8. District Heating Plants

The term district heating plants refers to plants with own generation of heat, but without power generation. The heat is distributed to a district heating system to which all consumers living within the system have the opportunity of being connected.

The use of forest chips at district heating plants has increased significantly since the first systems came into operation at the beginning of the 1980s. While there were only three wood chip-fired district heating plants in 1984, the number has increased to approx. 50 plants today. The consumption of wood chips in the same period has increased to approx. 725,000 m^3 l. vol per year which is equal to an amount of energy of approx. 1,800 TJ. At the end of the publication, there is a list of wood chip-fired district heating plants in Denmark.

Seen in an international perspective, the use of wood chips at district heating plants has increased tremendously during a relative short period of time. Only in few other countries, such as Sweden, Finland, and Austria, has the use of wood chips at district heating plants increased more than in Denmark.

Wood chip-fired district heating plants are established either in order to replace oil- or coal-fired district heating plants, connected to old district heating systems, or as new plants and systems (the so-called "urbanisation" projects). Wood chip-fired boilers at Danish district heating plants are designed for the generation of heat in the range of 1 MW and 10 MW; the average being 3.5 MW.

Subsidies are granted under the State-Subsidised Promotion of Decentralised Combined Heat and Power and Utilisation of Biomass Fuels Act /ref. 57/. It is obvious that this is financially beneficial to these projects, and it is assumed that the subsidy scheme is of great importance to the continuos enlargement of the district heating supply based on biomass. "Urbanisation" projects are started from scratch. The heating plant, the district heating system and the consumer service installations thus all have to be established. These plants require a considerable total investment and have typically been implemented in small communities, wherefore wood chip-fired boilers used here are smaller than the average of 3.5 MW mentioned above.

About 7 to 9 manufacturers in Denmark are making turn-key wood chip-fired district heating systems. In addition a large number of manufacturers are supplying small systems for farms and institutions or parts of systems (see List of Manufacturers).

The biomass technology has recently received increased interest by trade compagnies and industries. This is due to the fact that the compagnies no longer can deduct energy and environmental taxes on indoor heating. Trade and industry are also offered the opportunity of being granted subsidies from the Danish Energy Agency for investments in installations which may reduce emissions of e.g. CO_2 /ref. 58, 59/.

Choice of System Size

When deciding the size of a new chip-fired system at a district heating plant, it is necessary to know the annual heating demand of the district heating system. It is also necessary to know the changes in the heating demand of the district heating system per day and per year.

/Ref. 60/ describes how to decide the boiler size in relation to the heating demand of the district heating system. The method is the same for straw and wood chip plants, so the example in /ref. 60/ can be transferred directly to wood chip-fired heating plants.

It is important for new district heating plants, in particular, to pay attention to the distribution loss. In Danish District Heating Association's statistics from 1995/96, information is given on distribution losses for 19 wood chip-fired heating plants. The average distribution loss in that period was 26% with the highest distribution loss being 36% and the lowest being 19%. There were approx. 3,300 degree days in 1995/96. When correcting to a normal year, the average distribution loss of the 19 plants is approx. 28%.

Plant Technology

The typical wood chip plant is constructed around a solid fuel boiler with step grate or travelling grate. The boiler has refractory linings round the walls of the chamber in order to ensure the combustion temperature despite the relatively wet fuel. The plant designs are highly automated so that e.g. the feeding system of wood chips from the storage onto the grate is carried out by means of a computer controlled crane that simultaneously keeps track of the storage.

photo: biopress/torben skøtt

When a district heating plant has its own outdoor storage as in Ebeltoft, it seems as if the forest has entered the town. There are advantages in relation to management and economy, but it requires adequate distance to neighbours.

All the systems have the same main components:

- Wood chip storage
- Crane or other chip handling
- Feeding system
- Combustion chamber and boiler
- Flue gas purifying
- Flue gas condensation
- Chimney
- Handling of ash

The following describes the main principles of the technique that is typically used at wood chip-fired district heating plants.

Wood Chip Storage

The size of the fuel storage depends on various factors, e.g. the contract made with the fuel supplier. However, a storage of wood chips that equals the consumption of minimum 5 days and nights at max. heat production should always be available for the purposes of operation during week-ends and for security of supply during extreme weather conditions.

Most plants settle for an indoor storage and leave the handling of larger storages to the suppliers of wood chips. However, a few plants also have an outdoor storage of their own and may therefore receive a discount from the supplier of wood chips. Due to the risk of spontaneous fire, the wood chips are piled to a height of max. 7-8 metres, and this also applies to indoor storages. Wood chip storages are discussed in Chapter 3.

During work in the wood chip storage, there may be a risk of breathing in allergy-causing dust and micro-organisms, such as fungi and bacteria. It must be strongly recommended never to work alone in wood chip silos. Working environment issues are also discussed in Chapter 5.2.

Handling of Fuel

The majority of operating problems experienced is no doubt caused by the plant system for transport of wood chips from storage to the feeding system. The entire transport system from storage to boiler should be viewed as a chain in which the reliability of operation of the individual links is equally important. The entire district heating plant stops in case of a “missing link” in the transport chain, e.g. a defective crane wire.

Wheel Loader

At plants with outdoor storage, it is normal to use a wheel loader with a large shovel for the transport of wood chips to the indoor wood chip storage.

