10. Gasification and Other CHP Technologies

Small scale CHP generation is of immediate interest to district heating plants, large institutions, and industries, and the technology has market potentialities both in Denmark and abroad. The major driving force behind the development of gasification systems is the prospect of higher electrical power efficiencies than, e.g. by means of steam turbine systems the same size. This chapter deals with Danish development projects in the field of pilot and demo systems, supported by the Danish Energy Agency's Development Scheme for Renewable Energy among others. The projects work in the field of CHP generation by different systems such as updraft gasification, several forms of downdraft gasification, Stirling engine and steam engine.

CHP with Thermal Gasification

Small scale CHP plants using natural gas as a fuel are easily designed just by letting a combustion engine operate a generator for the generation of electrical power and utilise the engine waste heat for district heating. However, it is not that easy when the fuel is wood. Not even in the form of powder can wood be used directly as a fuel in a combustion engine or perhaps a turbine. First the wood must be converted to gas. This can be accomplished in a gasification process in a gas generator that is also termed a gasifier. The secret of gasification is the conversion of wood into gas at the least possible loss of energy and in a way that the combustible gas thus produced - product gas - is as purify as possible. The gas engine is damaged if the gas contains tar and particles, and the process must not result in polluted water. Thus there are many requirements to comply with at the same time.

During World War II, dried beech blocks the size of tobacco tins were used for the operation of cars. Today this fuel can only be obtained in very limited quantities at reasonable prices. Commercial fuel chips are available today, but they are normally wet when coming directly from the forest. In addition fuel chips are not so much cheaper than gas and oil that investing in the large-scale technology needed for a CHP-based gasification work is economically feasible.

In order to produce combustible gas, the wood should first be heated. It is most common to heat it by burning a small proportion of the wood. The heating dries the fuel, and not until then will the temperature be increased. At a temperature of approx. 200 °C, the so-called pyrolysis begins where the volatile constituents of the wood are given off. They consist of a mixture of gases and tars. When the pyrolysis is completed, the wood has been converted to volatile constituents and a solid carbon residual (the char).

The char can be converted into gas by adding a fluidising agent which may typically be air, carbon dioxide, or water vapour. If using CO_2 or H_2O, this process requires heat and will only occur at a reasonably acceptable speed at temperatures above approx. 800 °C. The combustible constituents in the product gas are primarily carbon monoxide, hydrogen, and a little methane. Together they constitute approx. 40% of the volume of the gas when using air for the gasification, while the residual part consists of incombustible gases such as nitrogen and carbon dioxide. The major part of the tars from the pyrolysis can be converted to gas, if heated to 900-1,200 °C by passing through a hot char gasification zone. Many different types of gas generators have been developed over the approx. 100 years the technology has been known. Normally, gas generators are classified according to how fuel and air are fed in relation to one another. In the following, development projects will be used, which apply updraft gasifiers and downdraft gasifiers. There are also other gasification principles, e.g. fluidized bed gasification, which has its stronghold in large systems. Atmospheric fluidized bed gasification of wood in large systems may be considered fully developed abroad. Also forced draught fluidized bed gasification is used for expensive demo systems abroad. The international development is monitored, but it has not yet been planned to have that type of system constructed for wood in Denmark.

Updraft Gasifiers (Counter Current Flow Gasification)

In updraft gasifiers (gas generators) the combustion air is drawn in underneath the grate in the bottom and passes the fuel from beneath and upward (Figure 28). Fuel is fed from the top of the gasifier undergoing the various processes as it moves to the bottom of the gasifier against the air and gas flow. In traditional types of gasifiers, all substances that are produced during the heating of the fuel, including tar and acetic acid, will leave the gas generator without having been decomposed first. Up to 20-40% of the energy may in that case be bound in this tar. The gas cannot be

