

CHP with alternative processes

Alternative processes are sophisticated enough to be put in practice but are not yet implemented in great numbers.

The following figure shows different options for CHP with alternative processes.

Table 15: CHP with alternative processes

Alternative processes
steam-engine process
ORC-process

In the following the steam-engine process and the ORC process are explained in more detail.

^

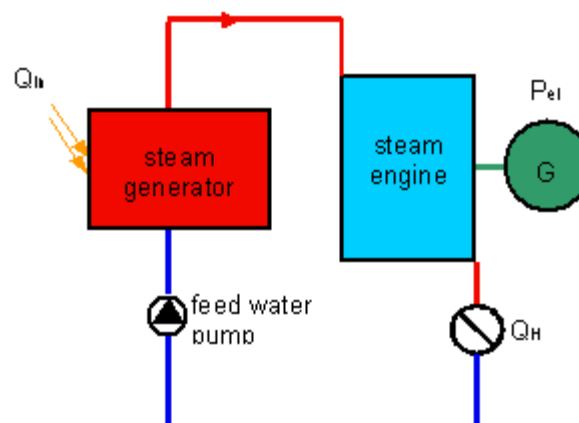
>> Steam-engine process

Functionality

Exhaust gas resulting from combustion is passing through a boiler in which steam is generated. The steam is then flowing into the steam-engine where by expansion it is performing mechanical work which is later converted into electrical energy in the generator. Now the steam is passed into the condenser where incidental condensation heat can be used as district or process heat. The water is brought to operating pressure by a feed water pump and is then fed to the boiler, thus closing the cycle. Therefore the process corresponds to a steam turbine cycle in which the turbine is replaced by a steam-engine. However, compared to the steam turbine cycle the steam-engine can produce power from 20 kWel which allows a decentralized application for lower output.

Set-up of a CHP plant with steam engine

Figure 23: Diagram of a CHP plant with steam-engine

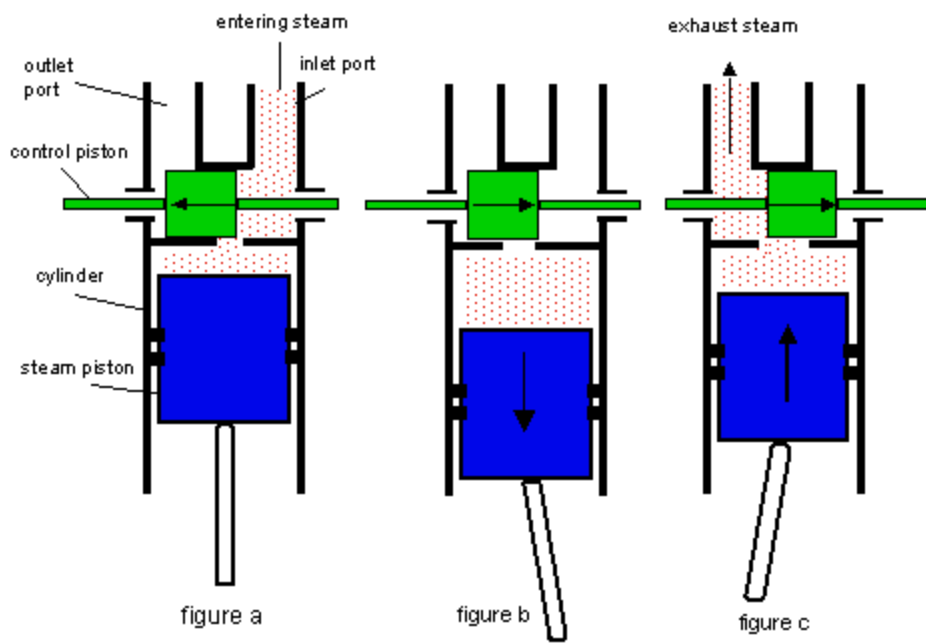


P_{eI} electrical output	— feed water
Q_H heat consumer	— steam
Q_H heat input	— shaft
G generator	

Principle of a steam-engine

The steam enters the cylinder (figure 24a) until the inlet process is stopped by control pistons. The steam expands and is performing work at the piston (figure 24b). Since thus the volume is increased, pressure is continuously reduced. When the piston has reached its dead center it moves to the right again which causes the control piston to unblock the outlet valve and the steam is leaving the cylinder again (figure 24c). Thus the process is restarted.

Figure 24: Principle of a steam engine



>> General information on CHP with steam engine

Application

- For decentralized power and heat supply of lower to medium output (from ~20 kWel to ~2000 kWel)
- Examples: housing estates, industry (drying processes), hospitals

Possible fuels

- coal
- petroleum
- biomass, garbage
- basically every fuel is possible

Advantages

- very good part-load performance
- technology maturity

Disadvantages

- low electrical plant efficiency
- requires much maintenance work
- noise intensive (acoustic insulation!!)

In table 16 some data from a plant within a certain range of performance is outlined.