Crane Transport

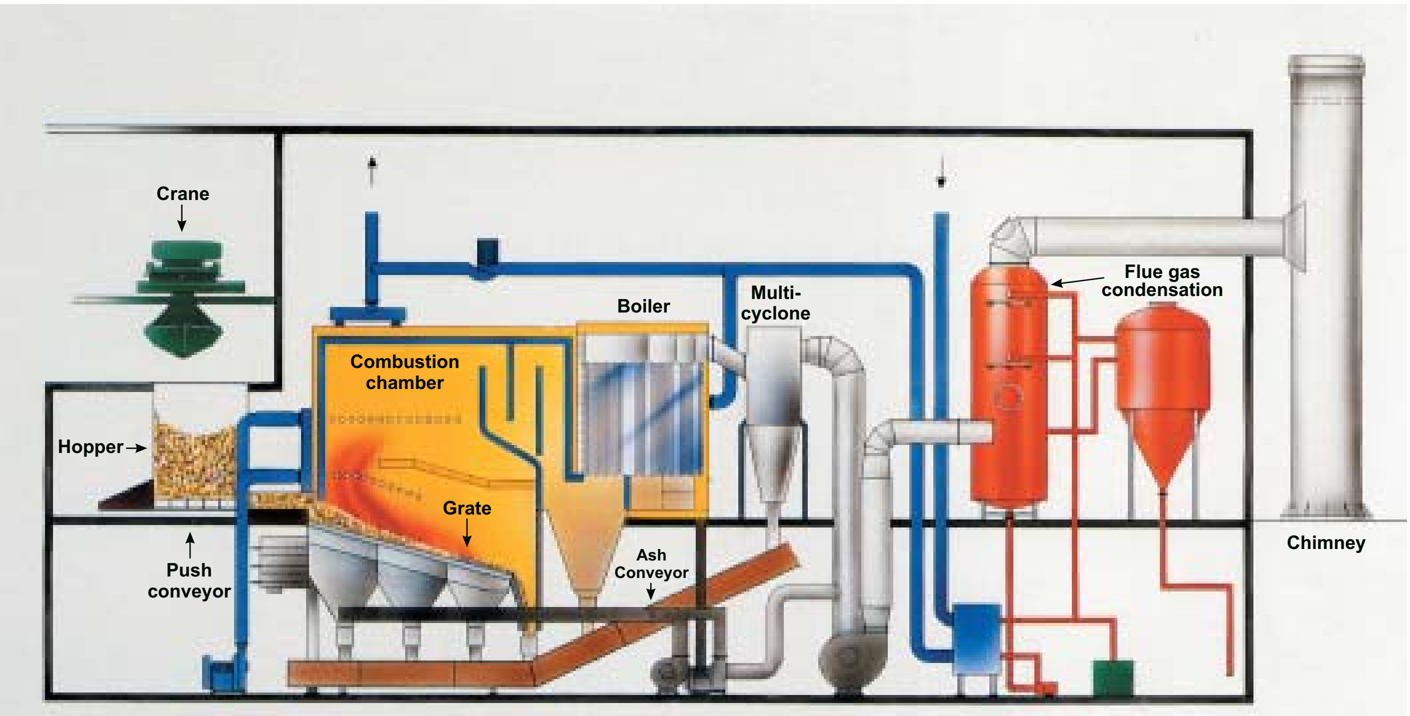
Between the indoor wood chip storage and boiler feeding system, a crane is often used for the transport of wood chips. The crane is flexible, has a high capacity, and is also the transport equipment that best tolerates a poor wood chip quality. However, it is important for the crane shovel to be toothed. If not toothed, it is difficult to fill and it easily turns over on top of the pile. For relatively large plants, the crane is also relatively inexpensive, while it is a too expensive solution for very small systems.

Hydraulic Push Conveyor

The hydraulic push conveyor is used for unloading rectangular silos with level floors. It is normally not as technically reliable as the crane solution. The hydraulic push conveyor is relatively inexpensive and is therefore particularly suitable for small systems (0.1-1 MW boiler nominal output).

Tower Silos

Tower silos with rotating screw conveyor should not be used for wood chips. The silo is time-consuming to fill due to the great tower height, and the mechanical parts in the silo bottom are not very accessible for the purposes of maintenance and repair work. Technical problems nor-



graphics: vølund systems a/s

Figure 21: In Thyborøn the district heating is supplied by a 4 MW chip-fired boiler. The system flue gas condenser produces an additional 0.8 MW heat at 50% moisture contained in the wood chips.

photo: dk-teknik/henrik houmann jakobsen

Mist eliminator in brilliant blue and insulating jackets with glittering surfaces situated on the flue gas condenser. The boiler room at Græsted Varmeværk being demonstrated to a foreign visitor look like a "sittingroom".

mally arise when the silo is full of wood chips. Before starting any repair work, it must be emptied - manually or preferably with crane grab. For storage of wood pellets, the equipment used in animal feed industry is normally suitable.

Screw Conveyors
Conveyors are inexpensive, but vulnerable to foreign matter and slivers. In general, screw conveyors with bolted-on top are recommended instead of conveyors enclosed in tubes. The recommendation is easily understood after just one experience of manually emptying of a tube conveyor blocked by slivers or foreign matter. Similarly, it may be considered erroneous projecting if screw conveyors are embedded in concrete floors or otherwise located so that repair work and replacement of parts are impossible. Like other mechanical conveyors, screw conveyors should be considered a part prone to wearing and must be easily accessible for maintenance work.

Correctly dimensioned, screw conveyors are an acceptable solution at small plants (0.1-1 MW boiler nominal output). But unless hardened steel is used, normal wear and tear will result in a relatively short life of the screw conveyor. Screw conveyors are seldom used as transport equipment at large district heating plants.

Belt Conveyors
Belt conveyors are rather insensitive to foreign matter. At this point, they are better than screw conveyors, but unless equipped with barriers, the belt conveyor cannot manage as high inclinations as the screw conveyor. High price and dust emissions (which may necessitate covering) are the major drawbacks of the belt conveyor.

Pneumatic Conveyors
In general, wood chips are not suitable for transport in pneumatic systems. If wood chips are available in a particularly uniform size, however, transport by pneumatic conveyors may be a possibility, but the energy consumption of pneumatic conveyors is great.

Feeding Systems

There are several types of feeding systems for wood chip-fired boilers. The choice of feeding system depends on the size of the plant and whether the use of other solid fuels than wood chips is desired.

