Stirling Engine an overview and future development regarding residential base CHP system with focus on ORC and Technologies of Stirling engine.

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Abstract:

This work provides a review of n solar-powered Sterling engines devices. Previous works have focused on the solar powered as well as low temperature differential engines. The aim of this work is to review working fluids for operation of this engine. Air was found to be a good alternative as a working medium for gamma type engines. Within the scope of a comprehensive study and two development and demonstration projects, variousTechnologies in the power range of up to 2 MWel for small-scale biomass-fired CHP plants have been investigated, evaluated and compared considering technical as well as economic aspects. Such plants should normally be operated on a heat-controlled basis in order to achieve a high overall efficiency and should run for more than 5,000 annual full load operating hours to ensure economical operation. Two of the technologies examined are very promising and innovative: the *Organic Rankin Cycle* (ORC) process and the *Sterling engine* process. The ORC process represents an economically interesting technology for small-scale biomass-fired combined heat and power plants in a power range between 400 and 1,500 kWel. A newly developed ORC technology with a nominal electric capacity of 1,000 kW was implemented in the biomass CHP plant Lienz (A) in the framework of an EU demonstration project. This plant was put in operation in February 2001. Stirling engines are a promising solution for installations with nominal electric capacities between 10 and 150 kW. A biomass CHP pilot plant based on a 35 kWel-Stirling engine was developed and put into operation in the end of summer 2002. Up to the end of June 2003 the plant has run for more than 4,300 hours with very promising results.

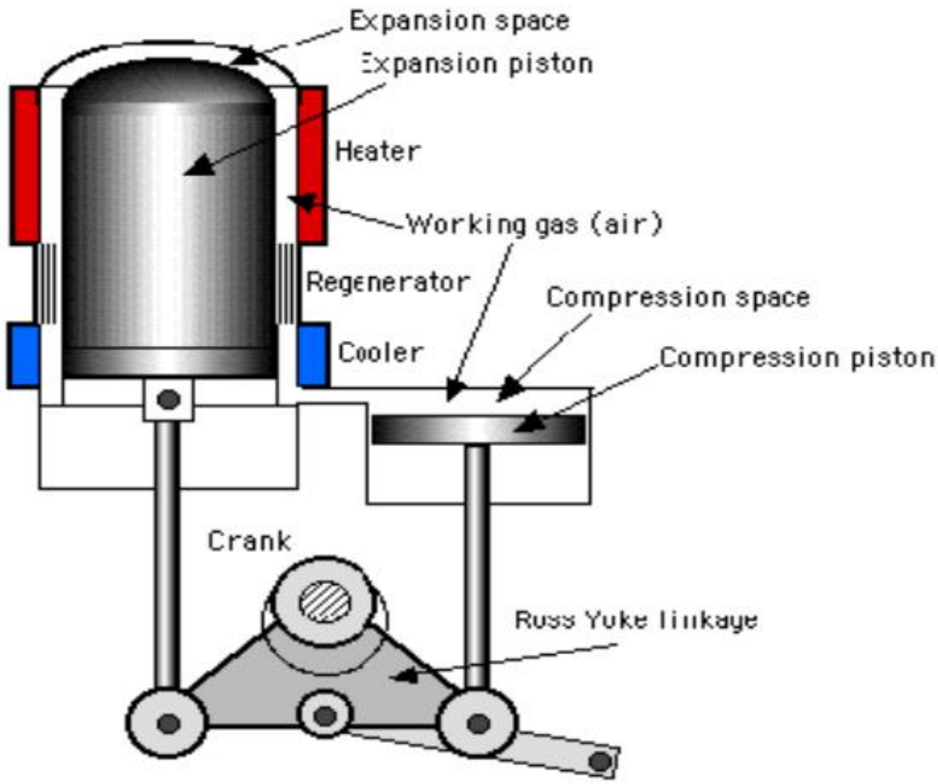
Keywords: *Stirling Engines, Biomass combustion, combined heat and power (CHP), Organic Rankine Cycle (ORC) process, Stirling engine process.*

1. Introduction

Stirling engines are considered promising for residential applications primarily because of (i) their high total efficiency, (ii) favorable ratio of thermal to electrical power, similar to a typical heat-to-electricity demand ratio of a domestic load, and (iii) low emissions with respect to alternative technologies, like internal combustion engines, allowed by their external and stationary combustion process

. In view of these issues with reference to the use of biomass, agricultural and other waste energy sources it was necessary to identify equipment which can be used in micro tri- and cogeneration plants dedicated for use in agriculture and forestry. The scope of the anticipated uses and the type of used energy can include such issues to agro-power plants. Considering the scope of anticipated application of the equipment and the local capacity of energy raw materials the desirability of meeting local energy needs has been indicated. Focusing on the local balance of power has forced an indication of small machines, high resistance to harsh operating conditions and resistance to changes in quality of energy resources. The possibility to use energy resources that are not used in the power industry and transport is very important. Additionally, energy facilities can be installed in residential or farm buildings. It turned out that the fulfilment of all of these conditions is possible using Stirling engines.

Stirling engines are heat engines with external combustion. Due to this fact, the type of sources of heat used to drive this type of engines, the source of fuel is of lesser importance than in internal combustion engines. This property is the cause of the growing interest in engines of this type. This is due to the possibility of using a variety of fuels without strictly followed restriction of special quality requirements. First of all, in the heat engines with external combustion there is greater freedom of choice and frequent changes of specific fuels.



The second important feature of engine called the Stirling engine is the possibility of direct use of these engines a different heat sources with variable temperatures. In this case, heat sources may include solar thermal, geothermal and waste energy of heating installations, cooling installations and electrical systems. Extremely quiet operation is the third reason for interest in Stirling engines. Low noise allows installation of engines of this type in houses, farm buildings, recreational yachts, quiet submarines, recreational and quiet airplanes. As a result, these motors improve the quality of life in residential areas, improve the working conditions in industrial areas, are of interest for military applications, as well as play a role in recreational facilities and meet the environmental requirements of agricultural and forestry areas. The current state of knowledge makes it possible to build a Stirling engine with properties comparable to the current operating performance of other types of combustion engines. It is estimated that the cost of a Stirling engine of the same power as other commonly used internal combustion engines is two times higher. However, the energy cost of fuel used for propulsion of Stirling engines may be substantially lower. Due to the large volume of low-energy fuel consumed, it is reasonable to use these engines in stationary installations, and not in mobile. On the other hand, there is the possibility of using high-energy fuels to power Stirling engines used for transportation purposes. In this case, the costs of engines are much higher than engines commonly used in transport.