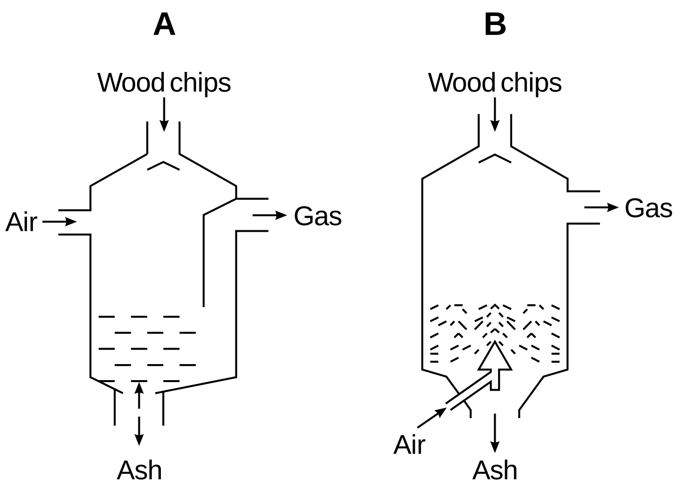


Figure 28: Schematic diagram of the gas generator principles, A - downdraft gasifier, B - updraft gasifier /ref. 77/.

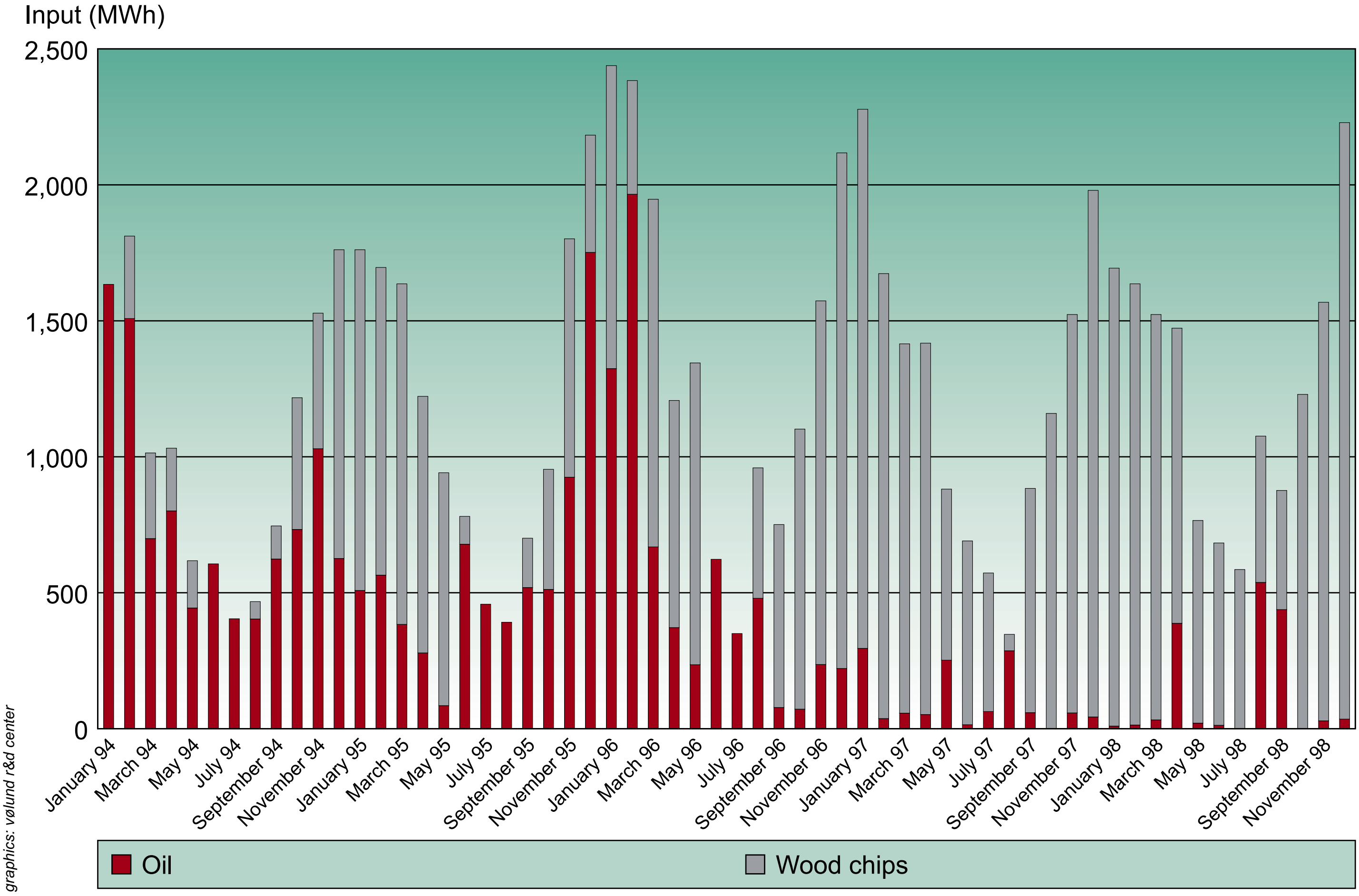


Figure 29: When Harboøre Varmeværk was put into operation, a large amount of oil was consumed for the supply of heat and only a small amount of wood chips, but now the situation has been reversed. The figure showing the fuel consumption of oil and wood chips per month illustrates that the reversal took place during 1996. The most recent couple of years the gasification system has covered more than 90% of the town's heat demand, and the oil boiler now plays a minor part.

used for driving engines without an intensive purification, so therefore the application of updraft gasifiers in connection with wood makes heavy demands on the gas purifying system. For the same reason, updraft gasifiers in the 1940s were primarily used for fuels with a low tar content such as anthracite and coke. /ref. 77/. The great advantage of the updraft gasifier is its ability to gasify both very wet fuels (up to a moisture content of approx. 50%) and fuels with a low slag melting point such as straw.

Downdraft Gasification (Co-Current Flow Gasification)

Downdraft gasifiers fed with wood were the predominant principle used for operation of cars during World War II. The fuel is fed from the top of the gasifier, undergoing the various processes as it moves downward to the bottom of the gasifier. The air is injected either in the middle section of the gasifier or from the top above the fuel storage (Open Core principle) and passes downwards in the same direction as both the fuel and the gases so developed (Figure 28). For tar forming fuel such as wood, this principle is particularly usable, because tar, organic acids, and other pyrolysis products pass down through the combustion zone and decompose to light, combustible gaseous compounds.