Hydraulic Feeding System
Many plants use this quite reliable feeding system. Wood chips fall from a hopper into a horizontal, square box, from where hydraulic feeding devices force wood chips on to the grate. The construction of the system is of decisive importance to its reliability. If correctly designed as most often seen today, it is among the best feeding systems for wood chips.

Stoking
Small systems (0.1-1 MW boiler nominal output) often have screw stokers feeding the boiler. At some plants, the screw stoker is positioned across the longitudinal direction of the grate. This gives a good distribution of the fuel over the width of the grate.

Grate with Feed Hopper
Some wood chip plants have a simple hopper that feeds the wood chips on to the grate. The system is known from coal-fired boilers with travelling grate and requires that the height of the wood chips in the hopper will be high enough so as to function as an airtight plug between the feeding system and the boiler. The problem of the blocking of the hopper can be remedied by an appropriate design of the hopper, and as a last resort by mechanical stirring/scraping systems.

Spreader Stoker
Wood chips are thrown into the combustion chamber by a rotating drum in a spreader stoker. Only a few plants use the system.

Pneumatic Stoker
Wood chips are blown into the combustion chamber and fall on to the grate. Spreaders and pneumatic stokers are often used in connection with combustion of wood chips with a high moisture content.

Combustion Chamber and Boiler

Wood chips are introduced for combustion on the grate in the combustion chamber that is often situated immediately below the boiler. The most common type of grate in wood chip-fired systems in district heating plants is the step grate/inclined grate and the chain grate/travelling grate. For both grate types, the primary air that is needed for the combustion is supplied from underneath the grate and passed up through the grate.

The step grate has the advantage that wood chips are turned upside down when tumbling down the “steps”, which increases the air mixing and burnout. The travelling grate is known from coal-fired systems. There the wood chips lie without moving in a uniform layer, whose thickness is controlled by a sliding gate. During combustion the grate and the chips move towards the ash chute.

Air for combustion is introduced by two air fans in the form of primary and secondary air (see Chapter 6). For the combustion of moist wood chips, the combustion chamber has refractory linings round the walls. This insulation ensures a high combustion temperature and suspended arches radiating heat to the wood chips. The amount and the design of the lining are factors of great importance to the combustion quality during the combustion of wet fuels. When firing with dry fuels, e.g. wood pellets, the lining is of no benefit to the combustion quality. Rather the opposite, since the combustion temperature will be too high, thereby risking soot in the flue gas and grate slagging. Therefore, the type of fuel and its water content should be determined before choosing installation.

Combustion Quality

Chapter 6 sets out in detail the requirements for a good combustion quality. These requirements can be “boiled down to” “the 3 T’s” (Temperature, Turbulence and Time). The temperature should be sufficiently high to enable efficient drying, gasification, and combustion. Air and combustible gases should be mixed adequately (turbulence), and finally there should be space and time for the gases to burn out before they are cooled too much by the boiler water.

Boiler

The flue gases pass from the combustion chamber to the part of the boiler, where the heat is given off to the circulating boiler water. Most often, the boiler is situated above the grate. The flue gas flows inside the tubes that are water cooled on the outside surface.

In small systems, the combustion unit and the boiler may be completely separated, since wood chips are burnt in a separate pre-combustor, from where the flue gases are passed into the boiler.

In the boiler unit or as a section after this unit, an economiser may be installed that cools the flue gas down to a temperature of approx. 100 °C. The increased cooling improves the efficiency. The boiler room should be large enough for repair work and for ordinary maintenance work, including boiler purifying, to be carried out in a proper way. The building round the boiler should be designed so as to give room for purifying of the boiler tubes and replacements of tubes. With respect to the boiler life, it is important that the temperature of the return water to the boiler is sufficiently high. It is recommended to keep a return water temperature of at least 75-80 °C in order to reduce the corrosion of the boiler tubes in particular. The life of tubes varies a lot at the various wood chip-fired plants. In addition to the operating temperature, the boiler life depends on the operational patterns, fuel, combustion quality, and choice of material.

Flue Gas Purifying - Fly Ash

The fly ash is the part of the ash that remains in the flue gases on its way through the boiler. Flue gas purifying is first and foremost a question of reducing the amount of fly ash emitted through the chimney. The emission of other pollutants is discussed later on in this chapter.

The fly ash is transported from the flue gas purifying unit to the remaining part of the ash system by screws. The separation of fly ash from the flue gas may be accomplished either by means of multicyclone, bag filter, or other flue gas purifying equipment.

The fly ash from the combustion of wood consists primarily of relatively large particles that can be trapped by means of a multicyclone. Most plants are equipped with multicyclones. A well-dimensioned system can purify to a level of approx. 200 mg/m^3n /ref. 61/ (1 m^3n is a normal cubic metre, i.e., a cubic metre of gas converted to standard conditions 0 °C and 1 bar). Multicyclones that are inexpensive to buy and maintain, are used for precleaning before the flue gas condensation unit.

Bag filters can purify to a level of 10-50 mg/m^3n. Normally, bag filters are only capable of withstanding flue gas temperatures of up to approx. 180 °C. In order to avoid embers and sparks in the bag filters, the flue gas must pass cyclones or a filter chamber situated before the bag filters. Bag filters are automatically deactivated if the max. temperature or the max. value for the oxygen content in the flue gas are exceeded.

Like the bag filter, the electrostatic precipitator (ESP) cleans efficiently, but it is more expensive to install in relatively small wood chip-fired systems. However, operating costs are lower, however, than those of the bag filters. Bag filters, ESPs etc. are not extensively used today at wood chip-fired district heating plants.

