electrical power generation. The maximum boiler temperature is 120°C and the maximum pressure is 6 bar. The average size is 3.7 MW. The largest plant has an output of 9 MW and the smallest 0.6 MW. All plants are designed for big bales of the dimensions 2.4 x 1.2 x 1.3 m. The average bale weight is 520 kg.

## Boiler Size

The boiler rating is fixed on the basis of the maximum heat amount to be supplied to the distribution net on the coldest day of the year. The heat amount can be divided into the net heating requirements of the houses (space heating and hot water) and piping loss in the distribution net. The sum of these to two figures yields the heat production ex plant. As an example, the maximum district heating load for a town where the heat production ex plant is 40.7 TJ/per annum or 11,200 MWh/per annum can be calculated. This is equal to the heating requirement of 400-450 single-family houses.

The distribution loss is 30% of the heat production, and the consumption of hot water is 10%. These figures can be used as a guide in respect of a normal year of 3,112 “ELO degree days” (ELO is the acronym of Energy Control Scheme (EnergiLedelses-Ordningen)) and with a distribution net corresponding to the small communities where the straw-fired plants are established. In the Danish District Heating Association statistics from 1995/96, the distribution losses of 37 straw-fired district heating plants are stated. The average distribution loss was 28% with the highest distribution loss being 42% and the lowest 16%. There were 3,300 degree days in 1995/96, and the average distribution loss is thus 30% when correcting to a normal year. The maximum boiler output can be calculated on the basis of /ref. 40/.

The factor 3.2 is an empirical figure for the maximum space heating requirement on the coldest day of the year. The 8760 hours is the number of hours of the year. A district heating plant load throughout the year can be illustrated by a duration curve, see Figure 17.

Normally, a oil-fired boiler is installed so as to cover the entire output requirement of 3 MW to be used at peak loads, repair, or damage of the straw-fired boiler.

The straw-fired boiler is usually selected for 60-70% of the maximum load (here 66% equal to 2 MW). With

$$\text{Maximum output} = \frac{3.2 \times 6{,}720 \text{ MWh} + 4{,}480 \text{ MWh}}{8{,}760 \text{ hours}} = 3 \text{ MW}$$

Of this, space heating makes 60% = 6,720 MWh.
Of this, distribution loss and hot water make out 40% = 4,480 MWh

this boiler size, the summer load of 0.5 MW will be approx. 25% of 2 MW, which can yield a reasonable summer operation in terms of combustion. When the boiler is selected for 2 MW, it is capable of operating at the maximum load for more than 1,000 hours per annum.

The duration curve is created by plotting the hourly load over the year (totalling 8,760 hours) with the heaviest load on the left and then the other one according to decreasing values.

The duration curve illustrates the following points:

- The total area under the curve is equal to the annual production of 11,200 MWh.
- The Yellow area is equal to the straw-fired boiler production. It makes out 93% of the area under the curve, equal to 10,400 MWh or 37,400 GJ. With an annual boiler efficiency of 84% and a calorific value of 14.5 GJ/t for straw, the requirement will be approx. 3,000 tonnes of straw per annum.
- The heat production based on oil is approx. 800 MWh distributed on 550 MWh at peak load and 250 MWh during 3 weeks suspension of operations during the summer season for service purposes, the brown area. The energy consumption is 87,000 litres of oil per annum.
- The summer consumption is only distribution loss and hot water. The output requirement is 0.5 MW. That is the lower part of the curve on the right, and the summer load lasts 8,760 - 6,500 = 2,260 hours. Three weeks suspension of operations during summer for service purposes is shown. During that period, oil is used.

Plant statistics show that the straw share of the total heat production is in the range of 85 - 93% /ref. 9/.

## Types of Boiler Plants

The various types of boiler plants have different firing principles that require different equipment for transport of straw and handling of straw from storage to boiler.

The 58 plants can be grouped in 5 typical systems/ref. 9 and 10/ :

- Boiler plant for chaffed straw: 7 plants
- Boiler plant for shredded straw: 24 plants
- Boiler plant for sliced bales: 3 plants
- Boiler plant for cigar firing: 11 plants
- Boiler plant for whole bales: 13 plants

There are 2-3 manufacturers in the market that deliver all-in-one systems (see Section 14). The main components are both manufactured by themselves or they purchase sub-contracts in the form of filters, chimney, crane, and electric equipment etc.