Table 16: Data of a steam-engine process

Plant size ~500 kW_{el}(biomass-fired)	Unit	Value
Specific investment costs	[EUR/kW _{el}]	~ 1.500
Specific maintenance costs	[EUR/kW _h el]	0,007 - 0,011
Electrical efficiency [eta] _{el}	[%]	6 - 20
Overall efficiency	[%]	~ 80 - 90
Emissions (NO _x)	-	depending on fuel 1)
1) at the scale of gas engines (ca. 50-500 mg/Nm ³ , according to output)		

Best operational mode

Power or heat operated

Design

The steam engine can consist of one to six working cylinders. Each cylinder has its own control piston; thus the engine consists of two shafts, one regulator shaft and one working shaft. In the following important correlations concerning the steam engine are described.

Control

The amount of entering steam can be controlled through the control piston stroke. The stroke of the control piston is adjusted at the regulator shaft with the help of an eccentric with a centrifugal governor. The regulator shaft can be separated so that it is possible to run individual cylinders with different steam inlet and outlet conditions in multi-piston engines.

Steam condition Dampfzustand

The steam engine can work with saturated steam as well as with superheated steam. If, however, superheated steam is used, the same engine can produce up to 60% more electrical output. The reason for this is the utilization of the higher enthalpy drop of superheated steam compared to the one of saturated steam.

Inlet pressures of the steam can range between 6 and 60 bar.

Steam quantities range from 0,2 to 20 t/h according to requirements.

Feed water treatment

Compared to the steam turbine the steam engine is less sensitive to soiling. This makes simpler feed water treatment plants possible (costs !!).

Operating performance

When run at part load the produced amount of steam decreases at unchanging temperature and pressure. The released mechanical energy and thus also the electrical energy decreases. It is important though that the greatest possible efficiency of the plant is not reached at the highest electrical output but slightly below it. This is an advantage of the steam engine if it is run at part load. After all, electrical part load efficiency amounts to 90% of the highest possible electrical efficiency when run at half load.

Maintenance

- daily check on cylinder oil (takes about half an hour)
- condensate samples at sporadic intervals to check oil content (takes about half an hour)
- After about 8000 hours:
 - Oil change in the crank case of the engine
 - components of the steam engine have to be checked

- Replacement of piston and seal rings according to their condition
- Replacement of the piston every 3 - 5 years
- Regular check on the filter equipment

It can basically be assumed that a steam-engine reaches a service life of more than 200.000 operating hours if maintenance is sufficient and proper.

Ecological aspects

The oil obtained in the steam-engine can either be burnt in the firing equipment or has to be disposed of separately.

During the vaporization process of water the salts contained in the water remain in the boiler. In order to avoid high salinity (scale build-up!) water is continuously desalinated (1-5 % of the circulated feed water).

In addition it is necessary to discharge the mud resulting from material abrasion and the remaining salts in the water (manually or automatically).

When discharging sewages into a stream or into the sewerage system, the corresponding legal regulations have to be complied with.

Weak points

Because of the high noise level (up to 95 dBA) an application of this technology is not possible without corresponding noise suppression measures in residential buildings etc.

Stage of development

Since service life of such a plant highly depends on the maintenance work carried out by the staff, attempts are made to reduce these works to a minimum in the future.

An important approach for achieving this is the development of piston materials that do not need lubrication. This would on the one hand improve operator convenience and on the other hand service life could generally be increased. Besides that, lubricant waste and thus also environmental impact could be reduced.

Some important parameters regarding stage of development and outlook are summed up in the following table.

Table 17: Stage of development / outlook

Stage of development / outlook	status
Present stage of development	ready for the market 1)
Short term cost reduction potential	low 2)
Short term development potential	medium 2)
1) Stages of development: concept stage, laboratory stage, pilot stage, demonstration stage, market maturity 2) 1 year...high, 2 years...medium, 3 years...low	

>> CHP on the basis of an ORC process (Organic Rankine Cycle) with biomass ^

Difference compared to the steam turbine cycle

The difference compared to the steam turbine cycle is that instead of water an organic working fluid (hydrocarbons like isopentane, iso-octane, toluene or silicone fluid) is used. Since this working fluid vaporizes at lower temperatures than water, the process can better be adjusted to a fuel like biomass with its low combustion temperatures.

In order to delay the ageing process of the working fluid, the permitted temperatures close to the wall may not be exceeded. Therefore an intermediate thermo oil cycle allowing better temperature control is necessary.

The thermo oil cycle further allows depressurized operating at high temperatures and thus does not require a steam guard.