Flue Gas Condensation

Flue gas condensation units are now in general use in both new and existing systems. It is a technique that both purifies the smoke/flue gas for particles to a level

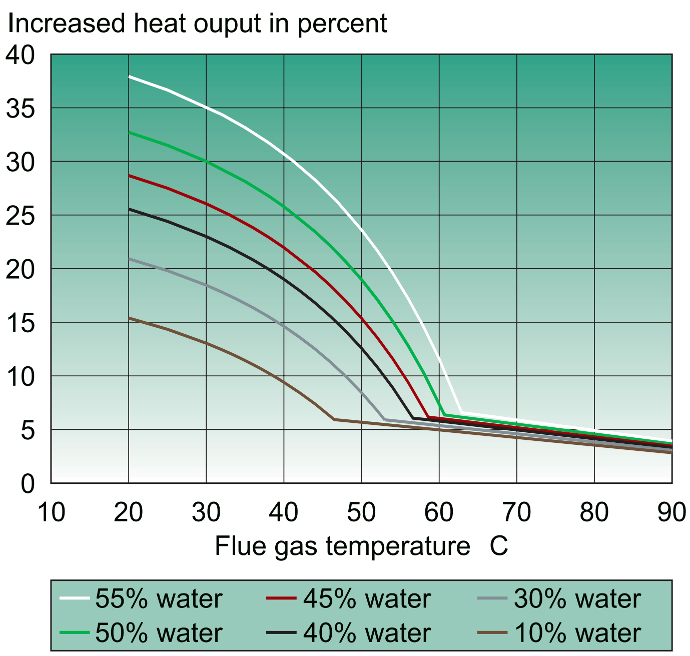


Figure 22: Flue gas condensation increases the generation of heat and the efficiency of the plant. The graph illustrates how the additional heat output depends on the flue gas temperature and on the wood chip moisture content.

almost similar to that of bag filters at the same time of increasing the energy efficiency. Most of the Danish wood chip-fired district heating plants have either been delivered with flue gas condensation or have had the equipment installed with the boiler system.

Like most other fuels, wood contains hydrogen. Together with oxygen from the air, the hydrogen is converted to water vapour by combustion, and the water vapour forms part of the flue gas together with other products of combustion. Furthermore, wood chips used at district heating plants typically have a moisture content of 40-55% of the total weight. By the combustion, this water is also converted to water vapour in the flue gas.

The flue gas water vapour content is interesting because it represents unutilised energy that can be released by condensation. The theoretical amount of energy that can be released by the condensation of water vapour is equal to the heat of evaporation for water plus the thermal energy from the cooling.

When flue gas is cooled to a temperature below the dew point temperature, the water vapour will start condensing. The more the flue gas is cooled down, the larger is the amount of water that is condensed, and the amount of heat that is released is increased. The lowering in temperature from the normal flue gas temperature of the system to dew point temperature automatically increases the heat output. The effect increases, however, when the condensation starts, and the heat of evaporation is released. Figure 22 illustrates in percentages the increased generation of heat that can be achieved by lowering the flue gas temperature. The normal operating situation that forms the basis of the calculations is a flue gas temperature of 130 °C with CO_2 being 12%. The various lines in the figure illustrate various values for the wood chip moisture content in percentage of the total weight.

The curves show the theoretical improvement of the efficiency that can be calculated on the basis of the moisture content and the flue gas temperature. Experiences acquired from condensation units in operation indicate that an increase in efficiencies can also be achieved in practice /ref. 62/. Thus, the annual efficiencies for almost all plants are above 100% (based on the net calorific value of the fuel which does not include the condensation heat).


photo: dk-teknik/henrik houmann jakobsen

Fly ash from the cyclone is stored in the ash container to the left, while bottom ash from the heating plant is deposited in the large container.

The return water from the district heating system is used for cooling the flue gas. The water should be as cold as possible. The flue gas cooling unit is therefore the first unit the water passes when it returns from the district heating system.

Condensate

Condensate consists of water with a small content of dust particles and organic compounds from incomplete combustion. There is also a minor content of mineral and heavy metal compounds, and of chlorine and sulphur from the wood.

The pH value of the condensate varies a lot from system to system, and it also varies with the operational pattern. A typical value lies between pH 6-7, but there have been measured pH values from 2.7 to above 8. The dust particles contained in the condensate affects the pH value heavily. High pH values are connected with large particle contents - i.e. the fly ash seems to be alkaline/basic, and the majority of it by far is dissolved in the condensate. Indissoluble particles only contribute 10%.

The condensate should be treated before being discharged. The minerals and heavy metals contained in wood, such as cadmium that has been absorbed during the growth in the forest, concentrate in the condensate and may reach a level exceeding the limit values for discharge. Investigations have shown that the large amount of cadmium contained in the condensate is found in the condensate particles and not in dissolved form in the water. The particles can be removed from the condensate liquid by filtering, so that the cadmium content is reduced to below the limit values for discharge /ref. 63/. This is the reason why filtration equipment for the separation of condensate particles is being installed in an increasing number of plants right now. After treatment and neutralisation, the condensate is generally discharged into the municipal sewage system.

When the flue gas leaves the flue gas condenser, it should pass through an efficient mist eliminator for the collection of entrapped droplets, thereby avoiding mist being carried further into the tube, exhaust fan, and chimney.

The first prerequisite of success with flue gas condensation is a return flow temperature in the district heating system that is so low that the vapour in the flue gas can be condensed. In addition, the fuel should have a high moisture content. Wetter fuel increases the overall efficiency of the plant! This applies only as long as the moisture content is not so high as to result in incomplete combustion. Forest chips with a moisture content in the range of 40 and 50% are ideal for systems with flue gas condenser.

The installation of flue gas condensers may often make the installation of other equipment for flue gas purifying unnecessary. If the installation of a bag filter can be avoided, the money thereby saved can often pay the investment in the flue gas condensation unit. Consequently, the energy saved is almost free.

Chimney

Before chimney and flue gas condenser an exhaust fan is installed, which creates negative pressure throughout the flue gas passes of the heating system. A control device ensures that the exhaust fan in interaction with the combustion air fans keeps a preset negative pressure in the combustion chamber. The exhaust fan then forces the flue gas into the flue gas condenser and the chimney. Individual chimney heights should be determined on the basis of the environmental requirements. Further information about chimney heights can be found in /ref. 64/. For small plants with flue gas condenser, the chimney should be designed so as to avoid corrosion damage, i.e., glass fibre or rust-proof materials should be used.