In its traditional design the downdraft gasifier principle has the drawback that it is not suitable for fuels with a low ash melting point. Straw will therefore not be suitable, while wood can be used with a good result. Another drawback is that it requires relatively dry fuels with a max. moisture content of 25-30%. When the fuel is delivered directly from the forest, it should be dried before it can be fed into a downdraft gasifier. A modified design of the downdraft gasifier according to a two-stage principle is another option under development at the Technical University of Denmark, and with this design it has been possible to improve the weak points of the downdraft gasifier.

Systems in Process of Development

Updraft Gasification (Counter Current Flow Gasification) System at Harboøre

Ansaldo Vølund A/S has constructed the system and operates a full scale gasification system at Harboøre. The system is designed for conventional forest chips that can be fired without prior drying. The system input is 4 MW and consists of an updraft gasifier, gas purifying, and a gas burner installed on a boiler, where the gas is burnt for the generation of heat. The heat is supplied to Harboøre Varmeværk. The plant has been in operation since 1993 only producing heat and the plant holds the world record in respect of unmanned hours of operation with forest chips as a fuel. At the same time ongoing development has constantly increased the system reliability, which currently tends to even surpass the reliability of conventional chip-fired plants.

The aim of the system is to produce both electrical power and heat. This requires thorough gas and water purifying, because wet wood chips produce a gas that contains relatively large amounts of tarry condensate. Every effort has been made to purify the gas to a level that makes it fit for the purpose of gas engines. This aim has most probably been achieved by now, so in 1999 two gas engines are being installed with output (guarantee data) of 1.3 MW_e. The electrical power efficiency calculated from fuel to electrical power is estimated at approx. 32%, based on the operating data for the gasification system and the data provided by the supplier of the engine. The future operating results shall prove whether the updraft gasification technology for CHP generation is now ready to be commercialised.