All boiler plants consist of the same main components:

- Straw storage with straw scales
- Straw crane and straw conveyor (straw table)
- Chaff cutter/shredder/slicer (the 3 first-mentioned types)
- Firing system and boiler
- Combustion air fans
- Flue gas cleaning and ash/slag conveyor
- Chimney and flue gas fan
- Control and regulation equipment

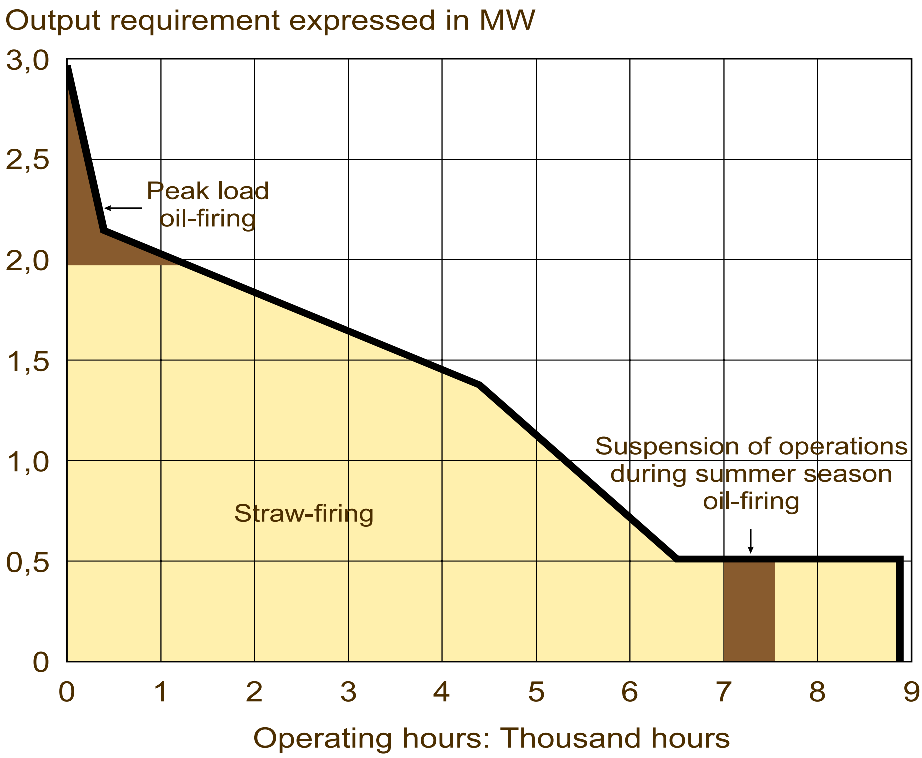



*Figure 17: The duration curve for a 3 MW boiler plant with a 2 MW straw-fired boiler. Peak load and stand-by load by a 3 MW oil-fired boiler*

## Boiler Plant Designed for Chaffed and Shredded Straw

This section also describes those parts of the boiler plants that are common for the 5 boiler types.

### Storage

The storage is space consuming. On average, the plants have storage facilities for 8 days operation at full load which for the average plant is equal to 3.7 MW or more than 400 big bales. The aggregate storage floor space including driveway etc. for this amount of straw is approx. 600 $m^2$. The straw supplier delivers the straw to the plant by truck or tractor-towed trailers. The plant takes care of unloading by fork-lift truck. The bales are weighed on unloading, and the water content is determined. The plants receive straw with up to approx. 20% water content. Bales with a water content higher than that are returned, since combustion would thereby be too uneven, especially at part load.

Working in the straw storage creates the risk of breathing in straw dust containing allergy promoting fungus spores and micro-organisms. As a guide in respect of permitted limit values, the Directory of Labour Inspection Report No. 10/1990 on working environment problems in connection with waste management can be used.

### Weighing and Water Content

The weighing takes place either on a weighbridge or a platform scales. It is illegal to settle with the suppliers via a weighing cell mounted on the truck. The weighbridge is the fastest, since only 2 weighing operations shall be carried out (gross and tare of the truck).

photo: biopress/torben skøtt

*Measuring the water content in big bales at the heating plant.*

The platform scales is used by the truck driving on to the platform with the front wheels and is weighed every time a bale is unloaded. This results in a slower flow of work. A weighbridge is 2-3 times more expensive than a platform scales, so the choice between the two options is a matter of increased investment against increased working time. The scales should be calibrated every 4 years by a DANAK-approved laboratory. DANAK is short for Dansk Akkreditering, and the approval should secure the quality of the calibration.

For the determination of the water content, a measuring instrument equipped with a spear for insertion into the straw bale is used. The resistance over two electrodes is measured and converted into water percentage on an indicator. Normally, three measurements are taken of the same bale, and on the basis of that, the average water content is calculated. Depending on practice and the wording of the contract, acceptance may be refused of either a few bales or the whole load. The limit for refusal of straw is normally 20%.

### Crane

All large plants are equipped with an automatic crane that lifts the bales from storage to straw table. The crane is programmed to pick up the bales in a certain order, and it is therefore important that the truck driver/forklift driver places the bales in marked sections when unloading. Some of the small plants do not have cranes but a long conveyor on which the bales are placed. The bales are conveyed on to the straw table, the strings are cut, and the bales continue to a chaff cutter or shredder.