It is possible that the current production costs could be lowered by a sufficiently large scale of production. However, silent Stirling engine used for public transport may be a disadvantage declining road safety, rather than an advantage, as in stationary equipment. For these reasons, at present there is no indication of the desirability of widespread use of Stirling engines for transportation.

Energy saving usually increases the real cost of power grid capacity, as usually it is associated with increased daily uneven load on the power grid. For this reason, the transmission costs included in total energy costs are separated from the cost of actual consumption of electricity. In general, the cost of energy transmission power grid and services are comparable to the cost of consumed electricity. For these reasons, we can say that electricity charges are two times higher than the cost of electricity. Therefore, the power grid maintenance costs are comparable to the cost of consumed electricity. As a result, while searching for energy savings, it becomes advisable to reduce costs of transmission. The most favourable possibility seems to be a total elimination of transmission costs. However, such an approach undermines the idea of commonly used, large extensive power grids. Implementation of an alternative idea of dispersed, autonomous energy systems requires a change in legal form. Until now, energy law has imposed a monopoly on large grids. Until recently, it could be said that it is a state monopoly. However, at the moment it is unknown who is legitimately the monopoly owner. Most modern countries live from taxes of all economic activity. For this reason, it seems possible that the extensive grid of monopoly power can be removed without harming the system of modern economic. Some energy companies might be interested in this process because it will create a new market for training, services, and energy equipment. The new proposed organizational concept will also enforce the need for a more flexible approach to the quality standards of electricity. In dispersed system of micro agropower plants, there appear needs to build and exploit periodically working installations, which are excluded from present demands of quality, especially with respect to the continuity of electricity supply. The development of an alternative idea of dispersed, autonomous systems requires a market of appropriate micro power equipment. From the perspective of country's economic development, it is beneficial as it increases all economic indicators. In a paradoxical way, when aiming to increase the consumption of energy equipment, we can achieve energy saving. Even the sense of a variety of local patriotism and a sense of the expectations of the local energy security, can lead to support such distributed autonomous micro agro power plants system.

A Stirling engine consists of following components:

1) Heat source-as fuel does not come in direct contact with the working fluid, Stirling engines can work on fluids which may damage parts of a conventional engine.
2) Regenerator-the function of regenerator is to use the waste heat from being lost to environment by storing it temporarily, thus helping to achieve high efficiencies close to an ideal Carnot cycle. A simple configuration consists of fine mesh of metallic wires. In an ideal Stirling cycle, the connecting space between hot and cold ends acts as regenerator.
3) Heat sink-typically the ambient environment acts as an ideal heat sink; otherwise the cold side can be maintained by iced water or cold fluids like liquid nitrogen.
4) Displacer piston-it causes the displacement of working gas between hot and cold regions so that expansion and contraction occurs alternatively for operation of engine.
5) Power piston- transmits the pressure to crankshaft.

In a Stirling engine, hot air expands when heated and contracts when cooled. This principle of operation was most properly understood by Irish scientist Robert Boyle from his results on experiments on air trapped in a J shaped glass tube. Boyle stated that pressure of a gas is inversely proportional to its volume and product of pressure and volume occupied is a constant depending on temperature of gas.

Hence PV=NRT

Various assumptions which are made in this cycle are:

1. Working fluid is an ideal gas.
2. Conduction and flow resistance is negligible.
3. Frictional losses are neglected.
4. Isothermal expansion and contraction.

This cycle can be described by following stages:

Phase C-D: Isothermal expansion-the working fluid undergoes an isothermal expansion absorbing the heat from source. The power piston moves out, hence increasing the volume and reducing the pressure. The work done in expansion of gas is given by:

$$We = RTln\left[\frac{V_D}{V_C}\right] = \int pdv = nRTc\ ln\left[\frac{V_D}{V_C}\right] \quad (1)$$

Phase D-A: Power piston now reaches the outermost position and stays there so that volume is constant. The working fluid is passed through the regenerator where it gives up heat for use in next cycle. Hence its temperature and pressure falls. No work is done during this phase.

Phase A-B: The power piston stats moving inwards, reducing its volume and increasing its pressure the working fluid gives up heat to cold sink. The work done in compressing the gas is given by:

$$Wc = RTln\left[\frac{V_B}{V_A}\right] = \int pdv = nRTh\ ln\left[\frac{V_B}{V_A}\right] \quad (2)$$

Phase 2-3: The power piston is at its most inwards point and stays there to keep volume constant. Working fluid passes again through the regenerator, recovering the heat lost in 2nd phase, hence its pressure and temperature goes up.

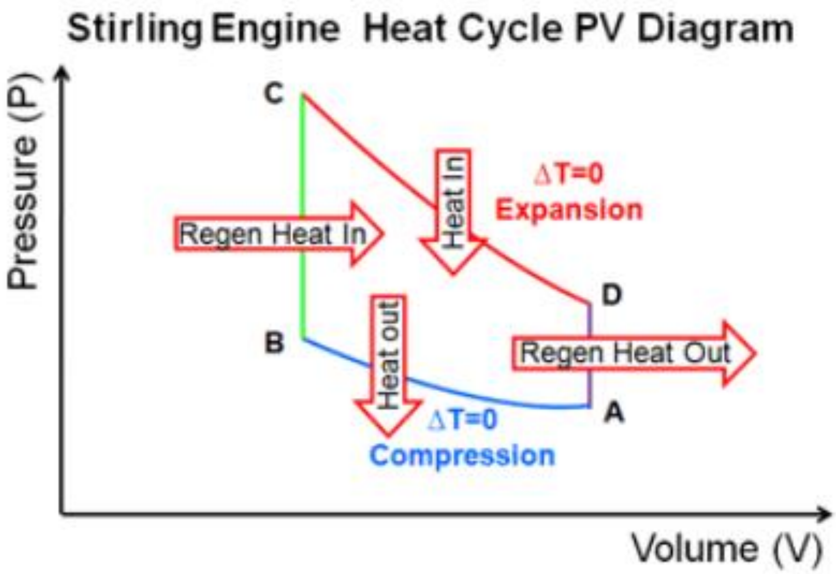
$$Wnet = We - Wc$$
$$= nR[Th - Tc]\left[\frac{Vmax}{Vmin}\right] \quad (3)$$