Two-Stage Downdraft Gasification Systems

Since the middle of the 1980's, the Technical University of Denmark in Lyngby has carried out research work in the field of the gasification of biomass. At the beginning, the activities were concentrated on the gasification of straw, and new processes were developed. The two-stage process has been named so because pyrolysis and char gasification processes are kept separate from one another. A system was constructed for 50 kW input, and for the first time the researchers succeeded in demonstrating the operation of an engine by using straw. Since then the researchers have focused on wood.

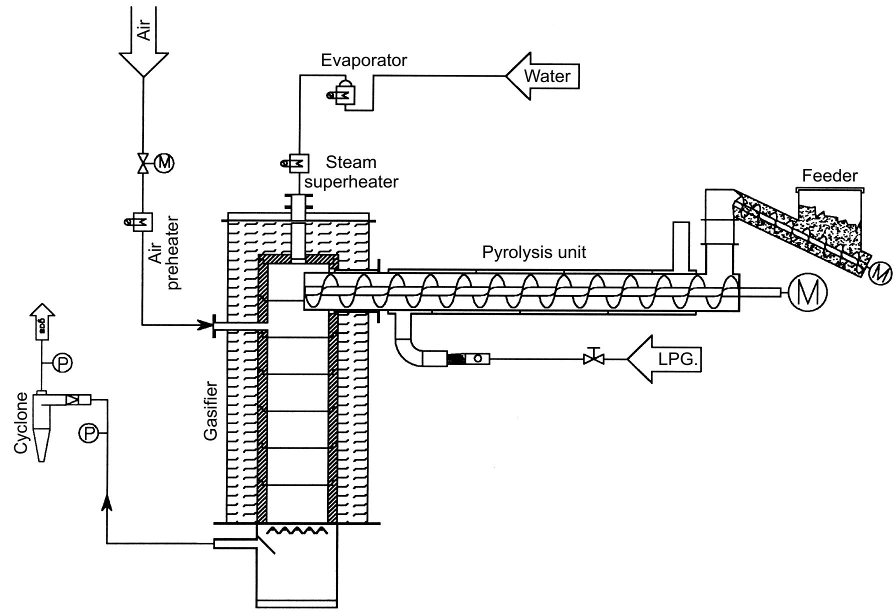
At present a system set-up of 100 kW input with a test engine connected to it has been installed at the Technical University of Denmark. Together with Maskinfabrikken REKA A/S, a complete system with 400 kW input capacity and a 100 kW gas engine has been constructed at a farm in Blære. The system in Blære has been operated for more than 100 hours generating CHP from the gas engine. The Technical University of Denmark has described in detail both the theoretical aspects and demonstrated the gasification process applied in practice, so the process should now be considered perfected. The practical tests have shown that the system is capable of producing perhaps the cleanest gas ever produced by a gasification system. It is also characterised by a high hydrogen content. The two-stage system can manage higher moisture contents in the fuels than other downdraft gasifiers, and due to the efficient gasification process, the condensate from the gas purifying plant is so purify that it most probably can be discharged without any further treatment. As the process uses exhaust heat from a connected engine as energy source for the pyrolysis, this gasifier has a high energy efficiency.

Downdraft Gasification (Co-Current Flow Gasification) in Høgild

The district heating system in the village Høgild has a downdraft gasification system as basic supply system. The system was built by Herning Kommunale Værker. When the gas from the gasifier has been purified by passing a wet scrubber and a fine filter, it is used as a fuel in a gas engine coupled to an electric generator. As with the original downdraft gasifiers, the air is injected in the middle section of the system. The fuel is dried blocks of industrial wood, while it has not yet been possible to use forest chips with a good result. The gasifier was originally bought in France in 1993, but toward the end of 1997, it had to be totally replaced. Only the gas engine and fine filter from the French system was kept. As a replacement a new Danish construction of a downdraft gasifier from Hollensen Ingeniør- and Kedelfirma ApS (engineering and boiler enterprise) was installed. The retrofit system was put into operation in January 1998 and has already been operating for more than 1,500 hours generating electrical power /ref. 78/. Thus it is the system in Denmark so far (November 1998) with most hours of generating electrical power. The input is approx. 500 kW, while the electrical power output is approx. 120 kW. The electrical power efficiency is 19-22% according to information provided.