### Chaff Cutting, Shredding, and Firing

The chaff cutter has a higher electrical power consumption, and the costs of maintenance are also higher than those of the shredders and is therefore substituted at existing plants as time goes on.

The purpose of the shredder is to try to bring the straw back to the condition before the baling. The bales are conveyed towards the shredder that revolves at up to 30 rev./min. The output can be varied from 15-1,000 kg/h.

A different type of shredder is called "straw-divider". The bales are conveyed towards a set of upward and downward moving racks that tear apart the straw. It falls through a hopper on to a screw stoker or ram stoker that passes the straw into the boiler.

It applies to all firing systems that a fireproof tunnel is established in front of the boiler. It should prevent fire from starting outside the boiler (backfire/burn-back).

### Boiler

The straw is passed via a screw stoker or ram stoker into the bottom of the boiler. The boiler bottom consists of a grate that is a heavy cast-iron construction on which the combustion takes place. The grate is normally divided into several combustion zones admitting combustion air through the grate (primary air). The combustion can be controlled in each zone, and a good burning of the straw can be achieved. The grate can simultaneously make a forward and backward movement, whereby the burning straw is transported through the boiler towards the ash outlet. The energy content of the straw consists to a great extent of volatile gases (approx. 70%) that are driven out during heating for burning in the combustion chamber (furnace) over the grate. In order to secure combustion air to the gases, secondary air is introduced via many nozzles in the boiler wall. The nozzle air speed should be high so as to secure a good mixture of gases and combustion air. If there is insufficient secondary air in the system, the result is high percentages of carbon monoxide and smell (unburnt hydrocarbons) in the flue gas. This results in poor efficiency, since the unburnt gases disappear through the chimney.

From the combustion chamber, the flue gases pass to the convector unit. The convector unit usually consists of vertical rows of tubes through which the flue gases pass. Most boiler plants are equipped with an economiser, i.e., a heat exchanger positioned after the convector unit. There the flue gases give off further heat to the boiler water resulting in a higher overall efficiency.

## Boiler Plants for Sliced Bales

The whole bale is sliced by a hydraulic knife, and the slice is pushed into the boiler by a ram stoker. Before slicing, the bale is raised to a vertical position, and the knife slices from the "bottom" of the bale.

photo: biopress/torben skøtt

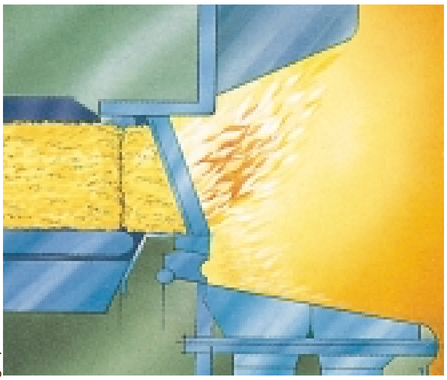
*The forklift truck places the big bales in marked sections so that the automatic crane can find them. Stacking in a height of 4 bales. The automatism sees to it that the crane places a bale on the straw table from where the bale is conveyed to the shredder.*

## Boiler Plants for Continuous Firing of Whole Bales

Instead of cutting strings, chaff cutting/shredding of the straw, the whole bales are pushed into the boiler in an endless line where they burn from the end. The crane places the bale in a feeder box, and a hydraulic ram stoker forces the bale into a tunnel from where it via carriers are carried towards the burner in the boiler wall. The volatile gases are driven out in the burner and are burnt by means of a large number of secondary nozzles. Then the bale is still pushed forward, and the unburnt straw and ash fall on to a water cooled grate for final combustion.

photo: biopress/torben skøtt

*The automatic crane in waiting position, waiting for the boiler automatism calling for straw. The crane lifts the bale up to the "straw divider" and places it on the left where the gate opens automatically. The upward and downward racks are mounted farthest on the right in the "straw divider".*



graphic: vølund

*"Cigar firing principle". Big bales are pushed continuously into the combustion chamber where they burn from the end. Combustion air is introduced via nozzles in the inclined burner front. Ash and partly burnt straw fall on to the inclined grate and burns out before being pushed towards the slag hopper farthest on the right in the picture.*

## Boiler Plants for Firing of Whole Bales

The crane places the bale in a fireproof tunnel that passes it to a feeder box and hence the pre-heating chamber gate opens, and the bale enters. In the "pre-heating chamber" that is almost like a gasification chamber, the bale is ignited by the amount of fuel that is already present, and it burns partly from the front and top, depending on where air is introduced. The introduction of air is controlled on the basis of the flue gas temperature and oxygen percentage. In the bottom of the pre-heating chamber, devices are mounted that transport the burning bale towards the ash outlet.