Soot emission from chimneys of systems with flue gas condensation causes problems at some heating plants. The smoke is saturated with water vapour. It also contains dissolved salts and perhaps impurities from the flue gas condensate, which may be deposited in the chimney. Soot emission occurs when the deposits in the chimney loosen and are passed along with the flue gas flow. Efficient mist eliminators, low velocities in the chimney, and perhaps the installation of a wash-down system in the chimney can be recommended so as to eliminate the problem /ref. 65/.

Handling of Ash

Wood chips contain 0.5-2.0% of the dry weight in the form of incombustible minerals which are turned into ash in the combustion process. The ash is handled automatically at all district heating plants. The manual work in connection with the ash system is limited to ordinary inspections and intervention in case of operations stoppage. The composition of wood ash means that slagging is not a widespread phenomenon at wood chip-fired heating plants.

The ash drops from the grate onto an ash conveyor or other ash collection system. The sludge from the flue gas condensate contains a large amount of heavy metal and is collected separately for later disposal.

The ash system may be arranged as a wet or dry ash system. A wet ash system is a dual function system, since it is efficient as a trap hindering false air entering the boiler at the same time as extinguishing glowing ash. A drawback of the system is the heavy weight ash in the ash container and the corrosion resulting from the wet ash. The emptying of the containers varies with the consumption of wood chips, i.e., from approx. every second week to once every three months.

Category	Description	Max. Cd content (mg Cd/kg DM)	Max. amount of application (tonnes DM/ha/year)
H1	Straw ash, mixed	5	0.56
H2	Straw ash, mixed	2.5	1.12
H3	Straw ash, bottom ash	0.5	5.6
F1	Wood chip ash, mixed	15	0.19
F2	Wood chip ash, mixed	8	0.35
F3	Wood chip ash, bottom ash	0.5	5.6
H+F	Mixed straw/wood chip ash	5 (as H1)	0.56

Table 14: Limit values for cadmium and the max. allowable amount of application according to the "Executive Order on Ash from Gasification and the Combustion of Biomass and Biomass Residual Products for Agricultural Applications", submitted to the Ministry. DM stands for dry matter.

Disposal

Ash contains the unburned constituents of fuel, including a range of nutrients, such as potassium, magnesium and phosphorus, and it can therefore be used as fertiliser in the forests if the content of other substances that are problematic to the environment is not too high. When the biomass agreement is fully implemented in the year 2005, the annual amount of biomass ash produced will be in the range of 80 to 100,000 tonnes. With the amount of ash being that huge, it is important to find a reasonable and environmentally acceptable use of it, thereby utilising the nutrients of the ash in the best possible way.

Using the ash in agriculture requires permission from the county. Applications submitted to the county are being considered at the time of writing (at the beginning of 1999), thereby also having regard to the Department of the Environment Executive Order No. 823 September 16, 1996 on Residual Products for Agricultural Applications /ref. 66/. However, this executive order is primarily directed towards industrial residual products, sewage sludge, compost etc., and is not particularly suitable for the administration of the application of ash. The low cadmium limit values make it difficult for biomass heating plants to comply with the executive order, and the use of the ash has therefore to a high extent been based on exemptions granted by The Danish Environmental Protection Agency and permissions from the county. In the event of no exemption being granted, the ash should be dumped at a controlled disposal site. However, in the long term perspective basing waste disposals on exemptions is an unwise solution, and therefore an independent executive order for ash has recently been submitted to the Ministry of Environment and Energy. The coming executive order "Executive Order on Ash from Gasification and the

Heavy metals	Limit value (mg per kg dry matter)
Mercury	0.8
Lead	120 (private gardening 60)
Nickel	30
Chromium	100

Table 15: Limit values for the remaining heavy metals according to the " Executive Order on Ash from Gasification and the Combustion of Biomass and Biomass Residual Products for Agricultural Applications", submitted to the Ministry.

	Cut-off levels (mg per kg dry matter)
Sum of Acenaphthene, Phenanthrene, Fluorene, Fluoranthene, Pyrene, Benzofluoranthenes (b+j+k), Benzo-a-pyrene, Benzo-g-h-i-perylene, Indole-1-2-3-cd-pyrene	6 (From July 1, 2000, the value is 3)

Table 16: In addition to heavy metals, the ash may also contain the so-called polyaromatic hydrocarbons (PAH), which typically occur in connection with incomplete combustion. The concentration cut-off levels for PAH as designated in the Executive Order on Ash from Gasification and the Combustion of Biomass and Biomass Residual Products for Agricultural Applications", which is at the reading stage, are listed here.

Combustion of Biomass and Biomass Residual Products for Agricultural Applications" is based on the view that it seems to be reasonable to return straw and wood chip ash to the areas from where the straw and wood chips come. With straw or wood chips remaining in the field or in the forest, heavy metals would remain in the soil. When burning the straw or wood chips the heavy metals in the ash will of course concentrate, but if the ash is returned in reasonable amounts, the heavy metal impact will not be different from the situation where the straw and wood chips remain in the field/forest. The limit values in the new executive order are therefore modified according to the existing executive order, while the max. allowable application amount secures that the application of heavy metals to the areas will not exceed the amount that is normally removed with the biofuel during the harvesting of it.

Pure straw ash should only be applied to agricultural land, while pure wood chip ash should only be applied to forest areas. Mixtures of wood chip and straw ash can be applied to both forests and agricultural land. Ash applied to agricultural land can be dosed as an average over 5 years, while ash applied to forest areas can be dosed as an average over 10 years. The max. allowable application to forest areas is 7.5 tonnes of dry matter per ha per rotation (100 years).

As there is a certain connection between the combustion quality and the PAH contained in the ash, an analysis of unburned carbon in the ash must be made in connection with each of the heavy metal analyses according to the suggested executive order. If the residual carbon in the ash is below 5%, PAH analyses must be made every second year, but if the result of an analysis of unburned carbon exceeds 5%, thus indicating incomplete combustion, then a PAH analysis must be made immediately.