Open Core Downdraft Gasification (Co-Current Flow Gasification)

The development project that started as a pilot project with dk-TEKNIK ENERGY & ENVIRONMENT being the project manager, was based on the fuel charac-



graphics: dtu, institut for energiteknik

Figure 30: The Technical University of Denmark's 100 kW two-stage gasifier consists of a feeding system, a preheated pyrolysis unit, a gasification reactor, and air- and steam inlet. Wood chips are transported from the feeder to the pyrolysis tube. In the test system the pyrolysis tube is heated by the gas from a LPG-gas burner flowing in a vessel outside the pyrolysis tube; (in "real" systems exhaust gas is used). The pyrolysis products and char are fed from the top of the gasifier where air and pyrolysis gas mix. The gas so produced passes though the char and out though the gasifier reactor, whereby a cyclone separates the largest particles.

teristics of forest chips and the Open Core principle of gasification that had shown successful results abroad based on wood chips.

The concept behind the system is designed for ordinary wet forest chips that are dried in a rotary drum drier heated by residual heat from the gas engine before it reaches the gasifier. In 1995 the construction and testing of a pilot system with a gas generator and gas purifying at Zealand was implemented. The system input is 210 kW, and it is capable of operating a gas engine with an approx. 50 kW electric generator. In the developed Open Core gas generator, the air for the process is injected at several stages, so that a partial combustion of the pyrolysis gas takes place, similar to that of the Danish Technical University two-stage gasification system set-up, before it passes through the char bed.

So far the test system has had approx. 350 manned hours of operation in connection with testing. In November 1998 a gas engine was coupled to it in order to also acquire practical operating experiences with the engine. At the first actual start-up of the engine, it was operated non-stop for 24 hours before it was decided to stop the testing. This was followed up by operating testing over five days in December 1998, when 100 hours' non-stop successful test operating of the system was completed. Of the 100 hours, 86 hours were used for operating the engine.

photo: biopress/torben skøtt

The gasification system in Høgild is now a retrofit system which fully meets the Danish standard. Preben Jensen from Herning Kommunale Værker in front of the new gasifier.

New Gasification Projects

At the end of 1998, several new gasification projects were implemented.

Thomas Koch Energy A/S is developing a downdraft (co-current) two-stage Open Core gasifier based on De La Cotte's principle. The gasifier will generate electrical power in the range of 50-1,000 kW_e and use wood chips as a fuel. The gasifier consists of an internally heated pyrolysis unit that is situated above a combustion chamber and en char gasifier. In the pyrolysis unit the wood chips are separated into tarry gas and char. The tarry gas is burnt in the combustion chamber, and the char is gasified by means of the heat from the burning of the gas. Gas passes via a cyclone, a cooler, and a filter to an engine, where electrical power and heat are generated. The system rated output is 60 kW_e, and it is financed by the Danish Energy Agency and Thomas Koch Energy A/S and is expected to be put into operation in August 1999.

Danish Fluid Bed Technology ApS (DFBT) and the Technical University of Denmark, Institute for Energy Technology, carry on a project supported by the Danish Energy Board for testing and further developing an innovative circulating fluidized bed (CFB) gasifier. Initially, the intention behind the gasifier is to use it as a so-called coupled gasifier, i.e. for co-firing with straw at power plants. The gasifier can operate at relatively low temperatures, thereby avoiding both problematic ash melting and crude gas cooling. It is expected that the concept will be suitable for other types of biomass, including pulverised dry wood. The construction height will be considerably lower than in normal CFB-gasifiers which will hopefully contribute to making the gasifier competitive in sizes down to an input of 1-2 MW. Thus combustible gas can be produced for e.g. small boilers, directly fired gas turbines, and (larger) Stirling engines. At present a test system is being constructed for inputs in the range of 50-75 kW at the Danish Technical University, and the first operating experiences based on straw will be available in the spring of 1999.