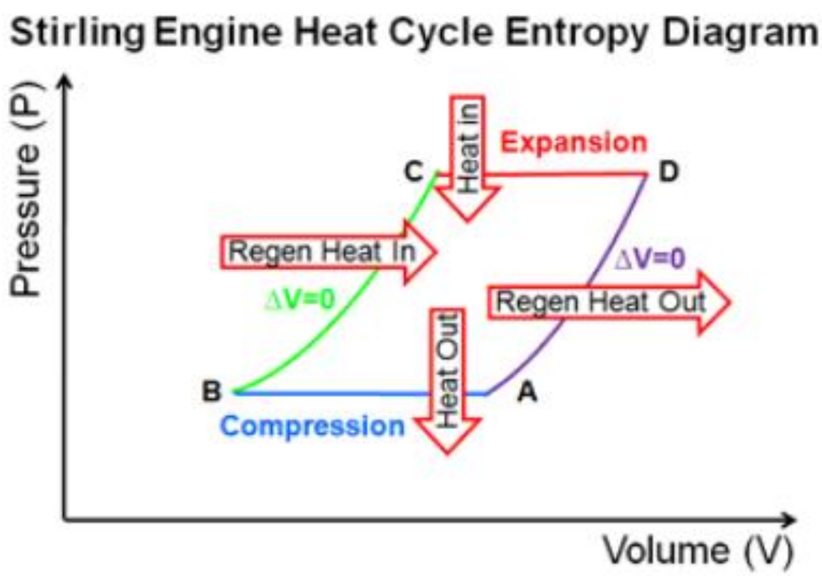
But

$$V_B = V_C \ \&\ V_A = V_D$$

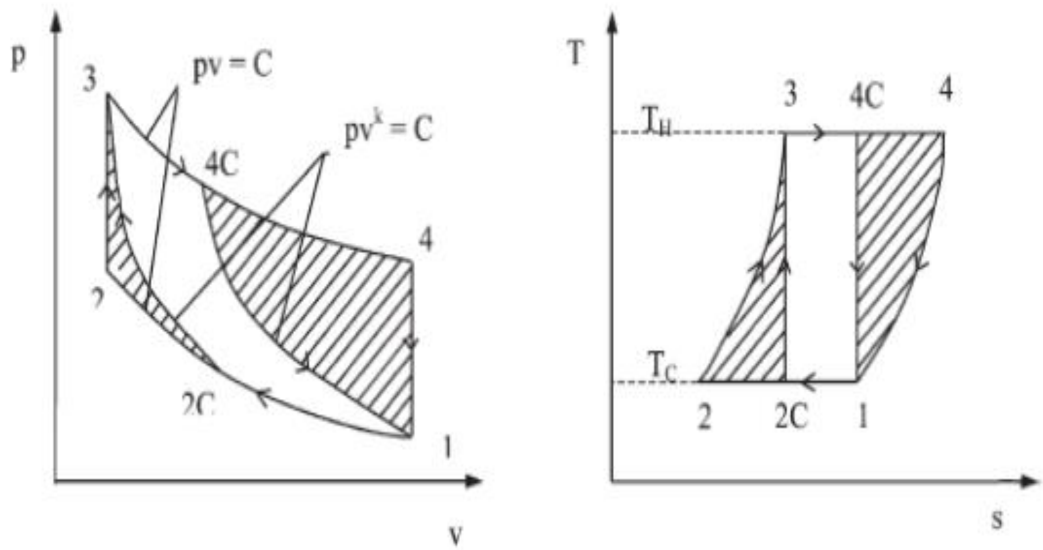
$$efficiency\ of\ engine = \eta = \frac{Wnet}{Qe} = \frac{nR(Th - Tc)\ln\left[\frac{Vmax}{Vmin}\right]}{nR\ Th\ \ln\left[\frac{Vmax}{Vmin}\right]}$$

$$\eta = \frac{Th - Tc}{Th} \quad (4)$$





In Stirling cycle, two Isochoric processes replace the two Iso-entropic processes s in an ideal Carnot cycle. Hence more work is available than a Carnot cycle as net area under P-V curve is more. Thus there is no need for high pressures or swept volumes. This can be seen in the figures presented below.



REVIEW OF LITERATURE

Mahendru [8], make case study on solar powered water pumping project in Samastipur, Bihar, India. In this technology solar panel operating voltage-220V×8 panels, maximum power per panel-230 W, maximum power of solar array1840 W, submersible pump-2HP, water discharge12000 lit/hour on sunny day, size of each pond-1 Acre, total ponds-44. Khandker et. al. [9], suggested that the provision of high quality energy services to rural areas has lagged behind urban areas. It is both financially and physically more difficult to service remote and poor populations compared to those living in urban areas. There are still significant challenges in improving the reliability of power supply in rural area in the country. The challenges are basically two-fold: How to improve the access of rural households to electricity beyond the current rate of 56 percent and how to ensure reliable and adequate supply of electricity. Although rural energy activities receive significant support from the Government of India, our findings would tend to confirm that there is still a long way to go to ensure that the rural poor can take advantage of the many benefits of modern energy and the services that they provide to consumers.