When the new executive order has come into force, it is expected to offer better outlets for a reasonable and environmentally acceptable use of the biomass ash.

	Unit	Typical value	Typical variation
SO_x as SO_2	g/GJ	15	5 - 30
NO_x as NO_2	g/GJ	90	40 -140
Dust, multicyclone	mg/m^{3}n	300	200 - 400
Dust, flue gas condensation	mg/m^{3}n	50	20 - 90
CO_2 (see text)		0	0

Table 17: Typical emission values in connection with wood chip firing. The figures vary very much in practice, even beyond the typical variations listed /ref. 67/.

Size of system Input in MW	Recommended limit value for dust mg/m^{3}n at 10% O_2	
	Systems with dust filters	Systems with condensing or technology without dust filters
> 0,12 < 1	100	300
> 1 < 50	40	100

Table 18: Recommended limit values for dust from wood-fired systems /ref. 61/.

Environmental Conditions

This section describes the impact on the air environment in connection with firing with fuel chips at district heating plants. Table 17 illustrates typical emission values for chip-firing.

Dust

After intensifying the emission standards in 1990 for air pollution, most of the municipalities decided to require lower emission levels for dust from small wood chip-fired heating systems than earlier. Emission standards for dust from heating systems are described in the Danish Environmental Protection Agency's guide, Limitation of Industrial Air Pollution /ref. 64/. The guide designates emission levels for a range of heating systems, but not for wood, though.

When dealing with applications for wood-fired systems, the approving authorities have most often used the limit values for "other dust pollutants" in which the limit value for dust is fixed in proportion to the size of the mass flow before purifying. In some instances regard has also been had to the recommended limit values for straw-fired systems larger than 1 MW input, designating not only dust but also the recommended limit value for a carbon monoxide content not to exceed a volume percentage of 0.05 at 10% O_2. In 1996 the Danish Environmental Protection Agency had a report prepared, Dust Emission Standards for Wood-fired systems smaller than 50 MW /ref. 61/, designating the recommended limit values for wood-fired systems, in particular.

When fixing the limit values for dust, the report suggests that regard should be had to both the size of the system and the technology applied to firing and dust purification.

Carbon Monoxide (CO)

A high CO content is a certain indication of incomplete combustion and should be as low as possible, because:

- CO is a combustible gas. A high CO content results in poor efficiency.
- Odour nuisance and a high CO value go together.
- PAH, dioxin and a high CO value go together.
- Exposure to high concentrations of CO is hazardous.

According to The Danish Environmental Protection Agency's guide /ref. 64/, the CO content in the flue gas may not exceed 0.05% for straw-fired heating plants. The same requirements apply to the environmental approval of many wood chip-fired heating plants. During normal operating the wood chip-fired heating plants can comply with this, but in connection with starting up, very wet fuel and other unusual operating situations, problems may arise.

Carbon Dioxide (CO_2)

The emission of CO_2 to the atmosphere is problematic, since CO_2 is considered a major cause of the greenhouse effect. During the combustion of wood chips and other wood fuels, not more CO_2 is developed than bound during the growth of the tree. Furthermore, during combustion the same amount of CO_2 is developed as during the decomposition that is the final alternative to the use of the wood for energy purposes. Wood chips are thus considered CO_2-neutral.

Sulphur Dioxide (SO_2)

Sulphur from the combustion of wood chips comes from sulphur compounds that have been absorbed by the tree during its growth. Therefore, the combustion of wood chips does not change the total amount of sulphur present in the environment, but it entails that the emission of sulphur with the smoke contributes to the pollution of the air. However, pure wood from the forestry contains only a very limited amount of sulphur. During combustion approx. 75 % of the sulphur in the wood will be captured in the bottom and fly ash, so that only the remaining 25 % will end as SO_2 in the flue gas /ref. 68/.

Many analyses of the sulphur content in fuel chips show values that are below the laboratory equipment limits of detection. The average of a range of analyses shows a sulphur content of approx. 0.05% (percentage by weight in proportion to the dry matter content in the fuel) /ref. 67/.

Firing with wood chips at heating plants causes much less SO_2 emission than the fuel oil or coal the wood chips often replace. If the alternative is natural gas, and if it is sulphur-free at production, there will be no SO_2 advantage by using wood chips as a fuel.

Nitrogenoxides (NO_x)

During the combustion of wood chips, approx. the same amounts of NO_x are produced as during the combustion of other fuels. NO_x is the sum of NO and NO_2.

The formation of nitrogenoxides occurs on the basis of the nitrogen contained in the air and the fuel. Both nitrogen contained in the fuel and the design of the system combustion chamber play an important role in the production of NO_x. Of important parameters for low NO_x formation can be mentioned:

- Low nitrogen content of the fuel.
- Staged combustion at low excess air during the first stage /ref. 69/.
- Low flame temperature.
- Recirculation of flue gases.

Other Pollutants

In addition to particles, SO_2, NO_x and CO, flue gases may contain other pollutants, such as polyaromatic hydrocarbons (PAH), dioxins, hydrogen chloride (HCl), etc.

PAH is a joint designation for a range of chemical compounds consisting of carbon and hydrogen. It occurs by incomplete combustion. Some of them are noxious (some even cancer-causing) and should therefore be avoided. Since 1985 several investigations have been carried out all showing that there is a close connection between the formation of PAH and CO. Low CO content and low PAH content go together /ref. 70/.

Like sulphurdioxide, hydrogen chloride (HCl) contributes to the acidification, but condenses faster (to hydrochloric acid) and can therefore locally contribute to damage to materials in particular, but also to plants. The emission of HCl depends on both the condition of the wood chips (wood chips from nearshore forests contain salt from sea fog) and on combustion conditions and flue gas purifying, including condensation, which removes a considerable part of the HCl contained in the flue gas.