## Flue Gas Cleaning

The flue gas from the combustion should be cleaned in order to comply with statutory requirements. The Danish Environmental Protection Agency has suggested the following limit values concerning straw-fired boilers above 1 MW/ref. 42/:

Dust emission: Maximum 40 mg/ $Nm^3$ ($Nm^3$ = normal cubic meter, i.e. at 0°C). Carbon monoxide percentage maximum 0.05%. (volume percentage at 10% oxygen in the flue gas).

For plants below 1 MW, there are no well-defined requirements, but the authorities that grants certificates of approval normally use the above values in respect of district heating plants below 1 MW.

Flue gas cleaning reduces the amount of fly ash, thereby avoiding particles spreading over the surrounding buildings. The carbon monoxide content is set out in more detail under the section on environmental conditions.

Flue gas cleaning equipment may consist of:

- Multicyclone: Cleaning, thereby extracting dust particles from the flue gas by centrifugal action taking place in vertical tubes.
- Bag filter: The flue gas passes through fine-meshed/pored bags that trap the suspended solid particles.
- Electrostatic filter: The flue gas passes through an electric field, and the particles precipitate on electrodes.

| Material | Operating temp. °C | Chemical resistance | | | Flex | Price/$m^2$ |
|---|---|---|---|---|---|---|
| | | Acids | Bases | Hydrolysis | | |
| Polyester | 150 | +++ | + | - | ++ | 1 |
| Dralon T | 125 | + | ++ | + | ++ | 1,5 |
| Nomex | 210 | 0 to + | +++ | 0 | +++ | 4 |
| Teflon | 230 | +++ | +++ | ++ | 0 | 20 |

- Unstable
0 Moderate stability
+ Stable
++ Good stability
+++ Extra good stability
Flex: Stability towards impact of handling
Price/$m^2$: Prices are relative prices where polyester is estimated at 1

*Table 4: Filter bag properties and individual prices /ref. 11 and 43/. Hydrolysis is a chemical reaction that requires heat and during which water combines with organic material (the bags) thereby decomposing the material.*

- Flue gas scrubber: The flue gas passes through a shower so that the particles are trapped/caught in the water.
- Flue gas condensation: The flue gas is cooled to below the dew point, and the particles are absorbed/trapped by the dew.

The normal equipment is a multicyclone to serve as spark arrester and for coarse particles followed by a bag filter. The multicyclone cleans the flue gas from 1,000-2,000 mg dust/$Nm^3$ to 500-600 mg/$Nm^3$. Much of the fly ash from straw firing is so fine-grained (below 0.01 mm) that the filter bags are the best and cheapest solution for complying with the requirement of 40 mg dust/ $Nm^3$. The particle content of the dust after filter is under normal operation 20-30 mg dust/ $Nm^3$ with bags without cracks. See also the section on environmental conditions.

Electrostatic filters may give problems in connection with straw-fired plants. Two plants that originally had electrostatic filters have replaced them with bag filters.

The dust particles are difficult to ionise in the electrostatic filter, and it is difficult to make them leave the electrodes and fall off to the ash system due to the very small mass. Some of the particles therefore condense and deposit like coating in the chimney, and, in particular, when the plant is started up, lumps of soot are carried along and fall down in the neighbourhood of the plant.

A few heating plants have installed a flue gas scrubber. The principle is that the flue gas passes through a "waterfall" of atomised water, thereby absorbing the dust particles, thereby transporting them with the water. This method creates a waste-water problem for the plant instead of an ash deposition problem.

As something new, the district heating plant Hals Fjernvarme has installed a flue gas condenser. Experiences gained over the first years are good despite the low water content of straw. The operating costs for electrical power are approx. 5% lower for the entire plant. The costs of maintenance are 1/3-1/4 compared to the filter bags.

## Chimney

The cleaned flue gas is released through the chimney to the atmosphere. There is a separate flue gas tube for each of the boilers. In each individual case, the height of the chimney should be decided on the basis of the requirements by the authority in question. The Danish Environmental Protection Agency Directions No. 6 and 9/1990 "Industrial Air Pollution Control Guidelines" apply to straw-fired plants. The directions also instruct how to calculate the heights of chimneys /ref. 42/.

## Ash

Straw contains 3-5% ash. Part of the ash falls off the grate into a hopper under the boiler and passes via the chain scraper to the ash container. The chain scraper usually lies in a water bath where an automatic water addition takes place simultaneously with the water evaporating and being carried together with the ash to the container. Wet transport of the ash is the most normal procedure at the plants, and a water bath in the chain scraper is an efficient trap so as to prevent the introduction of false air to the boiler through the ash conveyor system.

The fly ash consists of the suspended solids that follow the flue gas through the boiler and are separated in cyclone and filter. From there, the particles are transported via worm conveyors to the chain scraper. The application of the ash as fertiliser is described under Section 11.