Christoph et. al. [10], analyze the Stirling engine from economic point. They pointed that (i) Only a very small power operation can carry out a Stirling engine, which contributes a lot to energy conservation. (ii) If solar is used to produce energy for the Stirling engine, the cost would be cut down for quite a lot, it costs much to manufacturing. (iii) Stirling engine exhausts cleanly and avoid lot of pollution, which reduce so much cost for pollution control and government. (iv) At the end of 18th century and the early 19th century the heat engine efficiency is very low, only 3% to 5% but now the efficiency of Stirling engine can come up to 80% or even more. So another part of cost is saved. Risberg [11], built a Stirling engine with specification as follow: Crankshaft – 7 inches long with a ½ inch depth, Crankshaft supports – 4.5 inches high, 1.25 inches wide, Pressure Vessel and displacer – 3 9/16 inch diameter, Displacer Bottom - 1.3 inches high, Displacer Top pin - 2.2 inches high, Stand - 3.5 inches high. Efficiency, Torque, Power, Angular speed, and acceleration are all unknown since the engine did not successfully run.

Kwankaomeng and Burapattanon [12], develop a gamma type Stirling engine with double power piston working temperature range of 512-54°C at the hot head engine and air cooler section respectively. The prototype has displacer diameter and stroke of 218.5 mm and 80 mm respectively. And power piston diameter and stroke of 98.5 mm and 110 mm respectively. The engine was improved and tested over wide range of operating conditions for comparison. The results indicate that power of the improved prototype is better than unpressurized engine and using air as working gas. The maximum engine power was 5.05 W at 68.7 rpm and maximum torque was 0.978 N-m at 45 rpm. Maximum engine speed was 130 rpm at temperature of 560° C. The test results showed that the engine started operation in 5 minute at temperature about 490° C on the hot engine head and temperature of 47°C at air cooler section. Hirata et. al.[13], evaluate performance for a 100 W Stirling engine on the basis of pressure, pressure loss, leakage of working gas, buffer space loss, indicated work and power, mechanical loss etc. analytical and compare with model.

From this they conclude that

1. The pressure loss at the regenerator, the gas leakage and the heat transfer in the buffer space was presented. It can simulate the engine performance adequately.

2. The buffer space loss of the prototype engine is estimated adequately, when it is considered the heat transfer with the number of heat transfer unit, NTU=0.1.3. Working gas flowed without an enough extending in the regenerator in the prototype engine. Koichi [14], develop compact and low cost a gamma type Stirling with simple moving-tu4be-type heat exchangers and a rhombic mechani4sm. Its target shaft power is 50 W at speed of 4000 rpm and mean pressure of 0.8 MPa. The test was done in without load, using air in atmospheric condition.

Also, a mechanical loss measurement was done in highly pressurized condition in which the engine was driven by motor. Thombare and Verma [15], published review paper on isothermal analysis, heat transfer in isothermal and adiabatic model, maximum obtainable efficiency, Schmidt's theory, heat transfer phenomenon in different parts of sterling engine such as heater , cooler, regenerator analysis, engine configuration and classification, working fluid, power and speed control, performance governing factor and different characteristics of Stirling engine. Stirling Energy Systems (SES) [16] Company in partnership with Sandia National Lab managed to break the world record for solar-to-grid conversion efficiency at an amazing 31.25 % on January 31, 2008. SES Serial 3 was erected in May 2005 as part of the Solar Thermal Test Facility which produced up to150kW of grid ready electrical power during the hours of sunlight.

Each dish consisted of 82 mirrors that can focus the light into an intense beam (Systems, 2008). SES solar Stirling engine, named Sun Catcher, was awarded the 2008 Breakthrough Award winner by Popular Mechanics for its role as one of the top 10 world-changing innovations. The Sun Catcher is a 25 kWe solar dish Stirling system which uses a solar concentrator structure which supports an array of curved glass mirror which are designed to follow the sun and collect the focused solar energy onto a power conversion unit.

The diagram below illustrates the workings of SES's Sun Catcher. Minassians and Sanders [17], make feasibility study of a low-cost solar-thermal electricity generation technology, suitable for distributed deployment, based on nominating solar concentrators, integrated with free-piston Stirling engine devices incorporating integrated electric generation. Concentrator collector operates at moderate temperatures, in the range of 120°C to 150°C.

This temperature range is consistent with the use of optical concentrators with low-concentration ratios, wide angles of radiation acceptance which are compatible with no diurnal tracking and no or only a few seasonal adjustments. Therefore, costs and reliability hazards associated with tracking hardware systems are avoided. They further outline the design, fabrication, and test results of a single-phase freepiston Stirling engine prototype.

A very low loss resonant displacer piston is designed for the system using a very linear magnetic spring. The power piston, which is not mechanically linked to the displacer piston, forms a mass-spring resonating subsystem with the gas spring, and has a resonant frequency matched to that of the displacer. The design of heat exchangers is discussed, with an emphasis on their low fluid friction loss; an appropriately dimensioned Stirling engine candidate is discussed. Wood et. al. [18], preliminary design a linear motion free-piston Stirling engine / blower coupled to a rotary turbine / generator. The design combines several features of prototype free-piston machines that are nearing commercial production.

The Stirling driver is comprised of two conventional, displacer types, free-piston engines configured as a dynamically balanced opposed pair. Using the outer face of its power piston, each engine drives a single acting blower. The single turbine / generator use commercial units and are separate from the engines and connected by ductwork. The engines and turbines utilize the same helium working fluid. Moon and Miller [19], complete a rigorous computational model of the engine using Fluent fluid dynamics software.

After that attempt they made to model the engine in Solidworks' Floworks application, that software proved inadequate for analyzing the transient states present in Stirling engine operation. Then they conduct another experiment in order to determine the actual heat flux concentrator capable of producing, in order to closely match the performance of engine with that of our dish. Finally, they finalize all design elements and. They also wrote all CNC code using Solidworks and Mastercam, in order to do the required machining using SDSU's facilities. Kangtrageal and Wongwises [6], published a review of solar power Stirling engine. They give some idea about low temperature differential Stirling engine, its characteristics. Also state that engine operation of the Stirling engine depends on the material used for construction. Engine efficiency ranges from about 30% to 40% resulting from a typical temperature range of 923-1073 K and a normal operating speed from 2000 to 4000 RPM, motion diagram , engine indicated work, Stirling engine feasibilities for rural and remote areas, engine optimization techniques, utilization of solar energy using concentrating collector, solar disc technology.