KN Consult ApS has been granted an amount of money by the Ministry of Environment and Energy for dimensioning, constructing and testing a 150 kW test gasifier for the gasification of straw according to the principle of updraft gasification. The test gasifier is a pilot project of the actual project "Updraft gasification of straw" that deals with dimensioning and putting into operation a 500 kW test system for the gasification of straw. The work will be carried out in co-operation with KN Consult Polska Sp. z o.o. in Poland, and the results of the 150 kW system will be available during 1999.

CHP with Combustion

The hot flue gases from the conventional combustion of biomass in boiler systems can also be utilised for small scale CHP generation. Two projects under development concerning a Stirling engine and a steam engine respectively will prove it in practice.

Stirling Engine

In the Stirling engine there is no combustible gaseous fuel mixture in the engine cylinders, but only a gas as the working fluid which is heated and cooled by turns. The heat for the Stirling engine working fluid comes from the combustion process as known from conventional grate fired systems. The transfer of the heat from the combustion process to the engine working fluid takes place by means of a heat exchanger.

At the Technical University of Denmark, a project is underway on the development of three engines with electrical power outputs of 9, 35, and 150 kW respectively. The 9 kW_e engine is designed for gaseous fuels, e.g. natural gas and biogas and will not be described in more detail. The 35 kW_e engine is supported by the Danish Energy Agency, and the project is carried through in co-operation with the enterprises Danstoker a•s, I.B. Bruun, and Klee & Weilbach. Maskinfabrikken REKA A/S, has developed the combustion unit for the first system in co-operation with Planenergi A/S. Ansaldo Vølund R&D is developing the combustion unit for the next system.

The design of a 150 kW engine was carried out with support from ELKRAFT A.m.b.a., but in 1998, the work was suspended, the reason being that the decision whether or not to manufacture a prototype is awaiting the experiences acquired from operating the 35 kW_e engines.

The Danish Technical University's Stirling engine is designed for the purpose of utilising biomass only. The heating surface design is based on the experiences acquired from the kind of biomass systems that are working at high temperatures. It is characteristic for the Danish Technical University's engine that it is hermetical in the same way as a hermetical refrigerator compressor. The electric cable is the only external connection, and even the cable entry point has been sealed. Inside the pressurised engine casing are both the engine mechanical parts, which have greased bearings, and the electric generator itself. The difficulties in connection with leakage of working fluid (gas or oil) in the working spaces, troubling other Stirling engine producers, have been avoided.

A high temperature at the heating surfaces is decisive for a high engine efficiency. In practice this means 650-700 °C, so when the flue gas leaves the heating surface, it still contains much energy. When leaving the engine, the hot flue gas can be utilised for preheating the combustion air, and not until then is the remaining part of the flue gas heat used in a boiler. The hot combustion air exhausted by the engine increases the entire temperature level in the combustion system and makes heavy demands of the combustion chamber design and the choice of material. The risks of slagging and deposits on the engine heating surfaces have been taken into account when designing the combustion system for the engine. The heating surfaces have also been designed with the particle content in the flue gas in mind. Large dimensions and large spaces between the heating surface tubes have been used in order to avoid depositions clogging it.

A complete demo plant with 35 kW_e engine for firing with forest chips has been developed and put into operation. The system is set up at a farm in Salling, and so far it has operated for approx. 700 hours (September 1998) for CHP generation. It is perhaps the first Stirling engine in the world that has demonstrated unmanned automatic operation for a long period of time with forest chips as a fuel. The electrical power efficiency is 18-19% when operating on forest chips with a moisture content of 49%. Overall fuel utilisation efficiency is more than 90%. It has only been necessary to purify the engine heating surfaces once after approx. 500 hours' operation /ref. 79/. With this construction the problems of dust and slagging that can otherwise close the heating surfaces by depositing, have been avoided, nor is there any sign of corrosion. The positive experiences acquired from this heating surface design are among the most important partial aims of the project. The testing has also proven that the system is capable of using wood chips and bark with a moisture content of up to 60%. It is most probably the powerful preheating of the air that contributes to the system capability of coping with the above-mentioned fuel moisture contents.