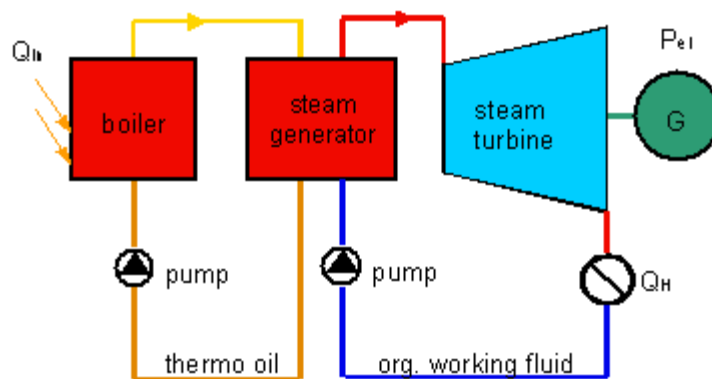
Functionality

The exhaust gas resulting from the combustion process in the biomass boiler supplies heat to the thermo oil cycle. Later the heat is fed to an organic working fluid which therefore vaporizes. The vaporized fluid is expanded in a turbine and the obtained mechanical work is passed to a generator where it is converted into electrical energy. The expanded fluid then enters a condenser where the discharged heat is available at a temperature level which allows the operating of a hot-water network for district or process heat supply. Later the condensate is brought to operating pressure by the pump and is fed to the evaporator again.

In order to increase electrical output, the working fluid escaping from the turbine can be passed through a recuperator (not included in the figure) before it enters the condenser.

Set-up of an ORC plant

Figure 25: Set-up of an ORC process



P_{eI} electrical output

Q_H heat consumer

Q_{in} heat input

G generator

— org. working fluid

— steam

— shaft

Application

- For decentralized power and heat supply of medium output (~300 kW_{el} and more)
- Examples: timber industry, industry (drying processes), housing estates

Possible fuels

- biomass
- basically every fuel is possible

Advantages

- very good part-load performance
- technology maturity

Disadvantages

- intermediate thermo oil cycle necessary (costs !)
- little experiences with ORC plants with biomass firing
- relatively high investment costs

In table 18 some data from a plant within a certain range of performance is outlined.

Table 18: Data of an ORC process

Plant size ~500 kW _{el} (biomass-fired)	Unit	Value
Specific investment costs	[EUR/kW _{el}]	~ 2.300
Silicon oil	[EUR/l]	~ 22
Specific maintenance costs	[EUR/kW _{he} l]	0,007
Electrical efficiency [η _{th}] _{el}	[%]	10 - 20
Overall efficiency	[%]	up to 85
Emissions (NO _x)	[mg/Nm ³]	Depending on fuel~ 250-400

Best operational mode

Power or heat operated

Design:

ORC plants are offered as complete modules. The electrical output of an ORC module ranges between 200 and 1500 kW_{el}. Higher plant output can be achieved by a parallel operation of modules.

The main part of heat supply is realized in the combustion chamber; but exhaust gas heat can further be utilized by releasing the heat in an economizer. The recovered heat can be used additionally for district and process heat, thus increasing overall efficiency of the plant. Besides that, exhaust gas utilization in the economizer allows a lower operating temperature of the condenser because the necessary heat for reaching the required final temperature for process heat is supplied by the economizer. Thus the electrical efficiency of the plant can be improved.

Usually silicone fluid is used as an organic working fluid in a closed cycle because it is neither toxic nor a greenhouse gas.

Picture of an ORC plant:

Figure 26 shows an ORC plant like it was used for the timber industry in Admont.

Figure 26: ORC plant in Admont (Source Bios Bioenergiesysteme)



Control:

Control of the ORC process can be reached through the heat supply in the boiler.

Operating state:

- Evaporating pressure of the working fluid: 10 bar
- Exhaust gas temperature from the boiler: 300 °C

Maintenance

ORC plants basically require little maintenance work. Maintenance works amount to about 4 hours a week.

The working fluid (usually silicone fluid) has to be replaced after about 20 years.

Ecological aspects

The frequently used silicone fluid doesn't have any ozone-depleting potential, it is easily combustible but not explosive. Because of the low flash point (34°C) leakage losses of the working fluid have to be widely avoided.

Because of the high service life of the fluid (up to 20 years) no replacement is required.

Conditions for an efficient operating on biomass basis

- High amount of annual full-load operating hours (> 4000 h) achievable through proper plant design
- High possible efficiency achievable through heat-oriented design
- Utilization of cheap fuel assortments e. g. sawing by-products, production waste

Weak points

The low process temperature resulting from biomass utilization and limited upwards by the thermal stability of the working fluid and the thermo oil only allows relatively low efficiency.

Stage of development

In the field of geothermics there are already many ORC plants used. Therefore the process represents a proven technology.

In 1999 Austria's first biomass-fired ORC plant was put in operation by the timber industry in Admont (Styria). Further plants are being planned.

Some important parameters regarding stage of development and outlook are summed up in the following table. (Source: Dezentrale Biomasse-Kraft-Wärme-Kopplungstechnologien).

Table 19: Stage of development / outlook

Stage of development / outlook	status
Present stage of development	demonstration stage 1)
Short term cost reduction potential	medium 2)
Short term development potential	low 2)
1) Stages of development: concept stage, laboratory stage, pilot stage, demonstration stage, market maturity 2) 1 year...high, 2 years...medium, 3 years...low	