OBJECTIVES

Some innovative technologies for electricity production in the power range of up to 2 MWel have recently been newly developed or improved, thus rendering them suitable for application in small-scale biomass-fired CHP plants. In a study various CHP technologies have been investigated, evaluated and compared considering technical (technical side constraints, operating characteristics, process control, partial load behaviour, maintenance requirements, environmental aspects, state of development) as well as economic (investment and electricity production costs) aspects [1].

Among them are two innovative technologies based on biomass combustion which are of high interest for small-scale biomass CHP plants. These technologies are the Organic Rankine Cycle (ORC) process and the Stirling engine process. The ORC process has attained a high level of development and demonstration units are already in operation. This technology is applicable for small-scale biomass CHP plants with nominal electric capacities between 400 and 1,500 kW. For small-scale CHP systems using biomass as fuel Stirling engines are a promising solution for installations with nominal electric capacities between 10 and 150 kW.

The objective of this paper is to give an overview about the state-of-development, about the operating experiences already obtained as well as about the future development potential of these two innovative small-scale biomass CHP technologies. Moreover, the paper points out the constraints which have to be considered or which are given when implementing a small-scale biomass CHP plant.

TECHNOLOGIES AND CONSTRAINTS FOR THE APPLICATION OF SMALL-SCALE BIOMASS CHP PLANTS.

Typical fields of application for small-scale biomass-fired CHP plants are wood-processing industries and sawmills, district heating systems (newly erected or retrofitted systems) as well as industries with a high process heat demand. These applications represent a great market potential in Europe. Due to the relatively low electric efficiency achievable with small-scale CHP plants, a basic requirement for an ecological and cost-effective operation of such plants is that not only the electricity but also the heat produced can be utilised as process or district heat (heat-controlled operation of the overall system).

The following technologies are available for CHP plants based on biomass combustion:

1) Steam turbine process
2) Steam piston engine process
3) Screw-type engine process
4) ORC process
5) Gas turbine processes
6) Stirling engine process

Fixed-bed gasification processes also represent a future potential for small-scale biomass CHP plants but have not yet achieved a level of development which allows commercial application.

Depending on the amount of full-load operating hours, the size of the CHP plant and the biomass fuel price, small-scale biomass-fired CHP plants can produce electricity at costs between 70 and 150 €/MWhel (no investment subsidies considered). The steam processes and the ORC process are presently the best developed and the most economical systems available. The most important influencing variable on electricity production costs are the annual full load operating hours of the CHP plant. For economic operation a minimum value of 5,000 hours can be recommended which shows the importance of an optimal "sizing" of the CHP unit according to the annual heat output line.

3 ORC PROCESS

3.1 Description of technology

The principle of electricity generation by means of an ORC process corresponds to the conventional Rankine process. The substantial difference is that instead of water an organic working medium with favourable thermodynamic properties is used [1,2,3]. The working principle and the different components of the ORC process are shown in Figure 1. The ORC process is connected with the thermal oil boiler via a thermal oil cycle. The ORC unit itself operates as a completely closed process utilising a silicon oil as organic working medium.

This pressurised organic working medium is vaporised and slightly superheated by the thermal oil in the evaporator and then expanded in an axial turbine which is directly connected to an asynchronous generator (see Figure 1). Subsequently, the expanded silicon oil passes through a regenerator (where in-cycle heat recuperation takes place) before it enters the condenser. The condensation of the working medium takes place at a temperature level which allows the heat recovered to be utilised as district or process heat (hot water feed temperature about 80 to 100°C).

The liquid working medium then passes the feed pumps to again achieve the appropriate pressure level of the hot end of the cycle. In order to obtain a high electric efficiency (= net electric power produced / thermal power input) of the ORC unit itself, it is necessary to keep the back-pressure of the turbine as low as possible and thus to minimise the necessary temperature for district heat utilisation at the condenser of the ORC plant (approximately 80 °C feed water temperature).

This can be achieved by optimising the operation and control of the district heating network in order to keep the necessary feed-water temperature as low as possible as well as by an optimised hydraulic integration of the ORC in the district heating network. In order to achieve this goal, the ORC should be directly connected to the return of the district heating network and the feed water temperature at the ORC outlet should be kept as low as possible by placing the hot water economiser and the hot water boiler downstream of the ORC (see section 3.2, Figure 2 and Figure 3). Following this approach, the ORC can be operated at feed-water temperatures of about 80°C the whole year round, although the feed-water temperature required for the district heating network amounts to 90 to 95 °C in winter. ORC plants are relatively silent (the highest noise emissions occur at the encapsulated generator and amount to about 85 dB(A) at a distance of 1 m.

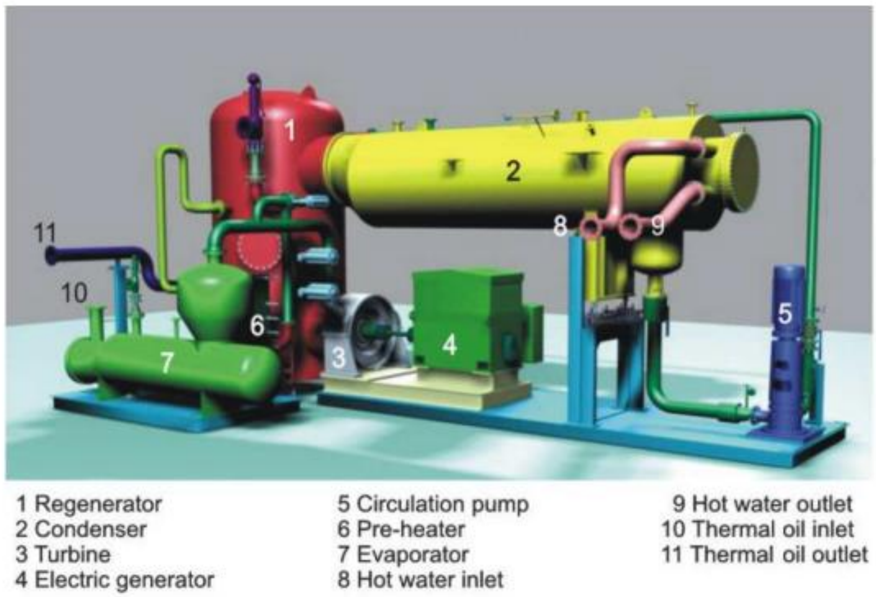


Figure 1. View of an ORC plant. Source: TURBODEN Srl, Brescia, Italy.