## Storage Tank

Storage tanks have been installed at 23 heating plants. The average tank is 400 $m^3$. This size of tank costs approx. DKK 1 million (1995 prices).

The advantages of installing a tank are the following:

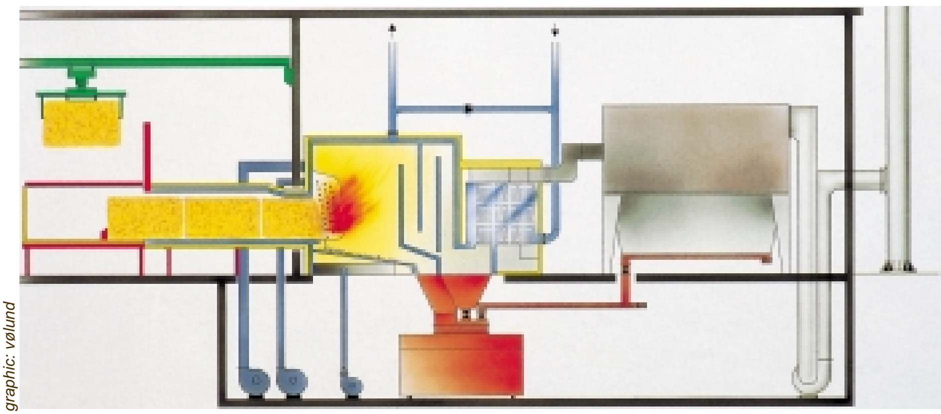
- Peak load morning and evening during the winter season can be smoothed out, thereby avoiding oil firing.
- During suspension of operations, the heat consumption can be drawn from the storage tank, thereby avoiding oil firing. A 400 $m^3$ tank can supply heat for 7 hours at full load at an average plant.
- At off-peak load during summer, the boiler can operate at full load for a short period while the storage tank is filled, and then boiler is closed. The result is improved efficiency and lower emissions compared to continuous operating at off-peak load.
- The personnel's roster becomes more flexible, since, e.g., the boiler can be closed over the week-end during summer.

The drawbacks are increased expenses for investment and maintenance of the tank, and also straw should be purchased in order to cover the tank heat loss.

## Control, Regulation and Monitoring/Supervision

Control, regulation and monitoring/supervision of the plant is called the SRO system (Styring, Regulering and Overvågning). The system usually consists of two computers:

- A PLC (Programmable Logic Computer) that collects operating data from the plant and keeps the plant to chosen values for pressure, temperature, flow etc.
- An ordinary PC that shows the operator the actual data from the PLC



graphic: vølund

*A district heating plant with cigar-fired boiler. The automatic crane places the big bales in the feeder box, and the bales are passed on for combustion. The flue gases pass through the 4 empty passes and out into the convector unit that consists of vertical fire tubes. The ash falls via hoppers off to the ash container. The flue gas passes through the bag filter, and via the flue gas fan in the basement, the cleaned flue gas is released through the chimney. All fans are located in the basement for noise considerations.*

on a visual display screen and via printouts. The chosen values can be changed on the PC, and the plant operating conditions can be changed via the PLC.

The system is divided into three main functions covering the following:

- The control takes care that the entire process takes place in a pre-set sequence. The crane, e.g., is programmed not to pick up a new straw bale until the preceding bale has been fed into the boiler and the boiler working thermostat calls for more heat.
- The regulation takes care that the values chosen for pressure, temperature etc. are maintained.
- The monitor signals malfunctions. The alarm can via a bleep be transmitted to the person on duty in or outside the plant. Usually the plant is manned from 08:00 - 16:00 hours during the 5 working days of the week.

## Environmental Conditions

The authorities and the public debate are very concerned about the impact on the environment by energy production. Straw is $CO_2$ neutral, and that is the major reason why it is a political desire to promote the use of straw in the energy supply.

In the period from 1987-93, a series of emission measurements was made at 13 plants (Table 5). No differences in emission depending on various firing principles were found /ref. 11, Videnblad 61/.

In Table 5, the CO value of 1,200 mg/Nm$^3$ is equal to 0.096% which is above the Danish Environmental Protection Agency's limit value of 0.05%. The CO content in the flue gas depends on how good the combustion is. The content should be as low as possible, since

- CO is poisonous
- CO is a flammable gas. A high CO content decreases the efficiency
- high CO value and odour nuisance from the chimney go together
- high CO value and the presence of PAH and dioxin in the flue gas probably go together

It is desired for the $NO_x$ formation to be reduced, since the presence of $NO_x$ contributes to

- the formation of "smog" in the atmosphere
- acid deposits

The $NO_x$ is formed by the nitrogen content of the air and the fuel and depends on how the combustion takes place in the combustion chamber. Of important parameters for a low $NO_x$ emission can be mentioned:

- low excess air
- low flame temperature
- rapid cooling of the flue gases

| Parameter | Mg/Nm$^3$ at 10% $O_2$ | Mg/MJ |
|---|---|---|
| Particles[1)] (dust) | **80** (5 - 200) | **40** (3 - 100) |
| CO (carbon monoxide) | **1200** (240 -2300) | **600** (120 - 1150) |
| $NO_x$ (nitrogen oxides)[2)] | **180** (80 - 300) | **90** (40 - 150) |
| $SO_2$ (Sulphur oxides)[3)] | **260** (200 -340) | **130** (100 - 170) |
| HCl (hydrogen chloride) | **80** (30 -150) | **40** (15 - 80) |
| PAH | **0,35** (0,20 - 0,60) | **0,18** (0,10 - 0,30) |
| Dioxin (Nordic tox. eqv.)[4)] | $(0{,}01 \cdot 10^{-6}$-$0{,}4 \cdot 10^{-6})$ | $(0{,}005 \cdot 10^{-6}$-$4 \cdot 10^{-6})$ |
| Dioxin (PCDD + PCDF)[4)] | $(0{,}8 \cdot 10^{-6}$-$8 \cdot 10^{-6})$ | $(0{,}4 \cdot 10^{-6}$-$4 \cdot 10^{-6})$ |

1) The figures apply to plants with bag filter
2) Calculated as $NO_2$ equivalents
3) The figure is determined by calculation on the basis of the sulphur content of straw (20 straw analyses). Measurements in 1997 have shown that 35-43% of the sulphur is bound in the ash /ref. 59/.
4) Measurements have been conducted at two plants, one value per plant

*Table 5: In the period from 1987-93 a series of emission measurements has been made at 13 district heating plants. The figures in bold are mean values, and the figures in brackets show at which interval it can be expected to find approx. 90% of the measuring results. Dust- and carbon monoxide emissions are beyond the Danish Environmental Protection Agency's limit values.*

Sulphur dioxide ($SO_2$) is formed on the basis of the fuel content of sulphur. $SO_2$ causes:

- Acidification of the atmosphere
- Corrosion in boiler and filter by formation of sulphuric acid.

Both $SO_2$ and $NO_x$ can be removed from the flue gases, but the processes are too expensive for small plants like district heating plants. Measurements at 2 district heating plants have shown that an amount of 57-65% of the sulphur is released through the chimney. The remainder is bound in the ash /ref.59/.

Hydrogen chloride (HCl) also contributes to $SO_2$ acidification of the atmosphere and corrosion in the boiler plant. The chlorine content of straw may probably be due to the use of fertiliser and pesticides.

PAH (polyaromatic hydrocarbons) is a generic term for a long range of hydrocarbon compounds characterised by smelling. Dioxin is also a generic term for substances that contain carbon, oxygen, hydrogen, and chlorine. PAH and dioxins are formed by incomplete combustion and are hazardous to health. A connection between a high CO content and the formation of PAH and dioxins has been demonstrated /ref. 44, 45 and 46/.

## Noise

In connection with public approval of the heating plant, the following levels can be established:

- Noise limit in boundaries: 40 dB (A)
- Noise limit in existing housing areas:
  - 45 dB(A) Monday - Friday from 07:00-18:00 hours and Saturdays from 07:00-14:00 hours
  - 40 dB (A) Monday - Friday from 18:00-22:00 and Saturdays from 14:00-22:00 and Sundays and non-working days from 07:00-22:00
  - 35 dB (A) all days from 22:00 - 07:00.

As a comparison, the background noise in a housing area is 31-32 dB (A). An efficient way of controlling the noise from noise sources is to place fans, hydraulic engines etc. in a basement.

## Safety

In-plant safety includes fire safety and personnel safety. The plant must be approved by the local fire authorities before starting up. The plant should be divided into fireproof sections, e.g., as follows:

- Straw storage
- Straw feeding
- Boiler room
- Other rooms: Offices, canteen, workshop etc.

The greatest risks are fire in the straw storage or explosions in the flue gas. If flue gases leak to the rooms, e.g. due to malfunction of the feeder system, sparks from electric switches, or from the boiler itself may ignite the flue gases thereby causing an explosion. Usually the section around the feeder system should be equipped with explosion relief doors in order to reduce the damage caused by a flue gas explosion.

The Danish Directory of Labour Inspection shall approve the personnel safety. It includes safety from suffering scalding, burn, poisoning with flue gas or dust, and injuries caused by cranes, conveyors, shredders etc.

## Co-firing with Other Fuels

As mentioned under the section on rating, all plants are equipped with oil-fired peak and stand-by load boiler capable of supplying the entire heat requirements of the net.

The debate over the recent years in respect of straw resources and the meagre straw year 1993 occasioning local shortage of straw has resulted in 11 plants having upgraded the storage, feeder system and boiler for co-firing with wood. It is primarily dry waste wood from the wood industry or wood pellets that are used. At four plants, it is possible to mix fatty sludge and straw/ref. 47 and 48/.