If including the initial engine testing on natural gas, the system has operated for more than 1,000 hours. This is an impressive performance that can be considered a major breakthrough for the Stirling engine, and the Danish Technical University's engine thus seems a really promising system for small scale CHP generation.

A new 35 kW_e engine subsidised by the Danish Energy Agency is being developed. Based on experiences acquired from the first 35 kW_e engine, the engine design has been modified. The new engine is much simpler to construct and assemble than the first prototype. At the same time it is expected that the new en-

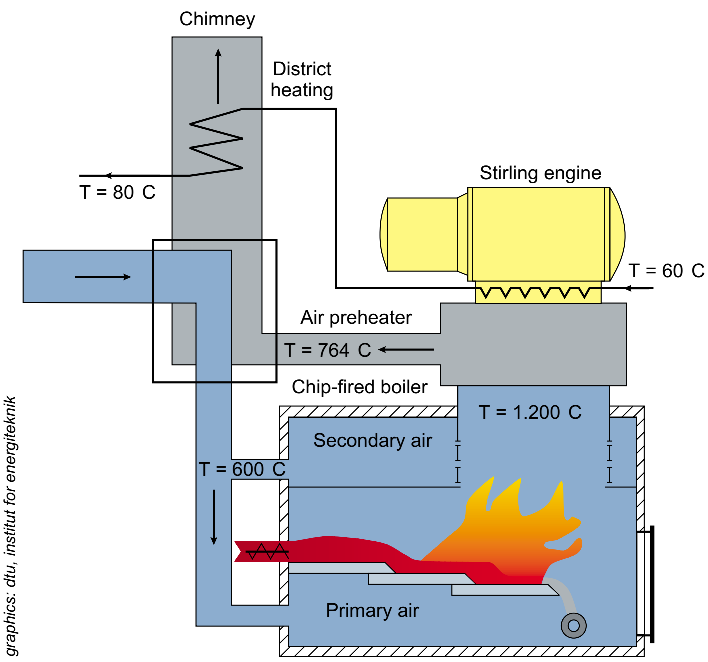


Figure 31: The heating system of the first Stirling engine is based on a conventional boiler, which has been modified so that the ash particles do not deposit on the engine heating surfaces. The electric generator is built into the engine, so that all its moving parts are under pressure and leakage avoided.

gine has improved efficiencies. The engine is equipped with a high temperature gas burner and an updraft gasifier for wood chips, developed by Ansaldo Vølund R & D. The system is expected to be ready for testing during the second half of 1999.

Steam Engine

Steam engines represent a familiar technique invented before the combustion engine. It is in fact considered the starter of the Western industrialisation, because it efficiently - by the standards of that time - could supply mechanical energy to the machines of industry. Today there is still a potential of the steam engine in small scale CHP.

With a view to producing a modern steam engine, a prototype is in the process of development by Milton Andersen A/S and dk-TEKNIK ENERGY & ENVIRONMENT. The aim is to avoid the technical drawbacks and low efficiencies which previously were connected with steam engines. The project is supported by the Danish Energy Agency and EU.

The main problems associated with the old types of engines were that lubricating oil leakages at the cylinders spoiled the steam quality, and that the old-fashioned slide-valve gear resulted in low efficiencies.

A two cylinder prototype has been constructed with a steam pressure of 24 bar and a steam temperature of 380 °C with oil-free piston rings of graphite and computer supervised servo-hydraulically controlled valves. The prototype is rated for an output of 500 kW_e. The initial testing of the prototype has been carried through, and it is now being connected to a steam supply at an industrial enterprise with a view to load testing and perhaps long-time testing of the engine.