Since the cycle of the ORC process is closed and thus no losses of the working medium are possible, the operating costs are low. Only moderate consumption-based costs (lubricants) and maintenance costs are incurred. The usual lifetime of ORC units is greater than twenty years, as has been proven by geothermal applications. The silicone oil used as working medium has the same lifetime as the ORC since it does not undergo any relevant ageing.

3.2 EU demonstration project Lienz with optimised ORC process integration

The biomass CHP plant in Lienz is located in East Tyrol, Austria, and supplies the town of Lienz with district heat (see Figure 2) [4]. It started operation in autumn 2001 and will cover the heat requirement of approximately 70 % of all buildings in the supply area by the end of 2003. The residential and industrial heating systems replaced are mainly oil-fired boilers which results in a considerable CO2 reduction.

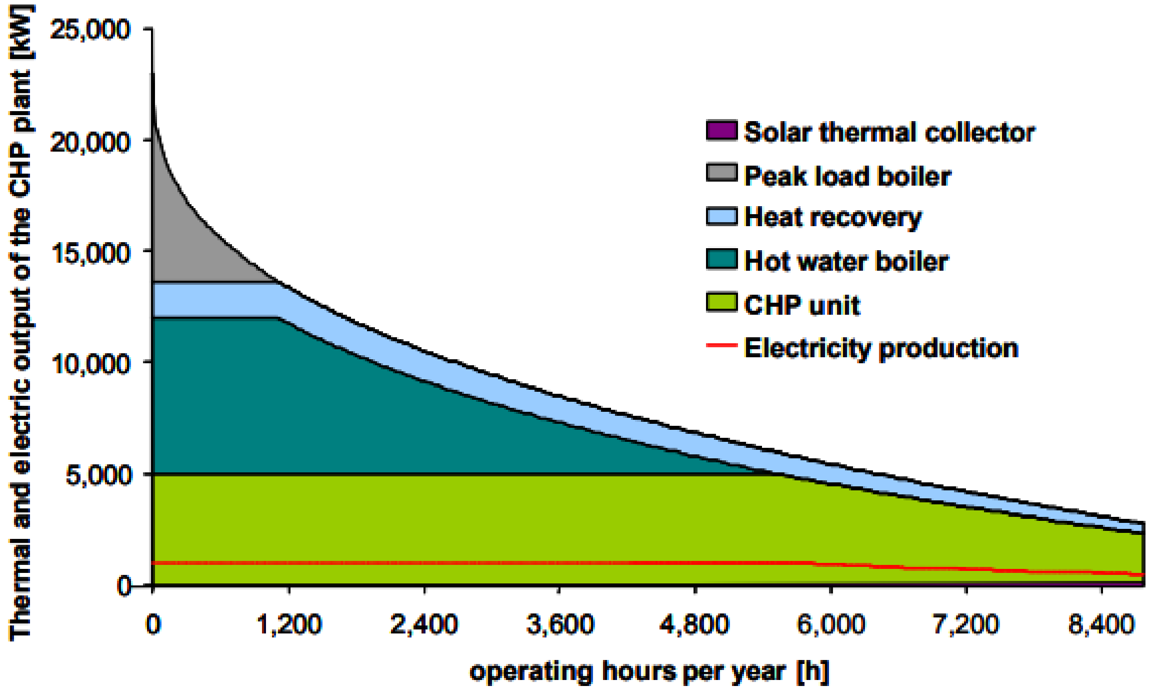


Figure 2. Annual heat and electricity output line for the final stage of development of the district heating network – biomass CHP plant in Lienz

Figure 2 shows the annual heat and electricity output line for the biomass CHP plant in Lienz. The thermal oil boiler with a nominal capacity of 6,000 kWth covers the base load, the hot water boiler with a nominal capacity of 7,000 kWth is additionally in operation for medium load coverage and the peak load is covered by a fuel oil fired boiler with a nominal capacity of 11,000 kWth (see Table 1). The thermal oil boiler supplies the ORC process with heat. The heat recovery unit with a nominal capacity of 2,000 kWth comprises a thermal oil economiser, located downstream of the thermal oil boiler, and a hot water economiser which recovers energy from the flue gases of both biomass-fired boilers. The heat recovery unit increases the overall plant efficiency. The solar collector panel located on the roof of the plant has a surface area of 630 m² and achieves a thermal power of up to 350 kWth (see Table 1). The main innovative part of the new biomass CHP plant in Lienz is the ORC process with a nominal electric capacity of 1,000 kWel and a nominal thermal capacity of 4,400 kWth. The relevant technical data of the ORC process are listed in Table 1. The ORC was manufactured and supplied by TURBODEN Srl, Brescia, Italy

Table 1. Technical data of the biomass CHP plant Lienz

Technical data of the biomass CHP plant		
Solar thermal collector	630	m^2
Nominal power - thermal oil boiler	6,000	kW
Nominal power - thermal oil economiser	500	kW
Nominal power - hot water boiler	7,000	kW
Nominal power - hot water economiser	1,500	kW
Nominal power - oil boiler (peak load)	11,000	kW
Maximal thermal power - solar collector	350	kW
Production of heat from biomass	60,000	MWh/a
Production of heat from solar energy	250	MWh/a
Production of electricity from biomass	7,200	MWh/a
Technical data of the ORC process		
Thermal power input - ORC at nominal load	5,560	kW
Net electric power output - ORC at nominal load	1,000	kW
Thermal power output - ORC at nominal load	4,440	kW
Net electric efficiency - ORC at nominal load	18	%
Thermal efficiency at nominal load	80	%
Electric and thermal losses	2	%
Heating medium	Thermal oil	
Inlet temperature	300	°C
Outlet temperature	250	°C
Working medium	Silicon oil	
Cooling medium	Water	
Inlet temperature	80	°C
Outlet temperature	60	°C

The overall electric efficiency of the CHP plant (= net electric power produced / fuel power input into the biomass-fired thermal oil boiler [NCV]) has been considerably increased by a new and improved approach of coupling of the thermal oil boiler with a thermal oil economiser and an air preheater (see Figure 3). Using this approach, the thermal efficiency of the biomass-fired thermal oil boiler reaches 82% (= thermal power output / fuel power input [NCV]), which is about 10% higher than corresponding values from conventional biomass-fired thermal oil boilers [5].