Mariager District Heating Plant is one of the plants that has been converted into burning both waste wood and straw. The plant has a 6 MW biofuel boiler and has had the following fuel consumption during 1995:

| | |
|---|---|
| Straw: | 4,944 tonnes |
| Wood: | 1,310 tonnes |
| Oil: | 57.4 $m^3$ |

Oil share in relation to the total heat production of 23,200 MWh is only 2%.

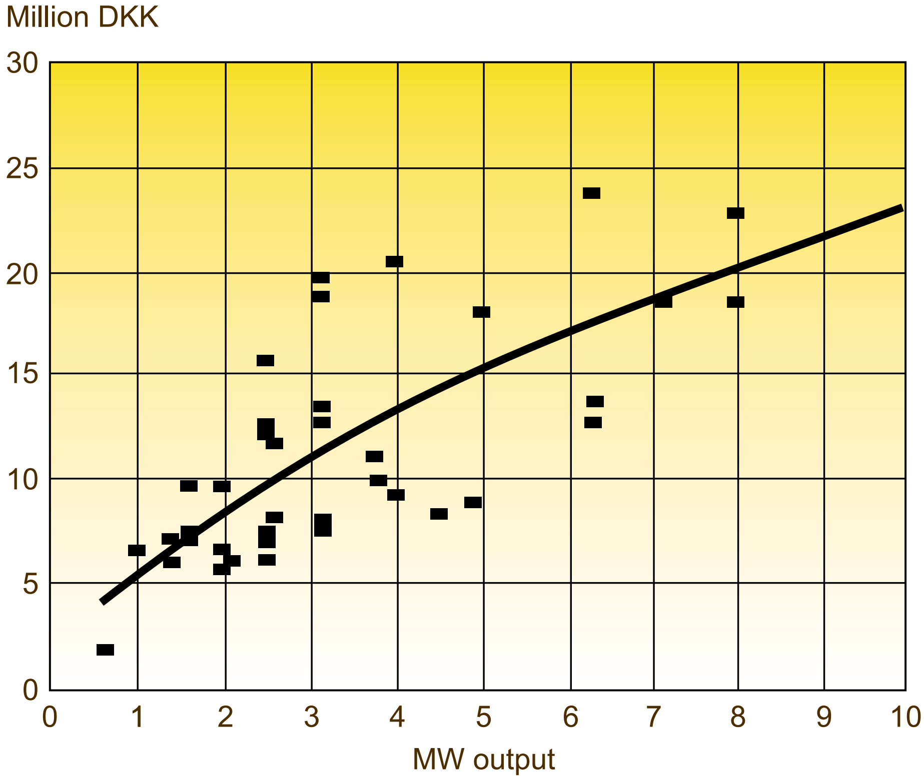



*Figure 18: Cost of construction by the million (DKK) per MW installed output, adjusted to the price level of 1995. The price includes site, land development, buildings, installation of machinery, and projecting. The information is based on 40 plants that only use straw. The price spread can be explained by different size of storage, the general quality of the plant, fluctuations of the market in the period from 1983-1995, and that individual plants have included a storage tank in the price.*

## Investment and Operating

### Construction Investment

For the purpose of the report "Anlægs- og driftsdata for halmfyrede varmeværker. 1996" (data on the construction and operation of straw-fired heating plants) /ref. 9 and 10/, information has been collected about initial expenditures in respect of site, land development, buildings, installation of machinery and projecting. All prices are 1995 prices so that they are comparable. Only very few plants have storage tank included in the price. Figure 18 illustrates the prices for the individual plants as a function of the straw boiler output.

As an example, the cost of construction will be set out in detail for a town where both a new plant and a new distribution net is established. It is important for a new project to get "a head start". Therefore, at least 80% of the oil-fired boilers and all public large-scale consumers should join it right from the beginning. Public large-scale consumers are municipality offices, schools, sports centres, etc. Contrary to earlier practice, industrial enterprises and liberal professions will not be reimbursed for energy and environmental taxes in connection with space heating and are therefore also a target group.

The data of the example are partly from Figure 17 and are per annum:

| | |
|---|---:|
| 260 consumers: | 4,550 MWh |
| 10 large-scale cons.: | 3,300 MWh |
| Net losses in percent: | 30% |
| Heat production: | 11,200 MWh |
| Heat production, straw-based: | 93% |
| Heat production, oil-based: | 7% |
| Maximum output requirement: | 3 MW |
| Straw-based boiler output: | 2 MW |

For a densely built-up town, the distribution loss for a year with 3,112 Energy Control Scheme degree days ("ELO degree days") is approx. 30%. If the area is sparsely built over or in case of small towns connected via transmission piping, the distribution loss rises to above 35%.