Noise

The heating plant must comply with the conditions of the environmental authorities regarding the limitation of noise - cf. the Danish Environmental Protection Agency Guide No. 5/1984 /ref. 71/. The noise level load should be measured according to the Danish Environmental Protection Agency Guide No. 6/1984 /ref. 72/ No. 5 respectively /1993 /ref. 73/.

If the heating plant is located in a residential neighbourhood, the noise limits here will normally be:

- 45 dB(A) during days (weekdays from 07:00 - 18:00, Saturdays from 07:00 - 14:00)
- 40 dB(A) during evenings (weekdays from 18:00 - 22:00, Saturdays from 14:00 - 22:00, Sundays and non-working days from 07:00 - 22:00)
- 35 dB(A) during nights (all days from 22:00 - 07:00)

The noise limits vary with the various types of area and may not be exceeded at any point in the neighbourhoods. If the heating plant is located in an industrial area, where the noise limit is 60 dB(A) during all periods of the day and year, the noise limits in an adjacent residential neighbourhood may be decisive. The noise comes primarily from fans and air inlets or exhaust systems (including the chimney), but also from other machines (compressors, cranes, belt conveyors, screw conveyors, and hydraulic systems) and from all the traffic on the plant site. For most areas, the noise limit is lowest during the night, and it will therefore normally be this limit that will form the basis of the dimensioning. However, the delivery of fuel may often give rise to problems, although it takes place during the day if the driveway of the plant is inexpediently located.

It is important already at the stage of planning to take into account the noise emissions, since subsequent antinoise measures are often very expensive, and also operational restrictions (such as how to avoid all traffic during evening and night periods) may be problematic. Today it is possible to forecast the noise in the surrounding neighbourhood, so that the suppliers should warrant not to exceed the noise limits.

Fire Protection

When firing with forest wood chips, the risk of fire is lesser than by firing with dry fuels. However, certain safety regulations must be complied with.

The fuel system should be equipped with an airtight dividing wall, thereby preventing fire from spreading backwards from the combustion chamber to the storage. At most plants, the feeding systems are designed with an airtight "plug" of wood chips and a sprinkler system located just before the combustion chamber.

Attention should be paid to the risk of flue gas explosions. Unburned gases in an incorrect mixture with atmospheric air may cause extremely violent explosions if gases, e.g. due to a positive pressure in the combustion chamber leaking into the boiler room or the feeding system. Flue gas explosions may also occur in the combustion chamber if, e.g. the fuel due to suspension of operations has been smouldering with too little atmospheric air, and air is suddenly introduced.

In the wood chip storage one should beware of the risk of spontaneous combustion. Here storage height, wood chip storage time, moisture content, and the access to air will be a decisive parameter. During firing with wood pellets and dry wood waste, there is a risk of dust explosion in the storage and the feeding system. Here fire extinguishing equipment should be built in just before the boiler. The risk of fire in the fuel storage also applies to pellets.

Control, Adjustment, and Supervision

Control, adjustment, and supervision (Styring, Regulering og Overvågning) is called the SRO system. The system is designed on the basis of two computers:

- A PLC (Programmable Logic Control) with system data recording controls the plant's various flows according to pre-set operating values.
- An ordinary computer displays the flow of data from the PLC to the operators' monitor. The preselected operating values in the PLC can be changed via the computer.

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

- The control ensures that the system performs according to a preselected sequential order.
- The adjustment unit ensures that the preselected values for pressure, temperature etc. are complied with.
- The supervision unit sets off alarms in case of malfunctions.

The SRO system enables automatic operation of the plant, thereby making the permanent pressence of operators unnecessary. In case of operation failures, the remote supervisory and monitoring unit calls in the operators via the public telephone network. In emergency situations, an oil-fired furnace is automatically started, taking over the supply of heat.

Plant Manpower

The manpower necessary for the operation of the plant naturally depends on the degree of automation, the scope of own wood chip handling, the age of the heating plant etc. Individual small heating plants are designed so as to remove the need for permanent on-site attendance even during the day. By being on call via telephone and daily inspections, the plant manager can occupy another job at the same time.

When estimating the manpower required, the calculation can be based on systems from approx. 1.5 MW to 5 MW requiring approx. 1-2 man-years for the operation. Systems above 5 MW will require approx. 2-3 man-years for the operation. The construction of the system is of decisive importance to the amount of maintenance work.

In-Plant Safety

In-plant safety includes fire safety and personnel safety. Before commencing production, the plant must be approved by the local fire authorities.

In-plant personnel safety must be approved by the Danish Working Environment Service. It includes safety measures against scalding, burn, poisoning with flue gas or dust, and injuries caused by cranes or other machinery.

Organisational Structures

Wood chip-fired heating plants can be established as:

- An A.m.b.a. - i.e. a co-operative society with limited liability.
- An ApS - i.e. a private limited liability company.
- An A/S - i.e. a limited liability company.
- A public corporation.

The wood chip-fired district heating plants in Denmark are typically organised as local user-owned co-operative societies with limited liability (A.m.b.a), where all users connected to the district heating system are attached to the company. The owners are only liable to the extent of their contribution, and they are all placed on an equal footing. In addition the organisational structure is already known by many people. Almost all wood chip-fired heating plants in Denmark are organised in the form of an A.m.b.a.. The organisational structure of the user-owned companies are democratic so that all users have the possibility of participating in decision making via the annual owners' meeting of the heating plant.