This increased thermal efficiency correspondingly also raises the overall electric efficiency of the CHP plant (= net electric power produced / fuel power input into the biomass-fired thermal oil boiler [NCV]) to about 15% (see Figure 4). The ORC unit in the biomass CHP plant in Lienz has been in successful and almost continuous operation since February 2002. According to operation data already evaluated, the net electric efficiency of the ORC plant amounts to 18% at nominal load and about 16.5% at 50%

partial load at feed water temperatures of 85°C (see Figure 7). This underlines the excellent partial load behaviour of this technology. The internal electric power demand of the ORC for the feed pumps amounts to about 60 kW at nominal load and constitutes the difference between the gross and the net electric power output of the plant. Thus, the gross electric efficiency of the ORC is about 19% at nominal load. Furthermore, the measurement data already obtained clearly show that the ORC plant can be operated at up to 120% of its nominal electric power, which is an additional advantage during the winter months.

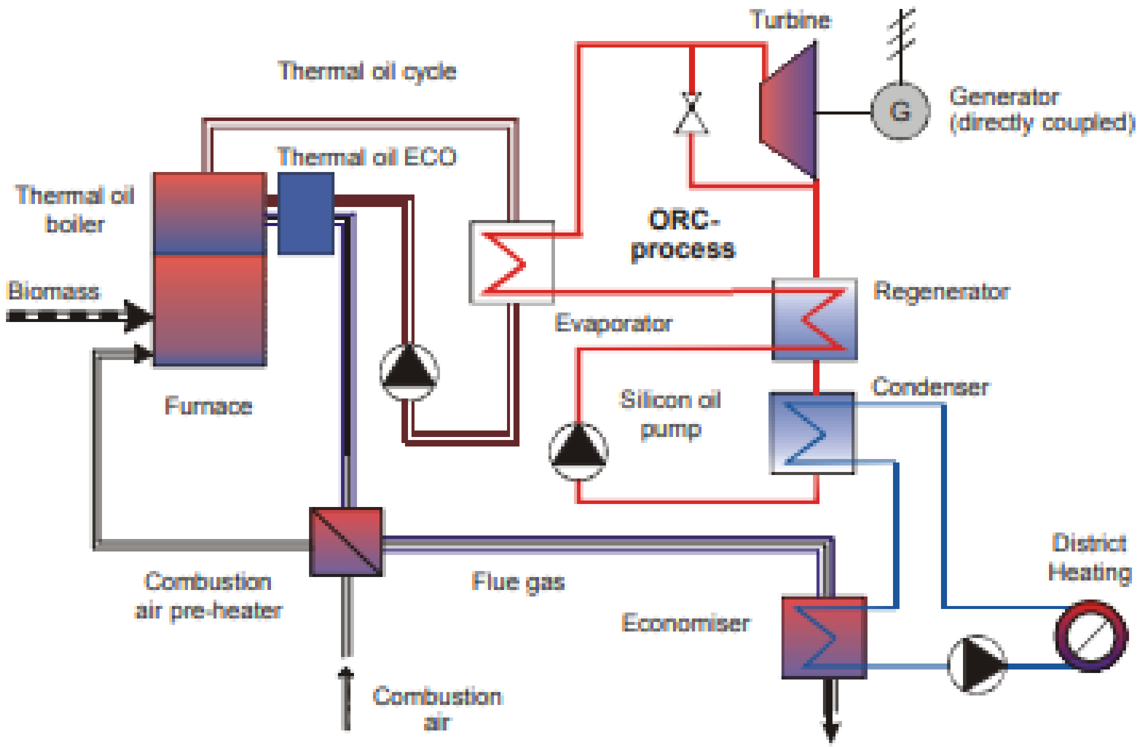


Figure 3. Working principle of the biomass-fired ORC process in Lienz

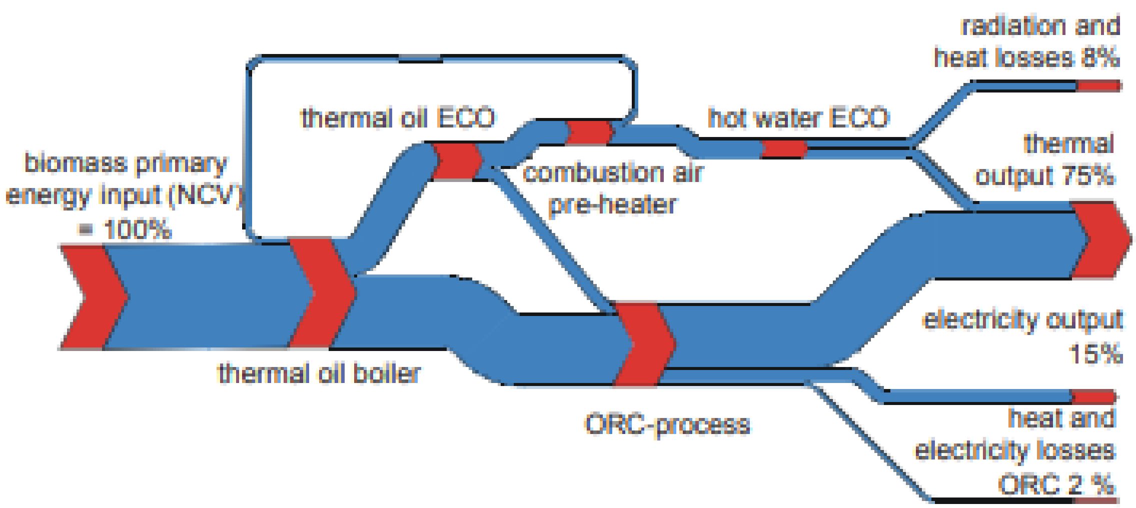


Figure 4. Energy balance of the biomass CHP plant in Lienz

The biomass-fired thermal oil boiler, the thermal oil economiser and the air preheater are equipped with an automatic cleaning system based on pressurised air. This system has already proved its good performance: during the first nine months of operation no manual boiler cleaning was necessary and boiler operation took place without rising flue gas temperatures at the boiler outlet.