The investment is as follows:

| | million DKK |
|---|---:|
| The heating plant | 9.0 |
| Distribution net | 10.0 |
| Consumer service pipes | 4.0 |
| Consumer house installations | 4.0 |
| Unforeseen expenses | 1.0 |
| Total cost of construction | 28.0 |
| Possible subsidies | 4.8 |
| Loan requirement | 23.2 |

The cost of construction can be financed fully by means of index-linked loan. Index-linked loan is a loan that is repaid by annual payments that increase concurrently with inflation. It is a cheaper type of loan than the ordinary loans, repayable by equal semi-annual instalments or annuity loans, as long as inflation is below 7% per annum. The structure of index-linked loan is set out in more detail in /ref. 41/. Applications for subsidies from the Danish Energy Agency can be filed until and including the year 2000.

## Operating Profit and Loss

The heating plant income derives from the sale of heat and is distributed on standard and variable prices for the heating. The tariff  for the sale of heat to the consumers may e.g. be:

| | |
|---|---|
| Variable charge | DKK 350/MWh |
| Fixed annual charge | DKK 1,000/con |
| Capacity charge, private | DKK 30/$m^2$ |
| Capacity charge, industry | DKK 30/$m^2$ |

In addition to that, VAT shall be included. For a private consumer in a house of 120-130 $m^2$ with an average consumption of 17.5 MWh, the heating expense will amount to DKK 13,800 per annum. This expense is more or less equal to the operating costs in respect of oil firing: Oil, chimney sweeping, and maintenance. The tariff will yield the following income:

| | Thousand DKK |
|---|---|
| Sale of heat, 7,840 MWh | 2,748 |
| Fixed annual charge | 270 |
| Capacity charge, private | 1,014 |
| Capacity charge, industry | 350 |
| Total income | 4,442 |

The expenses are as follows:

| | Thousand DKK |
|---|---|
| Purchase of straw, DKK 430/t | 1,235 |
| Purchase of oil, 87,000 litres | 295 |
| Maintenance, plant | 200 |
| Maintenance distribution net | 200 |
| Electrical power, chemicals | 100 |
| Other costs (insurance etc.) | 75 |
| Personnel and administration | 500 |
| Depreciation, 20 years | 1,160 |
| Indexation of instalments | 23 |
| Interest and contribution | 620 |
| Total expenses | 4,408 |
| Net result | 14 |

With regard to accounting practice, the straight line method of depreciation, which charges each year an equal sum, reflects in a better way the partial using-up of the life of the plant than does the other practice where the depreciation is booked as being equal to the instalments on the loan. By the last-mentioned method, the expenses will increase as the instalments rise over the period of repayment. Indexation of instalments is the expense for the annual appreciation of instalments with the index of net prices. The remaining debt also is revalued with the index of net prices. This item is booked in an exchange equalisation fund under the equity capital /ref. 11, Videnblad 117/.

### Forms of Organisation

Straw-fired heating plants can be established as privately owned companies:

- Co-operative society with limited liability (A.m.b.a.)
- Private limited liability company (ApS)
- Limited liability company (A/S)

or publicly owned companies.

The persons behind such company may be either:

- a group of farmers
- an association of straw suppliers
- an existing district heating company
- a group of consumers
- a municipality

If a straw-based heating plant is privately owned, it would be appropriate to organise it as a co-operative society with limited liability (A.m.b.a.). The owners shall only be personally liable for their contribution, and each consumer has one vote at the general meeting. In addition, the form of company is already known to many people. Almost all straw-based heating plants in Denmark are privately owned co-operative societies with limited liability. A partnership may also be the form chosen, or a limited liability company where the participants also are

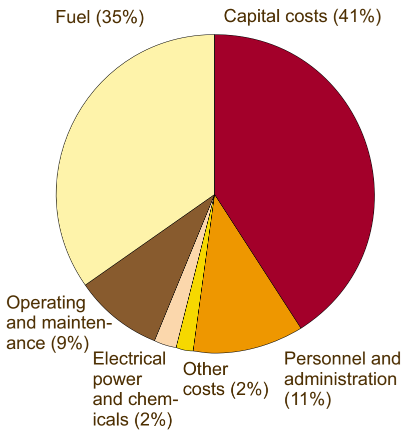



*Figure 19: Distribution of costs in percentages concerning the example illustrated/calculated. The costs in connection with repayment of loan (capital costs) and the purchase of straw and oil make out 76% of the plant's costs.*

liable only for the capital for which they have subscribed shares.

Straw-based plants shall not be liable to pay tax if the heat can be supplied to everyone living in the area they supply. Therefore it would not be appropriate to form a partnership (I/S), since it would not normally be possible to exploit the tax benefits. On the contrary, the partners are jointly and severally liable to the full extent of their property. This means that creditors may levy execution against all partners in the event that the company goes bankruptcy.