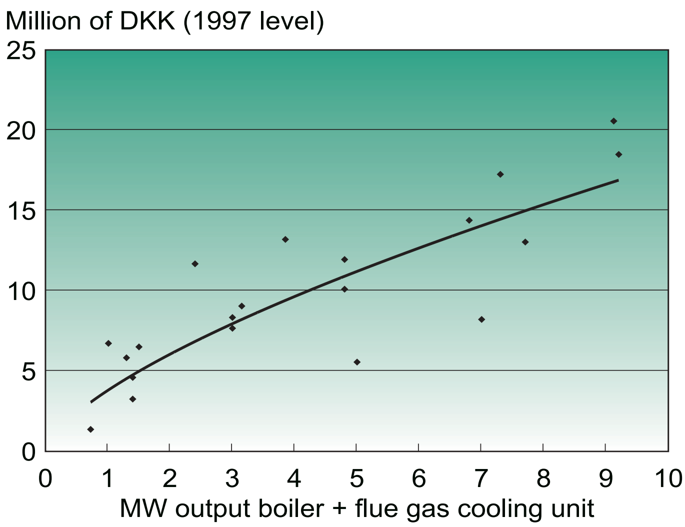


Figure 23: Initial capital investment regarding chip-fired district heating plants at 1997 prices in Denmark. The dots show the individual initial capital investments, while the line shows an approximate price formula /ref. 28/.

photo: biopress/torben skøtt

Trustrup-Lyngby Varmeværk at Djursland is a "urbanisation" project established in 1997.

A few plants are owned and operated by the municipality.

It is also possible to choose a private limited liability company (ApS) or a limited liability company (A/S), where the participants are liable to the extent of their invested share capital.

Investment and Operation

The following example illustrates the plant operating efficiency of a given 2 MW wood chip-fired heating plant established right from the beginning as a so-called "urbanisation" project. By "urbanisation" project is meant a town where both a new heating plant and a complete district heating system for the supply of heat to the consumers are established. The wood chip price is fixed at DKK 36/GJ, and the oil price at DKK 95/GJ. All figures in the example are exclusive of value added tax (VAT).

Capital investment
In the report Initial Capital Investment and Efficiencies of Wood chip-fired Heating Plants /ref. 28/, information has been collected in respect of initial capital investment regarding site, land development, buildings, installation of machines, and projecting. All prices are in terms of 1994 prices so that they are comparable with one another. The curve in Figure 23 shows projected 1997 prices for the individual heating plants in proportion to the total nominal output of the wood chip boiler and flue gas condenser.

It is important for a new project to get "a head start". Therefore, at least 80% of the previously oil-fired furnaces and all public large-scale consumers should participate in the project right from the beginning. Public large-scale consumers are local government offices, schools, sports centres, etc. Contrary to earlier practice, energy and environmental taxes in connection with indoor heating will not be refunded to industrial enterprises and liberal professions, which will therefore also be a target group.

The data of the example are:

260 small consumers	4,550 MWh/year
10 large consumers	3,300 MWh/year
Distribution loss	30%
Generation of heat	11,200 MWh
Heat from wood chips	93%
Heat from oil	7%
Max. output demand	3 MW
Chip boiler rated output	2 MW
Annual efficiency (wood chips)	100%
Annual efficiency (oil)	80%

For a densely built-up town, the distribution loss is 30% in a year with approx. 3,112 "ELO" degree days" (ELO stands for EnergiLedelsesOrdningen (Energy Control Scheme)). If the area is not so densely built-up or smaller towns are connected via a transmission line, the distribution loss will increase to above 35%.

It is possibly to apply to the Danish Energy Agency for subsidies to be granted for "urbanisation" projects according to the CO_2 statute /ref. 57/.

The initial capital investment is as follows:

	Million of DKK
The heating plant	6.8
Street piping/advisory service	10.0
Consumer service pipes	4.0
Consumer house installations	4.0
Unpredictable expenses	1.0
Total initial capital investment	25.8
Danish Energy Agency subsidised	4.4
Loan requirement	21.4

The initial capital investment can be mortgaged in full by means of index-linked loan. An index-linked loan is a type of loan that is repaid by annual payments that increase concurrently with inflation. It is a cheaper type of loan than the conventional loans, repayable by equal semi-annual instalments or annuity loans, as long as inflation is below 7% per annum. The structure of index-linked loans is set out in more detail in the following references /ref. 74, 75/. The real rate of return on index-linked loans, which was introduced with the government's economic intervention in the spring of 1998, is expected to be of decisive importance to whether or not this type of loan will continue being attractive to the financing of new heating plants.

Operating Costs and Income

The heating plant's income derives from the sale of heat and is distributed on fixed contributions and consumer charge for the heat. The standard charge for the sale of heat to consumers may, e.g., be:

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

Add to that value added tax (25%). For a private consumer in a single family house of 120-130 m^2 with an average consumption of 17.5 MWh (equal to approx. 2,500 litres of oil), the heating expenses will amount to DKK 13,800. This expenditure is more or less equal to the operating costs of oil firing: Oil, chimney sweeping, and maintenance.

This rate will yield the following income and expenses:

Income:	Thousand of DKK
Sale of heat, 7,850 MWh	2,748
Fixed annual charge	270
Capacity charge, private cons.	1,014
Capacity charge, industry	350
Total income	4,382

Expenses:	Thousand of DKK
Wood chips, DKK 36/GJ	1,350
Oil, 87,000 litres	295
Maintenance, heating plant	130
Maintenance, distribution system	200
Electrical power consumption	85
Water and chemicals etc.	30
Other costs	70
Personnel and administration	500
Depreciation (20 years)	1,070
Depreciation (indexation)	21
Interest and contribution	570
Total expenses	4,321
Net result	61

With regard to accounting principles, a straight line method of depreciation which charges an equal sum each year, more adequately reflects the decrease in value during the life of the heating 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 increase over the period of repayment. The indexation of instalments is the expense for the annual appreciation of instalments with the index of net prices. The remaining debt is also revalued according to the index of net prices. This item is booked in an exchange equalisation fund under the equity capital /ref. 75/.

Approval by the Authorities

As early as possible during the first stage of the project, it should be investigated whether either the local environmental or building restrictions or preservation regulations will constitute a hindrance to a new or retrofit heating plant. In order to be able to establish a district heating plant, the following approvals should be obtained from the authorities:

- Planning permission.
- Approval of draft project according to the Heat Supply Act.
- Environmental approval.
- Perhaps local planning.

Matters concerning the approval by the authorities are described in more detail in /ref. 76/.