Based on the project in Lienz and on experiences with other biomass CHP applications, comprehensive investigations concerning the economy of small-scale biomass CHP plants have been performed. The calculation of the production costs for electricity is based on the VDI guideline 2067. This cost calculation scheme distinguishes four types of costs: capital costs (depreciation, interest costs), consumption based costs (fuel, auxiliary energy, consumables), operation-based costs (personnel costs, costs for maintenance) and other costs (administration, insurance). The capital costs are based on additional investment costs (about 380 €/kWel for a 1,000 kWel ORC plant) , and consider only the surplus investment costs of a CHP plant in comparison to a conventional biomass combustion plant with a hot water boiler and the same thermal output. The additional investment costs form the correct basis for the calculation of the electricity production costs of a CHP plant. A clear distinction between heat and electricity related costs is also made for all the other types of costs in order to ensure a correct calculation

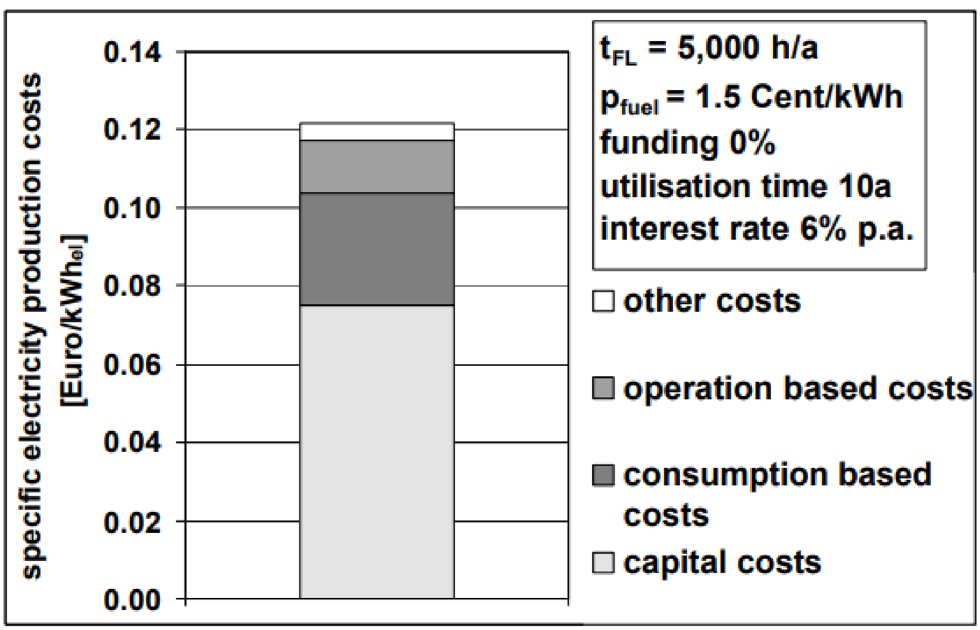


Figure 5. Specific electricity production costs of a biomass-fired CHP plant based on a 1,000 kWel ORC process

As shown in Figure 5 the specific electricity production costs calculated amount to approx. 0.12 €/kWhel. For an ORC unit with a nominal electric capacity of 500 kW and the same basic conditions, the specific electricity production costs increase by approximately 15% mainly due to higher specific investment costs (economy-of-scale effect). The most relevant cost factor are the capital costs, representing more than 60% of the overall specific electricity production costs. The fuel costs, the second relevant influencing parameter, account for about 20% of the specific electricity production costs.

3.3 State-of-the-art and future development of the ORC process

The new biomass CHP technology based on the ORC process is an economically and technologically interesting solution for small-scale applications [6, 7]. At present, the ORC technology represents the stateof-the-art and is available on the market. Compact ORC modules are available in container size with nominal capacities between 400 and 1,500 kWel. Further biomass CHP projects based on the ORC technology already implemented or in the implementation stage are located in Fussach (A) (nominal electric capacity 1,100 kW), near Vienna (nominal electric capacity 1,000 kW) and in Toblach (I) (nominal electric capacity 1,500 kW). Future developments focus on a further improvement of the electric efficiency by twostage ORC cycles as well as by combined hot air turbine - ORC cycles.

CONCLUSIONS

From the above study it can be concluded that there is a hope for rural area to develop gamma type Stirling engine. In this engine solar energy can be used for heating hot end of engine up to 4500C to 8000C and air cooled fin can be used for cooling the cold end of engine up to 350C to 700C. Theoretically designed such type of engine will give efficiency of about 52% to 72%. As there was limitation of availability of other working fluid; air will be the best working fluid for it. Based on Standardization of available centrifugal pumps in market the speed of the engine should be design as per the speed of pump i.e. 1000, 1500, 2500, 3000 RPM.

Hence new renewable source solar Stirling engine will give good hope and way for pumping water in rural areas.

Several technical side constraints are of great importance for decentralised biomass CHP plants. The technology must be robust and highly available and plants must be designed to run in unmanned operation. Therefore, a high level of process control and process automation is necessary. Other important factors are good partial load behaviour and the ability to handle quick load changes. Overall electric plant efficiency should be between 12 and 20%. A high number of full load operation hours and high overall efficiency are crucial factors for economical performance. Appropriate feed-in tariffs for electricity from biomass as well as a certain period of time over which these tariffs are guaranteed (at least 10 years) are essential in order to drive market introduction of smallscale biomass CHP technologies forward. These framework conditions are crucial for initiating serial production of such CHP systems, which is the most important factor for cost reduction, as capital costs account for about 60% of total electricity production costs. The ORC and the Stirling engine technologies described in this paper have proven their applicability for small-scale biomass CHP plants and represent an interesting future potential in this field.

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